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Characterization of Dogs Tooth Grass and its Delignification by Soda Pulping Process

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ABSTRACT

Chenopodium album, commonly known as dogs tooth grass, belongs to order *Caryophyllales*, family *Amaranthaceae* and is an interesting example of Eudicotyledons. Anatomy of *C. album* shows that the cells between vascular bundles become thickened and lignified together with the xylem and form a compact body of cylinder known as conjunctive tissue, which is an important hitherto unexploited source of cellulosic fibers at a time when most of the nations were searching new alternatives due to shrinking of forest resources. Fibers of *C. album* are short, libriform type, pointed with pitted walls and produce a bulky and opaque paper which is the most important property for writing and printing grade due to high Luce's shape factor, slenderness ratio, solid factor and Runkel ratio. Moderate amount of extractives with higher holocellulose contents (70.2%) and α-cellulose (39.7%) make *C. album* as promising raw materials for pulp and paper production. *C. album* contains medium lignin contents (21.5%). Therefore, it requires milder cooking conditions and can be cooked as a supplement raw material with other non-woody plants. *C. album* produces a screened pulp yield of 42.3% of kappa number 19.5 at an active alkali dose of 20% (as NaOH), time at 165^{0}C temperature 90 min and liquor to wood ratio of 4.5:1 by soda pulping process. Addition of 0.1% anthraquinone at optimum pulping conditions improves pulp yield marginally and reduces kappa number 2.3 units. *C. album* produces optimal strength properties at 40$\pm$1 ^{0}SR. The reaction kinetics study indicates that delignification is of first order.

Keywords: *Chenopodium album, Anatomy, Morphology, Proximate chemical analysis, Soda pulping.*

1. INTRODUCTION

Demand for pulp products continues to be strong with increasing literacy rate in the face of the common thoughts that advancement in information technology and computerization would result in a paperless global society. Dearth of good quality of wood fibers in most of the Asian countries including India has compelled the paper industries to search for new alternatives and other sources of cellulosic fibers. Many fast growing annual and perennial plants have been identified, cultivated and studied for their suitability in pulp and paper industry (Cunningham et al., 1970). World demand for paper and paperboard is estimated to grow from 300 million tonnes to over 490 million tonnes by the year 2020 (Hurter 1997) with an average rate of 2.8% per annum. Currently, India produces about 5.6 million tonnes of paper and paper-board per year, which accounts for about 1.6% of the total world's production. Forest cover in India is 20.6% of the country's surface area. This translates into a per capita forest area of only 0.8 ha per person, one of the lowest in the world. To bridge over the extended gap between demand and supply of pulp products as a result of shortage of wood fiber, plans of actions have been put into action to valorize various agricultural crops in Tunisia (Gezguez et al., 2009, Khiari 2010), India (Agnihotri et al., 2010, Dutt & Upadhyaya 1994, Dutt et al., 2004, Dutt et al., 2005, Dutt et al., 2007, Dutt et al., 2008, Dutt et al., 2009, Dutt et al., 2009, Dutt et al., 2010a, Dutt et al., 2010b, Dutt et al., 2010c, Dutt et al., 2010d, Kaur et al., 2011, Tyagi et al., 2004, Singh et al., 2011), Iran (Hedjazi et al., 2008) and Sudan (Khristova et al., 2005) and fast growing hardwoods through social forestry, for example in India (Lal et al., 2010, Malik et al., 2004).

C. album, commonly known as 'Dogs Tooth Grass' or 'Malabar nut', is a fast growing summer and annual weed of order *Caryophyllales* and family *Amaranthaceae*. It is a medicinal shrub and in Rigveda, it is reported to cure all diseases. In Athrva Veda (Vaidyakalpa), it is reported to be beneficial in piles, clearing worms, and application in the treatment of ailments like pectoral complaints, cough, abdominal pain, pulmonary obstruction, nervous infections and curing anorexia (Yadav et al., 2007). *C. album* is an interesting example of Eudicotyledons refers to a monophyletic group of flowering plants that had been called tricolpates or non-Magnoliid dicots (Walter et al., 2004). The most distinguishing feature is its white mealy coating on the seedlings. The plant is a native of tropical

Asia and is distributed throughout the plains of India and in the Sub-Himalayan tracts. The plant has been selected for its availability, well developed wood consisting of all elements, prolific growth and ease of handling (Maity et al., 1976). An enormous fibrous biomass in the form of stems and twigs from *C. album* is wasted every year. The trunk and twigs of *C. album* can be converted into a valuable product like paper and can be delignified as a supplement raw material with other non-conventional non-woody plants of identical delignification conditions. *Urena lobata* produce a screened pulp yield of 45.3% of kappa number 17.5 at an active alkali dose of 16.1% (as NaOH), time at temperature 1.5h and maximum temperature 165^0C (Dube et al., 1981) whereas, coconut trunk produces a screened pulp yield of 42.0% of kappa number 20.0 at an active alkali dose of 15.5.% (as Na_2O), time at temperature 1.5h and maximum temperature 165^0C (Sadawarte et al., 1975); kenaf (Rosella) produces a screened pulp yields of 52.4% of kappa number 23.7 at an active alkali dose of 16% (as NaOH), time at temperature 1.5h and maximum temperature 165^0C (Sadawarte et al., 1975). This paper aims at exploring the suitability of waste of *C. album* anatomically, morphologically and chemically for pulp production. Present study is also focused on optimizing the soda pulping conditions, determining the first order rate constant during bulk delignification and Arrhenius activation energy and effect of anthraquinone on pulp yield and kappa number.

