Evaluation of Certain Potential Annual Plants for Pulp and Paper Making

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ABSTRACT

Five species of fast growing plants, Hibiscus cannabinus, HC-583, Hibiscus sabdariffa, HS-7910, Sesbania aculeata, Baker, Crotalaria juncea and Tephrosia Candida were evaluated for their pulp and paper making properties. Data on growth characteristics and bio-mass yields, chemical constituents of raw materials, unbleached and bleached pulp yields, fibre dimensions and physical strength properties of paper sheets were obtained. The unbleached pulp yields were 45.7-52.5% with sulphate pulping, while with Soda Anthraquinone pulping, the yields were 46.5-54.6%. The amount of long fibre (2-15-0.90mm) recorded was 60% in case of pulps from H. cannabinus and C. junceae while the amount of long fibre was 20.6% in the pulp of S. aculeata. Laboratory hand made paper sheets with adequate strength properties were obtained from both sulphate and Soda AQ pulps prepared from these plant materials.

INTRODUCTION

The paper industry accounts for about 2.5% of world's industrial production. It is considered to be the highest consumer of forest based cellulosic materials. Paper being the primary medium of communication, the global demands for pulp and paper is therefore growing at 3% per annum (1). In our country with the increase in literacy level and industrialisation, the demand for paper and paper boards is likely to go up by the turn of the centuary and as such the demand for additional raw material supply is expected to rise. Over the last decade, the availability of forest raw material has been steadily declining due to various factors like enormous growth in population leading to occupation of more and more forest land for diverse purposes, diversion of forest produced to meet domestic fuel requirements, increasing deforestation without continuing afforestation methods, inadequate funds and lack of efforts of scientific studies and inadequate development of forests using adavance techniques. The national forest policy, Govt. of India 1988 bared the supply of forest wood raw materials to the indusrty and insisted on raising the raw materials by plantation and other means. Due to this, it is assumed that no further increase in the availability of forest resources for paper indusrty exists in coming years.

The plant kingdom provides a reservoir of 2,50,000-3,00,000 known plant species, out of which a few have been or are now cultivated to a great extent. Search for new fibre crops has been under way during last three decades or so, to find and develop new fibre supply for paper and cellulose industries. Many fast growing annual and perennial plants have been indentified, cultivated and their suitability for pulp and paper making has been studied (2-10). It is expected that the fast growing plants will be a potential source of raw material for future pulp

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and paper industry. With the begining of 21st century, the Indian paper industry has to accept new raw materials and new technologies have to be introduced to cope with not only the domestic demand of pulp and paper but also to thrive in the international competitive environment.

The quantum of availability of fast growing plant materials and their use in Indian pulp and paper industry is though not known, efforts are being made to develop cultivation technology and to introduce such plants as raw material for paper and pulp production (11). However, in developed countries like USA and Australia kenaf is being used as raw material for paper mills. It is also reported that in China and Thailand, the fast growing annual plants are being introduced in commercial paper making (12, 13).

Considering the importance of the fast growing plants, systematic studies were carried out at Regional Research Laboratory, Jorhat for development of appropriate agro-technology for cultivation of some of the important fast growing annual and perennial plants and also their utilization of producing paper grade and high quality pulps. In the laboratory experimental cultivation, per hectare of plantation of annual plants the expenditure varies between Rs. 4500.00-6000.00 and the cost/ton of pulpable biomass is calculated at around Rs. 300.00-650.00.

In this paper, laboratory scale studies on the pulp and paper making characteristics of five annual plants viz. Hibiscus cannabinus, HC-583, Hibiscus sabdariffa, HS-7910, Sesbania aculeata, Baker, crotolaria juncea and Tephrosia candida are presented alongwith some informations on growth characteristics and bio-mass yields of the plants.

EXPERIMENTAL

Raw materials

Matured plants of 120 and 150 days old were collected from the experimental farm of Regional Research Laboratory, Jorhat. The growth characteristics and bio-mass yields of the plants are recorded in Table-1.

