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Evaluation of the Pulp and Paper Potentials of a Nigerian Grown *Bambusa vulgaris*

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Abstract: Nigerian grown *Bambusa vulgaris* was examined to determine its potential value for pulp and paper making. The fiber characteristics and chemical properties were investigated at three different stages of its maturation, namely: growing stage, maturity stage and over-grown stage. The plant was subjected to soda pulping at different operating conditions. The result showed that the specific gravity varied between 0.49 and 0.79. The fibers were 2.32-2.92mm long, 15.5-18.8μm in diameter, 8.0-10.4μm in lumen width and 3.3-4.4 μm thick. The average ash, lignin and cellulose contents were 2.80, 27.13 and 52.5% respectively. The optimum pulp yield, 40.5%, was increased to 51.5% by the addition of 60% butanol to the cooking liquor. Increase in temperature adversely affected the pulp yield while lignin solubility was greatly enhanced.

Key words: Fibre characteristic · Chemical composition · Lignin · Pulp yield · *Bambusa vulgaris*

INTRODUCTION

In Nigeria, one of the problems in pulp and paper industry is inadequate supply of long fibre pulp for paper production [1, 2]. Nigeria's paper mills were designed to utilize mixtures of short and long fibre pulp. Short fibre pulp woods are available in commercial quantities and the chemical, morphological and pulping characteristics of some of them have been reported [3-6]. However, due to climate restrictions Nigeria has not been able to grow enough softwood to locally source for long fibre pulp. As a result it became increasingly difficult to operate the pulp and paper mills in the country on economic basis because the long fibre component is at exorbitant price.

Apart from raphia palms proposed by Odeyemi [7], there exist potential to produce long fibre pulp (even at small scale basis) from some nonwoods, woody grass and agricultural products. Unlike woods, these plant are easily delignified and can be produced annually. Besides, they offer wide variety of physical and chemical properties that can be utilized to produce virtually different grades of paper. It has therefore become necessary to characterize their pulps and ascertain their suitability or otherwise for paper-making. In this way, there would be substantial savings in foreign exchange arising from reduced importation of long fibre pulp.

One of such plants is *Bambusa vulgaris* (bamboo) which is a fast growing and high yielding naturally occurring perennial, giant, woody grass. It is self-propagating plant that takes 2 to 6 years to mature depending on the species. Bamboo is popular as a raw material for pulp and paper making in many countries of the world including Malaysia, China and India [8-10]. Khristova *et al.* [11] reported that bamboo is an ideal fibre blend for bagasse pulp in any desired proportions depending upon the grade of paper to be manufactured.

Various studies have been reported on the fiber dimensions, chemical composition of different bamboo species from different countries and their suitability for commercial pulping [12-16]. The proximate chemical compositions are similar to those of hardwoods, namely, holocellulose, 60-70%, pentosans, 20-25%, hemicellulose and lignin, 20-30% and other minor constituents like resin, tannins, waxes and inorganic salts. The average fiber lengths ranged from 1.3 to 5.0mm. The species of bamboo which grows in Nigeria include *Bambusa vulgaris, B. arundinacea, B. tulda, Dendrocalamus gigantes, and Oxytenanatheria abyssinia* [6]. These bamboos are found on land owned by individuals, families, private organizations, entities, religious, educational institutions and the various tiers of governments in the country. *Bambusa vulgaris* is one of the most common species especially in the southern part of Nigeria. The country reporting data about bamboo is on going and available literature showed that its pulp and paper characteristics have not been reported [6, 17]. The present study was aimed at investigating the fiber morphology, chemical composition and soda pulping characteristics of a Nigerian grown *Bambusa vulgaris*.

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MATERIALS AND METHODS

The Study Was Conducted in 2006: Samples of *Bambusa vulgaris* were collected along the marshy paths of Abadina community and the river banks of Baptist areas of the University of Ibadan, Nigeria. The University is situated 5 miles from the centre of the major city of Ibadan on latitude 7° 23'N, longitude 3°53'E and altitude 248 m above sea level. The specie was identified at the Herbarium section of the Department of Botany and Microbiology, University of Ibadan. The plants were sampled at three different stages of maturity, namely, the growing stage (~1 year), the matured stage (2-5 years) and the over-grown stage (=6 years). The samples were manually cut into chips, sun-dried and stored at room temperature in a polythene bag.

