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The Physical Properties, Fiber Morphology and Chemical Compositions of Sweet Bamboo (*Dendrocalamus asper* Backer)

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ABSTRACT

The physical properties, fiber morphology and chemical compositions of sweet bamboo (*Dendrocalamus asper* Backer) were investigated for utilization in pulp and papermaking. The results indicated that the variation of sweet bamboo properties along the culm depended on position (base, middle and top) and part (node and internode). The basic density and moisture content of sweet bamboo were 725 kg/m^3 and 60.24%, respectively. Data collected from sweet bamboo fiber morphology illustrated its fiber dimensions as follows: fiber length 3.11 mm, fiber width 18.03 µm, cell wall thickness 6.98 µm and cell lumen 4.35 µm. The chemical compositions were holocellulose 76.33%, alpha-cellulose 68.11%, lignin 28.70% and ash 1.46%. The solubility in different solvents were alcohol-benzene 5.91%, hot water 8.04%, cold water 7.03% and 1% NaOH 24.91%. According to the results, sweet bamboo has potential as a raw material for long fiber production in Thailand.

Key words: sweet bamboo, *Dendrocalamus asper*, basic density, fiber morphology, alpha-cellulose, lignin, solvent solubility

INTRODUCTION

In 2001, the overall consumption of pulp and paper in Thailand increased at 5%, the same level of 2000. The total was 2,920,000 tons consisting of 896,000 tons for pulp. The total domestic fiber consumption was 2,661,000 tons, which increased 2% over 2000. In Thailand, only long fiber pulp was 100% imported, mainly from Canada, Chile, USA and South Africa and its demand was about 205,000 tons, 2% higher than 2000. The prediction of pulp and paper demand in the next four years was to increase by 4% per annum, especially long fiber pulp will grow from 205,000 tons in 2001 to 237,000 tons in 2005 (Thai Pulp and Paper Industries Association, 2001).

Non-wood fiber, such as bamboo, will play an important role in the world's pulp and paper industries. The fiber morphology of bamboo has average fiber length of 1.5-4.4 mm and fiber width widely ranging between 7-27 µm, with an average of 14 µm (Casey, 1979). Sweet bamboo is easy to grow and utilized more than the other bamboo species in Thailand. In 1998, there was around 153,227 rai (ca. 24,516 ha) of sweet bamboo plantations in Thailand (Pungbun Na Ayudhya, 2000).

The physical and chemical properties of raw materials directly affect pulping and bleaching processes, and pulp properties. Thus such properties of sweet bamboo should be estimated and studied.

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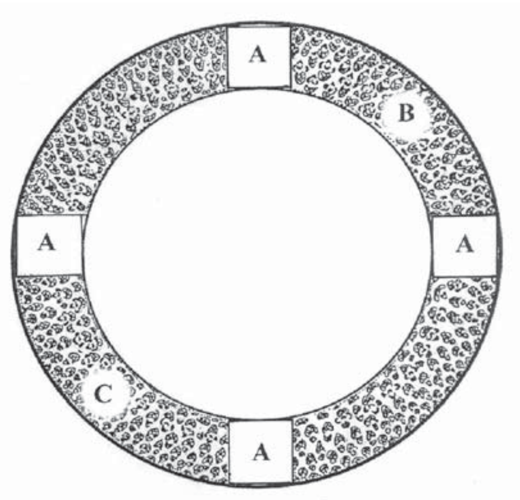
MATERIALS AND METHODS

Material preparation

Sweet bamboo of 3 years old from a bamboo plantation in Prachinburi province was used in this study. The bamboo culms were selected and cut at 0.30 m above ground. They were cut in 2 m lengths and separated into 3 positions as base, middle and top.

Analysis of sweet bamboo properties

Sweet bamboo culms were cut into disks every 2 m and divided for analysis into 2 parts as node and internode. Each disk was cut into 4 pieces for basic density and moisture content analysis according to TAPPI T258 om-02 and TAPPI T208 om-98 respectively (Figure 1). The rest of each disk was chopped into small pieces and milled to wood meal with a laboratory mill. Wood particles were screened and the accepted particles (over 60 mesh and under 40 mesh) were collected for chemical analysis as following: holocellulose (Wise method), alpha cellulose content (TAPPI T203 om-99), ash content (TAPPI T211 om-93), and lignin content (TAPPI T222 om-02). The solubility of sweet bamboo was also investigated, namely, water solubility (TAPPI T207 cm-99), 1% NaOH solubility (TAPPI T212 om-98), and alcohol-benzene solubility (TAPPT T204 cm-97). Franklin's method was used for fiber maceration and then continued to fiber length, fiber width, cell wall thickness and cell lumen measurement.