For studying physico-chemical properties, the stem portion of the plants were taken, after cleaning and removal of branches and leaves. The stems without debarking were cut into chips of 2-2.5 cm length for experiment.

The chips as prepared above were dried to moisture level 12% and then used for experimental work on over dry (od) basis.

Chemical analysis

The chemical constituents of the plant materials were carried out as per Tappi standard methods (14) and the results are presented in Fig. 1 (a, b, c, d).

TABLE-1

Growth Characteristics and bio-mass yields of the plant species

Plant species	Maturity status (days)	Plant height (m)	plant diameter (cm)	Moisture content (%)	Green biomass (t./hec.)	Dry Biomass biomass (t./hec.)
H. cannabinus	120	2.87	1.70	56.30	22.70	12.80
(HC-583)	150	3.85	2.00	51.70	30.37	15.70
H. sabdariffa	120	3.27	1.80	55.80	20.96	11.70
(HS-7910)	150	4.15	2.00	51.20	28.90	14.80
S. aculeata Baker	120	3.50	2.20	57.20	27.62	15.80
	150	4.90	2.90	53.50	36.44	19.50
C. juncea	120	2.25	1.80	54.70	9.69	5.30
	150	2.58	2.10	52.70	14.23	7.50
T. candida	120	2.15	1.70	54.60	13.60	7.40
	150	2.98	2.10	50.10	20.40	10.20

