Banana Plant – A potential source of raw material for hand made paper industry

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Abstract

Utilization of banana plant for making hand made paper and certain grades of specialty paperboards have been investigated. The physiochemical characteristics of the three species of banana plants viz. Musa velutina, M. paradisica and M. sapientum available in NE region of India were studied. The plants consists an average of 25 – 27 % sheath, 42 – 48 % core and 27 – 30 % leaves. The cellulose content was varied from 59 – 63 %, lignin from 15.3 – 18.2 % and pantosan from 13.5 – 15.2 %. in all the three plant species. The cooking experiments were conducted in an open vat under pressure free condition using NaOH and Na_2CO_3 as cooking chemicals. The percentages of cooking chemicals were varied from 6 – 10 % maintaining bath ratio at 1:6. The unbleached pulp yield was recorded 48 – 52 %. The bleaching of the pulps was carried out using $H – E – H_2O_2$ sequence to get 60 – 65 % brightness. The physical strength properties of hand made paper made from these three plant species showed tensile index 55.4 – 62.8 Nmg^{-1}, Tear index 10.4 – 15.2 $mNm2g^{-1}$, Burst index 6.2 – 8.7 $Kpm2g^{-1}$ with Double fold values 300+. However certain specialty paperboard such as leather board made out of banana pulp in combination with bamboo pulp showed breaking load 120 – 145 (Kg), Tensile strength (dry) 220 - 250 Kg/cm^2, elongation 39 – 42 %, linear shrinkage 4.0% and area shrinkage 4.2 - 4.5%. Another specialty boards such as solid toughened board made from the blends of rag and banana pulp showed very good physical strength with breaking load value160 kg and 90 kg respectively for 30 cm and 60cm span with minimum absorption of moisture.

Introduction:

The handmade paper industry has recorded a steady phenomenal growth in production over the years. In recent years, the domestic demand and the demand in the export market are also increasing simultaneously. At present around 55 percent of total demand of paper in India is based on consumer products and 45 percent is directed towards the industrial sector but in case of handmade papers, 95% demand is based on consumer product and 5% for industrial based product.

Evaluation of non-competitive grades of paper has helped this industry to progress. The varieties can roughly be categorized into 3 grades:

- High grades drawing paper for artists and engineers
- Industrial papers such as filter paper, Jacquard papers and electrical insulation papers and some specialty boards.
- Fancy papers used for certificates, greeting cards, decorative papers etc.

Hence, the handmade paper and boards have many uses as office stationary i.e. file covers and file boards, greetings card, invitation and visiting cards, in converting industries such as folders and albums, lamp shades and a wide range of decorative items.

With the increase of standard of education and number of technical and engineering institutions, the demand of specialty handmade papers like certificate papers, drawing papers etc are increasing along with certain non-competitive varieties of hand made paper like greeting cards and various decorative papers for domestic as well as for export. Being eco-friendly, the handmade papers made from recycled paper have their own identity in the market. Apart from the conventional raw materials like rags, waste paper etc other plant materials such as banana plant may be a potential source for hand made paper depending on the availability in the locality. Banana is an important fruit and vegetable crop belongs to the genus Musa. It grows wild and also cultivated on a large scale as a field crop as well as a backyard crop in households (Fig.1).

Fig. 1 Banana Plant – A potential source of raw material for hand made paper industry.

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Banana plants are available over wide areas through out the tropics from 30° N to 30° S of equator. India, being a tropical country, banana is cultivated in about 1,86,000 ha of land (Brahma et al., 1995). The plant has luxuriant growth in well-drained soil with ample moisture and decaying organic matter. It can also flourish on light sandy or gravelly soil as well as on stiff but well drain clay, if the soil is fertile and facilitates for irrigation. (Chadha,1962).

From the pseudo stem portion of the plant, crude fibres are extracted on small scale and utilized for making ropes and twines (Saikia et al., 1997). Recently, studies have been made on yield and properties of banana fibre extracted from a few cultivated varieties. The harvested stalks of the plant are utilized for extraction of fibres. The fibre is located primarily adjacent to the outer surface of the leaf sheath. It was reported that well cleaned and brushed decorticated whole leaf sheath yields 80-85 % long (4-6 mm fibre), slender (mean width 17-21 □m) fibres (Escolano et al., 1978).

With the growing shortage of cellulose fibre search for alternative fibre producing plant material has been initiated in many countries throughout the world. The generation of fast growing plant is thought to be one of the solutions to meet the shortage of cellulosic fibres (Atchison, 1976; Watson et al., 1976; Clark et al., 1971; Mohan Rao et al., 1983; Singh et al., 2003). The Banana fibre may serve partly as an alternative fibrous material in conventional paper making process. Assam and the other states of North Eastern region are very much rich in availability of banana plant (Fig. 2).