2. MATERIALS AND METHODS

2.1 Raw Materials Collection

C. album was collected in the vicinity of the Institute at district Saharanpur located in the foothills of Shivalik range of Western Uttar Pradesh (India). Leaves and flowers were removed by stroking on a hard surface. The whole stem and twigs were hand-chopped into 15–25mm long pieces after removing roots, and were kept in ventilated polythene bags after drying in air.

2.2 Anatomy and Morphology

Fiber length of whole stem of *C. album* was determined by macerating the small slivers with 10 mL of 67% HNO_3 and boiled in a water bath at 100±2°C for 10 min (Ogbonnaya et al., 1997). The slivers were then washed, placed in small flasks with 50 mL distilled water, and the fiber bundles were separated into individual fibers using a small mixer with a plastic end to avoid fiber cutting. The macerated fiber suspension was finally placed on a standard microscope glass slide (25 mm × 75 mm) by means of a medicine dropper of about 10 cm length and 8 mm internal diameter with one end fitted with a rubber bulb and the other carefully smoothened but not tapering. The tube was graduated to deliver 0.5 mL. All fiber samples were viewed under a calibrated microscope and a total of 50 randomly chosen fibers for a total of 150 fiber measurements were measured. For fiber diameter, lumen diameter, and cell wall thickness determinations, cross-sections of 25 µm thickness were cut on Leitz base sladge microtome 1300 and were stained with 1:1 aniline sulphate–glycerine mixture to enhance cell wall visibility, as it retains a characteristic yellowish color. The derived wood properties of Runkel ratio (2×fiber cell wall thickness/ lumen diameter) (Runkel 1949), Luce's shape factor [(fiber diameter^2−fibre lumen diameter^2)/ (fiber diameter^2 +fiber lumen diameter^2)] (Luce 1970), slenderness ratio (fiber length/fiber diameter) (Varghese et al., 1995), and solids factor [(fiber diameter^2−fibre lumen diameter^2).fiber length)] (Barefoot et al., 1964) were calculated.

2.3 Proximate Chemical Analysis

Whole stem of *C. album* were cut into small pieces and subsequently milled into powder in a laboratory Wiley mill (Weverk, A- 47054, Sweden). A fraction of mesh size 40/80 was used to determine ash (TAPPI T 244 cm-99 "Acid-insoluble ash in wood, pulp, paper, and paperboard), water solubility (TAPPI T 207 cm-99 "Water solubility of wood and pulp"), 1% NaOH soluble (TAPPI T 212 om-02 "One percent sodium hydroxide solubility of wood and pulp"), alcohol-benzene solubility (TAPPI T 204 cm-97 "Solvent extractives of wood and pulp"), pentosan (TAPPI T 223 cm-01 "Pentosan in wood and pulp"), holocellulose (TAPPI T 249 cm-00 "Carbohydrate composition of extractive-free wood and wood pulp by gas-liquid chromatography"), α, β- and γ-cellulose (TAPPI T 203 cm-99 "α-, β- and γ-cellulose in pulp), and lignin (TAPPI T 222 om-02 "Acid-insoluble lignin in wood and pulp"). Some of the lignin dissolved in acid solution during the test, known as acid-soluble lignin, was determined in a solution, after filtering off the insoluble lignin, by a spectrophotometric method based on absorption of ultraviolet radiation (TAPPI Standard Test Methods 2007) at a wavelength of 205 nm (Schoening & Johansson 1965).

2.4 Pulping Studies

Screened chips of *C. album*, that passed through 12.7 mm screen but retained on a 6.35 mm, were digested in a WEVERK electrically heated rotary digester of capacity 0.02 m^3 by a soda pulping process at different cooking conditions, such as maximum temperature 145-175 °C, cooking time 1.0-5 h, active alkali 14-22% (as NaOH), and liquor-to-wood ratio of 4.5:1. The cooked pulps were washed on a laboratory flat stationary screen with a 300-mesh wire bottom; disintegrated; screened through a WEVERK vibratory flat screen with 0.15-mm slot size; and evaluated for kappa number (TAPPI T 236 cm-85

"Kappa number of pulp"), screened pulp yield, lignin (TAPPI T 222 om-02 "Acid-insoluble lignin in wood and pulp"), screening rejects, and viscosity (TAPPI T 206 os-63 "Cupprammonium disperse viscosity of pulp") (TAPPI Standard Test Methods 2007). The Arrhenius activation energy and first order rate constants at different reaction temperatures during bulk delignification in soda pulping of *C. album* were investigated. At optimum cooking conditions, 0.1% anthraquinone (AQ) (based on oven dry raw materials) was added to observe its effect on pulp yield and Kappa number.

