Pulping potential of *Ricinus communis* stems from Sudan

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Abstract: *Ricinus communis* stems were examined for its suitability for pulping and papermaking. The physical properties, fibre dimensions, morphological indices, chemical characteristics and metal profile of raw material were reported. The pulping trails were carried out using ASAM, AS-AQ, soda-AQ methods and soda process as reference. The AS-AQ pulping gave the best results in yield, degree of delignification, mechanical and optical properties. When Ricinus communis cooked with soda-AQ, it showed increased yield and gave pulps with superior properties than soda especially with 0.1% AQ dose.

[Safaa Hassan Omer, Tarig Osman Khider and Osman Taha Elzaki. **Pulping potential of *Ricinus communis* stems from Sudan.** J Am Sci 2012;8(6):390-395]. (ISSN: 1545-1003). http://www.americanscience.org. 48

Keywords: *Ricinus communis*; Papermaking; Pulp properties; Fibre morphology; Chemical composition; Alkaline Pulping with additives

Introduction

Over the years, an increasing preoccupation regarding rational use of forest and agricultural residues has occurred. The production and consumption of paper throughout the world increased over the last few decades from 125 million tons in1970 to 365 million tons in 2006 [1] In the last years problems related to environmental issues such as the low degradability and biodegradability, combined with an increasing environmental awareness, have motivated an extensive research on environmentally friendly materials [2, and 3]

More interests are being directed into study of non-wood materials as a source of input for pulp and paper making [4] *Ricinus communis*, a non woody plant known as castor plant is a robust perennial shrub of *Euphorbiaceae* family [5] It is originating from east India and tropical Africa, naturalized all over Mediterranean [6] Growth height range 1-4 meters, *Ricinus communis* is cultivated as a decorative plant in gardens [7]. This species can be growing very well in all parts of Sudan [8]. It is a source of the highly toxic ricin especially the cover of the seed [9]. *Ricinus communis* seed oil is used as traditional folk medicine all over the world [10] and could be use in drug development for treatment of gastrointestinal, urinary tract infections and typhoid fever [11].

The aim of the present work was to investigate the stems of the Sudanese *Ricinus communis* characteristics and pulping potentialities by using soda and alkaline methods with additives

Material and Methods

Five shrubs, 1-2 year old *Ricinus communis* from Blue Nile state (South - Eastern Sudan) with average height up to 2.8-3 m were randomly selected and collected according to TAPPI standards [12]. They were prepared and cross cut into logs, further the logs were cut into discs 2.5 cm in thickness, all samples were left for air drying according to TAPPI standard (T_{257}-cm- 02). The bark- to- wood ratio was determined as a proportion of whole shrub including bark, both by volume and by mass. The basic density was measured as oven-dry mass/green volume. Fiber dimensions were determined microscopically at x300 and x400 magnification after staining with 1% aqueous safranine [13].

The chemical composition of *Ricinus communis* stems was determined according to TAPPI standard Test methods (T $_{204}$-cm-97 for solvents extractives, T_{207}-cm99 for water solubility, T_{211}-om- 93 for ash, T_{212}-om-98 for 1% NaOH extractives, T_{222}-om-02 for lignin and T223-cm-01 for Pentosans).while Kurchner –Hoffer cellulose was measured according [14]. Meal was prepared using star mill with standard sieve according to TAPPI standard (T_{11}- wd-79). The chips were done by 2.5X2.5X0.25 cm, cooking was carried out in the laboratory series digester consisting of six bombs each 2.5 liter capacity rotating in an electrically heated polyethylene glycol bath. The pulping conditions were, wood to liquor ratio (1: 3.5), active alkali charge range 16-22% as Na_2O at maximum temperature 165 ^{0}C with time to reach maximum temperature 90 min and 120 min at maximum temperatures, different doses of AQ were applied and NaOH: NA_2SO_3 ratios were 70:30 % and 60: 40 % for AS-AQ and ASAM methods. The methanol was added during ASAM [15] cooking on the basis of 15% by volume of white liquor. Beating was determined by using PFI mill.

