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Chemical composition and potential for utilization of *Dendrocalamus barbatus*

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Abstract: This paper reports on the feasibility of utilizing *Dendrocalamus barbatus* as a substitute for wood fiber, based on studies on its morphology and chemical composition. The bamboo appears as wood fiber-like filaments consisting of tubular end-to-end connections of individual cells. In the population studied, each cell averaged 4.52 mm long, 20.13 μm wide, and had 7.16 μm thick cell wall, length to width ratio of about 260.89, which are much more than that of other bamboo species. The chemical composition was 2.37 per cent ash, 1.24 per cent SiO_2, 10.26 per cent extractable by 90 per cent acetone, 1.70 per cent extractable by alcohol-benzene, 19.06 per cent pentosan, 27.96 per cent lignin, 31.03 per cent NaOH (1%) soluble fraction and 58.7 per cent carbohydrate. There were low contents of cold and hot-water extractables, 18.49 per cent and 19.58 per cent, respectively. Taken together, these features suggest that *D. barbatus* has good potential as a raw material for pulp and showed clear potential as a supplement for traditional medium strength wood pulps.

Key words: Dendrocalamus barbatus, chemical composition, pulp, fiber characteristics.

INTRODUCTION

The enormous global demand for pulp (McLaren, 1996; Rhiannon *et al.*, 1999) has stimulated research into various alternative non-wood fiber resources in both developing and developed countries (Xiang, 1997; Morimoto, 1998, 1999; Kobayashi, 1999). The paper industry has an installed capacity of 2.7 million tones covering 288 small, medium and large paper mills and produced about 1.65 million tones of paper and paper board during the year 1988. China is using the most variety of non-wood fiber raw materials and is the largest country producing non-wood fiber pulp and paper in the world (Zhong, 2000). Chinese pulp and paper industry is facing multifarious problems like tough competition from imports, obsolete technology, soaring environmental problems, depreciation of money and inadequate supply of

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low-cost fiber to survive in a globally competitive market. This combination has compelled the Chinese pulp and paper industry to spend heavily on imported long wood fibers. Bamboo is considered to be a unique raw material due to its quick growth, easy availability, straightness, smoothness, *etc*. It is used for various purposes such as construction of rural houses, ladders, mats, baskets, pipes, handicrafts, *etc*. But the highest demand is for the manufacture of paper. To meet the present and future demands and also to use the existing bamboo resources judiciously and efficiently, feasibility of using *Dendrocalamus barbatus* Hsueh and D. Z. Li in pulping and papermaking was studied.

MATERIALS AND METHODS

Preparation of the bamboo samples

Samples of *D. barbatus* culms of different ages were collected from the aquaculture ponds at the bamboo resource collection of Xishuangbanna Tropical Botanic Garden, Chinese Academy of Science, Yunnan, China. All the samples were chipped in a pilot plant chipper and screened to standard size, and transported to the laboratory in Beijing, rinsed with water and air-dried.

Morphological characteristics

Samples of these chipped specimens were taken in Petri dishes and observed under the microscope for measurement of fiber length, width and wall thickness (TAPPI, 1971). These data were analyzed statistically and their slenderness ratio calculated.

Chemical composition

The analysis was conducted in accordance with the TAPPI (1971) standard method. Cleaned and dried *D. barbats* culm specimens were placed in a Wiley mill and ground into powder. The powder was sieved through mechanical sieve sets to provide the portion passing 40 meshes and retained on the 100-mesh screen. Cold water extractives, hot-water extractives, alcohol-benzene extractives, acetone extractives, 1 per cent NaOH solution extractable, acid-insoluble fraction, and ash were determined. The Klason lignin determination was based on an improved method (the acid soluble fraction was not determined). Holocellulose determination was done in accordance with the Wise method, with 1 to 5 cycles of chlorination reaction. The pentosan content of the pulp was determined according to the acetic acid aniline colorimetric method for furfural of the JIS P8011 standard method (JIS, 1962). Total carbohydrate content was determined with the phenol-sulfuric acid color-metric method (Dubois *et al*., 1956) (using glucose to construct calibration line). Crude protein determination was based on the improved Kjeldahl method. The data were subjected to statistical analysis.