2.5 Evaluation of Laboratory Made Hand Sheets

The unbleached pulp of *C. album* obtained at optimum pulping conditions was beaten in a PFI mill (TAPPI T 248 sp-00 "Laboratory beating of pulp (PFI mill method)") at different °SR and drainage time was determined (TAPPI T 221 cm-99 "Drainage time of pulp"). Laboratory hand sheets of 60 g/m^2 were prepared (TAPPI T 205 sp-02 "Forming handsheets for physical tests of pulp"), conditioned at a temperature 27$\pm$1^{0}C and relative humidity of 65$\pm$1% (TAPPI T 402 sp-03 "Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products", and tested for various physical strength properties such as tear index (TAPPI T 414 om-98 "Internal tearing resistance of paper [Elmendorf-type method]"), tensile index (TAPPI 494 om-01 "Tensile properties of paper and paperboard [using constant rate of elongation apparatus]"), burst index (TAPPI T 403 om-97 "Bursting strength of paper"), double fold (TAPPI T 423 cm-98 "Folding endurance of paper [Schopper type tester]"), and apparent density was calculated dividing the paper thickness by basis weight of paper (TAPPI Standard Test Methods 2007). Porosity of laboratory handsheets was determined by Bendtsen method (IS: 9894-1981 "Method of test for smoothness/ roughness of paper") as per Bureau of Indian Standards, Bahadur Shah Zafar Marg, New Delhi.

3. RESULTS AND DISCUSSION

Transverse section of *C. album* contains several circles of collateral vascular bundles (Figure 1E), which are embedded in lignified so-called, conjunctive tissues (Figure 1A). Conjunctive tissue consists of fibers whose walls become extremely thick (sclerenchyma cells), and it provides a valuable source of papermaking fibers. It also shows that a part of stem contains inner vascular bundles consisting of both primary and secondary tissues enclosed by a cylinder of secondary vascular tissues. Phloem, in transverse section, is a compact oval or oblong mass of tissue (Figures 1B and C), bounded extremely and laterally by parenchyma cells (Figure 1D). This tissue later lignifies and together with the xylem of the bundles forms a compact body of cylinder in which appear embedded small islands of phloem (Figure 1F). The fibers are libriform type, short, pointed, and thin walled. The walls are sparingly pitted. The longitudinal course of the fibers is not absolutely straight in that, the ends of the fibers move away obliquely whereby, they become partly interlocked. These arrangements give the wood a special toughness (Figure 1E).

Table 1 reveals that the fibers of *C. album* resembles with *I. carnea* with respect to fiber length. The average fiber length of *C. album* is slightly on lower side compared to the fiber length of *Papavar somniferum* (0.71mm) (Chawla 1978). Conversely, fibers of *C. album* are thick-walled with narrow lumen and fiber diameter compared to *I. carnea*. Fiber diameter of *C. album* resembles with the fiber diameter of *Dendrocalamus strictus* (19.3µm) (Tiwary et al., 1982), and *Agave sisalania* (19.0µm) (Chawla 1978). Fiber diameter and wall thickness govern the fiber flexibility. Thick-walled fibers adversely affect the bursting strength, tensile strength and folding endurance of paper. The paper manufactured from thick-walled fibers will be bulky, coarse surfaced and containing a large amount of void volume. Luce's shape factor (89.59% and slenderness ratio (42.88%) of *C. album* are found to be much higher than that of *I. carnea*. Luce's shape factor and solids factor are related to paper sheet density and can significantly be correlated to breaking length of paper (Ona et al., 2001). The Runkel ratio of *C. album* fibers are 96.5% more compared to *I. carnea* fibers (Table 1). The fibers with a Runkel ratio above one is considered as thick-walled fibers, which are stiffer, less flexible and form bulky paper sheet of lower bonded area (Dutt et al., 2009). Runkel ratio is also related to paper conformability, pulp yield and fiber density (Ona et al., 2001). The thick-walled and narrow lumen fibers tend to retain its tubular structure on pressing and thus, offer less surface contact for fiber bonding (Dutt et al., 2004). Parenchyma cells are comparatively longer than that of vessel cells but vessel cells are wider compared to parenchyma cell. These cells present in the form of primary fines during pulping and may impersonate the problem of press picking or fluff generation at dryer part of paper machine (Dutt et al., 2005) due to larger surface area compared to fiber cells (Marton & Marton 1983). These fibers cells act as fillers and also affect mechanical strength and surface properties like porosity, smoothness and Denninson wax pick strength (Marton & Marton 1983, Htun & Deruvo 1978).

