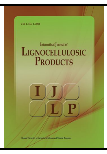

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Variation of chemical and morphological properties of different parts of banana plant (*Musa paradisica*) and their effects on pulping

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Abstract

Chemical and morphological characterization of different parts of banana plant (*Musa paradisica*) (peduncle, leaf stalk and pseudo stem) were carried out in order to assess their potentiality for chemical pulp. Each portion was tested for extractives, sodium hydroxide solubility, ash, lignin, cellulose and pentosan contents as well as their fiber length and width. These segmented parts were characterized as low amount of lignin (12.8–16.1%) and moderate amount of α-cellulose (31.6–43.3%) and relatively high amount of ash (7.6–19.1%), alkali solubility *(*32.4-51.4%*)* and water solubility. The morphological properties of the banana plant, in terms of fiber length and width were found to be a medium fiber with high slenderness ratio. Kraft process was applied for the three portions of banana plant to evaluate pulp properties. At the optimal pulping (Active alkali 22% for peduncle, 16% for leaf stalk and pseudo stem at 150 ^{o}C for 1 hour) pulp yields about 30.5–40.5% on oven dried (OD) raw material with kappa number from 16.9 to 26.1 were obtained when cooking was carried out for 1 hour. Mechanical properties of the unbleached pulp showed a high tensile, tear and burst index for pseudo stem.

Keywords: Banana plant (*Musa paradisica*), Chemical characteristics, Morphological characteristics, pulping.

1. Introduction

Bangladsh is a forest scarce country. Therefore, supply of fibrous raw material to the pulp mill is limited in Bangladesh. In recent years, interest is growing on non-wood lignocelluloses to produce pulp. Banana plant (*Musa paradisica*) could be one of important annual agricultural residues as each banana plant produces only one bunch of bananas and rest of the plant is left in the soil plantation or dumped in a place for decomposing.

Banana is one of the important fruit crop plants and belongs to the genus Musa. After harvesting the fruit, the plant is cut down and thrown away, mostly as waste. In Bangladesh *M. paradisica* variety of banana is cultivated hugely as cash crop. Day by day banana cultivation is increasing due to its huge demand for food among the mass people. So, every year colossal amount of banana plant remain as leftover creating environmental pollution. The banana plant is largely divided into three parts- pseudo stem, peduncle and leaf. The pseudo stem portion of the plant fibre is suitable for making ropes and twines (Saikia et al., 1997).

A comprehensive study on chemical composition and structure of components from different morphological parts of banana plant was carried out by Oliveira et al. (2007). The highest percentage of cellulose (37.3%) was found in leaf sheaths, starch (26.3%) in floral stalk, lignin (24.3%) in leaf blades and lipophilic extractives (5.8%) in leaf blades.

The chemical composition and the pulping potentialities of banana pseudo-stems growing in Madeira Island (Portugal) were studied by Cordeiro et al. (2004) and found that the lignin content was quite low but carbohydrate content was suitable for pulping. Similar results were also found by Li et al. (2010). Pulps yield was obtained about 37–38% with a Kappa number about 30–32 when cooking in the presence of 0.25–0.35% of anthraquinone at 120 ^{o}C for a short cooking time, i.e. 30 min (Oliveira et al. 2007).

The physical, morphological and chemicals characteristics of different Musa species were studied by Omotoso and Ogunsile (2010) and found that Musa species were rich in cellulose and low in lignin content compare to hardwood. The fiber lengths were varied from medium to longer range from species to species.

Despite low lignin content, banana plant could not be delignified easily by soda and sodium sulfite, or calcium bisulfite process (Kane and Marathe, 1949). Therefore, some studies were carried out on retted and unretted banana plant fiber and found that pulping of retted samples produced pulps with improved chemical and physical properties than that from of unretted samples (Heikal, 1976; Heikal and Fadl, 1977).

Banana pulp which is easily beatable reaches high ^{o}SR at short beating time. A good quality grease proof paper was produced from banana (*M. paradisica*) pulp (Goswami, 2008).

Certainly chemical and morphological properties of different parts of banana plant will vary. There are no results reported on the chemical, morphological properties of banana plant (*M. paradisica*) of Bangladesh and its pulping potential.

