Blending Of Banana Stem With Wheat Straw And Bagasse To Enhance Physical Strength Properties Of Paper

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ABSTRACT

Suitability of banana stem for papermaking was studied by blending it with agro residue raw materials viz. bagasse and wheat straw. Dewatered and wet cleaned banana stem was blended with wheat straw and bagasse in the proportions of 5, 10 and 20% prior to pulping.

Brightness of banana stem blended pulps were improved by 0.8-1.9% with comparable other optical properties excepting 2.8-4.6% reduction in opacity in the 20% blend of banana stem fiber. Tensile, burst and tear index of the banana stem blended wheat straw pulps were improved by 6-16.7, 3.8-15.6 and 1.5-3.8 respectively. Long fiber (>2.0 mm) content was increased to 7.5 from 2.0 % by blending of banana stem with wheat straw. Similarly tensile, burst and tear index of the banana stem blended bagasse pulps were improved by 11.7-26.8%, 2.2-15.0% and 2.8-14.4% respectively. Long fiber (>2.0 mm) content was increased to 12.7 from 6.8% by blending of banana stem with bagasse. Drainability of the unrefined wheat straw and bagasse pulps were reduced after blending the banana stem to some extent.

Banana stem can be blended along with agro residues raw materials prior to pulping up to a level of 5-20% to improve physical strength properties without any noticeable difference in pulping and bleaching process.

Keywords: *Banana stem, wheat straw, bagasse, mixed pulping, bleaching, physical strength properties, morphological properties.*

Introduction

India is the largest banana producing country in the world. Banana production in India was 29.8 million tonnes in the year 2010-11. About 65% of banana is produced in four states namely Tamil Nadu, Maharashtra, Gujarat and Andhra Pradesh (Indian Horticulture data base 2011). Banana is an annual crop and it generates ~10.0 million tonnes per year of OD fibrous material in India as waste from its stem and leaves (Anon, 2004). Paper industry is presently facing the problem of shortage of raw material and looking for alternative fibrous raw material. Among the variety of unconventional alternative fibrous raw materials banana stem has maximum potential to be used in paper industry specifically in agricultural residue based mills.

Very little work has been carried out on utilization of banana stem for paper making in India. Suitability of producing kraft (unbleached) paper from banana stem was attempted in 1960's but very low pulp yield was achieved (Guha, 1960). In 1970's banana stem was characterized for its chemical properties as a source of fibrous raw material and found that it contains high alpha-cellulose content and has long fiber length (Dasgupta et al., 1972). Pulping and papermaking properties of banana stem fibre have been studied by Singhal et al. in 1975, they found that use of banana stem fiber in paper manufacturing is neither technically or economically feasible (Singhal et al., 1975). Pulping and papermaking potential of the banana plant was studied by Fernandes in 1980 which shows its suitability for paper making (Fernandes, 1980). Laboratory scale studies on banana stem and few other agro wastes were also carried out by Ambuj and Dhake, they explored its suitability for paper making with the blend of other agro based fibers (Ambuj and Dhake 2001). Study of Cordeiro et al., show suitability of few species of banana stem for production of high value added paper and corrugated board (Cordeiro et al., 2003). Aguilar and Martinez, obtained pulp having similar properties like wood pulp from banana stem using soda pulping process and CE_PH bleaching sequence (Aguilar and Martinez 2006). Study carried out by Goswami et al., showed suitability of banana stem for making cellulosic leather board and solid toughen boards with the blend of waste paper and bamboo pulp (Goswami et al., 2006). The author also reported that from blend of banana fibre and bamboo pulp greaseproof paper could be made (Goswami et al., 2008). Li et al., studied chemical composition and morphological structure of banana stem, they found it an ideal material for paper making as it has high holocellulose content and low lignin content (Li et al., 2010).

Taking into consideration the large availability of banana stem waste in the country and shortage of raw materials for producing pulp and paper, studies have been carried out at TCIRD on utilization of banana stem for paper making. Present paper describes the suitability of utilization of banana stem along with agro-residue based fiberous raw materials viz. bagasse and wheat straw and its effect on pulping, bleaching, physical strength and morphological properties.