Table 2 reveals that water soluble in *C. album* is almost similar to that of *H. cannabinus*. In *C. album*, 1% NaOH soluble is higher (30.0%) than for *H. cannabinus* (25.8%) but resembles with *H. sabdariffa* (30.2%) (Dutt et al., 2010) and *Urena lobata* (30.0%) (Dube et al., 1981). The high 1% NaOH solubility of *C. album* is possibly due to the presence of low molar mass carbohydrates and other

alkali soluble materials. It indicates that *C. album* cannot be stored for a longer period after harvesting compared to *H. cannabinus*. *C. album* is comparatively less resinous than *H. cannabinus*, as evidenced by the alcohol-benzene solubility. Therefore, *C. album* will create less pitch problems, give a more homogeneous paper sheet (Ona et al., 2001), as resinous compounds adversely affects the runnability of process equipment due to choking of Fourdrinier wire and quality of paper in terms of shadow marking. Holocellulose, as a whole, adds to the overall strength of the paper. *C. album* has high holocellulose (70.2%) and α-cellulose (39.7%), both of which are important in assessing the suitability of a raw material for papermaking (Ona et al. 2001). α-cellulose of *C. album* is slightly higher than *Lantana camara* (38.5%) (Bist et al., 1981). According to the rating system designated by (Nieschlag et al., 1960), plant materials with α-cellulose greater than 34% are considered to be promising for pulp and paper production. In *C. album*, pentosan is slightly less (>1.72%) compared to *H. cannanbinus*. The quantity, chemical structure, distribution and degree of polymerization of hemicelluloses influence final paper strength. It is shown that the higher the hemicellulose content; better the swelling behavior of pulp, which lead to an increase in mechanical strength properties, including tensile and burst indexes and double folds and reduction in beating/refining energy (Tyagi et al., 2004). In *C. album*, lignin contents are 21.5% which resembles to that of sugarcane bagasse (20.30%) (Singh et al., 2011), *Sesbania aculeata* (21.9%) (Upadhyaya, J.S. et al., 1991) and *Populus deltoides* (21.80%) (Akhtar 2000). The functional significance of lignin has long been associated with mechanical support for plant organs; lignin enables growth in height [20, 21] and if lacking, plants cannot be upright (Zhong et al., 1997). The amount of lignin is directly related to the consumption of cooking liquor and the length of the cooking cycle. Also, the higher the lignin content, the greater will be the stiffness of the fibers (Dutt et al., 2009). *C. album* needs, in general, milder pulping conditions (lower temperatures and chemical charges) to reach a satisfactory kappa number. *C. album* contains higher ash content (2.89%), which may pose problems during recovery of chemicals from black liquor and may also contribute to mechanical wear and tear of the processing equipment.

Table 3 shows the effect of reaction time on residual lignin and pulp yield during soda pulping of *C. album* at 20% active alkali dose (as NaOH) and different temperatures. Figure 2A reveals the curves plotted between residual lignin and cooking time at different temperatures varying from 145°C to 175°C. The curves can be estimated by two straight lines at each temperature investigated. The curves with steeper and gentler slopes are associated with rapid solubilization of bulk of lignin (bulk delignification) and slow solubilization of the residual lignin (residual delignification) respectively. The bulk delignification phase corresponds to the removal of easily assessable lignin present in the middle lamella and the residual delignification corresponds to the removal of lignin present in the primary wall, secondary wall layers, and the central interconnection cavities. The delignification of wood in alkaline pulping is also associated with the solubilization of significant amounts of hemicelluloses (Kleinert 1965). These curves also indicate that as the temperature decreases from 175°C to 145°C, the time to reach transition from bulk to residual delignification and the lignin content of the pulp corresponding to this transition point both increase. Figure 2A also reveals that at lower temperature, the residual lignin decreases sharply while at higher temperature, the degree of decrease in lignin contents is slow. Moreover, at higher temperature the degradation of carbohydrates also increases, thereby reducing the pulp yield (Kleinert 1965). In other words, at the transition point, lower pulp lignin content is obtained at 165°C. Beyond 165°C, in addition to the peeling reaction, alkaline hydrolysis (depolymerization) of the polysaccharide chains occurs and is subjected to further degradation reactions (secondary peeling) (Hinrichs 1967; McGinnis and Shafizadeh 1980). The curves after transition points are almost horizontal lines, clearly indicating that the bulk delignification is over and it is not economical to continue the cooking operation beyond 165°C. The Arrhenius activation energy of bulk delignification in soda pulping of *C. album* was calculated and presented in Table 4 which is very low in comparison to softwoods and hardwoods (Wandelt and Surewicz, 1980) where as for residual Delignification was only about two thirds of this value. This explains either the existence of an association between lignin and carbohydrate in wood (Lindgreen 1958) or the formation of bonds during pulping (Kleinert 1966).

