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Studies on pulp and paper making characteristics of some Indian non-woody fibrous raw materials — Part II

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Indian pulp and paper industries are facing an acute shortage of good quality of wood fibre with other associated problems. So they could not match their final product vis-à-vis to the finished products in globally competitive market. To overcome a serious lack of domestic wood fibres, morphological as well as chemical investigations on abundantly available and fast growing non-woody fibrous plants, which resemble in some aspects with softwoods and bamboo, have been undertaken. Keeping this challenge in view the pulp and paper making characteristics of three non-woody plants namely, *Eulaliopsis binata*, *Cajanus cajan*, and *Sesbania sesban* have been studied extensively. *Eulaliopsis binata*, which is popularly known as `Sabai grass`, consists of long leaf fibres. The fibre length of sabai grass is more than that of bamboo but fibre diam is 2.5-times lower than bamboo. Sabai grass consists of high cellulose and pectose with low lignin content. *Sesbania sesban* popularly known as 'Jainti' and consists of both bast and woody fibres. The rigidity coefficient, wall fraction and runkel ratio resembles that of bamboo, however the fibre length lies in the vicinity of fibre length of eucalyptus. *Cajanus cajan shows* higher degree of conformability within the sheet due to lower value of runkel ratio, slenderness ratio, wall fraction and rigidity coefficient and result in greater degree of fibre collapse and higher degree of conformability within the sheet.

Keywords: Pulp production, Paper production, Raw materials, Non-woody fibrous plants

Introduction

Indian paper makers are facing a serious lack of better quality of fibrous raw materials. This inadequate supply of better fibrous material has forced the paper makers to spend heavily on imported wood fibre. The Indian pulp and paper industries could not match their final products in globally competitive market, both cost as well as quality-wise. With other associated multifarious problems also like, high manufacturing cost, minimum profit level due to less selling price of end products in such a competitive atmosphere with heavy expenditure to conserve environment. With modernization of process equipment, revamping of product quality along with cost reduction aspects; the paper technocrats have to think seriously on sustainable availability of cost-effective raw materials. However, paper manufacturers have thought intensely to overcome this serious lack of good quality of fibre including their sustainable availability along with cost-effectiveness as well as to attract the attention of nodal government agencies to make available the degraded land for plantation. This will help in solving the dual purpose of sustainable fibre supply with conservation of environment.

Another ray of hope is the augment use of non-woody fibrous raw materials for pulp and papermaking. In today's environment, it is evident that non-woody plant fibre will play an important role in the global scenario for pulp and papermaking. Besides agro-based residues, plenty of other non-woody plants are available abundantly in India. It has been proven that by selecting the approximate mixture of non-woody plant fibres and the appropriate pulping process, any quality of paper and paper-board can be manufactured with or without addition of any wood pulp.

Surprisingly the morphological characteristics of selected non-woody fibrous plants indicate that they may be better substitute for expensive long fibred materials expect some strength deficiency. The certain unique morphological characteristics of these non-

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woody plants make them suitable in imparting some unique property of specialty grade paper. The chemical composition of certain non-woody plants fibres also give some indication, as to where these fibres will fit into paper making system. The non-woody fibrous plants due to their open and loose anatomical features and low lignin contents make them suitable to pulp easily with milder cooking condition, to produce readily bleachable grade pulp. The fiber dimensions along with water drainage characteristics of the pulps, also indicate that they do not require extensive refining to develop fibrillation, hydration and inter fibre bonding.

The purpose of the present communication is to evaluate the morphological, chemical, and other paper making characteristics of some potential non-woody plants, which are abundantly available in India and added to their potential use for developing high value added specialty papers. In the series of potential use of non-woody fibrous plants for pulp and papermaking the authors have selected following three non-woody fibrous plants namely, *Eulaliopsis binata, Sesbania sesban,* and *Cajanus cajan.*

