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Pulp and Papermaking Characteristics of *Cajanus cajan* Stems from Sudan

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Abstract: The pigeon pea plant (*Cajanus cajan*) indigenous to Sudan was studied to determine its suitability for pulp and papermaking. Physical properties, anatomical features, fiber dimensions, morphological indices and chemical composition were evaluated. Pulping was carried out using soda, soda anthraquinone, alkaline sulfite anthraquinone and alkaline sulfite anthraquinone with ethanol. Paper hand sheets were formed and pulp and papermaking characteristics were studied. The average basic density for *C. cajan* stalks (350 kg/m^3) and the average bark-to-wood ratio (12.6%) were in the normal range for commercial pulp woods. Both wood species when pulped with 12-16% alkali charge as Na_2O for 120 minutes at 170°C gave bleachable Kappa values. The addition of 0.13% anthraquinone to pulping liquor reduced the active alkali consumption by 2-2.3% and increased the pulp yield.

Key words: Cajanus cajan fiber dimensions · Pulping characteristics · Papermaking

INTRODUCTION

The demand for paper products in Sudan have grown rapidly with continuous development. Agricultural residues as source of fiber can play an important role in pulp and papermaking industry. The use of non-wood fibers such as bamboo, sugar cane, cotton linters and kenaf is one way to preserve natural forests. The common name of Cajanus Cajan is pigeon pea; annual, short-term perennial shrubs may reach 4-5 m in height but usually 1-2 m only, woody at base, normally erect in habit, tolerates to a wide range of soils [1]. The true origin of pigeon pea is still disputable; most likely introduced into East Africa from India by immigrants in the 19th [2]. The average yield of 718 kg/ha and the maximum recorded yield 1087 kg/ha, however under research conditions (1500-2500kg/ha) [2]. The Indian subcontinent, accounts for about 90% of the global production [3]. which is grown as an annual crop in Sudan can be a good source of fiber. In irrigated fields, the annual biomass production can reach 30 tons/ha/year [4]. Pigeon peas are an important food in developing countries, excellent source of protein, used as flour additive to other foods, in soups and with rice [5].

Cajanus cajan stems from Bangladesh were characterized by shorter fibers compared to hardwood species [6]. The alkaline sulphite pulps from Cajan non-woody fibrous plant show good strength properties [7]. It showed high degree of conformability within the sheet due to the lower value of Runkel ratio [8].

This study aimed at a rational use of pigeon pea stalks which are considered as agricultural waste and addition of different qualities of pulp and paper with the addition of new types of fibers.

MATERIALS AND METHODS

Pigeon pea *(C cajan*) stalks of more than one meter in height were randomly collected from Gezira scheme (Central Sudan). The stalks were cut into small pieces and air dried. The average Basic density was determined using oven dry mass and green volume according to the British standards B.S.373 [9]. Wood to bark ratio was determined both by mass and volume. Wood fibers were macerated using hydrogen peroxide and glacial acetic acid method according to TAPPI standards [10].

Chemical analysis of stalk samples was carried out in accordance with the standard methods of TAPPI [10,11]. This included extraneous materials, ash, silica, cellulose, holocellulose, pentosans and lignin content.

Fibre dimension evaluation, after maceration with a mixture of 30% hydrogen peroxide and acetic acid (1:1) was carried out microscopically at 300x and 400x

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magnifications after staining with aqueous safranine [12]. Morphological indices including coefficient of cell rigidity, Runkel ratio, flexibility coefficient and felting ratio, were determined. Pulping was carried out in a 10-litre capacity rotating autoclave at a maximum temperature of 170°C for 2 hours. The stalks were cooked at different chemical charges of soda, soda-anthraquinone (SAQ), alkaline sulfite anthraquinone (ASAQ) and alkaline sulfite anthraquinone with methanol (ASAM). Wood to liquor ratio used was 1:4. Handsheets were prepared using a Rapid-Kothen sheet forming machine and tested in accordance with TAPPI and ISO standards.