Fig. 2 Banana Plantation

Different species of wild and cultivated varieties of banana plant are found in this region. Banana plant growing wild in the forests and hills and abundantly cultivated varieties remains waste in the field after harvesting the fruit. Considering the fibre quality and easy availability of banana plant, a study was undertaken at North East Institute of Science and technology Jorhat, Assam, India for utilization of such waste fibre for making suitable grades of hand made paper and boards. The results of the investigation are presented in this communication.

Materials and Methods:

Three species of banana plants viz, Musa velutina, Musa paradisica and Musa sapientum were collected from different areas of Assam. The leaves and roots of the plants were discarded and the stem portion was considered for the present study. The sheaths were removed from the stem and washed with cold fresh water. These were then converted to strips of 90 cm length and then crushed in a three-roll crusher to remove the excess water (Fig. 3).

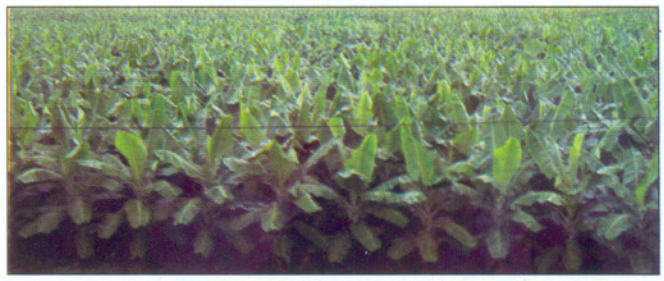

Fig. 3 Banana Plantation

The crushing action reduces the moisture content in the strips up to 45-50%. The crushed sheaths were then air-dried prior to chemical constitutional analysis. The physical characteristics of all the three selected plant species were determined in the field as well as in the laboratory and are presented in table-1.

Proximate chemical constituents

The air-dried strips were cut into the chips of the size 3cm length and dried in an oven. The dried chips were made in to powder in a willey mill. The powdered material passed through 40 BS mesh and retained on 60 BS mesh was taken for proximate chemical analysis adopting TAPPI standard method (TAPPI, 1980)

Pulping

For the preparation of pulp, crushed sheath material was converted to chips of 3cm length and then taken in a stainless steel vessel and digested under pressure free condition using NaOH and Na_2CO_3 cooking chemicals. The percentage for cooking chemicals was varied from 6-10% maintaining bath ratio at 1:6 for 3hrs at boiling temperature. The average pulp yield, their respective kappa numbers, pulp brightness and viscosity were determined as per the TAPPI standard methods. The bleaching of pulps were carried out using H-E-H_2O_2 sequence. The pulps after bleaching were washed with cold fresh water and then dried. The physical properties of the bleached pulps were determined and recorded in table-3.

Brightness

The brightness of the bleached pulp was measured in a Digital reflectance meter and the results were expressed on the basis of MgO=100

Scanning electron microscopy

A small portion of the disintegrated bleached pulp fibre samples of all the three species were taken separately and after properly dried, mounted on specimen holders with the help of electro conductive tape. The samples were coated with gold in an ion-sputter coater (JFC 100, JEOL, Japan) in low vacuum with a layer 150-200 nm thick. The observation was made in a JEOL, JSM-35M-35CF electron microscope at an accelerating potential of 15kV, micrographs were taken at this potential.

Paper sheet making

The unbleached and bleached pulps of all the three species of banana were taken in a laboratory valley beater and beaten up to 45°SR freeness (Schopper-Reigler) at 1.25% consistency. Hand made paper sheet of 62 ± 2 GSM was made in a hand made vat of the size 2′ by 2′ followed by pressing and drying.

Pulp stock preparation and board making

For making leather board, bamboo pulps were beaten up to the freeness of 45 °SR and was added to the banana pulp stock at 50 :50 ratio. 2-3% rosin and a polymeric emulsion along with a rubber chemical was also added to the pulp stock during beating. So also, for making solid toughened board, rag pulp was beaten up to 45 °SR freeness and then added to the banana pulp stock at 50:50 ratio. The pulp stock was sized with rosin and alum. A polymeric emulsion was also added to enhance the physical strength properties. A hardening agent was also added during the preparation of the pulp stock.

Testing of paper sheets

The paper and board samples made from different pulp stock were conditioned at 65% RH at 27±2°C for 2h and then tested the different physical strength properties of the hand paper sheet and the results are presented in table 5 & 6.