A = Basic density
B = Chemical compositions
C = Fiber morphology

Figure 1 Schematic of sweet bamboo disk for analysis of physical properties, fiber morphology and chemical compositions.

The collected data were analyzed using ANOVA and the differences of the average data were compared by Duncan's New Multiple Range Test (DMRT) at 5% level of significance.

RESULTS AND DISCUSSION

Physical properties of sweet bamboo

Table 1 shows the primary properties of sweet bamboo, namely, basic density and moisture content. The average basic density and moisture content of sweet bamboo culm were 725 kg/m^3 (610-870 kg/m^3) and 60.24% (47.3-69.71%), respectively.

The average basic density of this sweet bamboo culm was not significantly different from the work of Parkeeree (1997) which reported basic density of the same species as 730 kg/m^3. The basic density related to specific gravity by calculation and sweet bamboo specific gravity in this study was 0.61-0.87 g/cm^3. Liese (1995) found that the bamboo specific gravity varied from about 0.5 to 0.9 g/cm^3.

In the vertical direction both physical properties of sweet bamboo were significantly different, i.e. moisture contents decreased from base to top of bamboo culm but basic densities increased from base to top. There were no differences between node and internode for a given position.

Fiber morphology of sweet bamboo

The anatomy of sweet bamboo is illustrated in Figure 2 (A) with similar cell

Table 1 Basic density and moisture content of sweet bamboo culm.

Bamboo disk	Basic density (kg/m^3)	Moisture content (%)
Node (top)	870 ^{A}	52.70 ^{C}
Internode (top)	830 ^{A}	47.30 ^{C}
Node (middle)	740 ^{B}	64.07 ^{A,B}
Internode (middle)	660 ^{B,C}	62.19 ^{B}
Node (base)	640 ^{C}	69.71 ^{A}
Internode (base)	610 ^{C}	65.44 ^{A,B}
Average	725	60.24

Means in the same column followed by the same letter are not significantly different as determined by DMRT at 5% level.

structure as compared with other bamboo species, i.e. it comprised parenchyma ground tissue and vascular bundles. Liese and Grosser (2000) found that the vascular bundles of bamboo generally consisted of phloem, two metaxylem vessels and the protoxylem with attached sclerenchyma sheaths (fiber bundles or fiber stands) and the bundle type depended on the species. Sweet bamboo vascular bundle type was a mix between type III and IV. It consisted of two parts or three parts of the central vascular strand with four smaller sclerenchyma sheaths and one (type III) or two (type IV) isolated fiber bundles which were located at the phloem (type III) or the phloem and protoxylem side (type IV).

Figure 2 (B) shows the characteristic of sweet bamboo fiber, i.e. long, narrow, with thick cell wall and it had blunt or end point. The fiber dimensions of sweet bamboo are summarized in Table 2. It was found from this experiment that the average fiber length of sweet bamboo was 3.11 mm (2.15-3.99 mm) which was comparable to long fiber of softwood and much longer than short fiber of hardwood. For example, the fiber lengths of softwoods, black spruce, *P.* radiate and southern pine were 3.5, 3.0, and 4.6 mm, respectively (Smook, 1997), while fiber length of the hardwood, *E. camaldulensis* was 1.1 mm (Pattanopast, 1995). For a given position, the fibers in the node were considerably shorter than those in the internode. This result was similar to the study of Yulong and Liese (1997) which reported the fiber length of bamboo *Phyllostachys edulis*. The results show that the longest fiber was in internode of the middle part whereas there were no significant differences of fiber length in each node along sweet bamboo culm.