Experimental

Studies were conducted on banana stem collected from Haryana and Maharashtra, wheat straw and bagasse collected from Punjab states of India. Wheat straw and bagasse were depithed and washed prior to pulping. Dewatering of banana stem was carried out in roller mill (used for extraction of juice from cane), as the banana stem contains 85-90% moisture. Dewatered banana stem was further washed prior to pulping. Moisture content of raw materials was determined as per standard procedure prior to pulping experiments.

Pulping experiments were carried out in lab autoclave digester consisting of six bombs each of 2.5 liters capacity rotating in an electrically heated polyethylene glycol bath. Pulping conditions like time, temperature, bath ratio and sulphidity were maintained similar for all the experiments. Chemical doses were selected so as to get kappa number in the range of 12-13, which represents the current practice of Indian paper mills. At the end of the cooking, the bombs were removed and quenched in the water tank to depressurize. The digested material was dispersed with pulp disintegrator and washed with hot water to remove the black liquor and dissolved substances. After thorough washing, pulp was screened in laboratory Somerville screen of 0.15 mm slot width. Pulps were evaluated for unscreened and screed yield, rejects content, kappa number, brightness and viscosity as per Tappi test methods.

Analytical Procedures

- Moisture content: was determined as per Tappi Test Method T 210 cm-03
- Kappa no. of unbleached pulp: was determined as per Tappi Test Method T 236 om-99
- Brightness of the pulp: was determined as per ISO 2470
- Viscosity of the pulp: was determined as per Tappi Test Method T 230 om-04
- Cellulose: was determined as per Updegroff, D.M., Anal. Biochem., 32, 420 (1969)
- Hemicellulose: was determined as per Deschatelets, L. and Errest, K. C.U., Appl. Microbiol. Biotechnol., 24: 379-385 (1986)
- Holocellulose: was determined as per Wise, E., Murphy, M. and D'Addieco, A.A., Paper Trade J., 112(2), 35 (1946)
- Klason lignin: was determined as per Tappi Test Method T 222 om-85

All the experiments were performed in duplicate (triplicate in a few cases) and average values are reported herewith.

Results And Discussion

Banana stem has very high moisture content compared to other raw materials used in pulp and paper industry. Useful fiber content obtained

Table 1: Processing of banana stem

Particular	Value
As such banana stem taken (kg)	1000
OD banana stem (kg)	100
Dewatering	
Volume of Juice generated after dewatering (l)	545
Total solids in the Juice (%)	2.45
As such banana stem fiber obtained after dewatering (kg)	386
OD banana stem fiber obtained after dewatering (kg)	87
Wet cleaning	
Solids removed during wet cleaning (kg)	22
OD useful banana stem fiber obtained after wet cleaning (kg)	65

Table 2: Proximate chemical analysis of different raw materials

Particular	Banana stem	Wheat straw	Bagasse
Ethanol-Benzene Extractives (%)	1.8	3.2	2.7
1% NaOH solubility (%)	37.1	35.3	32.7
Cellulose (%)	53.7	47.8	47.2
Hemicelluloses (%)	15.5	23.6	24.7
Holocellulose (%)	69.9	72.7	71.5
Lignin (%)	12.4	19.9	19.2
Ash (%)	5.8	5.2	2.6

Table 3: Pulping of different blends of banana stem and wheat straw

Particular	Banana stem : Wheat Straw			
	0:100	5:95	10:90	20:80
Unscreened pulp yield (%)	53.7	53.7	53.2	52.9
Screen rejects (%)	0.5	0.6	0.8	1.0
Screened pulp yield (%)	53.2	53.1	52.4	51.9
Screened pulp kappa no.	11.0	11.0	11.3	12.2
Free alkali (g/l)	4.7	4.7	4.8	4.8
Black liquor solids (%)	14.0	14.0	14.3	14.3
Black liquor pH	12.4	12.4	12.4	12.5

NaOH 16.0%, AQ 0.05%, Bath ratio 1:4, Cooking temperature 160 °C, Cooking time 60 min

after processing one ton of banana stem was 65 kg only. Proximate chemical analysis of banana stem shows its suitability for pulp and paper. Banana stem has lower lignin content compared to wheat straw and bagasse. Results of processing of banana stem and proximate chemical analysis of wheat straw, bagasse and banana stem fibers are given in Table 1 and 2 respectively.