RESULTS AND DISCUSSION

The average basic density for C. cajan stalks as shown in Table (1) was at lowest range for commercial temperate pulp woods (350-650 Kg/m^3) [13]. The average bark-to-wood ratios both by mass and volume were similar to those of tropical hardwoods and suitable for pulpwood [14]. The fibre length for *C. cajan* as shown in Table 2 was short. It was similar to that of cotton stalks [15]. Hence it was considered as short fibred species; therefore it needs to be mixed with other long fibred wood pulp to obtain good paper properties. Due to the low felting power for *C. cajan* fibers, they were expected to collapse and produce good surface contact between adjacent fibres and hence, strong fibre-to-fibre bonding. The Runkel ratio and flexibility were similar to those of most good agricultural residues such as *Hibiscus sabdarifa* stalks and date palm rachis found by [16].

As shown in table 3 the average value for the inorganic constituents was higher for the Sudanese *Cajanus* (3.70%) compared to the Indian *Cajanus* (1.72%) but similar to that for agricultural residues [15]. The less amount of silica (0.22%) for the Sudanese *Cajanus* was close to that of hardwoods. The cellulose content was almost similar for both Sudanese and Indian *Cajanus* species (46.48% and 47.31%, respectively) and in the normal range for tropical hardwoods. Due to this, higher pulp yields were expected. The lignin content was higher for the Sudanese *Cajanus* (22.09%). This means that it needs more bleaching chemicals compared to the Indian one (18.72%). In general, the higher ash and water solubility for Sudanese *Cajanus* may need a little bit higher chemical charge than that for the Indian *Cajanus*. The great variation between the chemical composition of the Sudanese *Cajanus* and the Indian *Cajanus* may be due to the difference in growth and environmental conditions.

Table 1: Physical properties of *Cajanus cajan* stalks from Sudan

Physical property	
Basic Density (kg/^{3}m)	350
Bark-to-wood ratio by mass %	12.2
Bark-to-wood ratio by volume %	12.5

Table 2: Fiber dimensions and morphological indices for *C.cajan* from central Sudan

Fiber dimensions		sd
Av fibre length (mm)	00.672	0.092
Av. Fibre Diameter (µm)	34.1	0.403
Lumen diameter (µm)	24.32	0.401
Cell wall thickness (µm)	4.88	0.067
Morphological indices		
Flexibility coefficient %	68.93	
Wall fraction %	14.32	
Felting power	19.72	
Runkel ratio	0.40	

Table 3: Chemical Composition of *C. cajan* stalks from central Sudan compared to Indian *C. cajan*.

Chemical Composition %	Sudanese *C. cajan*	Indian *C. cajan*
Ash content	3.70	1.72
Silica content	0.22	0.56
Cold water solubility	12.50	3.42
Hot water solubility	14.26	5.10
Alcohol cyclo-hexane	2.15	4.14
1% Sodium hydroxide	30.93	19.60
Holocellulose	77.50	-
Pentosan	18.00	15.97
Cellulose	46.48	47.31
Acid insoluble lignin	22.09	18.72
Cellulose / lignin ratio	2:1	2.5:1

Table 4: Unbleached pulp evaluation for soda pulping of *C. cajan* from Sudan

Pulping conditions	CS 3	CS 4	CS 5
Active alkali as Na_2O on oven.dry raw material, (%)	17	18.6	20
Liquor / raw material ratio	4:1	4:1	4:1
AQ on oven dry raw material,%	0	0	0
Time to reach maximum temperature, (min)	90	90	90
Pulping Maximum temperature, (°C)	170	170	170
Time at maximum temperature, (min)	120	120	120
Total yield on oven dry raw material,%	51.87	49.41	47.21
Screened yield on oven dry raw material, %	45.18	49.34	47.18
Rejects %	6.69	0.07	0.03
Kappa number	26.20	20.57	15.80
Viscosity ml/g	746	810	808
ISO Brightness, (%)	24.10	31.60	43.50
pH	12.88	12.89	13.18
Residual active alkali	4.96	5.83	6.94
Total solids, (%)	12.62	12.80	13.37