Eulaliopsis binata — Eulaliopsis binata is commonly known as 'Sabai grass,' 'Bhabhar or 'Golden grass' is characterized by its durability, strength and hardness. Sabai grass is second only to bamboo in importance as a raw material for pulp and paper manufacture in India. Sabai grass is a tuft perennial grass 2-5 ft high with erect, slender culms, shiny and wooly at the base. It is hardy to both frost and drought regions. It can grow on poor soils not subject to water logging. It prevents soil erosion and its plantation on fresh road or railway embankments has been advocated as a measure of saving the cost of earthwork repair. Sabai grass is harvested twice annually in August-September and November-December[1]. The grass flowers during the cold weather and for the purpose of paper manufacture, the grass should be cut prior to or during the flowering stage. Sabai grass when carefully collected frees from weeds and foreign matter forms an excellent material for the production of printing and medium quality writing paper. It is also suitable for straw-board.

Sesbania sesban — *Sesbania sesban* a low-density quick growing short-lived shrub is commonly known as 'Jainti'. It attains a height of 1.6-8 m on maturity. *Sesbania sesban* can grow under widely different conditions, i.e., water logged conditions and acidic soil. Bast fibres are obtained from bark, which are originally used for making ropes[2]. *Sesbania sesban* is a light brown with wood density of 0.498 g/m^3.

Cajanus cajan — *Cajanus cajan* is an important leguminous crop commonly known as 'Arhar'. The plant is probably a native of Africa. It is drought resistant and suffers from water logging. It is highly adaptable with respect to climate and grown both in dry and moist tropics. The plant is light brown, perennial and attains a height of 1-1.2 m on maturity[3]. The basic density of chips of *Cajanus cajan* is 180-190 kg/m^3.

Experimental Methodology

Raw Materials Preparation — The stalks of *Eulaliopsis binata, Sesbania sesban* and *Cajanus cajan* were collected in the vicinity of Saharanpur, located in the foot hills Shivalik in Northern India and chopped by hand. The chips were then screened and those passing through 30 mm screen but retain on a 20 mm screen were collected. The accepted chips were air dried under atmospheric condition in polythene bags.

Morphological Studies — For morphological studies the samples were subjected to a chemo-physical maceration to segregate the individual cellular elements by dissolving middle lamella without damage. It involves the use of hot aqueous solution of CH_3COOH and $NaClO_2$. The slides for microscopic examination were prepared as per BIS specification 5285-1969. Fibre length, fibre width, fibre diam and cell wall thickness were measured by projecting the image at a magnification of 160 X, as per BIS specification. The results are reported in Table 1.

Proximate Chemical Analysis — The selected air-dry material disintegrated in laboratory WEVERK disintegrator. The portion of dust passing through 40 mesh sieve but retained on 80 mesh sieve was utilized for proximate chemical analysis were carried out as per TAPPI standard procedures. The results are reported in Table 2.

Pulping Studies — Screened chips of *Eulaliopsis binata, Sesbania sesban* and *Cajanus cajan* were digested in electrically heated WEVERK make rotary digester of 0.02 m^3 capacity by soda, soda-AQ, alkali-O_2, alkali-O_2-AQ, Kraft, Kraft-AQ, alkaline sulphite, alkaline sulphite-AQ, semi alkaline sulphite, semi alkaline sulphite-AQ and NSSC pulping processes at

Table 1 — Morphological characteristics of *Sesbania sesban, Eulaliopsis binata, Cajanus cajan* and bamboo

Sl No.	Particulars	*Sesbania sesban* woody fibers	*Eulaliopsis binata*	*Cajanus cajan*	Bamboo[12]
1	Colour	light brown	brownish yellow	light brown	light green
2	Density, g/cm^3	0.498	—	0.485	0.521
3	Fibre length, (L) mm	0.914	2.4	0.765	1.7
4	Fibre width (D), μm	19.17	9.0	22.12	23.60
5	Lumen diameter (d), μm	8.71	5.75	15.05	9.5
6	Cell wall thickness (w), μm	5.23	4.21	3.54	7.0
7	Flexibility coefficient (d/D) x 100	45.44	63.88	68.03	40.5
8	Slenderness ratio L/D	47.66	266	34.60	72.0
9	Rigidity coefficient 2w/D	0.55	0.93	0.32	0.59
10	Wall fraction (2w/D) x 100	53	93	32	59
11	Runkel ratio 2w/d	1.20	1.46	0.47	1.47
12	Ratio of wall thickness to lumen ratio	0.60	0.73	0.24	0.64