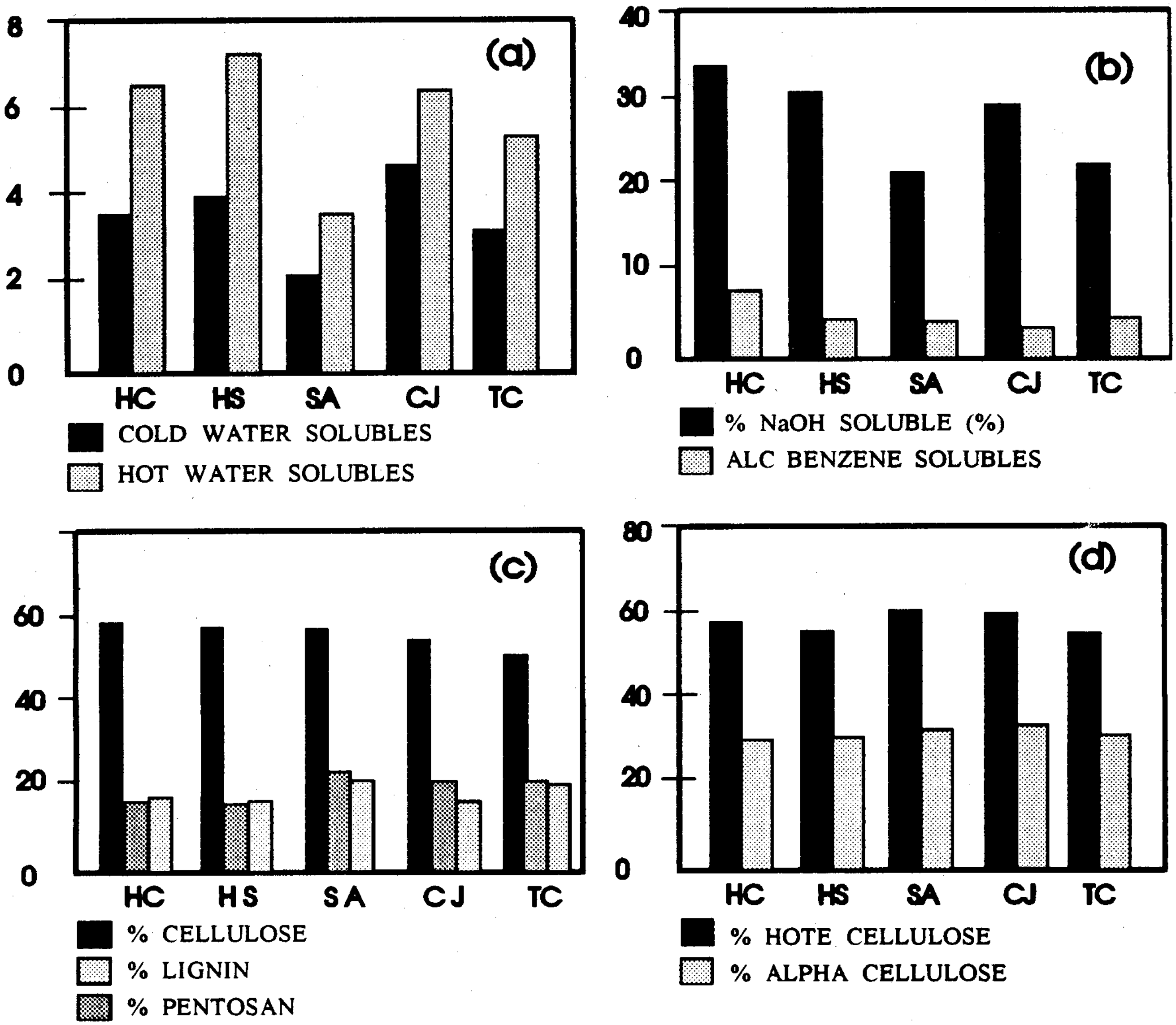


FIG. 1: Chemical analyses of the plants (a) Cold and Hot water solubles, (b) Alkali & Alcohol benzene solubles, (c) Cellulose, lignin and Pentosans (d) Holo and Alpha cellulose content:

HC = Hibiscus cannabinus, HS = Hibiscus sabdariffa, SA = Sesbania aculeata,

CJ = Crotalaria juncea, TC = Tephrosia candida

Pulping and bleaching

Kraft and Soda antraquinone (AQ) pulping were carried out in an electically heated rotary stainless steel reactor with thermostat controlled system. For both the pulpings, 1000 g chips (od) were charged into the reactor alongwith the required amount of cooking chemicals at a material to liquor ratio 1:4.5. The digestions were carried out at varying chemical concentrations from 15-17% at sulphidity 20% for 3 h (including 45 min time to raise the temperature to maximum) at 165 ± 2°C.

The pulps after digestion were throughly washed with cold fresh water. The unbleached pulp yields, kappa numbers, rejects etc. were determined. The black liquor after each digestion was collected for determination of total solids and residual active alkali. The results are given in Table-2.

The unbleached pulps were bleached by H-E-H sequence with approximately 5.5-6% total chlorine

TABLE-2

Pulping parameters and properties of unbleached pulps

Plant species Residual	Pulping process (%)	Cooking chemicals as Na_2O (%)	AQ (%)	Unbleached pulp yield (%)	Kappa Number	Screen Rejects solid W/W (%)	active alkali (asNa_2O)g/L	Black liquor Total
H. cannabinus	Sulphate	16		50.5	24.80	0.40	16.40	5.70
(HC-583)	Soda AQ	15	0.10	52.4	26.0	0.25	17.2	6.20
H. sabdariffa	Sulphate	17	-	49.5	26.5	0.70	17.7	6.30
(HS-7910)	Soda AQ	16	0.10	50.8	28.7	0.45	18.6	7.40
S. aculeata Baker	Sulphate	16	-	52.5	28.4	0.45	16.3	8.20
	Soda AQ	15	0.10	54.6	29.7	0.38	19.8	8.50
C. juncea	sulphate	16	-	52.2	18.8	0.31	17.2	7.80
	Soda AQ	15	0.10	53.1	19.2	0.25	18.4	6.70
T. candida	Sulphate	17	-	45.7	19.9	0.65	16.5	8.50
	Soda AQ	16	0.10	46.5	21.2	0.45	18.0	7.20

consumption to yield pulp of 75-80% brightness. The various physical properties of bleached pulps such as freeness, brightness, viscosity and degree of polymerisation were evaluated (11). The results are recorded in Table-3.