The fiber width and cell lumen of sweet bamboo fibers were 18.03 µm (16-23 µm) and 4.35 µm (4-5 µm), respectively. Its fiber was slender and cell lumen was smaller than those of softwood (Figure 2 (C)). Sweet bamboo cell wall thickness was 6.98 µm (6.04-9.38 µm) which is comparable to softwood cell wall thickness. It was demonstrated that black spruce and southern pine had average cell wall thicknesses of 6.50 µm and 9.50 µm, respectively (Smook, 1997). Thus, sweet bamboo cell wall was considered to be very thick. The fiber width, cell lumen and cell wall thickness were not much varied along sweet bamboo culm, except for nodes of the middle part, which had wider fiber and thicker cell wall than other sections.

Chemical compositions of sweet bamboo

The important chemical compositions of sweet bamboo are given in Table 3. The amount of these chemical components affect pulp qualities, hence they were used to estimate the suitable pulping and bleaching conditions for appropriate pulp application. The term of holocellulose refers to carbohydrate content in fiber that includes alpha-cellulose. Holocellulose and alpha-cellulose of sweet bamboo were 76.33% and 68.11%, respectively. The high amount of both components can be used to estimate that high pulp yield and good pulp strength would be obtained. Lignin content of sweet bamboo was 28.70% which is comparable to softwood. Lap (1999) reported that lignin content in mixed bamboo was 27% and it was difficult to bleach. His work indicated that five bleaching sequences as $OD_0ED_1D_2$ were required to reach the target brightness above 80%ISO.

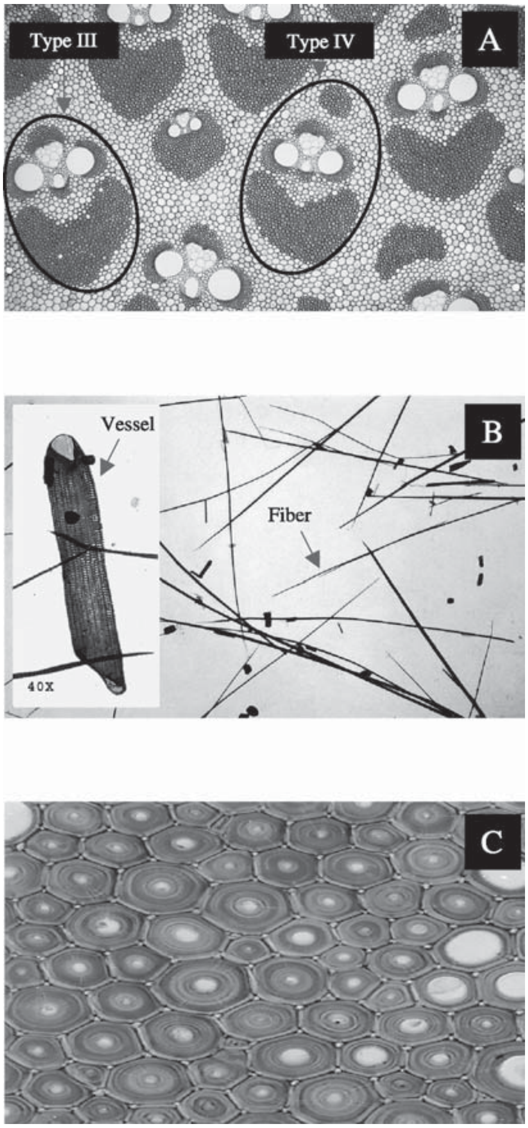


Figure 2 Anatomy of sweet bamboo.
(A) Vascular bundles (20X)
(B) Vessels (40X) and fibers (10X)
(C) Cell walls and cell lumens of fibers (40X)

The major components of sweet bamboo were significantly different between nodes and internodes in a given position. Holocellulose content of internodes was slightly higher than that of nodes, whereas lignin content of nodes was higher than that of internodes. The reason for that is the sweet bamboo fiber morphology has the nodal part with thicker cell wall than the internode part and bamboo lignin content depends on bamboo species. Muphy and Alvin (1997) indicated that bamboo thick cell wall had higher lignin content than bamboo thin cell wall and the result was clear in mature bamboo. However, this result was in contrast to Liese's (1995) work which reported that the nodes contained less lignin than the internodes.

