Pulp and Papermaking Characteristics of South Sudanese Cordia Africana (Gambil) Wood

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Research note

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Abstract

Objective The wood of an important indigenous Sudanese hardwood species, *Cordia africana* lam, was examined to determine its suitability for pulp and papermaking. Basic density, bark-to-wood ratio, fiber dimensions and chemical composition were studied.

Results Pulps were evaluated and papermaking characteristics were tested. *C. africana* wood showed medium basic density (410 kg m^{-1}). The average bark-to wood ratio by mass (6.82%) and volume (11.67%) were in the normal average for pulpwood and could be used for production of high grade pulp. The fibers of *C. africana* were long with an average fiber length of 1.13 mm, average fiber diameter was 30 µm with an average lumen diameter 20 µm and cell wall thickness of 5 µm. the wood showed high ash content (2.7%), high pentosans (25%), relatively medium lignin content (23.9%).*C. africana* pulped with 12-15% alkali charge as Na_2O for two hours at 170 ^{0}C gave good Kappa numbers with normal and relatively high yield with very low rejects. The addition of 0.13% anthraquinone (AQ) in cooking liquor reduced the active alkali consumption by 2-2.3%, increased the pulp yield and reduced bleachable Kappa numbers. The pulp produced suitable for wrapping paper and paperboard.

Introduction

The species *Cordia africana* Lam,family *Boraginaceae,* sub family *Cordiodeae* synonym: C. holstii., *Cordia abyssinica* R.Br [1] Its common names in different languages are East African cordia, large-leafed cordia, Sudan teak (English) Gambil (Arabic) Makobokobo (Swahili). Makumari, Muringa (Kikuyu), Samotet (Nan). It is small to medium-size tree occurs at medium altitudes, savannah and bush, near river banks. Its size between 6-9 meters, sometimes 16.6 m high [2-7]. Cordia composed of five species distributed in different areas of the Sudan [8], although there are great differences in morphological structure of the species [9], there are no anatomical differences of these species [10]. *C. africana* is the fast growing and has high economical value due to its timber uses [11].

The wood of *Cordia africana* is utilized for timber production, farm equipment, household utensils and fuel [12-16], and also used in construction and manufacturing of toys [16] Amhara tribes in Ethiopia use this tree in rituals of orthodox religion [17].

Although Sudan was politically divided into two countries in 2011, the social scientific relations still continuing, the border between the two countries open with more or less similar environmental, ecological conditions and plant tree composition [18 and 19].

South Sudan is largely dependent on the imports of paper products. The demand for these products have grown rapidly with continuous development. Pulp can be produced in many different yields depending on the suitability of the raw material and pulping conditions.

Wood as raw material for pulp and papermaking has offered precious services to man and decisively contributed to development [20]. Sudan and South Sudan is rich in different hardwood species many of

which could be a good source of pulp production [21]. The study of such wood species is important to determine their suitability for pulp production. Among the important indigenous Sudanese hardwood species is *Cordia Africana*. The species is naturally distributed in western Darfur (Jebel Marra), Blue Nile and southern Kordofan, and in South Sudan (Equatoria, Upper Nile and Bahr el Ghazal).

This study aimed to investigate the pulping and paper properties of *Cordia. Africana* stem with reference to fiber dimensions and chemical composition.

Main Text

Five *C. Africana* trees with average age six years, were randomly selected according to TAPPI standards 2002 [22], from Jelhag natural forest (Upper Nile state, South Sudan). The trees were felled and branches were removed, transported to Khartoum capital of Sudan by bus, stored in National Centre for Research NCR). Leaves, flowers fruits and seeds were collected for identification with taxonomists of Medicinal and Aromatic Plants Research Institute National Center for Research, Sudan [18].

Five logs of 100 cm long were exposed to air dry under sun, prepared according to TAPPI standard (T 257-cm- 02 [22], chipped with hands and packed in plastic bags for further analysis. The average basic density was determined using wood specimens according to the British standards [23]. Wood fibers were macerated using a mixture of 30% hydrogen peroxide and acetic acid (1:1). Fiber dimensions were determined microscopically at X100 and X 300 magnifications according to (TAPPI-232cm-01) after staining with aqueous safranin [24]. Standard deviation and arithmetical mean were used to determine fiber properties Morphological indices. The heat value of *C. Africana* wood was carried out using a Krocher oxygen bomb calorimeter [25].

About one Kg of chips was grinded for chemical Analysis of wood sample was carried out using 40 to 60 mesh wood meal in accordance with (TAPPI-264-cm-97). Sampling and testing for moisture (TAPPI-210cm-93), cellulose Kurshner and Hoffer [26] lignin (TAPPI-222), Pentosans (TAPPI-223-cm-01), ash (TAPPI-212) hot water soluble (TAPPI-T- 207) and solvent extraction of wood (TAPPI-204).