Fibre morphology

The length (L), diameter (D), Wall thickness (W) and lumen diameter (d) were determined separately for bast and woody portions of the plant materials. The observations were made under Dokuval photomicroscope (JEOL, Japan) at different magnifications and the data obtained are presented in Table-4. The amount of fibres of different length in the pulp were also calculated and shown in the bar diagram (Fig. 2).

Fibre fractionation

The well digested pulp fibres were classified using a Baur Mc Nett Fibre Classifier provided with 14, 30, 50 and 100 BS mesh. The fibres retained on different mesh are presented in Table-5.

Scanning electron microscopy

Fibres in the bleached pulp were separated and mounted on specimen holders with the help of electroconductive tape. The samples were coated with gold in an ion-sputter coater (JFC 100, JEOL, Japan) in low vacuum with a layer 150-200 ηm thick. The observation was made in a JEOL JSM-35M-35CF electron microscope at an accelarating potential of 15kV. Micrographs were taken at this potential.

Paper sheet formation and testing

The unbleached and bleached pulps were beaten separately in a laboratory valley beaker to 45° SR (Schopper Reigler) freeness at consistency 1.57%. Standard sheets of 60±1 gm^{-2} were prepared from the pulps in a British Standard laboratory hand sheet forming machine, followed by pressing and drying.

The paper sheets were conditioned at 65% relative humidity at 27°C for 2 h and then tested for various physical properties.

RESULTS AND DISCUSSION

Table-1 shows the results on growth characteristics and bio-mass yields of the annual plant species of 120 and 150 days maturity. It is evident that the plants of 150 days maturity show higher yield of bio-mass compared to 120 days matured plants. Among the five annual plants, Sesbania aculeata

TABLE-3

Physical properties of bleached pulp

Plant species	Bleached pulp yield (%)	Initial pulp freeness (^{0}SR)	Brightness (%)	Viscosity (C_p)	Degree of polymerisation (DP)
H. cannabinus (HC-583)	50.6	11	81.7	18.2	387
H. Sabdariffa (HS-7910)	47.8	12	80.5	15.7	325
S. aculeata, Baker	46.5	14	78.2	12.5	775
C. juncea	46.1	12	80.1	19.0	475
T. candida	40.8	16	78.9	13.5	325

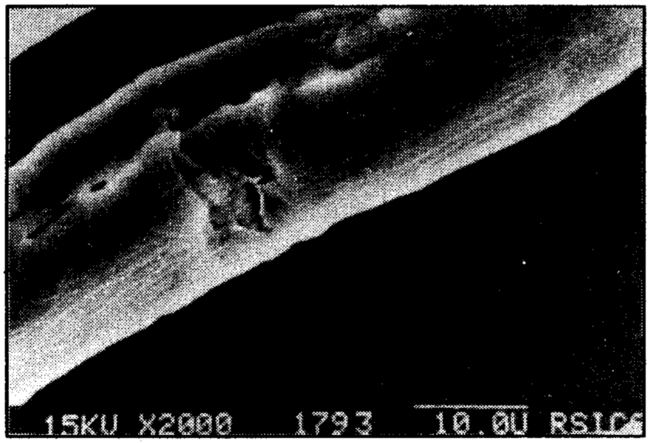
produces highest bio-mass (36.44 t green and 19.5 t dry bio-mass per hectre) followed by Hibiscus cannabinus (30.3 t green and 15.7 t dry bio-mass per hectre), while the lowest bio-mass yield was found in the palant C. juncea (14.23 t green and 7.5 t dry bio-mass per hectre). The plant height of 4.9 m was recorded as the maximum for S. aculeata and 2.5 m, the minimum for C. juncea. Similarly, the stem diameter of the plant was recorded maximum in case of S. aculeata (2.85 cm) and minimum for H. cannabinus (2.0 cm) for 150 days matured plants.