Table 2 — Proximate chemical analyses of *Sesbania sesban, Eulaliopsis binata, Cajanus cajan*, bagasse and bamboo

Sl No.	Particulars per cent	*Sesbania sesban*	*Eulaliopsis binata*	*Cajanus cajan*	Bagasse[4]	Bamboo[12]
1	Cold water solubility	2.37	3.60	3.42	5.91	7.60
2	Hot water solubility	6.30	9.50	5.10	7.85	8.50
3	Alcohol-benzene solubility (1:2 V/V)	4.45	4.10	4.14	6.30	3.40
4	1 per cent NaOH solubility	24.70	39.70	19.66	33.60	26.80
5	Lignin	17.65	22.00	18.72	20.30	24.30
6	Pentosan	19.00	23.90	15.97	23.86	18.30
7	Holocellulose	73.23	—	72.86	70.60	71.50
8	Hemicelluloses	27.80	—	25.24	28.45	27.60
9	α-cellulose	45.24	49.00	47.31	42.00	43.50
10	β -cellulose	11.12	—	11.56	—	13.40
11	γ -cellulose	16.42	—	13.50	—	14.00
12	Ash	1.40	6.00	1.72	3.80	2.10
13	Silica	0.38	—	0.56	2.10	1.40
14	Acetyl content	2.61	—	2.18	—	2.50
15	Methoxyl content	3.70	—	3.35	—	3.10

optimum conditions. The various pulping variables like chemical doses, time and temperature have been optimised in the Ph D thesis of the authors[4,5]. The pulp was screened through a laboratory vibratory flat WEVERK screen with 0.15 mm slits. The pulp yield, screening rejects and kappa number were determined. The pulps were bleached by CEHH bleaching sequence. Both unbleached and bleached pulps were beaten in WEVERK valley beater and hand-sheets were prepared on British sheet-forming machine. The hand-sheets were evaluated as per BIS method for various physical strength properties. The results at optimum conditions are given in Tables 3-5.

Results and Discussion

Eulaliopsis binata — Microphotograph-1 shows that sabai grass fibres are long, thin, slender, and taper off to pointed ends with some parenchymatous cells.

Table 3 — Pulp evaluation characteristics of *Eulaliopsis binata*[3]

Pulping processes	Cooking process			Kappa no.	Pulp yield[1], per cent	Pulp yield[2], per cent	Pulp brightness per cent, ISO	Strength properties of unbleached pulp				
	Alkali dose[9], per cent	Max temp, ^{0}C	Max cooking time, min					^{0}SR	Tear index mNm^2/g	Tensile index Nm/g	Burst index KPam^2/g	Porosity's
Soda	14	160	240	16.1	48.00	43.20	81.5	53	9.6	83.86	8.7	4.43
Soda-AQ[4]	12	160	240	15.7	49.80	44.50	80.0	54	9.1	84.53	8.9	8.12
Alkali-O_2[5,6]	13	165	120	14.2	51.24	46.30	83.4	52	9.2	86.43	9.2	7.21
Alkali-O_2.AQ[4,5,6]	13	165	120	13.4	51.78	46.50	82.7	53	9.3	86.78	9.1	7.14
Kraft[7,10]	12	165	90	12.5	52.30	46.90	82.0	51	9.4	86.60	9.5	8.2
NSSC[8]	—	160	240	34.5	51.30	—	—	48	9.0	65.25	9.3	—

1= Unbleached pulp, 2 = Pulp bleached by CEHH sequence, 3 = Bath ratio 1:3.5, 4 = 0.1per cent AQ, 5 = 0.1 per cent $MgSO_4$, 6 = O_2 pressure 8 kg/cm^2, 7 = Sulphidity, 20 per cent, 8= Na_2SO_3, 18 per cent and Na_2CO_3, 4 per cent, 9 = as NaOH, $\nabla\nabla$ = as Na_2O

