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CHEMICAL CONSTITUENTS AND PHYSICAL PROPERTIES OF *BAMBUSA HETEROSTACHYA*

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บทคัดย่อ

การศึกษาองค์ประกอบทางเคมีและคุณสมบัติทางฟิสิกส์ของไม้ไผ่อายุ ½, 1, 2, 3, และ 4 ปี ผลการศึกษาพบว่าความชื้น การหดตัว ยกเว้นความหนาแน่นมีความสัมพันธ์ในทางกลับกับอายุของไผ่ แต่องค์ประกอบทางเคมีมีความแตกต่างอย่างมีนัยสำคัญกับอายุ และความสูงของลำ (ยกเว้นสารที่ละลายในน้ำเย็น โฮโลเซลลูโลส และปริมาณเถ้า) เซลลูโลสในปริมาณสูงที่พบในไผ่ชนิดนี้แสดงให้เห็นว่าไม้ไผ่นี้มีศักยภาพในการใช้เป็นวัตถุดิบเพื่ออุตสาหกรรมเยื่อและกระดาษ

ABSTRACT

The chemical constituents and physical properties of ½-, 1-, 2-, 3- and 4-year-old *Bambusa heterostachya* were assessed. With the exception of density, the moisture content and shrinkage were negatively correlated with age. The chemical compositions, on the other hand, differed significantly with maturity and culm height (except for cold water solubles, holocellulose and ash contents). Despite of age and height, the high cellulose content of this species indicates its good potential as a raw material for pulp and paper.

INTRODUCTION

Bambusa heterostachya or locally called as `Buluh galah' is known to be cultivated rather than found in the wild. This medium diameter bamboo species is commonly used for tugging coconut fruits and oil palm fruit bunches, ropes, binds and basketries, especially in the southern part of Peninsular Malaysia, the area where it can be found abundantly.

Detail information on this species is lacking. The only available documentation was initiated by Abd. Latif *et al.* (1993a), with a special emphasis given on its culm characteristics and physical properties. Since this species shows potential in the development of bamboo industries in Peninsular Malaysia, more information are needed in order to assess its suitability for other end-uses. In this study, the patterns of

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variation in chemical constituents and physical properties of *B. heterostachya* at different levels of age and culm height were determined as a guide for their future application.

MATERIALS AND METHODS

Nine culms from each ½, 1-, 2-, 3- and 4-year-old *B. heterostachya* obtained from the plot established since 1987 at Parit Haji Salleh, Broleh, Batu Pahat, Johor were used in this study. The sampling was conducted in July, 1993 whereby the rainfall, temperature and relative humidity was about 169.5 mm, 31.7°C and 82.5% respectively. The culm length, diameter, wall thickness, internodal number and weight were recorded. Each bamboo sample was then equally divided into three portions of basal, middle and top.

The methods used for the determination of moisture content, density and shrinkage of bamboo were based on IS 6874 (Anon 1973). Proximate chemical analysis, on the other hand, was conducted on air dry milled bamboo samples according to the following standard methods:

a.	Cold water solubles	TAPPI T-207 (Anon 1978)
b.	Hot water solubles	TAPPI T-207 (Anon 1978)
c.	1% NaOH solubles	TAPPI T-212 (Anon 1978)
d.	Alcohol-benzene solubles	TAPPI T-204 (Anon 1978)
e.	Lignin	TAPPI T-222 (Anon 1978)
f.	Holocellulose	Wise *et al.* 1946
g.	Ash	TAPPI T-15 (Anon 1978)

RESULTS AND DISCUSSION

Culm characteristics

The physical characteristics of *B. heterostachya* such as diameter, internodal length and culm wall thickness are presented in Table 1. The stems of *B. heterostachya* consist of hollow culm with no branches at lower nodes. The culms are straight and tall with average lengths of 10 - 14 m and of about 2.8 - 5.4 cm in diameters. They grow in clumps of sympodial type and are easily recognized by the irregular pale green horizontal stripes of the culms. The total number of internodes were observed to be about 31 - 40 per culm with an average internodal length and culm wall thickness of about 22 - 66 cm and 2 - 10 mm respectively. The culm sheath is about 12 cm long, covered with black hairs on the back and with lacerated edge shape of ligule.