This paper deals with the morphological and chemical properties of the three parts of *M. paradisica* plant as well as their kraft pulping optimization. Pulp was evaluated through tensile, tear and bursting strength testing and water freeness.

2. Experimental

2.1. Raw material collection

Mature banana (*M. paradisica*) plants were randomly selected and harvested from a banana plantation in Kustia, Bangladesh. The banana plant was separated into three different morphological regions; pseudo stem, peduncle and leaf stalk. The pseudo stems were manually separated from the body one by one and leaf stalks from leaf blades. The separated parts were the air dried for approximately four days in the sun. The air dried parts were chopped by hand to 2-3 cm in length for subsequent morphological and chemical analysis and digestion. For chemical analysis, the plant was grounded in Willey Mill and screened to 40/60 mesh. The portion passed through 40 mesh and retained in the 60 mesh was collected for subsequent chemical analysis.

2.2. Morphological and chemical analysis

For the measurements of fiber length and width samples were macerated in a solution containing 1:1 HNO_3 and $KClO_3$ for 24 hours. A drop of macerated sample was deposited on a slide then dried to remove water. The slide was placed under an image analyzer, Labomed LX 400 equipped with software Digipro 4.0 for taking images to measure fiber length and width. Bulk density was measured using 50 ml picnometer.

The chemical compositions of the three parts were determined according to the following TAPPI test methods: extractives (T204 om88), water solubility (T207 om99), and Klason lignin (T211 om83). Holocellulose samples were prepared by treating extractives-free meal with $NaClO_2$ solution (Browining, 1967). The pH of the solution was maintained at 4 by adding CH3COOH-CH_3COONa buffer and the α-cellulose content was determined by treating holocellulose with 17.5% NaOH (T203 om93). Ash content was determined at by muffle furnace at 525 ^{0}C according to T211 om93. The pentosans content was determined using the bromide/bromate method. Three replicates were carried out for each experiment.

2.3. Pulping

Kraft pulping was carried out in an electrically heated, rotating digester. The capacity of the each digester was 5 liter. 250 g of oven dried material of three parts of banana plant was used for each cooking. Three replicates were carried out for each experiment. The pulping conditions were:

- Active alkali was varied 12, 14, 16 and 18% for leafstalk and pseudo stem and 16, 18, 20 and 22% for peduncle.
- Sulfidity : 28%
- Material/liquor ratio : 1:6
- Temperature: 150 ^{o} C
- Time at max temperature: 60 min

The cooked pulp was disintegrated in a laboratory blender for 5 min and screened in a flat vibrate screener having slots varying from 0.15 to 0.02 mm. Those did not pass throw the screener were considered reject.

2.4. Papermaking properties

For studying paper making properties of the banana pulp- optimum pulping conditions were selected as active alkali 16% for leafstalk and pseudo stem and 22% for peduncle. The pulps were beaten in a PFI mill to different revolution. Hand sheets 60 g/m^2 were made from the beaten pulp in a Rapid Kothen sheet making machine. Sheets were tested according to TAPPI standard methods- for tensile T494 om96, burst T403 om97, tear strength T414 om98.

3. Results and discussion

3.1. Chemical composition

The quantity of 1% alkali solubility of all parts of *M. paradisica* was really very high compare to wood (Jahan et al., 2011) and some other annual plants (Antunes et al., 2000.) which were 49.35% for peduncle, 32.44% for leaf stalk and 51.39% for pseudo steam of O.D material respectively. But the range of 1% alkali solubility was much higher than the reported values of *M. paradisica* by Goswami et al. (2008). A high amount of alkali solubility of *M. paradisica* can be attributed by the presence of low molecular mass carbohydrates. The values of cold water extraction of three parts of *M. paradisica* were also really high which were 30.14% for peduncle, 9.14% for leaf stalk and 22.85% for pseudo stem respectively. But, acetone extractions of parts of *M. paradisica* were comparatively low. Those were 2.78 for peduncle, 1.96% for leaf stalk and 3.25% for pseudo stem which was lower than other agricultural residues (Jahan et al., 2012). Some substances including resins, wax, fat, and acetone extracts can precipitate upon pulping and leave stains in the resulting paper sheets. So, it is expected that pulping raw materials need to be as low as possible.