Table 4 — Pulp evaluation characteristics of *Cajanus cajan*[3]

Pulping processes	Cooking process			Kappa no	Pulp yield[1], per cent	Pulp yield[2], per cent	Pulp brightness, per cent, Elrepho	Strength properties of Unbleached pulp				
	Alkali dose, per cent	Max. temp. ^{0}C	Max. cooking time, min					^{0}SR	Tear index MNm^2/g	Tensile index Nm/g	Burst index KPam^2/g	Opacity per cent
Soda[8]	18	165	180					44	4.10	57.70	4.44	81.0
Soda-AQ[4,8]	18$^{\nabla}$	165	120	32.0	48.80	43.90	68.7	45	3.78	58.20	4.38	82.0
Kraft[5,9]	16	160	120	29.5	50.20	45.60	70.6	38	5.62	62.83	5.49	82.2
Kraft-AQ[4,5,9]	16	160	90	30.0	51.30	46.40	69.6	42	4.48	66.18	5.59	82.0
Alkaline sulphite[6]	—	175	135	31.0	51.40	46.00	72.0	45	5.60	62.62	5.10	81.0
Alkaline sulphite-AQ[4,6]	—	175	135	30.0	51.70	46.40	73.2	44	5.40	62.72	5.30	79.4
Semi alkaline Sulphite[9]	18	170	210	52.5	62.20	56.20	72.3	47	5.12	57.76	4.92	84.0
Semi alkaline Sulphite-AQ[4,9]	18	170	180	40.6	61.60	55.10	73.6	42	5.20	62.08	5.30	79.8
NSSC[7]	—	160	120	112	70.90	—	—	42	5.16	47.70	3.80	—

1= Unbleached pulp, 2 = Pulp bleached by CEHH sequence, 3 = Bath ratio 1:3.5, 4 = 0.1per cent AQ, 5 = Sulphidity, 6 = Sodium sulphite, 10.8 and Sodium hydroxide, 6.2, 7= Na_2SO_3 : Na_2CO_3, 30:70, 8 = as NaOH, 9 = as Na_2O

Table 5 — Pulp evaluation characteristics of *Sesbania sesban*[3]

Pulping processes	Cooking process			Kappa no	Pulp yield[1], per cent	Pulp yield[2], per cent	Pulp brightness, per cent (Elrepho)	Strength properties of unbleached pulp				
	Alkali Dose, per cent	Max temp, ^{0}C	Max time, min					^{0}SR	Tear index mNm^2/g	Tensile index Nm/g	Burst index KPam^2/g	Opacity per cent
Soda[8]	18	165	180					43	4.22	56.65	4.13	95.2
Soda-AQ[4,8]	18	165	120	32.0	46.4	41.9	67.8	43	3.85	58.65	4.20	92.0
Kraft[5,9]	16	160	120	31.0	47.0	42.5	69.7	46	4.85	60.58	5.14	82.0
Kraft-AQ[4,5,9]	16	160	90	32.0	47.9	43.2	69.4	44	4.52	61.23	5.26	83.6
Alkaline sulphite[6]	—	175	135	32.0	49.0	43.9	69.5	47	4.37	56.37	4.74	82.0
Alkaline sulphite-AQ[4,6]	—	175	135	29.0	49.5	44.3	69.7	44	4.56	56.90	4.70	81.0
Semi alkaline Sulphite	18	170	210	52.8	58.2	52.3	71.0	43	5.11	53.53	4.90	83.0
Semi alkaline Sulphite-AQ[4,9]	18	170	180	42.6	57.8	52.6	71.2	45	4.50	62.00	4.95	81.6
NSSC[7,9]	—	160	120	108	70.0	—	—	42	5.10	44.23	3.56	—

1= Unbleached pulp, 2 = Pulp bleached by CEHH sequence, 3 = Bath ratio 1:3.5, 4 = 0.1 per cent AQ, 5 = Sulphidity, 6= Sodium sulphite, 10.8 and Sodium hydroxide, 6.2, 7 = Na_2SO_3: Na_2CO_3, 30:708 = as NaOH, 9 = as Na_2O