The effects of age and height on culm characteristics are given in Table 2. *B. heterostachya* culm, like other bamboos, tapers from the base towards the tip with a decrease in diameter (r = -0.70), internode length (r = -0.26) and culm wall thickness (r = -0.76). As the bamboo ages, the thickness and internodal length increase (r = 0.25 and r = 0.02, respectively). The data given in Table 1 further disclosed that bamboo attains its maximum height within six to nine months.

Table 1. Characteristics of *B. heterostachya* culms

Property	Age (years)				
	½	1	2	3	4
1. Weight (kg)					
- *Culm*	12.82	11.06	9.51	9.84	8.43
- *Branch*	0.59	1.04	1.26	2.13	1.01
- *Leaves*	0.15	0.60	0.72	0.95	0.52
Total	13.56	12.70	11.49	12.92	9.96
2. Culm length (m)	14.79	13.45	12.78	11.83	10.39
3. Number of internodes per culm	37	36	33	33	32
4. Internode length (cm)					
- *Basal*	44.88	35.25	35.60	33.35	43.10
- *Middle*	64.92	65.70	63.40	48.40	54.48
- *Top*	26.43	27.30	24.41	27.70	29.66
5. Internode diameter (cm)					
- *Basal*	5.38	4.70	4.71	5.22	5.41
- *Middle*	4.50	4.79	4.72	4.64	5.20
- *Top*	2.76	4.04	4.01	3.41	4.12
6. Culm wall thickness (mm)					
- *Basal*	9.10	9.45	7.58	8.89	10.59
- *Middle*	5.43	5.15	6.00	6.19	7.61
- *Top*	4.08	4.31	4.56	2.41	5.58

Notes: a. Values shown are averages of 9 culms
b. Shorter culm length at ages are due to incidences of broken tips or drooping culms

Table 2. Correlation coefficients of culm characteristics with age and height of bamboo

Characteristic	Age	Height
Diameter	0.33**	-0.70**
Internode length	0.02ns	-0.26**
Wall thickness	0.25**	-0.76**

Notes: ns: not significant at $p<0.05$
**: highly significant at $p<0.01$

With age increment, mature tissues start to develop and continue to change in density, strength properties, growth of branches and established root system (Chaturvedi 1988, Abd. Latif *et al.* 1992b).

Variation in physical properties

The average physical properties of *B. heterostachya* are given in Table 3 and the respective summary of analysis of variance are presented in Table 4. Tables 5 and 6 give the respective summary of Duncan's Multiple Range Test and correlation coefficients of different physical properties with age, height and culm characteristics of the bamboo. For convenience, each property is discussed separately below. The physical properties discussed are the variation in initial moisture content, oven-dry density and shrinkage.

Table 3. Physical properties *of B. heterostachya*

Portion	Age (years)				
	½	1	2	3	4
			Moisture content (%)		
Basal	122.5	116.3	109.1	127.1	120.2
Middle	157.8	132.1	128.0	126.6	136.5
Top	167.7	122.1	115.6	92.1	130.5
			Oven-dry density (g/cm^3)		
Basal	0.49	0.52	0.52	0.48	0.49
Middle	0.40	0.48	0.44	0.48	0.47
Top	0.39	0.51	0.51	0.58	0.48
			Shrinkage (%): longitudinal		
Basal	0.22	0.19	0.52	0.41	1.11
Middle	0.52	0.70	1.01	0.55	0.50
Top	0.57	0.34	0.25	0.26	0.54
			Shrinkage (%): radial		
Basal	18.11	17.16	19.09	19.18	15.10
Middle	31.13	21.92	23.10	23.49	27.25
Top	28.63	19.85	19.04	18.87	22.33
			Shrinkage (%): tangential		
Basal	10.57	8.20	9.17	9.06	9.63
Middle	12.53	10.88	9.22	6.83	8.06
Top	11.80	7.73	5.66	5.12	6.53
			Shrinkage (%): diameter		
Basal	10.35	9.50	7.89	7.61	7.83
Middle	10.13	7.61	8.39	9.61	8.86
Top	8.27	6.99	7.16	4.88	8.89
			Shrinkage (%): volumetric		
Basal	35.75	32.28	33.36	34.08	28.33
Middle	44.46	35.49	35.30	33.56	30.22
Top	35.72	30.22	29.53	20.98	27.20