Table 5 shows the effect of reaction time on residual lignin, pulp yield and kappa number during soda pulping of *C. album* at maximum temperature 165^0C and different active alkali doses. Figure 2B shows the curves plotted between residual lignin and cooking time at different alkali doses varying from 14-22% (as NaOH). Likewise, curves plotted at each alkali doses can be approximated by steeper and gentler curves and are corresponding to bulk and residual delignification phases respectively. The nature of the curves indicate that when the concentration of active alkali decreases, the cooking time to reach transition point from bulk to residual delignification and pulp lignin content corresponding to this transition point, both increases. In other words, at the transition point, a lower pulp lignin contents are obtained at higher alkali doses than at lower alkali doses. The gap between curves plotted lignin contents *vs* reaction time becomes narrow with increasing alkali doses and these curves coincide each other at alkali doses of 20 and 22%. It means that excessive active alkali charge which remains unconsumed

during the course of pulping adversely affect the pulp yield instead of lignin removal. It means that it is not advisable to continue pulping beyond an active alkali dose of 20%. The transition point between bulk and residual delignification phases is observed to a reaction time of 3h (Figures 2A and B). Therefore, on the basis of experimental data, a cooking time of 3h and cooking temperature of 165°C may be considered as optimum for *C. album*.

Table 5 reveals the effect of active alkali doses on screened pulp yield and kappa number at cooking conditions mentioned in Table 5. Screened pulp yield and kappa number decreases with increasing alkali doses from 16 to 20% (as NaOH) but decrease in pulp yield at 20% active dose is minimum (0.14%) and kappa number is reduced by 5.62 units. At higher alkali doses degradation of carbohydrates occur due to peeling reactions. It is evidenced by the decrease in pulp viscosity with increasing alkali doses. The addition of 0.1% AQ at optimum pulping conditions improves the screened pulp yield marginally and mitigates screening rejects and kappa number 2.3 units. The increase in pulp yield and reduction in kappa number can be explained on the basis of the redox catalytic activity of AQ. AQ is a pulping additive that accelerates delignification and protects carbohydrates against degradation. It works through a cycle, which leads to the reduction of lignin and the oxidation of the reducing end group of cellulose from an aldehyde to a carboxylic acid. In the latter case the carbohydrates are stabilized against the alkaline peeling reactions, by means of the so-called stopping reaction, leading to an increase in pulp yield. Because AQ goes through a cyclic process, it is typically used at about 0.1% on oven dry raw material basis, and results in an increase in pulp yield (Buchanan et al., 2000).

Table 6 reveals the mechanical strength properties of *C. album* at 20% active alkali (as NaOH). All the mechanical strength properties improve up to a beating level of 41 ± 1^0SR except tear index. The work done in tearing is measured by the loss in potential energy of the pendulum. At low level of beating, fibers will be pulled out intact as the fracture propagates across the sample, because the inter fiber bonds are weak compared to the strength of the fibers. The necessary work that has to be done to pull the fibers loose depends on the length of the fibers as well as the bond strength. Removal of primary wall exposes secondary wall layers during pulp beating. However, primary wall is permeable to water but does not participate in bond formation. Therefore, tearing energy required to pull the fibers from the mesh will be slightly more due to hydrogen bonding after removal of primary wall. At higher beating level, the inter fiber bond strength will be higher and fibers start to break instead of being pulled out intact. Instead of that, other beating actions like fiber cutting, external and internal fibrillation and brushing action affect the tear index adversely. Therefore, all other properties which depend upon hydrogen bonding except tear strength improve with pulp beating. On the other hand, tear strength first improves with beating and then declines sharply. Further, addition of 0.1% AQ improves all other mechanical strength properties because AQ accelerates the delignification rate without degrading carbohydrates. The sheets formed were of higher density about 0.62–0.73 g/cm^3. These values are found to be on higher side when compared to hardwoods and bamboo (Parthasarthy et al., 1983). Smoothness of laboratory made handsheets decreases with increasing pulp beating. It is due to progressive development of hydrogen bonding and better sheet consolidation due to improvement in fiber flexibility.

4. CONCLUSION

The thick-walled and lignified tissues known as conjunctive tissue in *C. abum* provide a valuable source of papermaking fibers. In spite of short fiber length, *C. album* produces a bulky and opaque paper which is the most important property for writing and printing grade due to high Luce's shape factor, slenderness ratio, solid factor and Runkel ratio. Moderate amount of extractives with higher holocellulose contents and α-cellulose make *C. album* a promising raw material for pulp and paper making. Lignin contents in *C. album* resemble with agro-based residues (sugarcane bagasse) and hardwoods (*P. deltiodes*). A pulp yield of 42.3% with kappa number of 19.5 is obtained at an active alkali dose of 20% (as NaOH), maximum cooking temperature 165^0C, time at maximum cooking temperature 90 min and liquor to wood ratio of 4.5:1. A beating level of 41 ± 1^0SR is taken as an optimum beating level to produce optimal strength properties. Further, addition of 0.1% AQ improves all other mechanical strength properties as AQ accelerates the delignification rate without degrading carbohydrates. The reaction kinetics study indicates that delignification is of first order and activation energy is 91.90 kJ/mole.