The fibres are of two types, thin walled and thick walled. The former have joined marks on the wall, higher lignin content and are known as lignified fibres. The later have smooth walls, narrower lumen, and lower lignin content and are known as libriform fibres. The parenchymatous content is about 30 per cent of the total cells. The parenchymatous cells are 30-220 µm in length and 10-50 µm in width. The epidermal cells are always presented, comparatively more numerous than in bagasse. The epidermal cells are not removed in acidic or neutral medium. Thus, in acidic pulping the pulp fibres remain with the epidermal cells which adversely affect the pulp quality. The epidermal cells can be dissolved to some extent during alkaline pulping process, thus this method is more suitable for sabai grass.

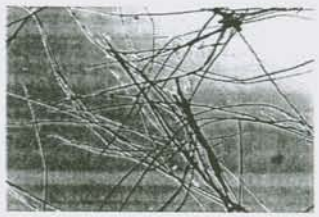
A Bauer-McNett fibre classification of soda pulp was carried out in Bauer-McNett fibre classifier having mesh no +28, +48, +100, +200 and -200 and shown in micro- photograph nos 1, 2, 3, 4, 5, and 6I (50 X). The per cent fibre weight at each mesh size is given below:

Mesh Size	Fiber weight, per cent
+28	46.7
+48	20.7
+100	9.7
+200	1.2

+28 fractions represent long slender fibres with some typical epidermal cells (Microphotograph 2). Fairly long fibres and lot of epidermal cells are observed in +48 fraction and fibres are short in comparison to fibres of +28 fraction (Microphotograph 3). In +100 fractions, short fibres and epidermal cell bundles varying in dimensions oriented in different directions are observed (Microphotograph 4). +200 fractions contains lot of thin walled parenchyma cells and rarely seen epidermal cells with some very short fibres (Microphotograph 5), while –200 fraction consists of lot of fine with thin walled parenchymatous cells (Microphotograph 6).

Table 1 shows the morphological characteristics of sabai grass and bamboo. The average fibre length of sabai grass is 2.4 mm compared to those of 1.7 mm for bamboo. The fibre diam of bamboo is 23.60 µ m, which is 2.5 times, more than sabai grass. The slenderness ratio of sabai grass is 266 against a

Microphotograph -1: Whole pulp shows long, thin, slender & with pointed ends fibres



Microphotograph -2: +28 fraction shows long, slender fibres with typical epidermal cells

Microphotograph -3: +48 fraction shows fairly long fibres with a lot of epidermal cells

Microphotograph -4: +100 fraction shows short fibres with epidermal cell bundels

Microphotograph -5: +200 fraction shows thin walled parenchymatous cells

Microphotograph -6: +200 fraction shows lot of fines with thin walled parenchymatous cells

slenderness ratio value of 72 in the case of bamboo. The slenderness ratio (L/D), which is also termed as felting power, is inversely proportional to the fibre diam. Due to high slenderness ratio, it is expected that such type of fibres is having low degree of collapsing and conformability. Therefore, such type of paper gives more tear, porosity, bulk, and opacity.

The runkel ratio of sabai grass is almost equal to the runkel ratio of bamboo and it is directly affected by cell wall thickness but not by lumen diam. The runkel ratio is related to fibre density[6,7], hence, breaking length, bursting strength, and double fold is determined by fibre density. However the runkel ratio of *Eulaliopsis binata* resembles that of bamboo but due to less fibre diam, the flexibility and the degree of collapse ness of fiber, both of which control the degree of conformability within the paper sheet and as such the size and number of inter-fibre bonds is improved in the case of *Eulaliopsis binata.* The mechanical properties along with other properties of paper related to wet plasticity may be increased by fibrillation and high hemicellulose content (around 33 per cent). The fibre length is of secondary importance