Table 4. Summary of analysis of variance on physical properties *of B. heterostachya*

Source of variation	df	Mean squares and statistical significance						
		Moisture content	Density	Shrinkage				
				Longi-tudinal	Radial	Tangen-tial	Diameter	Volume-tric
Age	4	1.2E5**	0.2**	10.3**	1.4E3**	1.7E3**	5.2E2**	3.5E3**
Height	2	6.2E3*	0.1ns	1.7ns	3.9E2**	3.2E1ns	1.5E2*	1.3E2**
Age x Height	8	6.0E3**	0.1ns	1.2ns	1.0E2*	1.0E1ns	1.4E2*	1.5E2**

Notes: ns= not significant at p<0.05 *= significant at p<0.05 **= highly significant at p<0.01

Table 5. **Duncan's Multiple Range test on the physical properties of bamboo**

Duncan's mean	Age (years)					Portion		
	½	1	2	3	4	Basal	Middle	Top
Moisture content (%)	149.3a	123.5a	117.6a	115.3 a	129.1a	143.8a	158.9a	167.8a
Oven-dry density (g/cm^3)	0.43a	0.50bc	0.49bc	0.52c	0.48bc	0.43a	0.46a	0.47a
Shrinkage (%):								
a. Longitudinal	0.44a	0.41a	0.45a	0.41a	0.72a	0.69a	0.94a	1.09a
b. Radial	25.96a	19.64a	20.41a	20.51a	21.56a	21.13a	26.94a	25.75a
c. Tangential	11.63b	8.94b	8.01ab	7.07a	8.07ab	10.32a	13.25a	9.73a
d. Diameter	16.25b	8.03a	7.81a	7.36a	8.53a	13.04a	12.95a	11.48a
e. Volumetric	38.64b	32.66a	32.72a	29.54a	28.58a	36.98a	39.40a	35.99a

Note: Means followed by the same letter (s) within the same row differ insignificantly at $p<0.05$

Table 6. **Summary of correlation coefficients of physical properties with age, height and culm characteristics of *B. heterostachya***

Parameter	Physical properties						
	MC	Density	Shrinkage				
			Longitudinal	Radial	Tangential	Diameter	Volumetric
Age	-0.57**	0.50**	-0.19*	-0.49**	-0.63**	-0.47**	-0.57**
Height	0.11ns	-0.04ns	0.07ns	0.16ns	-0.06ns	-0.03ns	-0.03ns
Internode length	-0.12ns	-0.04ns	0.08ns	-0.02ns	-0.07ns	0.10ns	-0.03ns
Culm:							
a. Diameter	-0.33**	0.24**	-0.07ns	-0.34**	-0.25**	-0.21*	-0.22*
b. Wall thickness	-0.24**	-0.21*	-0.13ns	-0.25**	-0.15ns	-0.16ns	-0.19*

Notes: ns=insignificant at $p<0.05$ *=significant at $p<0.05$ **=highly significant at $p<0.01$

Moisture content

The initial moisture content of *B. heterostachya* varies significantly with age, height and the interaction of age and culm height. In general, it tends to decrease with increases of age (r=-0.57) but insignificantly increases with height (r = 0.11). The initial moisture content, regardless of age and height, varies between 92.1 to 167.7 percent. The lowest and highest mean initial moisture content were observed in the respective top portions of the three-year-old (92.1 percent) and the half-year-old culms (167.7 percent), respectively. While the lowest moisture content at the top of the three-year-old bamboo could be associated with the decrease in percentage of parenchyma cells (the site of water storage) within the top portion of the culm (Liese 1987, Abd. Latif & Mohd. Zin 1992a), the latter is probably due to the thin-walled fibres and lesser concentration of vascular bundles distributed in the immature tissues of the younger bamboos (Abd. Latif & Mohd. Tamizi 1992).