Results and Discussions

Physical and fibre characterization of Ricinus communis

Ricinus communis has low average basic density 242 kg/m^3 (Table 1) outside the range for commercial pulpwoods (350-650 kg/m^3) [16]. It is higher than the basic density of *Typha domingensis*, (113kg/m^3) [17] and in the range of non- woody plants and agricultural residues, however low density means low digester capacity per unit volume and low yield although it will improve the penetration of white liquor. Bark to wood ratio by volume and mass were 2.8 and 12.6% (Table 1) respectively, were excellent for commercial pulping material.

Table 1. Physical properties, fiber characteristics and morphological indices for Ricinus communis

Property	Ricinus communis
Physical properties	
Basic density, Kg/m^3	242
Bark to wood ratio by mass, %	12.6
Bark to wood ratio by volume, %	2.8
Fibre dimensions	
Fiber length (mm)	0.9
Fibre diameter (µm)	40.5
Lumen diameter (µm)	29.5
Cell wall thickness (µm)	5.5
Morphological indices	
Flexibility coefficient, %	72.7
Wall fraction, %	13.6
Felting power	22.6
Runkel ratio	0.38

The principal factors controlling the strength of paper are fibre density (cell wall thickness), fibre length and fibre strength [18].The average fibre length of *Ricinus communis* was 0.9 mm (Table 1) considered short but longer than fibres of Eucalypts [19]. The wide fibre 40.5 µm with lumen diameter 29.5 µm indicted that fibres collapse easily on beating resulting in good interfibre bonding. The medium thin walls 5.5 µm expected fibres to be flattening easily and have good surface contact and adhesion. This supported further by very good flexibility coefficient 72.7% positively correlated to the bonding properties (tensile index and burst factor). The low wall fraction 13.6% and felting power 22.6 indicate an easy beating. The Runkel ratio was too low favorable for pulping material.

Chemical Characterization of Ricinus communis

The chemical composition of *Ricinus communis* (Table 2), in comparison with whole *Typha domingensis* [17] was in general much better. The ash and silica contents were lower than those of *Typh*a and were lower than usual of non woody plants and agricultural residues, especially silica. This meant normal alkali consumption and fewer problems at waste liquor recovery [20]. The cold water, hot water, organic solvents and 1% NaOH extractives were much lower compared to corresponding ones of whole *Typha*, but they were rather higher than usual for commercial pulp wood and tropical species. This is due to the high percentage of phenolic compounds and soluble polysaccharides present, to an easy access and degradation of cell wall materials by weak alkali. However the high extractives with organic solvents are totally undesirable for pulping (pitch problems.

The cellulose Kurscher-Hoffer of Ricinus communis (Table 2), higher than that of whole *Typha*, indicated acceptable yields. However the higher acid insoluble lignin meant moderate to rather high cooking chemicals. This is supported further by lower cellulose/ lignin ratio compared to whole *Typha*.

The trace elements profile of *Ricinus communis* (Table 2), the calcium and magnesium were present in high amounts, on the other hand manganese and copper in very small amounts. Thus less amount of chemicals (hydrogen peroxide and ozone) in regard to apply total chlorine (TCF) bleaching. This is supported further by high Mg/Mn ratio (714.3).