Table 5: Unbleached pulp evaluation for soda AQ pulping of *C. cajan* from Sudan

Pulping conditions	CSQ1	CSQ3	CSQ4
Active alkali as Na_2O			
on oven dry raw material, (%)	13	15	17
Liquor / raw material ratio	4:1	4:1	4:1
AQ on oven dry raw material, %	0.10	0.10	0.10
Time to reach maximum temperature.(min)	90	90	90
Pulping maximum temperature (°C)	170	170	170
Time at maximum temperature (min)	120	120	120
Total yield on oven dry raw material, (%)	49.48	47.77	46.29
Screened yield on oven dry raw material, (%)	48.60	47.60	46.24
Rejects %	6.88	0.17	0.05
Kappa number	19.04	16.61	12.51
Viscosity ml/g	1005	848	829
ISO Brightness, (%)	28.70	30.90	35.20
pH	11.64	12.22	12.70
Residual active alkali	1.49	2.48	4.09
Total solids (%)	10.88	11.79	12.18

Table 6: Unbleached pulp evaluation for AS-AQ pulping of *C. cajan* from Sudan

Pulping conditions	CSA2 ((60:40)	CSA5 (70:30)	CSA6 (70:30)
Active alkali as Na_2O			
on oven dry raw material, (%)	18.6	16.3	18.6
Liquor / raw material ratio	4 : 1	4 : 1	4 : 1
AQ on oven dry raw material, (%)	0.10	0.10	0.10
Time to reach maximum			
temperature (min)	90	90	90
Pulping maximum temperature (°C)	170	170	170
Time at maximum temperature(min)	120	120	120
Total yield on oven dry raw material, (%)	47.86	50.43	48.11
Screened yield on oven dry			
raw material, (%)	44.56	44.35	47.88
Rejects %	3.30	6.08	0.32
Kappa number	22.31	27.90	12.01
Viscosity ml/g	882	986	757
ISO Brightness, (%)	37.40	26.90	37.00
pH	11.31	11.15	12.36
Residual active alkali	3.11	2.48	3.97
Total solids, (%)	12.79	12.37	13.08

Table 7: Unbleached pulp evaluation for ASAM pulping of *C. cajan* from Sudan

Pulping conditions	CS3	CS4	CS5
Active alkali as Na_2O on	16.3	18.6	16.3
oven dry raw material, (%)	(60:40)	(70:30)	(70:30)
Liquor / raw material ratio	4:1	4:1	4:1
AQ on oven dry raw material, (%)	0	0	0
Time to reach maximum temperature (min)	90	90	90
Pulping Maximum temperature, (°C)	170	170	170
Time at max. temperature,(min)	120	120	120
Total yield on oven dry raw material,(%)	48.75	48.47	48.23
Screened yield on oven dry raw material, (%)	47.21	47.94	47.71
Rejects %	1.54	0.53	0.52
Kappa number	12.38	10.87	11.98
Viscosity, ml/g	1010	981	996
ISO Brightness, (%)	39.00	41.70	41.1
pH	11.08	11.63	11.66
Residual active alkali	2.36	2.98	2.62
Total solids, (%)	12.20	12.38	11.37

The soda pulping (Table 4), indicated that the application of high alkali charge 20% reduced the Kappa number to minimum 15.8, associated with reduction in rejects and total yields, although the viscosity was kept higher compared to that of lower active alkali charge 17%. On the other hand the use of 18.6% alkali charge as Na_2O improved the viscosity and screened yield with bleachable kappa number 20.57. However an increase of active alkali accompanied with an increase in residual active alkali and total solids. The addition of 0.1% anthraquinone to the soda cooking liquor (Table 5) resulted in lower active alkali to be apply to raw material and hence improved the viscosity when compared to soda cooks, reduced the rejects, increased the screened yields and produced bleachable Kappa numbers. However the initial ISO brightness were more or less similar to those of soda cookings.