After negotiations and suggestions with other coauthors the pulping conditions and cooking parameters were decided according to physical properties *Cordia africana* wood and mainly on its chemical components. The Soda and soda-anthraquinone conditions were 12-15% as Na_2O on oven dry weight of wood, the maximum temperature was kept constant at 170^0C. Time to maximum temperature was 60 minutes for all cooking trials, the time at maximum temperature was 120 minutes kept constant for all trials under study.

The pulps were subjected to beating in Valley beater according to TAPPI 200-sp-01, evaluated at 25 and 40 degree Schopper Reegler (^{0}SR) freeness of pulp (Canadian standard method TAPPI 227om-99), Kappa number (TAPPI-236 om-99), physical testing of pulp sheets (TAPPI-220-sp-01). Conditioning of testing atmosphere (TAPPI-402-sp-98), folding endurance (TAPPI423cm-98) Burst strength (TAPPI403om-97),

tearing resistance (TAPPI-414 om-98), and Tensile (TAPP-404-cm-92).Hand sheets were prepared using a rapid- Kothen sheet forming machine and tested using TAPPI standards.

Physical properties of *C. africana* wood were shown in (Table 1 supplementary materials). The average basic density was (410kg m^{-1}) and bark-to- wood ratio were in the medium range for tropical hardwoods [28]. This will not cause wear on chipper knives in pulp mills with normal liquor-to wood ratio (usually 4:1), impregnation will be easy as yield of pulp per unit volume is related to basic density. The heat value was 18187 K j Kg^{-1} indicating their suitability in coal firewood production and indicated a high lignocellulosic materials could be expected.

The fiber length for *C. Africana* (1.31 mm) as presented in Table 1 was considered as medium fibred species, therefore it does not need to be mixed with other long fibered wood pulp to obtain good paper properties very good tear resistance could be expected from this raw material. The comparatively wide lumen and fiber diameter indicated that to collapse easily and produce good surface contact between adjacent fibers of *C. africana*, this supported further with morphological indices (Table 1).

The chemical constituents of *C. africana* wood were reflected in Table 2, the inorganic components (ash and silica) were high (5.84% and 2.65% respectively) may cause an increase in alkali consumption and negatively affect the black liquor recovery. The average cellulose content (48.7%) was in normal range for tropical hardwoods and good pulp yields could be expected from *C. Africana* wood, it is well known that Kurschner- Hoffer cellulose gave less percentage when compared to alpha cellulose thus may results of high yield of this raw material if appropriate cooking conditions used. The lignin content was medium (23.9%) which indicated normal delignification of wood chips. However 1% NaOH soluble (20.2%) reflected normal cooking parameters should be applied.

The cooking conditions and yield for *C. africana* wood were given in Table 3. At same pulping conditions *C. africana* chips have shown lower screened yield (41.5 and 44.7%) when cooked with soda process, whereas the screened yield was increased with addition of 0.13% AQ to 47.7% and 53.6%. The bleachable pulps resulted when soda-AQ cooking were used [29-32]. These results indicated clearly the superiority of soda cooking when anthraquinone applied as catalyst, thus improve yield, and reduce rejects with bleachable Kappa numbers although the initial ISO brightness more or less similar during soda pulping with or without anthraquinone.

The unbleached pulps evaluation was given in (Table 2 supplementary materials), indicated that when hand sheets of C*. africana* tested at both 25 and 40 ^{0}SR gave high tensile index, tear index, burst index and folding endurance(Figure 1 and 2 supplementary materials), all the mechanical strength properties were increasing with increase of beating degree showed that still fibers were strong enough even at high degrees of beating and pulps of this raw material can be used for wrapping paper and paperboard.

Limitations

Based on physical and morphological properties, the wood of *Cordia Africana* could be considered as medium range pulpwood. The use of soda-AQ pulping process for *C. africana* wood has accelerated delignification and beating rate, decreased the alkali consumption and increased yield.

The final products of pulping with this raw material is strong enough for wrapping paper and paperboard.

Cordia africana tree is hard wood distributed in both Sudan and South Sudan, it is grown naturally, it is fast growing species, with all promising results of physical properties, chemical composition, fiber morphology and pulping with low cost soda with anthraquione cooking conditions could be one of tree species to establish integrated pulping industry between the two neighboring countries. However due to lack of equipment of bleaching stages were not carried out. The difficulty of transportation will one of limitations for integrated pulp and paper industry between two neighboring countries, and lack of industrial polices to establish pulp and paper mills as of promising economical investment sector.