Table 2. Chemical composition of Ricinus communis in 9percentage of oven dry weight of wood) and the metal profile in ppm

Chemical property	Ricinus communis	*Typha domingensis* (Khider *et al*, 2012
Chemical component,, %		
Ash content	2.03	10.5
Silica content	0.03	0.1
Solubility in		
Cold water	7.4	18.7
Hot water	7.8	24.7
Alcohol	7.0	13.6
Alcohol cyclo-hexane 1:2	1.9	5.3
1% Sodium hydroxide	24.7	32.8
Holocellulose	72.5	67.6
Pentosan	9.1	32.8
Cellulose, Kurschner- Hoffer	47.6	38.7
Acid insoluble lignin	23.3	17.5
Cellulose/ lignin ratio	2.0	2.1
Metal component, ppm		
Ca	15	
Cu	0.075	
Mg	15	
Mn	0.021	
Co	0.072	
Mg/ Mn	714.3	

Table 3. Ricinus communis, pulping conditions and unbleached pulp evaluation

Pulping Process	% of active alkali charge	Pulp yield			Pulp evaluation			B/L analysis		
		Total %	screen %	reject %	Kappa No	Viscosity ml/g	Brightness %	pH	RAA	Total solid
Soda										
RS1	20	42.7	41.2	1.5	30.6	793	27.1	11.9	5.6	10.2
RS2	22	40.3	40.2	0.1	24.2	611	32.3	13.4	7.8	12.6
Soda-AQ										
RS3 $_{AQ(0.1\%)}$	18	44.2	43.9	0.3	22.4	780	26.3	12.0	5.3	10.2
RS4 $_{AQ(0.05\%)}$	20	42.9	42.6	0.3	20.6	704	28.1	13	6.2	12.4
RS5 $_{AQ(0.1\%)}$	20	42.1	42.0	0.1	20.3	755	28.5	13	6.7	13
RS6 $_{AQ(0.1\%)}$	22	40.5	40.5	nil	15.1	689	32.3	13 3	9.9	13.5
AS-AQ										
RS7 $_{(60:40)}$	18.6	52.5	48.3	4.2	36.2	861	26.8	-	-	-
RS 8 $_{(70:30)}$	18.6	45.2	44.8	0.4	20	898	31.7	12	3.5	13.4
RS9 $_{(60:40)}$	20	46.8	46.3	0.5	22.2	884	33.8	-	-	12.1
RS10 $_{(70:30)}$	20	44.6	44.6	nil	15.1	886	35.2	12.5	3.7	13.8
ASAM										
RS11 $_{(70:30)}$	16	46.3	45.9	0.4	20.1	899	32.6	11.6	2.3	12.6
RS12 $_{(70:30)}$	18.6	45.9	45.8	0.1	17.7	858	34.6	-	-	13.5

B/L: Black liquor RAA: Residual active alkali
Note: the following pulping conditions were constant for all cookings
Maximum Temperature: 165 ^{0}C
Time to maximum temperature 90 min
Time at maximum temperature 120 min

Pulping of Ricinus communis

The cooking conditions of *Ricinus communis*, maximum temperature 165 ^{0}C, time to maximum temperature 120 min and time at maximum temperature 90 min were constants for all cooking trials. On the other hand the alkali charges were varied 16-22% as Na_2O and different doses of anthraquinone were applied to soda cooks (Table 3).

In soda pulping of *Ricinus communis*, alkali charge 20-22% as Na_2O were applied as reference cooks, res ulted in 40.3-42.7% total yields, 40.2-41.2% screened yields, kappa numbers 24.2-30.6, ISO brightness 27.1-32.3% and viscosities 611-793 ml/g. The addition of AQ with (0.05-0.1%) doses to soda cookings improved the delignification rate (kappa numbers 15.1-22.4) with higher total yields 40.5-44.2%, screened yields 40.5-43.9% compared to reference soda cooks. This is could be attributed to the preservation of polysaccharides by the anthraquinone. The AQ addition reduced the active alkali consumption by 2% and furthermore, it improved the strength properties (Figs. 1-6).

The use of 0.1% AQ dose gave less rejects amounts, better viscosity 755ml/g, more or less similar kappa numbers and ISO brightness, when compared to 0.05 % AQ dose during constant other cooking conditions (Table 3) with active alkali 20% and the same black liquor analysis results. This is indicating of the suitability of 0.1% AQ dose for cooking of *Ricinus communis*.