Specific Gravity and Fiber Dimension: The specific gravity was determined using representative samples from each plant part in accordance with the ASTM standard procedure designated D 2395-89 method B [18]. Fiber dimensions were determined by reducing some representative chips of the *Bambusa vulgaris* into splints of about 20-40 mm and placed in a mixture of equal volume of glacial acetic acid and 50% hydrogen peroxide in a covered bottle. The macerated splints were disintegrated by shaking for some days to release the fibers. The fibers were mounted on a slide and the fiber length (L), fiber diameter (D), lumen width (d), and cell wall thickness of 30 samples each corresponding to the top, middle and bottom of the plant were measured under a Reichert visopan projector. The following morphological indices were determined from these measurements:

$$\text{Runkel ratio} = 2CWT/d$$

$$\text{Slenderness ratio} = L/D$$

$$\text{Flexibility coefficient (\%)} = (d/D)\times 100$$

Where:
L = Fiber length; D = Fiber diameter; d = Lumen width; CWT= Cell wall thickness

Chemical Analysis: The proportions of the chemical constituents that affect the characteristics of the plant were determined on ground samples of *Bambusa vulgaris* corresponding to the different stages of maturity. The ash contents, alcohol-benzene extractive, water and 1% soda solubilities of the samples were determined by the ASTM standard methods [19]. The Kurschner-Hoffer cellulose method [20] was used for the cellulose while the standard method of TAPPI was used for the Klason lignin [21].

Pulping Experiment: Soda cooking liquor was prepared from a standard concentrated solution of sodium hydroxide by serial dilution with de-ionized water. Soda-butanol pulping liquor was prepared by mixing equal volume of the respective solutions of sodium hydroxide with a mixture of butanolwater, 60/40 (v/v). The samples were pulped in a 10-liter electrically heated stainless steel digester. Chips from the *Bambusa* vulgaris were weighed and charged into the digester with the required amount of chemical solution at liquor to solid ratio of 6:1 and 10:1. The digester was heated to the operating temperatures (150 and 170°C) and time (30, 90 and 150 minutes), which was then maintained throughout the experiment. The resulting pulp was thoroughly washed with tap water and the pulp yield was determined gravimetrically after drying at 102°C to constant weight in the oven. The pulps were analyzed for Kappa number as described in TAPPI standard [22].

RESULTS AND DISCUSSION

Specific Gravity: *Bambusa vulgaris* was characterized with high values of specific gravity (Table 1). The average specific gravity ranges between 0.58-0.69 which fell within the range of 0.3-0.8 reported for bamboo elsewhere [12]. The high density value is an indication of normal liquor to solid ratio, impregnation and cooking periods and high pulp yield by digester volume [23]. It was observed that the average specific gravity of the growing bamboo was significantly lower than that of the matured and over grown plant. This may be due to the thick cell wall which occurs mostly in the early years of it growth.

Fiber Characteristics: The fiber dimension is presented in Table 2. The fiber lengths of *bambusa vulgaris* varies from 2.37-2.92mm. This indicates that strong paper with good tearing resistance could be obtained from the plant since a strong relationship exists between the strength properties of pulp and the fiber length constituting the pulp [24]. Thus on the basis of fiber length, the bamboo

Table 1: Specific gravity of the Bambusa vulgaris

Bambusa vulgaris	Range	Average
Growing stage	0.49-0.64	0.58±0.08
Matured stage	0.62-0.79	0.69±0.09
Over-grown stage	0.57-0.66	0.62±0.05