Declarations

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Authors' contributions

SOT carried out practical and technical work and revised the draft manuscript. OTE designed the work and review the draft manuscript, TOK wrote the draft manuscript. All authors read and approved the final manuscript.

Competing interests

Not applicable.

Availability of data and materials

We have already included most of data in the manuscript, the lab and data, some data not included in the manuscript attached as Additional file.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

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References

1. Friis, I. Forests and Forest Trees of Northeast Tropical Africa - Their Natural Habitats and Distribution Patterns in Ethiopia, Djibouti and Somalia. London: Her Majesty's Stationery Office. 1992.
2. Sahni, K. C. "Important Trees of the Northern Sudan", Khartoum University Press, Sudan U. N. D. P and FAO. 1968.
3. Bolza, E and Keating, W.G. African Timbers - The Properties, uses and Characteristics of 700 species, Div. of Building Research, 723 p1972.
4. Palgrave, K.C. Trees of Southern Africa. Revised edition. C. Publishers, Cape Town, South Africa 2003.
5. - EL Amin, H.M. Trees and Shrubs of Sudan. Ithaca Press, Exeter, 484p. 1990.
6. Orwa C, A Mutua, Kindt R, Jamnadass R, S Anthony. Agroforestree Database:a tree reference and selection guide (http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp) 2009.
7. Raga D. Denu, D. Population Density of Cordia africana Lam. across Land Use Gradients in Jimma Highlands, Southwest Ethiopia. Population Density. Basic and Applied Research (IJSBAR). 2017; 35, (2): 157-166
8. Andrews F W. The flowering plant of the Anglo. Egyptian Sudan, vol.3, Buncle & Co.ltd. Arbroath, Scotland. 579p. 1956.
9. Guyassa, E. Tesfaye, S. Joseph A. Abdulkadir A. Gures, A. Morphology Characterization of Cordia africana Populations at Six Provenances in Northern Ethiopia. Int. J. Agri. Sci. & Res. 2013; 3(2):175-186.
10. Ahmed, H.O. Kordofani, M.A. Morphological and anatomical studies of *Cordia abyssinica*Br. and *Cordia sinensis* Lam. (Boraginaceae) in Sudan. J. Chem. & Pharm. Res. 2012; 4 (10):4582-4588
11. Tamene, W. G. Germinatio and Early Growt Performances of *Cordia africana* in Potted Vertisol and Nitosol in Bichena Town, East Gojjam Zone Amhara Regional State. M.Sc. Thesis, Addis Ababa University, Department of Zoological Sciences, Ethiopia 67p. 2017.
12. Emmanuel Neba, N. Implications Of Fuel Wood Yield, Availability And Harvest In Tubah Mountain Forest, Cameroon. Global J. of Human-Social Science Res., 2010;10 (3): 49-55.
13. Ecocrop Cordia africana. Available at: <http://ecocrop.fao.org/ecocrop/srv/en/cropView?id=4855> (accessed: 28 12 2009). 2007.
14. *Cordia africana.* A tree species reference and selection guide World agroforestry center database. Nairobi: ICRAF. Available at: http://www.worldagroforestry.org/treedb2/AFTPDFS/Cordia_africana.pdf (accessed: 4 10 2008) 2008.
15. Jansen, P. C. M. Spices, condiments and medicinal plants in Ethiopia, their taxonomy and agricultural significance. Wageningen, Landbouwhogeschool: Centre for Agricultural Publishing and

Documentation, Issue 906 of Agricultural Research Reports. 327 pp. 1981.