Blending of banana stem fiber with wheat straw

Pulping results in detail are presented in Table 3. To obtain 11-12 kappa number pulp by Soda-AQ process, banana stem and wheat straw blends required 16% alkali charge. Blending of banana stem in proportion to 5% with wheat straw could not affect pulp yield whereas

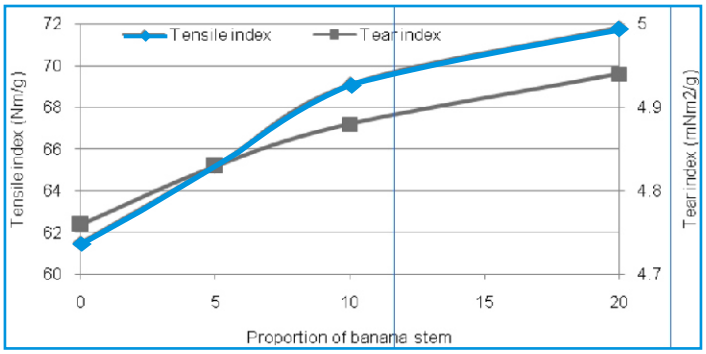

Figure 1: Effect of blending of banana stem with wheat straw on tear and tensile index

increase in proportion of banana stem to 10-20% reduced the unbleached pulp yield by 0.5-0.8% and increased the screen rejects by 0.3-0.5%.

Unbleached pulps produced with different blends of banana stem and wheat straw were bleached by $D_0E_{OP}D$ sequence. Bleaching results of different blends of banana stem and wheat straw pulps are given in Table 4. Bleachability of banana stem blended pulps was comparable with wheat straw pulp. Brightness of banana stem blended bleached pulps were higher by 0.3-0.5% in comparison to wheat straw pulp. Viscosity of banana stem blended bleached pulps were lower by 0.6-1.5 cp in comparison to wheat straw pulp.

Strength properties of different blends of bleached banana stem and wheat straw pulps are given in Table 5. Bleached pulps produced with different blends of banana stem and wheat straw showed better strength properties as compared to wheat straw pulp. Blending of banana stem with wheat straw by 5-20% showed improvement in tensile index by 6-16.7%, tear index by 1.5-3.8%, burst Index by 3.8-15.6% and double fold by 8.6-41.4% compared to wheat straw pulp. Effect of blending of banana stem with wheat straw on tear and tensile index of bleached pulp is shown in Figure 1.

Bleached pulps produced with different blends of banana stem and

Table 4: Bleaching results of different blends of banana stem and wheat straw pulps

Particular	Banana stem : Wheat straw			
	0:100	5:95	10:90	20:80
D_0 Stage (ClO_2 – 0.85%, Consistency - 5%, Temp. – 60°C, Time – 45 min)				
ClO_2 added (%)	1.0	1.0	1.0	1.0
Final pH	2.3	2.5	2.3	2.2
ClO_2 Consumed (%)	97.8	97.9	98.9	98.9
E_{OP} Stage (H_2O_2 – 0.5%, NaOH 1.6%, Consistency - 10%, Temp. – 80°C, Time – 120 min)				
Final pH	10.8	11.0	10.9	10.9
E_{OP} Kappa No	2.9	2.9	3.1	3.2
Brightness (% ISO)	75.6	75.6	75.6	75.0
D Stage (Consistency - 10%, Temp. – 75°C, Time – 180 min)				
ClO_2 (%)	0.9	0.9	0.9	0.9
Final pH	4.2	4.1	4.4	4.3
Brightness (% ISO)	82.0	82.3	82.3	82.5
CIE whiteness	68.5	68.7	68.7	68.8
Opacity (%)	71.5	70.7	69.5	66.9
Shrinkage (%)	9.1	9.3	9.9	10.4
Viscosity (cp)	11.3	10.7	10.0	9.8

Table 5: Strength properties of different blends of bleached banana stem and wheat straw pulps