Table 2: Fiber characteristics of *Bambusa vulgaris*

Bamboo stage	Sampled parts	Fiber length (mm)	Fiber diameter (μm)	Lumen width (μm)	Cell wall thickness (μm)	Runkel ratio	Slenderness ratio	Flexibility coefficient
Growing	Top	2.48±0.7	18.4±4.6	10.4±3.0	4.02±1.2	0.77	134.8	56.5
	middle	2.48±0.7	17.5±4.0	9.7±2.7	3.88±0.9	0.80	141.7	55.4
	Bottom	2.47±0.7	17.8±3.9	9.8±2.5	4.00±1.1	0.81	138.8	55.1
Matured	Top	2.48±0.7	16.8±3.5	8.0±2.7	4.42±0.8	1.11	147.6	47.6
	Middle	2.52±0.8	16.3±3.7	8.5±2.6	3.92±1.1	0.92	154.6	52.1
	Bottom	2.38±0.7	16.6±3.4	9.3±2.6	3.67±1.0	0.79	143.4	56.0
Over-grown	Top	2.37±0.6	18.8±4.4	10.4±2.4	4.21±1.3	0.81	126.1	55.0
	Middle	2.92±0.9	17.6±3.6	9.0±2.2	4.31±1.1	0.96	165.9	51.1
	Bottom	2.56±0.6	15.5±4.9	9.0±2.8	3.29±1.3	0.73	165.2	58.1

Table 3: Chemical composition of *Bambusa vulgaris*

Bamboo stage	Growing	Matured	Over-grown
Ash (%)	3.50	1.60	3.32
Acid-insoluble lignin (%)	26.5	26.0	29.0
Acid soluble lignin (%)	3.50	2.0	2.50
Cellulose (%)	49.9	55.8	51.8
Alcohol-benzene solubility (%)	1.71	4.70	1.19
Cold water solubility (%)	3.88	3.98	5.55
Hot water solubility (%)	6.14	5.37	7.28
1% NaOH solubility (%)	25.1	19.6	20.1

is on the lower range of softwoods (2.5-4.6 mm). Similar fiber length ranges of 1.5 to 2.9mm and 1.46 to 2.91mm were obtainfor bamboos in Sudan and Thailand respectively [15, 16]. It was generally observed that there was no significant difference in the fibre dimension of Bambusa vulgaris at the various stages of maturity. This implied that the plant could be utilized at various stages of it growth. The fiber diameter and lumen width was within the range reported for coniferous and commercial pulp woods [9, 24], while the cell wall thickness (3.29-4.31 μm) on the other hand was closed to 3.7 μm reported for bamboo in Sudan [15].

The result of the morphological indices (Table 2) revealed that *Bambusa vulgaris* had average derived values. The Runkel ratio at the different stages of maturity showed that the bamboo would be good for paper making. The felting power as indicated by the slenderness ratio was highly favourable and comparable to most soft woods. The flexibility coefficients were on the average indicating bulk papers with moderate strength properties [24].

Chemical Composition: The cold water (3.88-5.55%), hot water (5.37-7.28%), alcohol-benzene (1.19-4.70%) and 1% caustic soda solubles (19.55-25.0%) as presented in Table 3 suggests the presence of high contents of inorganic compounds, tannins, gums, sugars, colouring matter and starches in the bamboo. A detail characterization of the extractives may reveal their contents and potentials. The high solubles also indicate easy access and degradation of the cell wall by weak alkali [25]. It therefore means that the alkali charge must be kept low in order to preserve the cellulose content and enhance good pulp yield. The ash, lignin and cellulose contents at different stages of maturity are shown in Table 3. The contents of ash were relatively high, especial for the growing and over-grown bamboo, although the values were within the range of 1.7-5.0% reported for bamboo and tropical species [24]. High ash content is undesirable for pulping as they affect normal alkali consumption and give problems at waste liquor recovery [23]. The cellulose contents were high and desirable and predicted good pulp yield. However, the lignin contents were high and suggested high liquor consumption and long cooking cycle.