16. Obeng, E.A., *Cordia africana* Record from PROTA4U. Lemmens, R.H.M.J. 2010.
17. Baye, D.Socio-Economic Importance of Selected Indigenous and Exotic Tree Species used in Dabat District, North Gonder, Ethiopia. M.Sc. Thesis Addis Ababa University Ethiopia, 53p. 2016.
18. Issa, T.; Mohamed, Y.; Yagi, S.; Ahmed, R.; Najeeb, T.; Makhawi, A; Khider, T. Ethnobotanical investigation on medicinal plants in Algoz area (South Kordofan), Sudan J. Ethnobiol. Ethnomed, 2018;14, 31. 4
19. Elzaki, O.T. Otuk, S. Khider, T.O Sulfur-Free Pulping Of Crateva Adansonii from Sudan. of Forest Prod. & Indus. . 2012; 1(1), 23-26
20. Khristova, P, Gabir, S and Taha, O. Physical, morphological and chemical characteristics of some exotic fast growing species in Sudan, Cell. Chem. and Tech., 1989; 23:121-129.
21. Elzaki, O.T. Utilization potentialities of some Exotic Fast Growing wood species grown in Western Sudan. Ph.D. thesis University of Khartoum, Sudan, 228p. 1990.
22. TAPPI Standards and Suggested Methods. TAPPI Press, Atlanta, Georgia, USA. 2002.
23. S.373. The British Standard Methods of Testing Small Clear Specimens of Timber. British Standards Institute, London. 1957.
24. Horn, R. Morphology of Pulp Fiber from Hardwoods and Influence on Paper Strength. Forest Prods. Lab. Report, Madison, 312p. 1978.
25. Khider, T.O. Elzaki, O.T. Heat Value of Four Hardwood Species from Sudan. Journal of Forest Prod. &Indus., 2012;1(2): 5-9
26. Obolenskaya, A.V., V.P. Tshegolov, G.I., Akim, N.C., Kossoviz, N. L., Emelyannova, I.Z. Practitcheshie Raboti po Himii Drevesinii Tzellulozi. Moscow, Lesporm. (In Russian) 1965.
27. Tuphach, S.O. Suitability of Some Wood Species from Upper Nile State for Pulp and Papermaking. M.Sc. Thesis Faculty of Forestry, University of Khartoum, Sudan 94p. 2008.
28. - Rhydolm, S.A. Pulping Processes. Inter science Publishers, New York. Pp 50-52. 1965.
29. Shomeina, S.K., Elzaki, O.T., Yagi, K., Mohieldin, D., Khider. T.O Crude extracts of *Sesamum Indicum* roots used as anthraquinone source effect on pulping with sodium hydroxide of Sudanese bagasse. BMC Research Notes., 2019 12:26 https://doi.org/10.1186/s13104-019-4075-9
30. Khider, T. O., Omer, S., Elzaki , O., Mohieldin, S., Shomeina , S. Application of alkaline Pulping to Pruned Branches of *Citrus limon* from Sudan. Walailak Journal of Science and Technology (WJST), 2021 (in press) Retrieved from http://wjst.wu.ac.th/index.php/wjst/article/view/9409
31. Elzaki, T., Khider, T.O., Omer, S.H., Mohieldin, S.D., Shomeina, S.K. Suitability of Sudanese pearl millet stalks *Pennisetum glaucum (L.)* for alkaline pulping with additives. Songklanakarin J. Sci. Technol., 2020. 42 (1), 118-123 DOI: 10.14456/sjst-psu.2020.16
32. Omer, H., Khider, T.O., Elzaki, O.T., Mohieldin, S.D., Shomeina, S.K., Application of soda-AQ pulping to agricultural waste (okra stalks) from Sudan. BMC Chemical Engineering 2019.1:6

Tables

Table 1. Fiber dimensions and morphological indices of *Cordia africana* wood

Fiber dimensions	Measured value	Standard deviation
Fiber length, mm	1.31	0.86
Fiber width, µm	30.4	0.55
Lumen width, µm	20.2	0.43
Wall thickness, µm	5.1	0.57
Morphological indices		
Runkel index	0.50	
Wall fraction	33.6	
Flexibility coefficient, %	66.4	
Rigidity coefficient, %	16.8	
Felting power (slenderness)	43.1	

Table 2. Chemical Constituents of *Cordia africana* wood

Chemical components, %	*Cordia africana* wood
Ash	5.84
Sulfate ash	2.39
Total silica	2.65
Solubility in	
Hot water	18.1
Cold water	0.6
Alcohol	2.9
Alcohol: cyclohexane (1:2)	2.3
1% NaOH	20.2
Kurschner- Hoffer cellulose	48.7
Holocellulose	69.5
Pentosans	25.0
Lignin	23.9
Total extractives	7.3
Cellulose lignin ratio	2.04

Table 3. Pulping conditions and yield results of *Cordia africana* wood

Pulping Process	Soda	Soda	Soda-AQ	Soda-AQ
Cook code	CA1	CA2	CA3	CA4
Pulping conditions				
Active alkali as Na_2O on oven dry wood, %	15	12	12	14
Anthraquinone on oven dry wood, %	0	0	0.13	0.13
Liquor to wood ratio on oven dry wood ,	4	4	4	4
Maximum temperature, ^{0}C	170	170	170	170
Time to maximum temperature, min	60	60	60	60
Time at maximum temperature, min	120	120	120	120
H-factor	1620	1620	1620	1620
Yield results				
Total yield, %	41.8	51.8	53.9	53.7
Screened yield, %	41.5	44.7	47.7	53.6
Rejects, %	0.3	7.1	6.2	0.1
Kappa number	27.3	29.5	26.6	21.4
ISO brightness, %	21	22	23	22

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