When 70:30 as (NaOH: Na_2SO_3) ratio used, compared to 60: 40 during alkaline sulphite anthraquinone (Table 3),showed improvement of viscosities, reduction in total yields, screened yields and rejects with better brightness. The higher share of sodium hydroxide was intensifying the delignification process. The overall results of AS-AQ cooks reflect higher yields, viscosities, lower kappa numbers and excellent initial brightness in contrast to soda-AQ cooks. The AS-AQ (RS8) cook gave astonishingly more or less similar screened yield 44.8%, total yields, viscosity 898 ml/g and initial ISO brightness 31.7% as the ASAM (RS12) at the same active alkali with addition of 15% v/v methanol. However this indicates the lesser importance of alcohol during cooking of *Ricinus communis* may be due to open anatomical structure of the raw material, which facilities impregnation and delignification. From economical point of view, it would be beneficial to carry out alkaline sulphite pulping of *Ricinus communis* without methanol addition.

Comparison of the strength properties of *Ricinus communis* unbleached pulps (Figs.1-6) indicated, in general the superior strength properties of the AS-AQ (RS9) , (RS10) and ASAM (RS11). The high bonding strength (tensile index and burst factor), which is mainly based on the good bonding ability of the fibers results from the high carbohydrate content of AS-AQ and ASAM pulps due to the high stability of xylan and cellulose in the outer cell wall layers. However the soda-AQ (RS5) showed the same pattern. The soda pulps (RS2) reflected lower tensile and burst indices (Figs.2 and 3). Although the soda pulps (RS2) had higher apparent density (Fig.1), it reflected inferior tear resistance (Fig.4) compared to soda-AQ pulps (RS5). (Fig.5) showed highest folding Kohler for AS-AQ pulps (RS9) and soda-AQ pulps (RS5). The highest porous sheets were soda (RS2) with AS-AQ (RS10) most compact sheets (Fig.6).

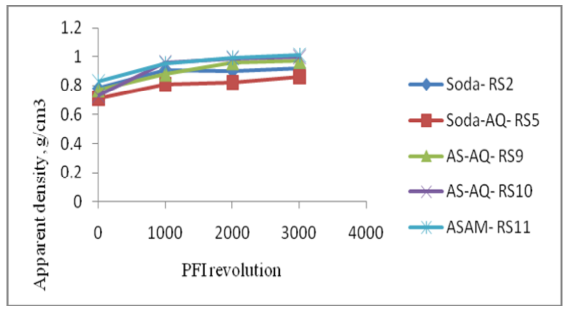

Fig. 1: Apparent density vs. PFI revolution of *Ricinus communis* unbleached pulps