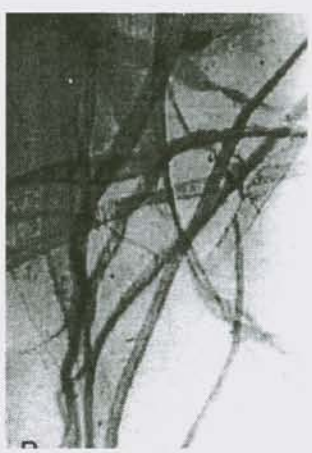
in determining the breaking length with other properties. The effect of fibre length has been ascribed to stress dissipation; the longer the fibre, the greater the area over which the stress is dissipated[8,9]. The fibre length of sabai grass is 2.5-times more than the fibre length of bamboo. Hence, it is expected that all the mechanical strength properties of sabai grass will be better than the mechanical strength properties of bamboo. The rigidity coefficient, runkel ratio and wall fraction of sabai grass is also in close proximity with bamboo. Based on morphological characteristics the sabai grass is quite comparable and even somewhat better in some characteristics than that of bamboo fibers. Therefore, paper mills located at such places where bamboo are not available in plenty, sabai grass may be utilized as a substitute by selecting appropriate pulping processes, in order to impart special properties of paper.

Table 2 indicates the proximate chemical analysis of sabai grass along with bamboo. Sabai grass is rich in cellulose and having low lignin content. The digestion can be carried out under milder process conditions along with less bleach consumption. The pulp yields of good quality pulp are slightly more than that of bamboo. Moreover in comparison to bamboo, the sabai grass produces a stronger and more durable paper. Sabai grass is singularly homogenous in quality throughout the whole plant. Even the nodes are not resistant to the action of cooking liquor and consequently it is reduced to a clean and regular pulp by simple digestion. Sabai grass consists of 33.2 per cent pectoses, which has positive significant effect on the size, number, and strength of bonds[10,11] and refining of pulp.

Table 3 shows pulp evaluation characteristics of sabai grass digested by various pulping processes like, soda and soda-AQ, alkali-O_2, and alkali-O_2-AQ, kraft and NSSC-AQ etc. The pulp produced by soda and alkali-oxygen processes is brighter in colour. However the pulp produced by alkali-O_2 process is stronger than soda because addition of 0.1 per cent $MgSO_4$ helps in mitigating the depolymerisation of carbohydrate fraction, which results in an improvement in overall pulp quality and yields. The pulps were bleached by OCEH bleaching sequence in order to achieve the predetermined objectives of pulp brightness, pulp strength with low environment pollution load. Hence, this bleaching sequence fulfils the targeted objectives up to somewhat extent.

Due to comparatively narrower fibre diam and high cost of sabai grass fibre, it is essential to carry out blending studies with other pulp in order to manufacture cultural papers. The sabai grass is suitable for manufacturing of wood free writing and printing, glassine and grease proof, condenser, cigarette paper, light weight printing and writing, fire work paper, high grade bond, ledger and other cultural papers when it is blended with other paper furnish[12]. Presently, some of the Indian pulp and paper industries are using sabai grass as a supplement raw material along with their furnish for manufacturing of specialty papers.

Sesbania sesban — Table 1 shows the morphological characteristics of *Sesbania sesban* along with bamboo (Microphotograph 7). The various inter-relationship have also been established between fibre length, fibre width, cell wall thickness, cell wall thickness to lumen diameter or cell wall thickness to fibre diameter and fibre width to explain their effect on principal properties of paper. The fibre length of *Sesbania sesban* is 0.914 mm, which is almost equal to fibre length of eucalyptus, and fiber width is 19.17 µm, which is lower than the fiber width of bamboo. The rigidity coefficient of *Sesbania sesban* is comparable to rigidity coefficient of bamboo. The fibres of *Sesbania sesban* tend to retain their tubular structure, which results in decrease in the fibre flexibility with less conformability within the sheet, and more bulk and tear. This increase in bulk lowers the resistance of passage of air[13,14-18]. The runkel ratio, which is directly related to the ratio of twice the cell wall thickness and lumen diam, is 1.20 for *Sesbania sesban* compared to 1.47 for bamboo. The degree of collapseness of fibre will be minimum due to rigid



Microphotograph -7: Fibres of Sesbania sesban

nature of fibre, thereby produces more bulky or less denser paper sheet. Fibre density which determines the degree of fibre collapse ness and flexibility, both of which thereby control the degree of conformability within the sheet; and as such the size and number of inter fibre bonds[19-21]. The rigidity coefficient, wall fraction and runkel ratio of *Sesbania sesban* resembles those of bamboo except fibre length.