Assessment of chemical compositions of plant materials is pre-requisition to use as pulping raw material. The chemical compositions of different morphological parts of banana plant are shown in Table 1. The amount of klason lignin content of *M. paradisica* is considerably lower (13-16%) than the other annual agricultural residues such as lentil, wheat straw, rice straw, mustard straw, corn straw (Jahan et al., 2012). Similarly, Omotoso and Ogunsile (2010) also observed lower lignin in different species of Musa. Low lignin content can make it worthy raw material for pulping. As shown in Table 1, acid soluble lignin is notably higher than the other wood and nonwood (Jahan et al., 2004, Jahan and Rahman 2012, Jahan et al., 2013). Acid soluble lignin mostly represents syringyl unit, which is easier for pulping.

Table 1. Chemical properties of the three parts of banana plant.

Experiment (%)	Peduncle/kadhi	Leaf stalk/leaf	Pseudo stem
Cold water solubility	30.14±2.0	9.14±0.9	22.85±1.4
NaOH solubility (1)	49.35±2.1	32.44±1.9	51.39±2.3
Klason Lignin	13.65±1.1	16.02±1.2	12.76±1.0
Acid soluble lignin	8.32±0.8	5.55±0.5	5.05±0.5
Ash	19.06±1.3	7.55±0.7	13.93±0.9
Holocellulose	52.55±2.4	71.60±2.7	50.22±2.3
α- Cellulose	31.59±1.7	43.25±1.8	32.55±1.5
Extractive Acetone	2.78±0.3	1.96±0.1	3.25±0.3
Pentosan	20.33±0.9	26.65±1.2	16.17±1.6

Table 2. Morphological properties of the three parts of banana plant.

Experiment	Peduncle/ kadhi	Leaf stalk/leaf	Pseudo stem
Fiber Length, L (mm)	1.53±0.13	1.64±0.01	2.21±0.03
Fiber width, D (μm)	30.6±1.4	16.7±1.1	22.2±1.5
Slenderness ratio, L/D	50	98.2	99.54

α- cellulose content of raw material is the prime factor in selection a material for pulping. α- cellulose of peduncle, leaf stalk and pseudo stem of *M. paradisica* which were 31.59%, 43.25% and 32.55%, respectively reported in Table 1, which was lower than Goswami's results (Goswami, 2008). The α- cellulose in leaf stalk was considerably higher than the other two parts. Therefore, leaf stalk could yield high pulp. It was found that α- cellulose content of *M. paradisica* was almost half of holocellulose which made it a lower grade raw material for pulping. Therefore, hemicelluloses which could be calculated from the difference of holocellulose and α- Cellulose, was considerably high in *M. paradisica* .The result was concluded by considering the amount of pentosan content which showed in Table 1. Pentose sugar content was the highest amount in Leaf stalk (26.65%) followed by Peduncle (20.33%) and pseudo stem (16.17%). Remarkably, all parts of banana plant contained rather higher amount of ashes (7.55–19.06%), which are not common in other fast growing plants and annual agricultural plants (Atchison, 1993). Ash content was the highest in peduncle part (19.06%) which was supported by L. Oliverira et al. (2007). This is because the part of plant acts as transporter of minerals to banana fruit. Cordeiro et al. (2006) showed that small mineral crystals build up over the fiber of peduncle of banana plant. Oliverira et al. (2007) showed that mainly potassium, calcium and silica are present in ashes from banana plant. Ashes particularly silica causes a huge adverse effect on kraft pulping (Ilvessalo-Pfaffli, 1995; Obernberger et at., 1997) on chemical recovery and pulp properties. From ash content point of view, banana plant can be considered as worse material for pulping.