The initial moisture content of *B. heterostachya* tends to remain stable or slightly decreases after six months to three-year-old but seems to increase again at the age of four-year-old. While the decrease in moisture content after six months (juvenile stages) may be related to its growth establish -ment (such as the development of branches and leaves), the increase after three years old (mature stages) might be due to its lower transpiration rate which is closely associated to the reduction of the total above ground biomasses (Table 1) (Liao 1990, Noggle & Fritz 1979).

With regards to culm height from bottom to top, it appears that density of bamboo does not vary much with height but it slightly tends to have a lower value near the top of the culm (r = -0.04) especially at the age of less than one-year-old. This could be due to the higher percentage of moisture content within the immature tissues. The higher oven-dry density of the top portion of the bamboo culm could be attributed to the gradual decrease in the actual number and size of the vascular bundles, i.e. they get close together with thinner culm walls (r = -0.21) towards the top thus reduce the initial moisture content but increase the density (Grosser & Liese 1971, Abd. Latif & Mohd. Tamizi 1992, Abd. Latif & Mohd. Zin 1992 b).

Shrinkage

All the shrinkage values of *B. heterostachya* vary significantly with age, height (except for longitudinal and tangential shrinkages) and the interaction of age and culm height (except for longitudinal and tangential shrinkages) (Table 4). Regardless of age and height, the shrinkage values ranged from 0.19 - 1.11 percent (longitudinal), 15.10 - 31.13 percent (radial), 5.12 - 12.53 percent (tangential), 4.88 - 10.35 percent (diameter) 20.98 - 44.46 percent (volumetric). The results (Table 5 and 6) further show the magnitudes of shrinkage are almost similar in that they generally decrease with age and culm height thus indicating that the dimensional stability of the top portion and older bamboo were much greater than that of the basal and young ones. These phenomena are probably correlated with high density but low initial moisture content within the older bamboo; and higher amount of vascular bundles per square unit within the top portion (smaller diameter and thinner wall) of the culm (Abd. Latif & Mohd. Tamizi 1992).

The norm that the shrinkage in tangential direction is highest than the radial as specified in wood (Panshin & De Zeeuw 1970) and some Malaysian bamboos (Abd. Latif & Mohd. Zin 1992a and b) seems contradicted with the results obtained in this study. The ratio of tangential to radial shrinkage was found to be within the range of 0.34:1 (three-year-old) to 0.46:1 in the half-year-old culm. Espiloy (1987) in her study on *B. blumeana* and *G. levis* also found similar patterns of variation. As mentioned by Sulthoni (1989), this order of magnitude of shrinkage is still questionable and seems required to be studied further. From the utilization point of view, bamboo may shrink less than timber. As argued by Liese (1987), this reflects the properties of the parenchymatous tissue of bamboo which shrink less, while the vascular fibres shrink as much as those in the timber of the same density. Compared to wood, *B. heterostachya* seemed to have better dimensional stability with maturity.

Proximate chemical analysis

The approximate chemical composition of buluh galah are tabulated in Table 7. The analysis of variance and Duncan Multiple Range tests on the effects of age and culm height on the chemical properties are shown in Tables 8 and 9 respectively.

The results indicate that the contents of all the chemical components of *B. heterostachya* varied significantly with age and height (except for cold water solubles, holocellulose and ash contents). The contents, however, generally increased with age (except for cold water solubles and holocellulose content) but decreased along the culm height (except for lignin, holocellulose and ash contents).