The proximate chemical analyses of the plant materials were carried out and the results are presented in bar diagrams in Fig. 1 (a, b, c, d). From figure 1 (c), it is evident that the plant materials contain 58.7-59.5% cellulose and 38.5-42.0% alpha-cellulose, which entail them as suitable raw material for pulp production.

TABLE-4

Morphological characteristics of the fibres

Plant species	H. canabinus	H. sabdariffa	C juncea	S. aculeata	T. candida
Fibre length (mm)					
Bast	2.60	2.47	3.75	2.45	2.10
Woody	0.50	0.61	0.60	0.55	0.50
Combined	1.25	1.01	1.20	0.98	1.10
Fibre width (μm)					
Bast	15.0	16.2	24.0	16.0	16.50
Woody	31.2	30.0	30.8	32.0	33.10
Combined	33.7	34.5	36.0	34.0	34.70
Cell wall thickness (μm)					
Bast	3.9	3.56	3.25	4.0	3.75
Woody	5.3	4.58	4.80	5.8	4.72
Lumen width (μm)					
Bast	8.1	9.2	8.0	9.5	9.7
Woody	19.0	18.2	20.0	17.3	18.7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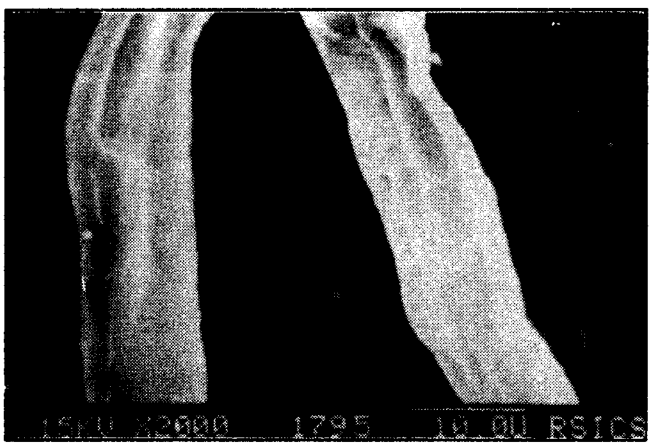
(a)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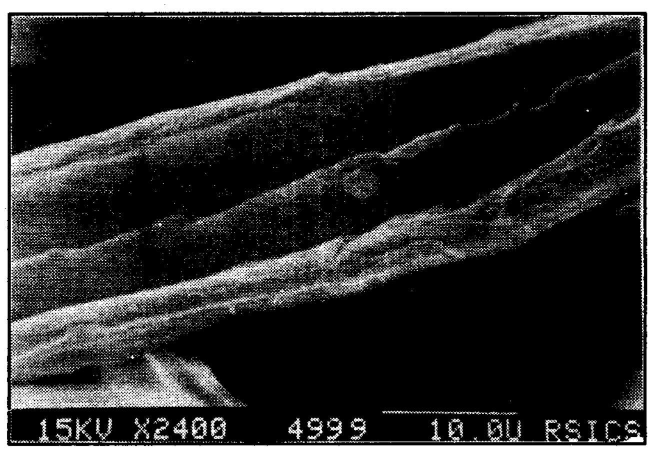
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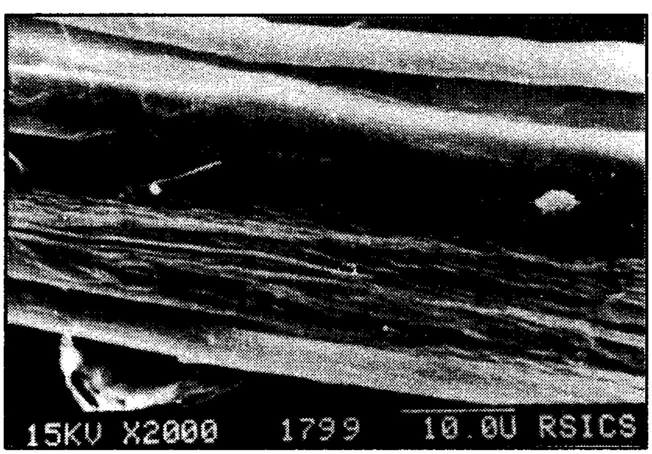
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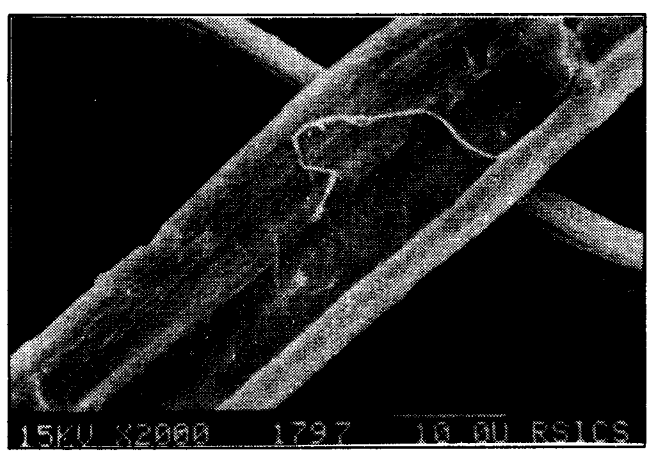
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(e)