Table 2 shows the proximate chemical analysis of *Sesbania sesban* along with bagasse and bamboo. The hot water soluble of *Sesbania sesban* is 6.30 per cent, in comparison to that of 7.85 per cent for bagasse and 8.50 per cent for bamboo. However the value of alcohol-benzene soluble lies between the values of bagasse and bamboo. The hemicelluloses contents are comparable to those of bagasse and bamboo; whereas the holocellulose contents are more than bagasse and bamboo. *Sesbania sesban* contains 17.65 per cent lignin in comparison to 20.30 per cent for bagasse and 24.30 per cent for bamboo. Therefore, *Sesbania sesban* requires lesser cooking chemical and shorter cooking cycle. It can be concluded that the proximate chemical analysis of *Sesbania sesban* shows its suitability for pulp and papermaking.

Table 5 shows the pulp evaluation characteristics of *Sesbania sesban* digested by soda and soda-AQ, kraft and kraft-AQ, alkaline sulphite and alkaline sulphite-AQ, semi alkaline sulphite-AQ and NSSC pulping processes. The screened pulp yields are between 45.7 per cent to 70 per cent (on o d wood basis). The pulp shows good response towards bleaching. The packing density of *Sesbania sesban* is about 230-245 kg/m^3 and is adaptable to batch digester. A pulp freeness of 42±2 °SR seems to be optimum to develop good physical strength properties, in order to preserves tear. In order to manufacture specialty papers, it is necessary to blend it with long fibred pulp. By selecting an appropriate blend ratio of *Sesbania sesban* pulp and long fibred pulp depending upon the end use of the paper, cultural paper can be manufactured.

Cajanus cajan — Table1 indicates the morphological characteristics of the *Cajanus cajan*. The fibre length of *Cajanus cajan* is 0.76 mm and fibre diam is 22.12 µm (Microphotograph 8). It gives a slenderness ratio of 34.60. It means these fibres have a little tendency to flocculate in the head box and give a uniform sheet. The ratio of cell wall thickness to lumen diam the runkel ratio is three times less than

Microphotograph -8: Fibres of Cajanus cajan

that of bamboo. The fibres become more flexible and show high wet plasticity. These fibres have high degree of collapseness and high degree of conformability within the paper sheet. The density of fibres determines its flexibility, which in turn influences the extent of bonding within the sheet. Therefore, all such properties, which depend upon the extent of bonding, will be improved. The rigidity coefficient and wall fraction is very low than that of bamboo. Such fibres on delignification tend to collapse readily to double walled ribbon structure and provide more fibre contact area for bonding[22]. A decrease in these variables which is measure of the flexible nature and wet plasticity of fiber results in:

- A grater degree of fibre collapse, and
- A higher degree of conformability within the sheet, which give rise to a sheet of a higher density or lower bulk. However, the fibre length is only 0.76 mm, which is of secondary importance for determining the strength of paper. Hence it is necessary to blend *Cajanus cajan* with long fibred pulp in order to improve strength characteristics, drainage and runnability of paper machine.

Table 2 indicates the chemical analysis of *Cajanus cajan* along with bagasse and bamboo. *Cajanus cajan* consists of 5.10 per cent hot water soluble compared to 7.85 per cent in bagasse and 8.50 in bamboo, whereas alcohol: benzene soluble are less than bamboo and more than bagasse. The one per cent NaOH soluble is 19.66 per cent for *Cajanus cajan*, 33.60 per cent for bagasse and 26.80 per cent for bamboo. It indicates that the degree of fugal decay or degradation by heat and light is less. Hence the wood can be stored for a longer period. *Cajanus cajan* is

having low lignin content, thereby requires comparatively less cooking chemicals and shorter cooking cycle with improved tensile, burst, tear, double-fold and sheet density. The cellulose contents are 47.31 per cent for *Cajanus cajan*, 42 per cent for bagasse and 43.50 per cent for bamboo. This variation in the cellulose is directly related to pulp yield. This is not only the greatest importance for the economy in pulp production but the yield level is also reflected strongly in the properties the higher the cellulose content of the pulp the higher the load bearing capacity of the individual fiber in the pulp.