Table-1: Morphological characteristics of Banana plant

Particulars	Musa velutina	Musa paradisica	Musa sapientum
Stem length, cm	350	380	400
Stem diameter, cm	20	25	28
No of leaves	7	10	10
Length of the leaves, cm	165	150	155
No of sheath in stem	12	10	10
Diameter of the central core, cm	10	10	12
Green weight of the stem, kg	28	40	35
Dry weight of the stem, kg	2.24	3.18	2.86
Fibre yield %	45-48	42-45	45-48
Average constituents of the plant (% on OD basis)			
Sheath	27	25	27
Central core	45	42	48
leaves	28	27	30

Table 2: Proximate chemical analysis of Banana plant species

Particulars	Musa velutina	Musa paradisica	Musa sapientum
Solubility %			
Cold water	2.75	2.75	2.82
Hot water	2.85	3.10	3.10
1% NaOH	26.7	28.65	28.15
Alcohol benzene	2.7	3.10	3.24
Cellulose % (Cross & Bevan)	60.1	59.18	63.0
Pentosan %	14.7	15.2	13.5
Lignin %	15.3	18.21	17.50
Ash content %	1.8	1.40	1.50
Alpha Cellulose %	55.0	54.60	56.00
Silica %	0.60	0.42	0.56

Table 3: Physical properties of bleached pulps obtained from different species

Particulars	Musa velutina	Musa paradisica	Musa sapientum
Pulp yield % Unbleached	50	48	52
Bleached	46.3	45.3	48.4
Brightness (%)	62.4	60	65
Hemicellulose (%)	8.4	10.2	9.5
Cellulose (%)	34.8	33.7	37.8
Kappa number	22	25	24
CED* viscosity (cp)	7.5	7.8	8.2
Initial pulp freeness (°SR*)	14	15	15
Final pulp freeness (°SR)	45	45	45

**CED- Cupriethylene diamine, SR*-Schopper Riegler*

Table 4: Morphological properties of banana pulp fibres

Particulars	Musa velutina	Musa paradisica	Musa sapientum
Fibre length, L (mm)	1.45	1.32	1.52
Fibre width, D (μm)	22	20	22
Average Lumen width d, (μm)	15	16	15
Average Cell wall thickness w, (μm)	6	6	6
Runkel ratio, 2 W/d	0.8	0.75	0.8
Slenderness ratio, L/D	65.90	66.0	69.1

Table-5: Physical strength properties of hand made paper sheets made from different bamboo pulp

Sample		Degree of freeness (°SR)	Beating time (min)	Burst index ($kPa\ m^2g^{-1}$)	Tear index ($mN\ m^2g^{-1}$)	Tensile index ($N\ mg^{-1}$)	Double Fold
Musa velutina	UP	45	120hrs	8.5	14.3	62.8	275+
	BP	45	120	6.8	11.5	58.7	250+
Musa paradasica	UP	45	100	7.5	12.6	57.6	250+
	BP	45	100	6.2	10.4	55.4	200+
Musa sapientum	UP	45	120	8.7	15.2	62.3	300+
	BP	45	120	7.0	12.4	57.4	300+

UP- unbleached pulp, BP- Bleached pulp

Table-6: Physical strength properties of cellulosic leather board				
Particulars	**Laboratory sample**		**Imported board sample**	
	A	**B**	**Shank brand**	**Bontex brand**
Apparent density,(g/cc)	0.95	1.0	1.0	0.75
Breaking load(kg)	120 140	125 145	-	-
Tensile strength,(kg/cm2)				
Dry	220	250	400	227
Wet	135	140	161	90
Elongation of break, %				
Dry	39	45	32	110
Wet	20	21	20	31
Stitch tear strength, (kg/cm thickness) Water absorption (% by mass)	9.2	8.7	4.8	8.7
30 min	12	11	41	57
2 h	18	23	44	60
8 h	30	38	73	68
24 h	100	95	101	74
Linear shrinkage, % at 170 0C for 1h	3.5	4.0	7.0	2.8
Area shrinkage, % at 100 0C for 1 h	5.4	4.	8.0	1.2

Table: 7 : Physical strength properties of solid toughened boards			
Properties	**Blend ratio (Banana: rag pulp)(50:50)**		
	M. paradisica	**M. sapientum**	**M. velutina**
Water absorption (%) (24h)	13.5	12.7	10.5
Weight of sheet (kg) 1X1.5m sheet	3.82	4.17	4.52
Water percolation test	Nil	Nil	Nil
Breaking load, kg			
30 cm span	110	145	160
60 cm span	58	75	90
Fire resistance	Satisfactory	Satisfactory	Satisfactory
De lamination	Nil	Nil	Nil

Results and Discussion:

It has been observed from the above investigation that good quality hand made paper and a few grades of specialty boards viz; solid toughened board and leather boards can also be made from banana fibre in combination with rag and bamboo pulps.