Pulp Characteristics: The results and conditions of the pulping processes are presented in Table 4 and 5. There was a general decrease in the pulp yield and Kappa number due to an increase in the pulping time at a constant temperature and alkali charge. At a particular charge of effective alkali, pulping for 150 minutes at 170°C resulted in the lowest yield while the highest yield was recorded for the pulp made for 30 minutes at 150°C. It was

Table 4: Pulping conditions, pulp yields and Kappa number of *Bambusa vulgaris* at a liquor to solid ratio of 6: 1

Experiment No.	Soda (%)	Butanol (%)	Pulping temperature (°C)	Time-to- temperature (minutes)	Pulp yield (%)	Kappa number
1	6	-	150	30	40.5	37.9
2	6	-	150	90	33.9	31.7
3	6	-	150	150	30.7	27.0
4	8	-	150	30	35.8	31.8
5	8	-	150	90	32.6	27.2
6	8	-	150	150	25.2	23.1
7	6	60	150	30	51.5	38.1
8	6	60	150	90	46.7	35.8
9	6	60	150	150	41.0	32.5
10	6	-	170	30	28.9	27.6
11	6	-	170	90	27.3	21.2
12	6	-	170	150	27.0	21.6
13	6	60	170	30	38.6	32.6
14	6	60	170	90	34.1	25.2
15	6	60	170	150	32.7	21.7

Table 5: Pulping conditions, pulp yields and Kappa number of *Bambusa vulgaris* at a liquor to solid ratio of 10:1

Experiment No.	Soda (%)	Butanol (%)	Pulping temperature (°C)	Time-to- temperature (minutes)	Pulp yield (%)	Kappa number
16	6	-	150	30	36.5	32.8
17	6	-	150	90	30.5	25.7
18	6	-	150	150	28.0	25.4
19	8	-	150	30	34.7	29.3
20	8	-	150	90	28.3	24.1
21	8	-	150	150	24.8	20.0
22	6	60	150	30	46.9	32.8
23	6	60	150	90	43.6	31.3
24	6	60	150	150	40.1	26.3
25	6	-	170	30	27.6	21.4
26	6	-	170	90	25.8	19.2
27	6	-	170	150	25.3	18.3
28	6	60	170	30	33.2	26.0
29	6	60	170	90	33.0	22.9
30	6	60	170	150	29.9	18.3

observed that about half of the original material was dissolved after 30 minutes of pulping. This may be attributed to the presence of high phenolic content or high amount of lignin – carbohydrate complexes in the plant [26]. It may also be due to the solving power of caustic soda. Further decrease in both pulp yield and lignin content was gradual especially when the alkali content was increase from 6 to 8%. Addition of 60% butanol to the pulping liquor resulted in a gradual increase in the pulp yield. For example, in Table 4, there was an increase in the pulp yield from 40.5% (experiment 1) to 51.5% (experiment 7). A similar trend was also observed in experiments 16 and 22 at liquor to solid ratio of 10:1 (Table 5). The presence of butanol in the pulping liquor thus reduces the solving power of the alkali and it degradation effect on the cellulose fibers even at high temperatures.

The effect of temperature on the pulp yield and lignin content was greater and more pronounced than that of time, concentration or liquor to solid ratio. Increasing the temperature from 150 to 170°C, for instance, resulted in a decrease in both pulp yield and lignin content of the pulp. During pulping both lignin and carbohydrates are dissolved out at different rates. These rates are much accelerated by increasing the temperature [27]. The rate of delignification increases with increasing pulping time. Thus increase in pulping time causes a relative reduction in pulp yield and lignin content as shown in Table 4 and 5. The liquor to solid ratio affected the lignin content much more than the pulp yield. Since there was no increase in the concentration of the pulping liquor, (Tables 4 and 5), the rate of lignin dissolution was increased by increasing the volume of the pulping liquor without drastically affecting the pulp.

In conclusions, the fibre characteristics and chemical properties of Nigerian grown *Bambusa vulgaris* were similar to typical values of commercial pulp woods. The bamboo was characterized with high specific gravity values. The average fiber lengths varied from 2.46-2.62 mm which predicted strong paper with good tearing resistance and increased mechanical strength suitable for writing, printing, wrapping and packaging purposes. The stages of maturity of the plant did not affect it fiber characteristics and chemical properties significantly. Soda pulp yield was increased by the addition of butanol (60%). The highest pulp yield was obtained at a reduced pulping time and temperature.

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