The average ash content in sweet bamboo was 1.46%. The ash contents of nodes were significantly higher than those of internodes, and decreased from top to base. Silica was an important part of ash content in bamboo. Liese (1995) found that silica content varied, on average, from 0.5-4%, increasing from bottom to top. The quantity of sweet bamboo ash content investigated by Satrakhom (1972) was 4.16%. Most silica was deposited in the epidermis, whereas the nodes contained little silica and the tissues of the internodes almost none. Silica content mainly affects pulping and chemical recovery processes (Dranfield and Widjaja, 1995).

Sweet bamboo solubility in various solvents is presented in Table 4. The average alcohol-benzene solubility, hot water solubility and cold water solubility of sweet bamboo were 5.91%, 8.04% and 7.03% respectively. The solubility in different solvents indicated the extractive contents, which were not cell wall components. Ethanol-benzene extractable content of the wood consists of waxes, fats, resins, photosterols, non-volatile hydrocarbons, low-molecular-weight carbohydrates, salts, and other water-soluble substances. The cold-water removes a part of extraneous components, such as inorganic compounds, tannins, gums, sugars, and coloring while the hot-water removes, in addition, starches (TAPPI, 2002). The solvent solubility of sweet bamboo internodes was significantly higher than that of nodes, which means that bamboo nodes had lower extractives than internodes. Liese (1995) found that bamboo nodes contained less water soluble extractives than internodes.

The 1% NaOH solubility of pulp indicates the extent of cellulose degradation during pulping and bleaching processes and has been related to strength and other properties of pulp

Table 2 Fiber morphology of sweet bamboo.

Bamboo disk	Fiber length (µm)	Fiber width (µm)	Cell lumen (µm)	Cell wall thickness (µm)
Node (top)	2.24 D	19.43 B	4.29 B	7.75 B
Internode (top)	3.50 C	16.37 C	3.94 C	6.22 C
Node (middle)	2.15 D	23.52 A	4.76 A	9.38 A
Internode (middle)	4.54 A	16.27 C	4.19 B	6.04 C
Node (base)	2.23 D	17.39 C	4.79 A	6.30 C
Internode (base)	3.99 B	16.87 C	4.14 B,C	6.37 C
Average	3.11	8.03	4.35	6.98

Means in the same column followed by the same letter are not significantly different as determined by DMRT at 5% level.

Table 3 Chemical compositions of sweet bamboo.

Chemical composition (%)	Bamboo disks						
	Node (Top)	Internode (Top)	Node (Middle)	Internode (Middle)	Node (Base)	Internode (Base)	Average
Holocellulose	75.65 D	76.72 B	76.36 C	77.36 A	75.59 D	76.31 C	76.33
Alpha-cellulose	67.07 C	67.33 C	68.53 B	67.67 C	68.39 B	69.64 A	68.11
Lignin	30.08 C	26.47 E	30.86 A	27.19 D	30.41 B	27.21 D	28.70
Ash	2.29 A	1.07 D	1.95 B	0.95 E	1.59 C	0.92 E	1.46

Means in the same row followed by the same letter are not significantly different as determined by DMRT at 5% level.

Table 4 The solubility of sweet bamboo.

Solubility (%)	Bamboo disks						
	Node (Top)	Internode (Top)	Node (Middle)	Internode (Middle)	Node (Base)	Internode (Base)	Average
Alcohol+benzene solubility	5.55 E	7.44 A	6.67 B	6.18 C	3.75 F	5.85 D	5.91
Hot water solubility	7.39 D	9.63 A	7.51 D	8.36 C	6.47 E	8.86 B	8.04
Cold water solubility	5.10 E	6.87 B	5.43 D	14.05 A	4.23 F	6.50 C	7.03
1% NaOH solubility	26.78 A	25.82 B	24.38 D	23.40 F	24.99 C	24.07 E	24.91

Means in the same row followed by the same letter are not significantly different as determined by DMRT at 5% level.

(TAPPI, 2002). It can be seen from Table 4 that sweet bamboo was more soluble in alkaline solution. Its solubility in 1% NaOH was 24.91%, which was higher than that of wood.

CONCLUSION

This study of some important properties of sweet bamboo demonstrated that its fiber could be comparable to softwood and could be used for substitution of long fiber from abroad. Hence, the appropriate pulping and bleaching conditions for sweet bamboo should be further investigated, including pulp and paper strength properties. Positive result will help promoting sweet bamboo as a new raw material for pulp and paper industries in Thailand.

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