3.2. Morphological properties

Fibre morphology is an important characteristic to evaluate as a pulping raw material. Fibre length, width and their slenderness ratios of different parts of *M. paradisica* are given in Table 2. Fibre dimensions, length and width greatly influence the different mechanical properties specifically tear and tensile strength of fibre. The average fibre length of peduncle, leaf stalk and pseudo stem were 1.53 mm, 1.64 mm and 2.21 mm respectively. Fiber lengths of pseudo stem were comparable to those of jute bast fiber (Jahan et al., 2007), kenaf bast fiber (Ververis et al. 2004) and softwood fiber. Omotoso and Ogunsile (2010) showed that the fiber length of *M. paradisica* stem was 2.83 mm. Width of the fibers were 30.6 µm for peduncle, 16.7 µm for leaf stalk and 22.2 µm for pseudo stem accordingly. Slenderness ration of three parts of *M. paradisica* varied from 50 to 99 (Table 2). Therefore, papers produced from *M. paradisica* fibers are expected to have improved mechanical strength and thus be suitable for writing, printing, wrapping and packaging purposes (Saikia et al., 1997; Neto et al., 1996).

3.3. Pulping

Effect of alkali charge on the pulping of different parts of *M. paradisica* is shown in Table 3. It was expected that the delignification would be easier as the lignin content in *M. paradisica* is lower (Table 1). But it is seen from Table 3 that peduncle portion needs much higher alkali to get a bleachable pulp. This can be attributed by higher ash content of peduncle, which consumed alkali during pulping process. At 22% active alkali charge, peduncle portion produce pulp with kappa number 16, while leaf stalk and pseudo stem reached to kappa number 24 and 25 at the alkali charge of 16%, respectively. Peduncle need comparatively high alkali charge than other two parts, this is because high amount of mineral restrain in this portion which consume alkali during pulping. Another possibility of higher kappa number can be explained by hexauronic acid content in the raw material, which contributes kappa number (Buchert et al., 1995). Moreover, some gummy material was present in peduncle portion which may consume some alkali during pulping. At optimum condition of pulping kappa number of peduncle was 16 whereas leaf stalk and pseudo stem were 22. This can be explained as such that more lignin was removed during pulping using more alkali.

Table 3. Effect of chemical charge on pulping of banana plant in kraft process at 25% sulfidity (w/w with respect to OD material).

	Active Alkali (%)	Time (min)	Temp (°C)	Kappa (no.)	Reject (g)	Screen yield (%)	Total yield (%)
Peduncle/kadhi	16	60	150	25	4.00	33.30	37.30
	18	60	150	18	3.36	33.48	36.88
	20	60	150	17	3.27	30.70	33.97
	22	60	150	16	0.66	29.79	30.45
Leaf stalk/leaf	12	60	150	27	7.63	39.17	46.80
	14	60	150	25	4.39	40.07	44.46
	16	60	150	24	0.58	36.92	40.49
	18	60	150	23	0.00	39.28	39.28
Pseudo stem	12	60	150	35	4.11	31.60	35.71
	14	60	150	28	3.26	30.74	34.00
	16	60	150	25	0.93	26.84	30.80
	18	60	150	24	0.00	25.70	25.70

Table 4. Physical strength properties of the three parts of banana plant.

Parameter	Peduncle/kadhi			Leaf stalk/leaf			Pseudo stem		
PFI Beating, Revolution no.	0	500	1000	0	500	1000	0	500	1000
Pulp freeness, ^{0}SR	28	72	83	22	51	83	33	87	90
Tear index , mN.m^2/g	11.7	7.3	6.9	15.0	10.5	9.4	12.4	8.7	8.2
Tensile index, N.m/g	55.6	81.3	85.2	37.3	83.5	84.8	62.8	86.0	88.8
Burst index, kPa.m^2/g	5.2	6.8	6.8	3.5	7.1	7.9	4.9	7.9	7.6
Density, x10^{2}kg/m^3	6.3	8.8	9.4	5.7	6.4	7.1	6.5	7 .0	7.6

As shown in Table 3, total pulp yield and screened pulp yield were decreased with alkali charge. Leaf produced higher pulp yield than the peduncle and pseudo stem, which can be explained by higher α-cellulose content (Table 1). At 16% alkali charge, reject of leaf and pseudo stem pulp were less than 1%.