RESULTS

Morphology and fiber characters

Knowledge of the morphological characteristics of fibers helps in determining the suitability of a raw material for paper making. Fiber length of bamboo is well documented. Fiber length is an important criterion in identifying the fitness of the wood in pulping as it has direct correlation with the tearing strength of the paper (Bublitz, 1980).

Microscopic observations confirmed that *D. barbatus* fiber consisted of many tubular cells connected end to end to form long filaments. The average cell length was 4.52 mm, and the average width 20.13 μm. The ratio of the length to width was 260.80. The thickness of longitudinal wall was 7.16 μm (Table 1). The morphological properties of *D. barbatus* culm fibers are better than those from different bamboo species in natural bamboo forests, which are important raw material of pulp making industry in China (Table 1).

Table 1. Cell length, cell width and cell wall thickness of *D. barbatus* and other bamboo species

Bamboo species	Mean length(mm)	Mean width (μm)	Mean ratio L/W	Mean wall thickness (μm)
Dendrocalamus barbatus	4.52 ± 0.752	20.13 ±2.439	260.80 ± 16.216	7.16 ± 0.847
D. giganteus	3.39	-	-	-
D. hamiltonii	3.36	-	-	-
D. sinicus	2.90	16.05	180	5.7
Bambusa polymorpha	4.19	-	-	-
Neosinocalamus affinis	2.00	16.2	123	6.6
Phyllostachys pubescens	1.99	15.0	133	5.7

Chemical composition

Proximate chemical analysis revealed *D. barbatus* is better suited for pulp and paper with higher holocellulose, lower SiO_2 content and normal lignin content. (Table 2). The ash content of *D. barbatus* was about 2.37 per cent. The content extracted by 90 per cent acetone and alcohol-benzene was 10.26 and 1.70 per cent respectively. The bamboo meal extracted with benzene alcohol had 9.1 per cent acid insoluble fraction (ash-free) (Table 3). Cold and hot water extractables amounted to 3.19 and 5.58 per cent respectively; that extractable by 1 per cent NaOH solution was 31.03 per cent and pentosan was 19.06 per cent (Table 3). The extracted meal had 74.2 per cent total carbohydrates (calibrated), while the unextracted meal yielded 78.1 per cent total carbohydrates (calibrated) (Table 3). However, the pentosans were higher than the hardwood species, besides 1 per cent alkali solubles were almost similar with that of other bamboos.

Table 2. Percentage (dry weight) of extractable materials from *D.barbatus* using various solvents

Bamboo species	Cold water soluble	Hot water soluble	Alcohol benzene	1% NaOH	90% Acetone	100% Acetone	Ash	SiO_2
D. barbatus	3.19 ± 0.217	5.58 ± 0.362	1.70 ± 0.093	1.03 ± 4.65	10.26 ± 1.48	8.94 ± 0.983	2.37 ± 0.322	1.24 ± 0.236
D. sinicas	2.90	4.31	2.72	25.17			1.43	0.49
N. affinis	3.21	4.64	1.24	24.27	-	-	2.36	1.39
P. pubescens	2.38	5.96	1.66	30.98			1.16	1.68

Table 3. Chemical component (% dry weight) of *D.barbatus* for total carbohydrates based on glucose

Bamboo species	Crude protein	Acid insoluble	Pentosans	Lignin	Cellulose	Total carbohydrate
D. barbatus	9.7 ± 1.04	9.1 ± 1.27	19.06 ± 3.06	27.96 ± 4.83	48.62 ± 7.15	78.1[a] 74.2[b] 59.2[c] 37.6[d]
D. sinicas	-	-	22.40	27.68	45.52	-
N. affinis	-	-	21.12	30.67	45.50	-
P. pubescens	-	-	19.46	24.52	44.35	-