The holocellulose content, regardless of age and height, varied from about 68 to 80%. The results also indicate that the increase in holocellulose content within and between age and culm height was usually accompanied by a decreasing amount of water solubles contents. Abd. Latif *et al.* (1994) in their study on one- to three-year-old culm of *G. scortechinii* also found a similar pattern. The highest and lowest mean holocellulose contents were observed in the top portion of the one-year-old culm (79.5%) and the basal portion of the two-year-old culm (68.8%). Duncan's Multiple Range test (Table 9) further revealed that eventhough the holocellulose content differed insignificantly with culm height, its value was lowest in the middle than the basal and top portions (71.66, 71.82 and 71.94% respectively); and was higher in the younger than the older culms (76.47 and 69.90% of the respective one- and four-year-old culm). While the higher holocellulose content of the younger culms could be due to its active developmental stage, the lower values observed in the older ones may be due to the regeneration processes. By comparing the holocellulose content of *B. heterostachya*

Table 7. Chemical compositions of *B. heterostachya*

Age (yrs)	Portion	Cold water solubles (%)	Hot water solubles (%)	Alcohol-benzene solubles (%)	1% NaOH solubles (%)	Lignin (%)	Holo-cellulose (%)	Ash (%)
1/2	Basal	4.5	6.1	3.1	23.4	20.9	73.5	2.8
	Middle	5.6	8.4	2.2	23.5	20.4	74.3	2.8
	Top	3.8	6.6	2.0	21.7	20.7	73.7	2.9
1	Basal	1.1	2.5	3.9	18.1	21.9	77.6	3.9
	Middle	2.2	4.7	1.9	21.4	21.7	76.0	4.5
	Top	2.8	3.6	2.5	19.3	21.5	79.5	4.2
2	Basal	4.9	6.3	1.6	19.0	23.1	68.8	2.7
	Middle	5.8	5.8	1.9	21.6	22.4	69.1	3.3
	Top	5.3	5.3	1.4	20.9	22.3	70.0	3.9
3	Basal	6.0	6.3	1.6	19.0	23.1	68.8	3.8
	Middle	6.4	6.9	3.3	26.8	19.7	69.4	3.3
	Top	5.9	6.1	2.7	24.6	21.3	70.2	2.7
4	Basal	7.3	9.1	3.0	28.0	20.0	70.0	4.4
	Middle	3.2	7.2	2.9	26.4	20.7	69.7	4.3
	Top	4.7	6.1	2.7	27.7	22.5	70.1	5.3

Table 8. Analysis of variance on the chemical properties of *B. heterostachya*

Source of variation	df	Mean squares and statistical significance						
		Cold water solubles	Hot water solubles	Alcohol benzene solubles	1% NaOH solubles	Lignin	Holo-cellulose	Ash
Age	4	66.19**	26.15**	11.74**	134.80**	10.36**	346.50**	68.60**
Portion	2	0.82ns	5.38*	5.60*	11.14**	4.51*	1.12ns	3.61ns
Age x portion	8	13.60**	3.82*	4.71**	5.82**	2.30ns	6.25**	9.16**

Notes: ns=insignificant at $p<0.05$ * =significant at $p<0.05$ **=highly significant at $p<0.01$

(68-80%) with those of 59-85% in Malaysian timbers (Khoo & Peh 1982), this bamboo, nevertheless, indicates its potential as an excellent material to be used in pulping.

The highest and lowest mean lignin contents were observed in the basal (23.1%) and middle (19.7%) portions of the two- and three-year-old culm respectively. Table 7 of the Duncan's test indicated that the amount of lignin increased from 20.6 in the half-year-old culm to 22.57% in the two-year-old culm, decreased to 20.82% in the three-year-old but increased again (eventhough differs insignificantly) to 21.3% in the four-year-old culm. This could be due to the fact that the full lignification of the bamboo culm is completed within one growing season with no further significant aging effects (Abd. Latif *et al.* 1994). The amount of lignin

Table 9. Duncan Multiple Range test on the effects of age and culm height on chemical composition