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Table1: Morphological Characteristics of *C. Album* and Comparison with *I. Carnea*

Parameters	*C. album*	*I. carnea* (Dutt et al., 2007)
Average fiber length, mm	0.60±0.05	0.60±0.04
Fiber length variation, mm	0.22-1.00	–
Fiber diameter, μm	19.04±1.5	33.18±2.5
Lumen diameter, μm	5.05±0.7	30.3±2.1
Cell wall thickness, μm	7.00±0.8	1.47±0.5
Luce's shape factor	0.869	0.0905
Slenderness ratio	31.51	18.0
Solids factor	0.20	0.1
Runkel ratio	2.77	0.097
Length of vessel, μm	104.3	–
Width of vessel, μm	35.3	–
Length of parenchyma, μm	134	–
Width of parenchyma, μm	27.8	–

± Refers to standard deviation.

Table2: Proximate Chemical Analysis of *C. Album* and Comparison with *H. Cannabinus*

Parameters (%)	*C. album*	*H. cannabinus* (Dutt et al., 2009)
Ash content	2.89±0.05	1.40
Cold water solubility	4.87±0.01	5.81
Hot water solubility	9.69±0.02	8.24
1% NaOH solubility	30.0±0.04	25.80
Alcohol: benzene (1:2 v/v) solubility	2.14±0.02	3.88
Pentosan	16.73±0.09	18.45
Holocellulose	70.2±0.07	71.40
α-cellulose	39.7±0.06	48.60
β-cellulose	16.2±0.05	9.56
γ-cellulose	14.3±0.03	13.20

Acid soluble lignin	21.5±0.06	18.45
Acid insoluble lignin	0.92±0.02	–

± Refers to standard deviation.
All results are expressed on extractive free basis.

Table3: Effect of Reaction Time on Residual Lignin and Pulp Yield during Soda Pulping of *C. Album* at 20% Active Alkali (as NaOH) and Different Temperatures

Temperature, ^{0}C	Time at temperature, h	Yield, %	Lignin, %
145	1	61.9	14.92
	1.5	60.2	13.37
	2	59.4	11.93
	2.5	57.2	10.25
	3	55.8	8.41
	3.5	54.2	7.22
	4	52.4	6.21
	5	49.7	5.40
155	1	60.3	13.22
	1.5	59.2	11.62
	2	57.1	10.15
	2.5	55.6	8.55
	3	53.5	6.27
	3.5	51.4	5.24
	4	49.4	3.95
	5	47.6	2.95
165	1	58.2	11.36
	1.5	56.9	9.85
	2	54.4	8.16
	2.5	51.3	6.22
	3	49.7	4.11
	3.5	48.4	2.87
	4	46.1	1.88
	5	47.6	1.23
175	1	56.6	10.94
	1.5	54.3	9.08
	2	51.6	7.13
	2.5	49.8	4.64
	3	47.5	2.71

	3.5	45.2	1.87
	4	42.3	1.24
	5	39.7	0.95

Results reported in duplicate. Pulping conditions: Time from ambient temperature to 105 ◦C= 45 min, time from 105 ◦C to maximum temperature = 45 min, liquor-to-wood ratio = 4.5:1.

Table4: First Order Rate Constant for Bulk Delignification in Soda Pulping of *C. Album*

Sl. No.	Temperature ^{0}C	Rate constant KS^{-1}
1	145	0.6461x10-4
2	155	1.1195x10-4
3	165	2.3509x10-4
4	175	3.4986x10-4
5	Activation energy, kcal/mole kJ/mole	21.96 91.90

Table5: Effect of Reaction Time on Residual Lignin, Pulp Yield and Kappa Number during Soda Pulping of *C. Album* at Maximum Temperature 165^{0}C and Different Active Alkali Doses

Active alkali doses, % (as NaOH)	Time at 165 ^{0}C, h	Lignin, %	Kappa no.	Yield, %
14	1	13.08		
	2	10.65		
	3	8.12	34.5	48.3
	4	6.32		
	5	4.73		
16	1	12.23		
	2	9.12		
	3	5.85	29.5	45
	4	4.45		
	5	2.74		
18	1	10.62		
	2	7.21		
	3	3.53	25	43.4
	4	2.04		
	5	1.22		
20	1	9.36		
	2	5.72		
	3	2.51	19.5	42.8
	4	1.11		

	5	0.45		
22	1	8.75		
	2	5.12		
	3	2.10	18.3	41.7
	4	0.98		
	5	0.40		

Results reported in duplicate. Pulping conditions: Time from ambient temperature to 105 ◦C= 45 min, time from 105 ◦C to maximum temperature = 45 min, liquor-to-wood ratio = 4.5:1.