Particular	Banana stem : Wheat straw			
	0:100	5:95	10:90	20:80
^{0}SR	30	31	32.5	35
Grammage (g/m^2)	62	60.1	61.1	62.7
Bulk (cc/g)	1.15	1.15	1.15	1.14
Tensile index (Nm/g)	61.5	65.2	69.1	71.8
Burst index (kN/g)	4.74	4.92	4.97	5.48
Tear index (mNm^2/g)	4.76	4.83	4.88	4.94
Porosity (sec/100 ml)	303	343	413	1350
Double fold (no.)	290	315	350	410

Table 6: Morphological properties of different blends of bleached banana stem and wheat straw pulps

Particular	Banana stem : Wheat straw			
	0:100	5:95	10:90	20:80
Average fiber length (mm)	0.75	0.80	0.82	0.88
Fiber width (μm)	17.9	18.0	18.2	18.3
Coarseness (μg/m)	79.7	78.6	69.8	68.5
Fiber proportion (%)				
0.2-0.5 mm	39.8	38.4	38.0	37.1
0.5-1.0 mm	35.1	34.3	33.2	31.0
1.0-2.0 mm	23.1	23.3	23.3	24.4
>2.0 mm	2.0	4.0	5.5	7.5

Table 7: Pulping of different blends of banana stem and bagasse

Particular	Banana stem : Bagasse			
	0:100	5:95	10:90	20:80
Unscreened pulp yield (%)	58.5	57.3	57.3	56.3
Screen rejects (%)	0.6	0.8	0.8	1.2
Screened pulp yield (%)	57.9	56.5	56.5	55.1
Screened pulp kappa no.	11.5	11.7	11.9	11.9
Free alkali (g/l)	4.2	4.1	4.0	3.9
Black liquor solids (%)	13.8	13.9	13.9	14.1
Black liquor pH	12.7	12.6	12.6	12.6

AA as Na_2O - 13.5%, Bath ratio 1:4, Cooking temp. - 160 °C, Cooking time 60 min

Table 8: Bleaching of different blends of banana stem and bagasse pulps

Particular	Banana stem : Bagasse			
	0:100	5:95	10:90	20:80
ODL (Consistency - 10%, Temp. – 85°C, Time – 45 min, Pressure – 3.5 kg/cm^2)				
NaOH (%)	1.0	1.0	1.0	1.0
Final pH	10.6	10.5	10.5	10.4
Kappa no.	9.5	9.5	9.6	9.7
D_0 Stage (ClO_2 – 0.85%, Consistency - 5%, Temp. – 60°C, Time – 45 min)				
ClO_2 added (%)	0.85	0.85	0.85	0.85
Final pH	2.0	2.0	2.0	2.0
ClO_2 Consumed (%)	99.4	99.4	99.4	99.4
E_{OP} Stage (H_2O_2 – 0.5%, NaOH 1.25%, Consistency - 10%, Temp. – 80°C, Time – 120 min)				
Final pH	10.8	10.7	10.8	10.9
E_{OP} Kappa No	1.95	2.09	2.04	2.14
Brightness (% ISO)	81.2	81.2	80.6	78.4
D Stage (Consistency - 10%, Temp. – 75°C, Time – 180 min)				
ClO_2 (%)	0.8	0.8	0.8	0.8
Final pH	3.9	4.0	4.0	4.0
Brightness (% ISO)	89.3	90.1	90.3	90.2
CIE whiteness	83.3	84.1	84.1	83.3
Opacity (%)	65.8	65.5	65.5	63.0
Shrinkage (%)	7.0	7.3	8.0	8.5
Viscosity (cp)	16.4	16.4	15.5	14.8

Table 9: Strength properties of different blends of bleached banana stem and bagasse pulps

Particular	Banana stem : Bagasse			
	0:100	5:95	10:90	20:80
^{0}SR	19.0	20.0	21.5	23.5
Grammage (g/m^2)	60.5	60.1	61.1	60.3
Bulk (cc/g)	1.29	1.28	1.27	1.25
Tensile index (Nm/g)	43.6	48.7	52.9	55.3
Burst index (kN/g)	3.13	3.2	3.4	3.6
Tear index (mNm^2/g)	6.06	6.23	6.61	6.93
Porosity (sec/100 ml)	25.5	48.3	50.3	85.4
Double fold (no.)	51	60	66	77