[a] Raw material; [b] Meal previously treated with benzene-alcohol solution
[C] Total carbohydrate after hot water extraction; [D] Total carbohydrate after cold water extraction

The holocellulose preparations were further subjected to total carbohydrate determination, so as to confirm the accuracy of the Wise method. The holocellulose content of *D. barbatus* determined by the modified Wise method gave a range of values depending upon the number of chlorination cycles. The highest value (46.2%) was from specimens treated for 1 h with hypochlorite solution, and the lowest value (39.3%) was from specimens after 5 cycles of reaction (Table 4). Total carbohydrate in holocellulose preparations after the 3rd and 4th cycles reached 92 per cent.

The results show that after the first reaction, the total carbohydrate fraction of W1 rose from 74.2 per cent for W0, and 78.1 per cent for un-extracted bamboo meal to 84.7 per cent. This means that the net carbohydrate fraction of W1 is 59.2 per cent. The result suggests that after holocellulose preparation, some of the low molecular weight polyoses were dissolved in the aqueous acetic acid and hypochlorite solution. The total carbohydrate fraction increases with increment in number of cycles reaching 92.1 per cent in W3, whereas the net carbohydrate fraction of W3 becomes 48.4 per cent, a gain of almost 7.5 per cent compared with W1. This suggests that as the number of reaction cycles increases, the purity of the holocellulose preparation also increases, while the yield reduces more slowly approaching the optimal condition. After the 4th cycle of reaction (W4), the total carbohydrate fraction reached a maximum of 95.1 per cent, whereas the 5th cycle yielded less total carbohydrate (92.6%) and lower net carbohydrate (39.3%), showing excessive degradation (Table 4). The optimal reaction cycles, therefore, should be between W3 and W4. During alcohol-benzene extraction of *D. barbatus*, a part of constituent sugars may also be lost to the tune of about 2.0 per cent.

Table 4. Yield and total carbohydrate (% dry weight) of *D. barbatus* holocellose

	Yield %	Total carbohydrate %*
Wise 1st step	46.2 ± 8.51^{a}	84.7 ± 15.81^{b}
Wise 2nd step	44.6 ± 8.37^{ab}	88.6 ± 17.29^{b}
Wise 3rd step	43.7 ± 9.62^{b}	92.1 ± 20.33^{ab}
Wise 4th step	41.5 ± 10.35^{bc}	95.1 ± 24.41^{a}
Wise 5th step	39.3 ± 9.44^{c}	92.6 ± 24.27^{ab}

*Total carbohydrate based on yield of previous step of the Wise method treatment
Mean values are accompanied by standard deviation. Differences within group means were F-tested using one-way analysis of variance (ANOVA). *Post hoc* Fisher's Least-Significant-Differences Test (LSD) was used to determine if any two means within a group were significantly different (designated with different superscripts).

DISCUSSION

Traditionally, length and width of wood fibers are measured to evaluate the contact area between fibers and this also serves the indirect purpose of assessing paper properties (Dinwoodie, 1965). In general, a high length to width ratio means a larger area of contact between the fibers, and hence leads to paper of greater strength (Kibblewhite and Bawden, 1991; Kibblewhite and Uprichard, 1996). Thus. *D. barbatus* hand-sheets made from pulp with longer strands were stronger and had better physical properties. Despite the holocellulose content, *D. barbatus* can be used directly for pulp either alone or blended with wood pulp. The main reason probably lays with the composition of bamboo cell wall polyoses. Usually, when the ash content of a paper increases, its opacity also increases. *D. barbatus* has lower ash content than other bamboo, such as *D. strictus* and *B. distegia* known to have high ash content (Maheshwari and Satpathy, 1988; Chen, 2006). As the global environment tends to degenerate, a trend toward sustainable development and utilization of natural resources becomes inevitable. The use of the filamentous marine *D. barbatus* as a substitution for the depleting traditional wood fiber sources may help to reduce our dependency on forest resources and perhaps, if culture is on a sufficiently large scale, can be used for local removal of carbon dioxide.

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