Table6: Effect of Active Alkali and AQ on Pulp Yield, Kappa Number, and Screening Rejects during Soda Pulping of *C. Album* and Evaluation of Physical Strength Properties at Distinct Beating Levels (20% Active Alkali)

Parameters	Active alkali doses, % (as NaOH)				
Active alkali, % (as NaOH)	16	18	20	22	20
Anthraquinone dose, %	–	–	–	–	0.1
Unscreened pulp yield, %	45.0	43.4	42.80	41.7	42.7
Screening rejects, %	1.58	1.10	0.50	0.05	0.10
Screened pulp yield, %	43.42	42.54	42.30	41.65	42.6
Kappa number	29.46	25.12	19.5	18.3	17.2
Brightness (ISO), %	24.7	25.4	26.9	28.2	27.6
Viscosity, cm^3/g	695	666	621	610	674
pH of spent liquor	13.0	13.5	13.25	13.40	13.29
Residual active alkali in spent liquor, g/L (as Na_2O)	3.0	4.28	5.75	6.10	5.89
Total solids in spent liquor, %	9.87	11.49	12.05	12.45	12.20
Mechanical strength properties of soda pulp of *C. album* at 20% alkali doses					
Beating levels, ^0SR	14	34	40	43	
Drainage time, s	3.7	13.2	16.4	17.3	
Apparent density, g/cm^3	0.62	0.65	0.72	0.73	
Tear index, mNm^2/g	2.3	4.9	4.1	3.5	
Burst index, $kPpa.m^2/g$	0.70	3.12	3.65	4.15	
Tensile index, Nm/g	12.15	46.77	55.65	56.70	
Porosity Bendtsen, mL/min	1620	710	425	230	
Folding endurance Kohler Molin	15	155	205	230	

Cooking conditions: Time from ambient to 105 °C = 30 min, time from 105 to 165 °C = 90 min, maximum temperature = 165 °C, time at maximum temperature = 90 min, liquor-to-wood ratio = 4.5:1.