Table 10: Morphological properties of different blends of bleached banana stem and bagasse pulps

Particular	Banana stem : Bagasse			
	0:100	5:95	10:90	20:80
Average fiber length (mm)	0.85	0.86	0.95	1.01
Fiber width (µm)	22.8	22.8	22.5	22.6
Coarseness (µg/m)	129.4	126.4	124.2	121.7
Fiber proportion (%)				
0.2-0.5 mm	38.2	36.8	34.6	33.5
0.5-1.0 mm	35.3	35.1	32.6	30.6
1.0-2.0 mm	19.7	20.8	21.9	23.2
>2.0 mm	6.8	7.3	10.9	12.7

wheat straw were characterized for morphological properties. Morphological properties of different blends of bleached banana stem and wheat straw pulps are given in Table 6. With the increase of banana stem percentage in wheat straw pulp the average fiber length was increased from 0.75 to 0.88 mm. Proportion of long fiber (>2.0 mm) was increased to 7.5 from 2.0% with the blending of banana stem in wheat straw.

Blending of banana stem fiber with bagasse

Pulping results of different blends of banana stem and wheat straw are presented in Table 7. To get 11-12 kappa number pulp by kraft process, banana stem and bagasse blends required 13.5% AA alkali as Na_2O. Blending of banana stem with bagasse reduced the unbleached pulp yield by 1.2-2.2% and increased the screen rejects by 0.2-0.6%.

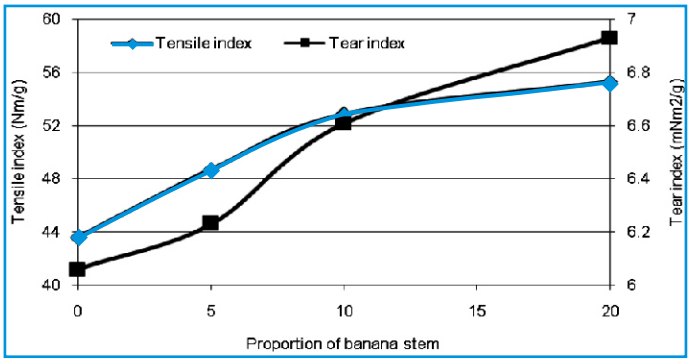

Figure 2: Effect of blending of banana stem with bagasse on tear and tensile index

Unbleached pulps produced with different blends of banana stem and bagasse were bleached by $OD_0E_{OP}D$ sequence. Bleaching results of different blends of banana stem and bagasse pulps are given in Table 8. Bleachability of banana stem blended pulps was comparable with bagasse pulp. Brightness of banana stem blended bleached pulps were higher by 0.8-1.0% in comparison to bagasse pulp. Viscosity of banana stem blended bleached pulps remains unaffected up to 5% blend of banana stem with bagasse whereas it was dropped by 0.9-1.6 cp in comparison to bagasse pulp when proportion of banana stem was increased to 10-20%.

Bleached pulps produced with different blends of banana stem and bagasse showed better strength properties as compared to bagasse pulp. Strength properties of different blends of bleached banana stem and bagasse pulps are given in Table 9. Blending of banana stem with bagasse by 5-20% showed improvement in tensile index by 11.7-26.8%, tear index by 2.8-14.4%, burst Index by 2.2-15.0% and double fold by 17.6-51.0% compared to bagasse pulp. Effect of blending of banana stem with bagasse on tear and tensile index of bleached pulp is shown in Figure 1.

Bleached pulps produced with different blends of banana stem and bagasse were characterized for morphological properties. Morphological properties of different blends of bleached banana stem and bagasse pulps are given in Table 10. With the increase of banana stem percentage in bagasse pulp the average fiber length was increased from 0.85 to 1.01 mm. Proportion of long fiber (>2.0 mm) was increased to 12.7 from 6.8% with the blending of banana stem in bagasse.

Conclusion

Banana stem can be blended along with agro residues raw materials prior to pulping up to a level of 5-20% to improve physical strength properties without any noticeable difference in pulping and bleaching process.

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