Table 1 & 2, shows some of the morphological characteristics such as height, diameter, green and dry weight, fibre yield etc of three different species of banana plants. It has been found that there is not much variation in morphological characteristics among the three species. However important plant constituents such as cellulosic content recorded maximum 63% in M. sapientum and minimum (59.18%) for M. paradisica. Likewise, the lignin content was recorded 18.2% in M. paradisica and minimum 15.3% in M. velutina. The other plant constituents such as different solubility, ash content, silica etc varies within a narrow range.

Table-3 shows the yield and properties of banana pulp. The unbleached and bleached pulp yield was recorded maximum 52 and 48.4% in M. sapientum while minimum 48 and 45.3% in M. paradisica. So also, brightness of bleached pulp was recorded 65 and 60 % respectively for M. sapientum, M. paradisica. The other properties like kappa number, cellulose content, CED viscosity etc of pulp did not show much variation among the species.

Table-4 shows morphological properties of pulp fibres. The fibre length recorded for M. sapientum was 1.52mm while 1.45 and 1.32 mm respectively for M. velutina and M. paradisica. The other morphological characteristics such as fibre width, lumen width, cell wall thickness etc did not show much variation among the species.

Table-5 shows the physical strength properties of unbleached and bleached paper sheets made from these three species. Tensile index (58.7 Nmg^{-1}) of bleached paper sheet recorded maximum in M. velutina while tear index and burst index shows maximum (15.2mN m^2g^{-1}) and (8.7 $Kpam^2g^{-1}$) M. sapientum shows maximum(15.2mN m^2g^{-1}) (8.7 $Kpam^2g^{-1}$) in the bleached paper sheets made from M. sapientum The tear index values recorded for M. velutina and M. paradisica were 11.5 and 10.4 Nm^2g^{-1} respectively. The burst index value did not show much variation among the species.

Table 6 shows the physical strength properties of leather boards made from the mixture of banana and bamboo pulps. Tensile strength of the laboratory sample shows higher values 250 and 140kg/cm^2 to that of Bontex brand (227 and 90kg/cm^2). Stitch tear strength values 8.7-9.2 kg/cm thickness were also more than shank (4.8kg/cm) and comparable to bontex board (8.7 kg/cm). The water absorption values, linear shrinkage and area shrinkage were also less than shank board.

Table 7 shows the physical strength properties of solid toughened board. Among the three species the minimum water absorption values 10.5% with maximum breaking load values 160 and 90 kg (30 cm and 60 cm span) were in the boards made form the pulps of M. velutina and rag pulps of 50 :50 ratio.. The other properties were more or less same in all the three species.

The SEM micrographs of banana fibre are shown in Figs. 4-6

Fig. 4 SEM of M. velutina fibre

Fig. 5 SEM of M. paradisica fibre

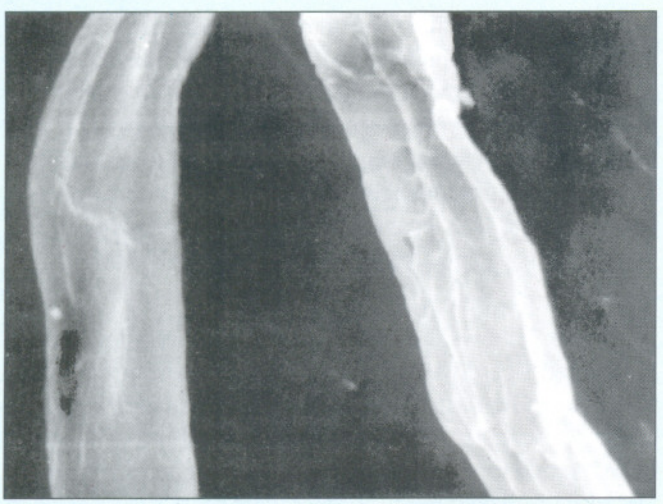

Fig. 6 SEM of M. sapientum fibre

Conclusion:

It has been observed from the above study that good quality hand made paper can be made from banana fibre. However, certain specialty boards such as solid toughened board and leather boards of good physical strength can also be made from the pulps of banana in combination with bamboo and rag pulps. Hence it may be concluded that banana fibre may be a potential source of raw material for hand made paper industry.

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