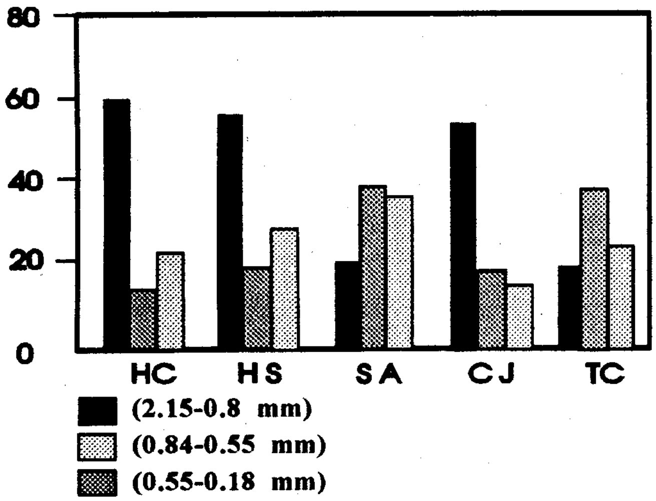

Fig. 2: Composition of pulp fibre in terms of fibre length.

Table-2 shows the unbleached pulp yield of the five plant materials. S. aculeata yielded 52.5 and 54.6% in Kraft and Soda AQ pulping, while the lowest pulp yield was found in T. candida (45.7 and 46.5%). The rejects obtained after digestion was minimum in C. juncea (0.31% and 0.25%) for Kraft and Soda AQ pulping, while maximum was recorded as 0.70% and 0.45% in H. Sabadariffa. The properties of black liquors obtained from the digestion of the five plants vary only within a narrow range.

The physical properties of bleached pulp fibres are shown in Table-3. Bleached pulp yield was recorded maximum (50.6%) in H. cannabinus which is followed by H. sabdariffa (47.8%), S. aculeata (46.5%), C. juncea (46.1%) and T. candida (40.8%). Intial freeness (°SR) was maximum for pulp of T. Candica (16°SR) and minimum for H. Cannabinus (11°SR) Brightness of the bleached pulp varied from 78.2-81.7%. The maximum value of pulp viscosity was for C. junceae (19.0 C_p) and minimum for S. aculeata 12.5 C_p). The D.P. values of pulp of S. aculeata was found to be highest and that of T. candida the lowest.