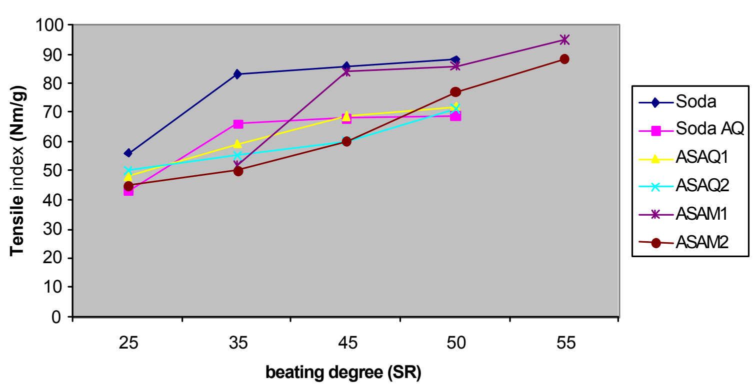

Fig. 1: Tensile index for different beating degrees of unbleached Cajanus cajan Pulps

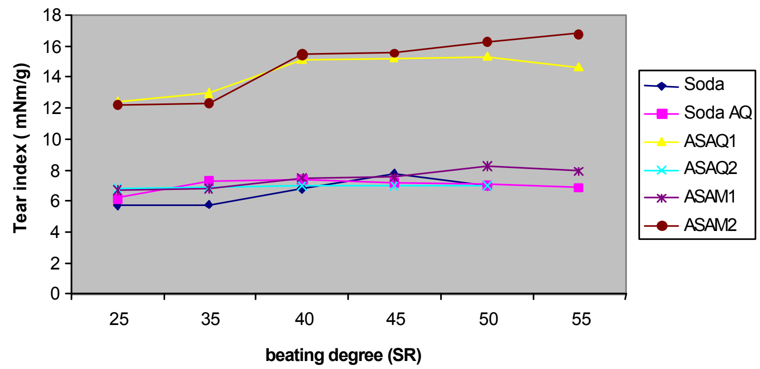

Fig. 2: Tear index in relation to beating degree of unbleached cajanus cajan pulps

In Alkaline sulphite pulping (Table 6), an application of two different ratios of NaOH :Na_2SO_3 were (60:40) and (70:30) indicted the suitability of (70:30) ratio for alkaline sulphite pulping of Cajan, thus the screened yield was improved by using the ratio (70:30) although the initial ISO brightness were similar when applying 18.6% active alkali charge. However the reduction of active alkali charge to 16.3% resulted in higher total yield as a result of increase in rejects. The viscosity was better compared to viscosities of both pulps of 18.6% active alkali charge associated with reduction of ISO brightness. 26.9%.

The addition of methanol to alkaline sulphite process-ASAM pulping (Table 7) improved viscosities, ISO brightness, with reduction in rejects, bleachable Kappa numbers, while screened yields were kept at high level, Proving the high selectivity of this process in preserving the carbohydrates and dissolving the lignin. It is highly recommended to use ASAM process during production of pulp from Cajan Stems, which was supported further in mechanical properties of pulps as indicated in Figures (1) and (2) which show that with higher beating degrees higher tensile strength was obtained from soda and ASAM1 (with ratio 70:30) pulps while soda AQ, ASQ1 and ASQ2 (with ratio 60:40) showed lower tensile index. Soda AQ showed higher index at SR 25 up to SR 35 then no clear effect was shown at more than 45SR. the ASAM2 and ASAQ1 gave higher tear indices compared to the other processes.

CONCLUSIONS

From the above Results the Following Conclusions Could Be Drown Out: *C.cajan* as a short fibered plant could be mixed with long fibered wood species for production of paper with good properties, increased the pulp yield. The best and economic processes suitable for pulping *C. cajan* stalks were found to be soda-AQ and specially alkaline sulfite anthraquinone with methanol.(ASAM) due to its high selectivity in dissolving lignin and preserving cellulose and hemicelluloses

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