3.4. Paper making properties

These pulps were beaten in PFI mill in different revolution and papermaking properties were determined and shown in Table 4. Fiber of *M. paradisica* was within the range of long fiber, so higher physical strength properties were expected. Initial drainage resistance (°SR) of these pulps was very high (22-33) due to the presence of higher fines and nonfibrous cells in the pulp (Figure 1). Some of the Musa species contain 60% fibers of lower than 0.5cm in length, which may cause even higher drainage resistance than the present investigation (Schott et al. 2003). The high fines increased hydration, hence improved beatability rapidly of pulp as shown in Table 4. The drainage resistance of leaf stalk, pseudo stem and peduncle was increased to 77, 51 and 87, respectively only with 500 PFI revolution. Tear index of leaf stalk, pseudo stem and peduncle were 15, 12.44 and 11.68 Nm^2/g respectively at zero beating. Tear index decreased as PFI beating revolution increased, but tensile index increased very rapidly (Table 4). At the tensile index value of 80 N.m/g, tear index of pseudo stem was 11 $mN.m^2/g$, which was 37% higher than the tear index of peduncle pulp (Figure 2). This can be explained by longer fiber length of pseudo stem (Table 2). The pulp sheet density of these pulps was extremely high as its high fines content, which was increased gradually as PFI revolution increased from zero to 500 and 1000. Fine content point of view, *M. paradisica* pulp could make a great problem in run ability of pulp in paper machine but high sheet density of this pulp makes it an advantageous property for certain specialty papers like greaseproof and release paper (Lakovlev et al., 2010).

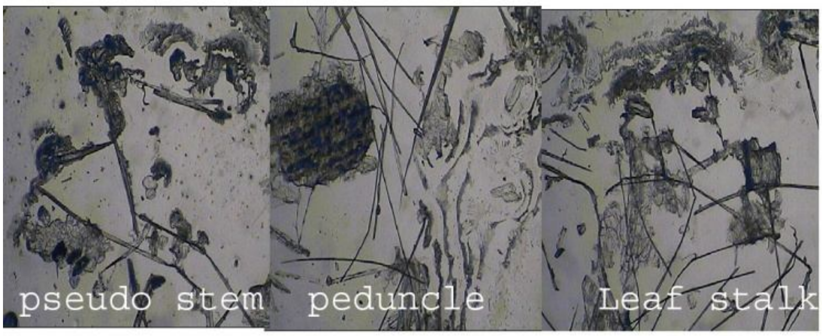

Figure 1. Microphotograph of pulps from different parts of banana plant.

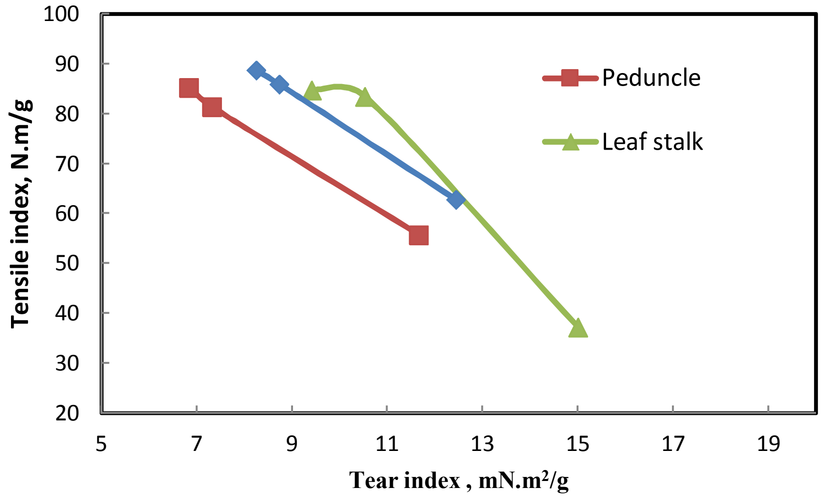

Figure 2. Tensile index and Tear index relationship of different parts of *M. paradisica.*

4. Conclusions

The chemical and morphological composition as well as paper making properties of pulp made from the three parts of *M. paradisica* of Bangladesh has been evaluated in order to estimate its potential applications. The results of analyses showed a significant variability in chemical composition, morphological properties and their paper making properties. The high ash content in all portions of *M. paradisica* could make problematic for pulp processing. But considerable amount of α-cellulose content, low lignin content and high fiber length were the advantageous property for papermaking. All fraction of banana plant contained high amount of water and alkali soluble, which need to be elucidated. Moreover, there are need more research to find out better chemical processing and new applications for this non-wood renewable source.

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