	Cold water solubles (%)	Hot water solubles (%)	Alcohol benzene solubles (%)	1% NaOH solubles (%)	Lignin (%)	Holo-cellulose (%)	Ash (%)
Age (years)							
½	4.60b	7.05ab	2.44a	22.85c	20.63b	73.78b	2.83d
1	2.05c	3.63c	2.80a	19.60d	21.65ab	76.47a	4.21b
2	5.34ab	5.80b	1.66b	20.45d	22.57a	69.02d	3.31c
3	6.13a	6.46ab	2.83a	25.23b	20.82b	69.87c	3.28c
4	5.06b	7.48a	2.88a	27.33a	21.30b	69.90c	4.66a
Portion							
Basal	4.77a	6.09ab	2.82a	22.55b	21.61a	71.82a	3.54a
Middle	4.64a	6.61a	2.47ab	23.91a	20.94a	71.66a	3.63a
Top	4.50a	5.55b	2.28b	22.82b	21.63a	71.94a	3.80a

Note: Means having the same letter down the column differ insignificantly at $P<0.05$

tended to decrease from basal (21.61 %) towards the middle (20.94%) but increased again to the tip (21.63%). This finding is contradicted to those reported in bamboos from China (Chen *et al.* 1987). As mentioned by Liese (1987), this reflects the individual characteristics of the bamboo itself. The lower mean lignin content of *B. heterostachya* (about 20-23%) than those of 24-28% in *G. scortechinii* (Abd. Latif *et al*., 1994), nevertheless, is within the range of that of four Indian bamboos that are widely used for papermaking (Subash & Sathapathy, 1990).

The ash content of *B. heterostachya* which ranged from 2.73 to 5.27% exceeds those of Malaysian hardwoods (0.1 to 2.5%) (Khoo & Peh, 1982) and *G. scortechinii* (1.09 to 1.18%), the most commonest bamboo species used in Peninsular Malaysia, but falls within the ranges of bamboos from India, Japan, Burma, Indonesia and Philippine (0.8 to 9.7%) (Semana *et al.* 1967). Since the ash content is commonly associated with the amount of silica in material like bamboo, thus affecting its working properties (Wong 1976), the selection of this material with its relatively high silica content for specific products such as furnitures, structural components and skewers is significant.

The hot and cold water solubles are important in the evaluation of water solubles extractives such as tannin, starch, sugar, pectin and phenolic compounds within the woody materials (Janes, 1969). Higher concentrations of these water solubles extractives (1.13-7.26% and 2.54-9.14% for cold and hot water solubles respectively) may influence the durability of the bamboo materials (Plank 1951, Purusotham *et al.* 1953). Generally, the portion of the culm in each age group with lower lignin content contained higher cold and hot water solubles but those portions with higher holocellulose contents had lower cold and hot water solubles. A similar trend was also observed in *G. scortechinii* (Abd. Latif *et al.* 1994).

The alcohol-benzene solubles of *B. heterostachya* ranged from 1.39% in the top portion of the two-year-old culm to 3.96% in the basal portion of the one-year-old culm, i.e. within the range for various bamboo species (Semana *et al.* 1967, Chen *et al.* 1987) and Malaysian timbers (Khoo & Peh 1982). The highest and lowest mean percentages of alkali solubles, on the other hand, were observed in the basal portions of the respective one- (18.1%) and four-year-old culm (28%). High alkali solubles could be associated with high degradation of cellulose and high polyphenol content (Clayton 1969, Tadena & Villaneuva 1971). Compared to Malaysian hardwoods (Khoo & Peh 1982), this bamboo appears to have high alkali solubility. The relatively lower yield from chemical pulping of the material due to this property could, however, be compensated for by its high hollocellulose content.

CONCLUSION

The physical properties of *B. heterostachya* were observed to be governed significantly by the age, diameter and culm wall thickness. The initial moisture content generally decreased towards the older age but correlated insignificantly with culm height. The density, on the other hand, increased with maturity and tended to have higher values towards the top portion of the culms. Older bamboos were also found to shrank less than the younger ones.

There is wide variation in the chemical constituents within the culms of the same age group and between culms of different age groups of the half- to four-year-old *B. heterostachya* samples studied. The considerably high holocellulose content is the attractive feature of this species for pulping. The relatively high alkali solubility may, however, affect the yield in chemical pulping.

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