Table 4 shows the pulp evaluation characteristics of *Cajuns Cajan* by various pulping processes i.e. soda and soda-AQ, kraft and kraft-AQ, alkaline sulpyhite and semi alkaline sulphite-AQ and neutral sulphite semi chemical pulping processes. The cooking chemical requirements are low with comparatively milder cooking conditions. The pulp yields range between 48 to 70.95 per cent. The wood is light with a packing density of 180-190 kg/m^3 and is more adaptable to continuous digester. A pulp freeness of 42±2 °SR seems to be optimum to develop physical strength properties in order to preserve tear strength. For improving the tear, opacity and to run on high speed paper machines, it is necessary to blend *Cajanus cajan* pulp with long fibred pulp depending upon the requirement of the pulp may be utilised to develop quality writing and printing grades, antitrust paper, S S map litho and other grades of paper[13].

Conclusions

- *Eulaliopsis binata* shows a slenderness ratio of 266 that result in lower degree of collapses and conformability within the paper sheet. The runkel ratio of sabai grass is equal to the runkel ratio of bamboo. The fibre length is 2.4 mm in comparison to 1.7 mm for bamboo. On the other hand the fiber diameter is 2.5-times more than that of bamboo.
- Sabai grass consists of high percentage of hemicelluloses, thereby affecting the number and strength on bonds.
- Sabai grass pulp produced by various pulping processes such as, soda and soda-AQ, alkali and alkali-O_2-AQ and NSSC processes produces pulp yield in the range between 48- 51.3 per cent. A good brightness is obtained by using OCEH bleaching sequence in order to preserve strength with low pollution load. Sabai grass is suitable for manufacturing of wood-free writing and printing, glassine, and grease proof, condenser, cigarette tissue, and light weight and printing papers.
- *Cajanus cajan* is an important leguminous plant in nitrogen fixation. The fibre length and diam are 0.76 mm and 22.12 µm, respectively. It gives lower slenderness ratio, runkel ratio, rigidity coefficient and wall fraction which results in a grater degree of fibber collapseness, less tendency to flocculate in head box and a higher degree of conformability within the paper sheet, thereby producing denser stronger sheet with low bulk.
- The basic density of wood chips of *Cajanus cajan* is 180-190 kg/m^3. Due to lower 1 per cent NaOH soluble the raw materials may be stored for a longer period.
- *Cajanus cajan* requires milder cooking conditions due to low lignin content and more open and loose anatomical structure. The screened pulp yields are between 48 to 70.9 per cent for soda and soda-AQ, kraft and kraft-AQ, alkaline sulphite and alkaline sulphite-AQ, semi-alkaline sulphite and semi alkaline sulphite –AQ and NSSC pulping process. By choosing an appropriate blend ratio with long fibred pulp, any cultural paper may be manufactured.
- The fibre length of *Sesbania seban* is 0.914 mm, which is equal to the fiber length of eucalyptus; and fibre width is 19.17 µm, which is lower than that of bamboo. The rigidity coefficient, wall fraction and runkel ratio is comparable to those of bamboo.
- Lower lignin content and high cellulose content indicates that it requires lower cooking chemical and shorter cooking cycle.
- The screened pulp yields range between 45.7 per cent to 70 per cent with soda and soda-AQ, kraft and kraft-AQ, alkaline sulphite and alkaline sulphite-AQ, semi-alkaline sulphite and NSSC pulping processes. A freeness level of 42±2 °SR was found to be optimum to produce a sheet with good physical strength with preservation of tear. By blending with long fibred pulp, various kinds of cultural paper can be manufactured.
- The packing density of wood is between 230-245 kg/m^3 and is adaptable to batch process.

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