The characteristics morphological properties of bleached pulp fibre are given in Table-4 The results are means of 10 determinations. The data were statistically analyzed. The fibre length of the pulp from the bast portion varied from 3.75-2.10 mm, while for woody and combined pulps, the length varied from 0.50-0.6 mm and 0.98-1.25 μm respectively. So also, fibre widths varied from 15.0t-24.0 μm for bast, and 30.00-33. 1 μm and 33.7-36.0 μm for woody and combined pulps.

The amount of fibres of different lengths present in a mass of pulp was calculated and represented in Figure-2. The maximum amount of long fibre (2.15-0.90 mm) recorded was 60% in case of pulps obtained from H. cannabinus and C. juncea while the same was 20.6% and 25.9% for S. aculeata and T. candida.

Fig. 3 (a, b, c, d, e) shows the Scanning electron micrographs of the fibres. Fig. 3 (a) represents a single H. canabinus pulp fibre which is large in diameter with occasional cracks visible on the surface. A number of pores and microfibrils are also seen. Fig. 3(b) shows a H. sabdariffa fibre, which is comparatively small in diameter. The shape of the fibre is irregular and the number of pores are comparatively less. Fig. 3(c) is that of fibre of S. aculeata which is large in diameter with less pores. A number of folds are visible on the surface of the fibre, Fig. 3(d) is of C. juncea pulp fibre which is cylindrial and uniform. A number of cracks and pores are visible on the surface but the fibrils are uniform and arranged in linear direction. Fig. 3(e) shows a fibre of T. candida which is large in diameter with distinct nodes and horizontal cracks on the surface.

TABLE-5

Baur McNett classification of pulp fibres

Mesh No.	Opening mm	Retention of pulp fibre (%)				
		H. cannabinus	H. sabdariffa	S. aculeata	C. juncea	T. candida
+14	1.18	44.50	46.0	5.61	35.5	8.60
-14, +30	0.595	20.75	18.7	9.37	22.6	8.10
-30, +50	0.297	11.80	10.2	49.78	7.8	45.6
-50, +100	0.150	3.85	5.1	17.73	3.5	22.7
-100		19.10	20.0	17.25	29.5	17.4

TABLE-6

Physical strength properties of paper sheets

Particulars		Plant species				
		H. cannabinus	H. sabdariffa	S. aculeata	C. juncea	T. candida
Bulk density (g/cc)						
UBPS:	A	1.52	1.50	1.40	1.45	1.45
	B	1.50	1.48	1.35	1.42	1.40
BPS:	A	1.40	1.38	1.36	1.39	1.35
	B	1.39	1.33	1.30	1.34	1.31
Tensile index (Nmg^{-1})						
UBPS:	A	65.72	62.50	65.20	63.50	57.80
	B	62.31	60.00	64.00	62.80	52.50
BPS:	A	40.20	42.25	39.20	47.82	40.85
	B	39.27	41.75	37.80	45.51	38.70
Burst index (Kpa m^2g^{-1})						
UBPS:	A	5.00	4.87	4.95	5.10	4.85
	B	4.87	4.75	4.82	4.87	4.21
BPS:	A	3.95	3.80	4.48	3.95	3.50
	B	3.75	3.64	4.25	3.70	3.02
Tear index (Kpa mNm^2g^{-1})						
UBPS:	A	10.25	12.00	6.97	10.80	5.72
	B	9.62	11.27	6.20	9.89	5.21
BPS:	A	5.80	6.50	6.21	9.70	4.40
	B	5.25	5.92	5.75	8.72	4.00
Folding endurence (double fold)						
UBPS:	A	340	325	900	425	310
	B	310	310	650	400	275
BPS:	A	115	130	325	250	155
	B	95	125	597	248	148