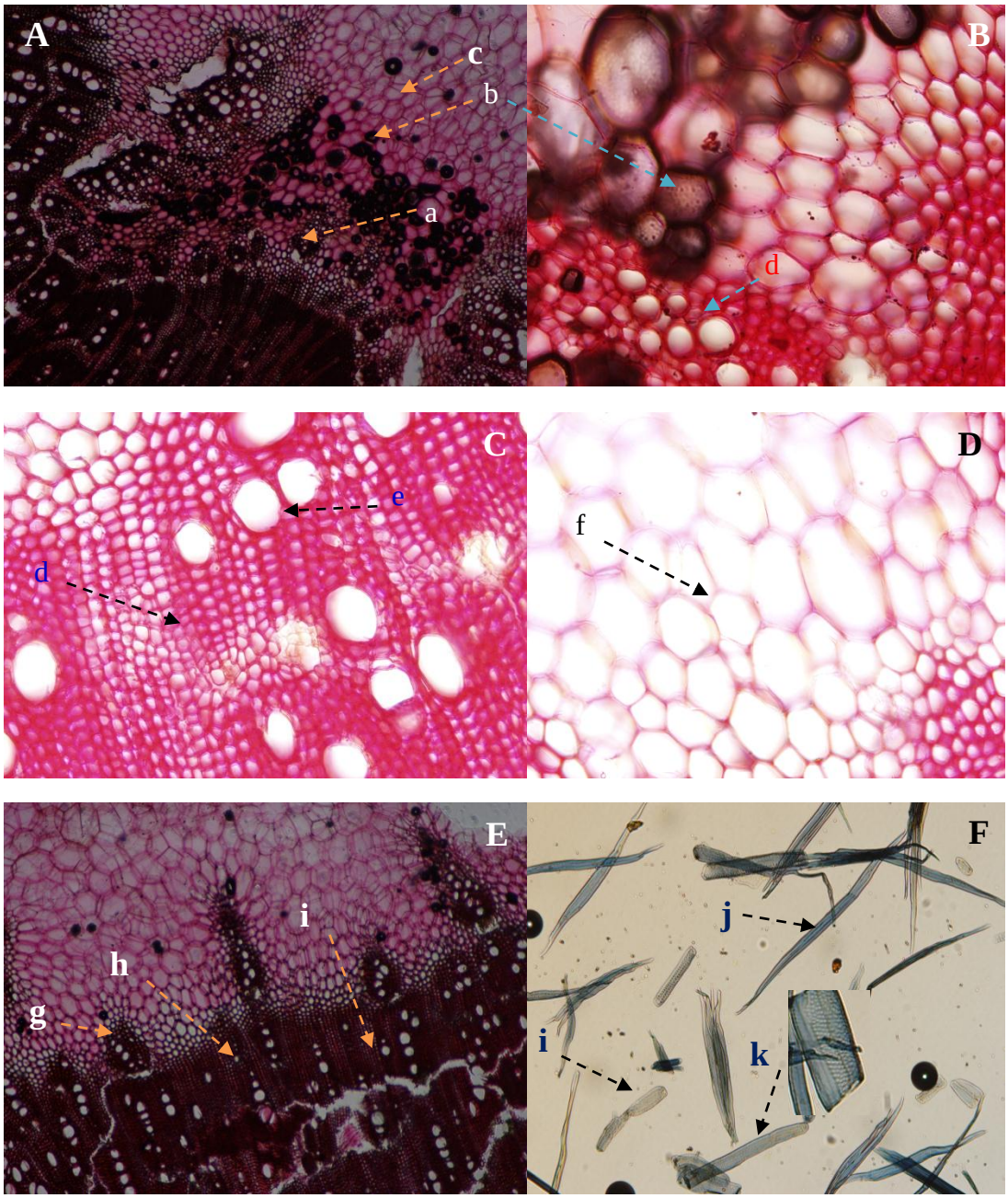

Figure1: (A) T.S. of stem showing vascular bundle (a), oil glands(b) and pith cells (c) (B) oil glands (a) and sclerenchymatous cells (d) (C) Vessels (e) and sclerenchymatous cells (D) Parenchyma cells (f) (E) T.S. of stem showing inner (g) and (h) vascular bundles and (i) conjunctive tissue (F) Fibers with pointed ends (j), vessels (k) and parenchyma cells (l) parenchyma cells

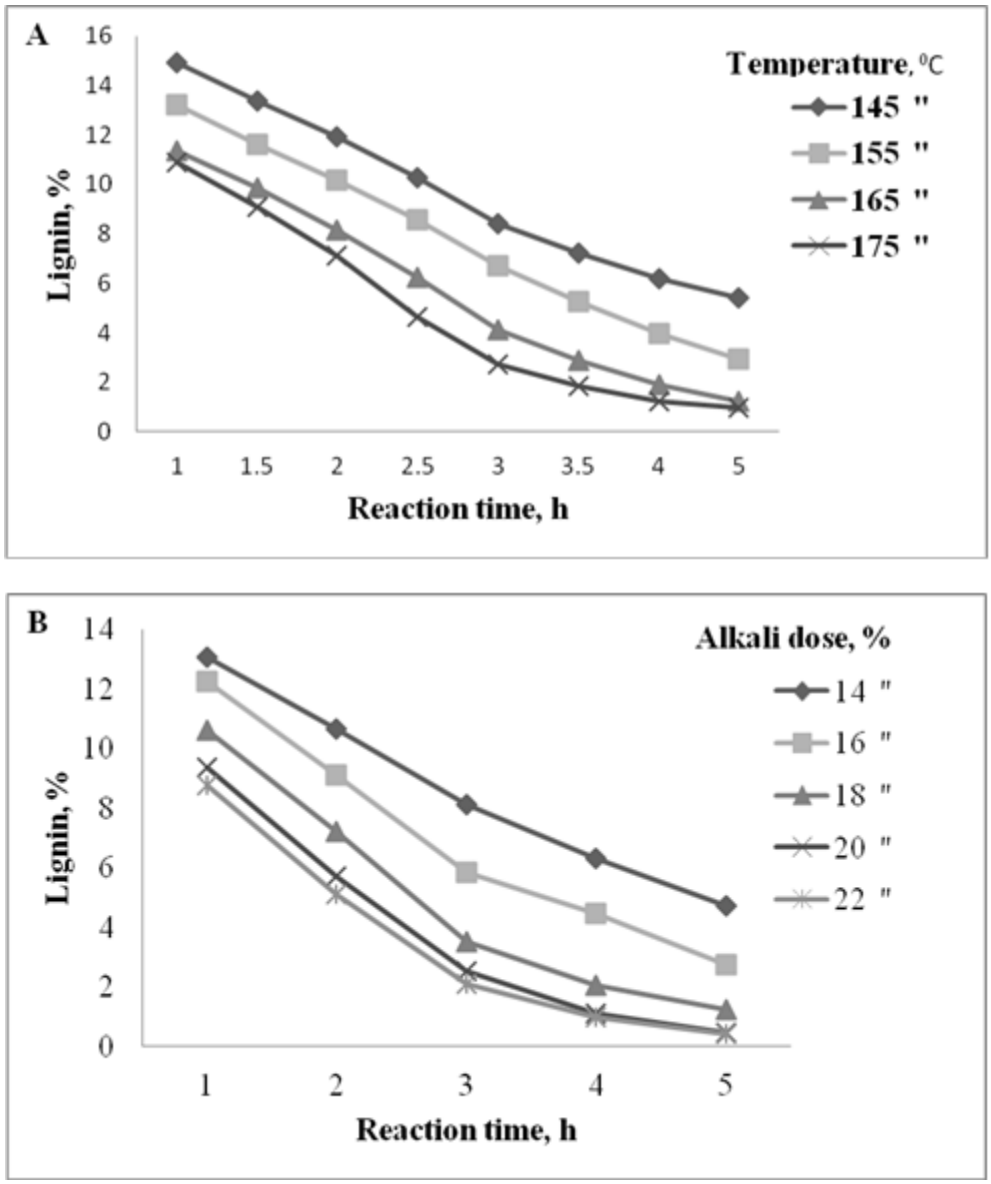

Figure2: Curves of Lignin vs. Reaction Time at Different (A) Temperature and (B) Alkali Doses during Soda Pulping of *C. Album*