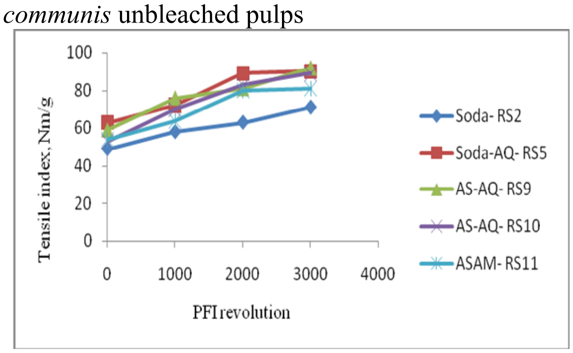

Fig. 2: Tensile index vs. PFI revolution of *Ricinus communis* unbleached pulps

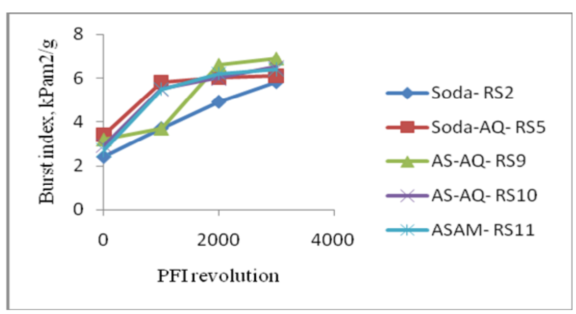

Fig. 3: Burst index vs. PFI revolution of *Ricinus communis* unbleached pulps

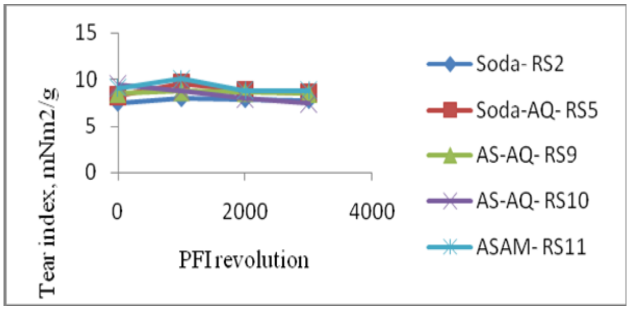

Fig. 4: Tear index vs. PFI revolution of *Ricinus communis* unbleached pulps

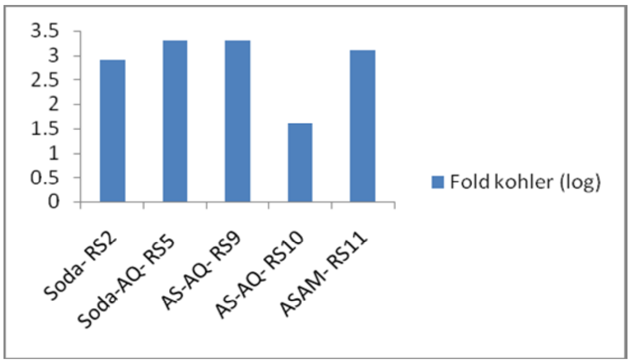

Fig.5: Histogram comparing the fold Kohler (log) of *Ricinus communis* unbleached pulps at PFI revolution 3000.

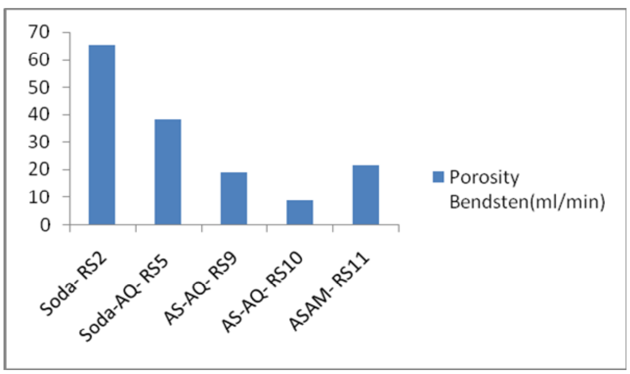

Fig.6: Histogram comparing porosity Bendsten of *Ricinus communis* unbleached pulps at PFI revolution 3000

Conclusion

The physical, fibre characteristics and morphological indices of the Ricinus communis were typical of non-woody plants and agricultural residues. The wide fibre, lumen diameters with high flexibility coefficient and favorable Runkel ratio indicated good paper properties of the corresponding pulps.

The chemical composition of Ricinus communis showed resemblance to the tropical species. However ash content, negligible silica, good carbohydrates and cellulose/ lignin ratio were favorable for alkaline pulping with acceptable charge and pulp yields could be expected.

Pulping with ASAM, AS-AQ and soda with and without AQ as reference, confirmed the beneficial effect of AQ-addition, especially 0.1% AQ dose. It accelerated delignification, improved yield, brightness, viscosity and strength properties, superior to those of soda, soda-AQ and even ASAM pulps. It is advisable, from economic point of view, to apply AS-AQ process for *Ricinus communis*, without addition of methanol.

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5/13/2012