UBPS = Unbleached paper sheet ***A = Soda anthraquinone pulp***

BPS = Bleached paper sheet ***B = Sulphate***

The physical strength properties of pulp sheets made from unbleached and bleached Soda AQ and sulphate pulps are given in Table-6. It may be seen that paper sheets made from bleached Soda AQ pulp gave better physical strength properties than that of sulphate pulps. The tensile indices varied from 39.2-47.82 Nmg^{-1} for Soda AQ pulps, while for sulphate sheets, it varied from 37.8-45.51 Nmg^{-1}. So also, burst indices were varied from 3.50-4.48 $kpam^2g^{-1}$ in case of Soda AQ and 3.02-4.25 $kpam^2g^{-1}$ with sulphate pulp sheets. The results of tear indices and folding endurance also showed similar trends.

CONCLUSION

■ From the study, it may be concluded that all the above annual plants yield pulpable biomass in the range of 7.5-19.5t/hec. In the experimental cultivation, the cost of production per ton of pulpable biomass comes within Rs. 300-650.00.

■ Papers with reasonably wide range of properties may be made from the pulps of these annual plants.

■ These plants, therefore, should receive serious consideration as source of raw materials for future pulp and paper indusrty of our country.

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REFERENCES

1. Khanolkar, V.D. (1996). National Seminar on "Energy Management and Environmental Preservation by pulp and paper industry." IPPTA, New Delhi, December 14-15.

2. Nelson, G.H., Clark, T.F. Wolff, I.A. Jones, Q (1996). A search for new fibre crops: Analytical evaluations, TAPPI, 49 (1):40.

3. Cunningham, R.L., Clark, T.F., Kwolek, W.F., Wolf, I.A., Jones, Q. (1970). A search for new fibre crops. XIII. Laboratory scale pulping studies, TAPPI, 53(9): 1697-1700.

4. Zarges, R.V., Neuman, R.D., Crist, John B. (1980). Kraft pulp and paper properties of Populus clones grown under short rotation intensive culture. TAPPI, 63(7): 91-94.

5. Saikia, C.N., Dass, N.N., Barua, J.N. (1991). High alpha cellulose and its acetylated products from H. cannabinus L. Indian J. Tech., 29, 40-45.

6. Saikia, C.N., Ali, F., Dass, N.N., Barua J.N. (1991). High alpha cellulose pulp from fast growing plant materials. 1 E(1) Journal-CH. (71), 72-76.

7. Ali, F., Sarma, T.C., Saikia, C.N. (1993). Pulp and paper from certain fast growing plant species. Bio-resource Technology, 45, 65-67.

8. Sarma, T.C. and Goswami, T (1993). Plantation of certain fast growing tree species under short rotation agro forestry system for production of bio-mass for paper pulp. "Advances in Forestry Research in India, Ed. R. Prakash, International Book distributors, Dehradun, India.

9. Goswami, T., Saikia, C.N., Barua, R.K. and Sarma, C.M. (1996). Characterization of pulp obtained from Populus deltoides plants of different ages using IR, XRD and SEM. Bio-resource Technology, 57, 209-214.

10. Ali, F, Saikia, C.N., (1997). Evaluation of H. sabdariffa and G. arborea as rawmaterials for production of high alpha cellulose pulp. J. Scientific & Ind. Res., 56, 618-626.

11. Panth, M.G., Narasinham, P., Chellam, T.S., Srinivasan, A.S., Basu, A. and Keshavamurthy, G.S. (1997), Jute and Kenaf-raw material supplement.

12. Young J. (1987) "Kenaf newsprint is a proven commodity.". TAPPI 70 (11):81-84.

13. Rangan, S.G. (1991) "Non wood fibrous raw material, pulping, washing, bleaching" IPPTA 3(3): I-III.

14. Tappi (1993). Standard and suggested methods. Technical Association of pulp and paper indusrty, Tappi Press, Atlanta, USA.