Perennial, 2024
Vol. 20 No. 1: 40-46
p-ISSN: 1412-7784

Tersedia Online:
http://dx.doi.org/10.24259/perennial.v20i1.34784
e-ISSN: 2685-6859

CHEMICAL PROPERTIES OF DOYO (*Curliglia latifolia*) LEAF FIBERS

Komponen Kimia Serat Daun Doyo (Curliglia latifolia)

Marwanto[1]✉, Nurhaida[1], Nanang Masruchin[2]

[1]*Faculty of Forestry, Tanjungpura University, Pontianak, Indonesia*
[2]*Research Center for Biomass and Bioproducts, National Research and Innovation Agency, Cibinong, Indonesia*

✉*corresponding author: marwanto@fahutan.untan.ac.id*

ABSTRACT

Local communities widely use natural fibers to fulfill their daily needs. Doyo (*C. latifolia*) leaf fibers are fibers used by the people of Kalimantan for clothing and weaving traditional mats. This shows that natural fibers originating from the Kalimantan have the potential to be developed into innovative derivative products. This research analyzed the fundamental properties of *C. latifolia* leaf fibers, including chemical components, functional groups, and crystallinity index. The soluble extractive content of polar solvents was higher than the extractive content of non-polar solvents in *C. latifolia* leaf fibers. The holocellulose content of *C. latifolia* leaves was 60.47 %. The alpha cellulose for *C. latifolia* leaves was 53.51 %. The FTIR test results also support the chemical component test results. The high alpha cellulose content will affect the fiber's crystallinity index. *C. latifolia* leaf fiber had a degree of crystallinity of 69.77%. *C. latifolia* leaf fiber is suggested as the raw material for crystalline nanocellulose.

Key words: Natural Fibers; Doyo (*Curliglia latifolia*) Fiber; Chemical Components

ABSTRAK

Masyarakat lokal banyak memanfaatkan serat alam untuk memenuhi kebutuhan sehari-hari. Serat daun doyo (*C. latifolia*) merupakan serat yang digunakan masyarakat Kalimantan untuk bahan pakaian dan tenun tikar tradisional. Hal ini menunjukkan bahwa serat alam asal Kalimantan mempunyai potensi untuk dikembangkan menjadi produk turunan yang inovatif. Penelitian ini menganalisis sifat dasar serat daun *C. latifolia* meliputi komponen kimia, gugus fungsi, dan indeks kristalinitas. Kandungan ekstraktif terlarut pada pelarut polar lebih tinggi dibandingkan kandungan ekstraktif pelarut non polar pada serat daun *C. latifolia*. Kandungan holoselulosa daun *C. latifolia* sebesar 60.47%. Kadar alfa selulosa daun *C. latifolia* sebesar 53.51 %. Hasil pengujian FTIR juga mendukung hasil pengujian komponen kimia. Kandungan alfa selulosa yang tinggi akan mempengaruhi indeks kristalinitas serat. Serat daun *C. latifolia* mempunyai derajat kristalinitas sebesar 69.77%. Serat daun *C. latifolia* disarankan sebagai bahan baku pembuatan nanoselulosa kristal.

Kata kunci: Serat alami; Serat Doyo (*Curliglia latifolia*); Komponen kimia

---

Submitted: 3 May 2024; Accepted: 10 June 2024

A. INTRODUCTION

Natural fiber from lignocellulosic materials is one potential fiber source that can be developed in many applications. This is due to its abundant availability, renewable nature, and environmentally friendly (Kathirselvam et al., 2019). Several plant fibers worldwide can substitute synthetic fibers, such as kenaf, sugar palm, bamboo, corn, hemp, straw, pineapple leaves, banana, sisal, etc. (Li & Li, 2022). Using natural fibers for composite purposes can also solve problems such as production energy consumption, leaving no carbon residue, and reducing disposal problems in the final product.

Determining potential raw materials that can be used efficiently is important in a manufacturing industry. This phenomenon is also observed in the utilization of natural fibers. The main problem with the limited use of natural fibers is the varying characteristics of each desired lignocellulosic fiber. This can be caused by several factors: fiber anatomy, morphology, physics, and the chemical components of lignocellulosic fibers (Lee et al., 2014). Lignocellulosic fiber has three main components: cellulose, hemicellulose, and lignin. Each lignocellulosic material contains different chemical components (Hartono et al., 2022). This can affect the production of the desired product, which is related to energy, chemicals, and the time required.

Research by Marwanto *et al.* (2021) shows that differences in the characteristics of raw materials, such as balsa and kapok fibers, affect the crystalline nanocellulose produced. Selecting suitable raw materials for making specific polymers from lignocellulosic materials must be considered carefully. Appropriate raw materials are natural, readily available, and have potential for future development in the local area.

West Kalimantan is one of the provinces on the island of Kalimantan with a very high level of biodiversity. This can cause a variety of traditional processed products originating from lignocellulosic fibers, especially bamboo and rattan, as well as pandanus types (Brata et al., 2022; Sasmita et al., 2021). Some of the lignocellulosic fiber derivative products are traditional clothing, traditional clothing equipment, daily necessities such as woven mats, etc. This shows that natural fibers originating from the Kalimantan have the potential to be developed into innovative derivative products. This phenomenon assumes that natural fibers are strong and have high resistance. Natural fibers also have potential as raw materials for cellulose and nanocellulose technology, such a raw oil palm leaves (*Elaeis guineensis*) (Hussin et al., 2020), pineapple crown leaf fiber (PCLF) (Fitriani et al., 2021), cattail leaves (Wu et al., 2024), banana fiber (Madhushani et al., 2022), N36 ananas comosus leaves (Gnanasekaran et al., 2022), areca nut leaf sheath fibers (Elanthikkal et al., 2021). The island of Kalimantan has various sources of natural fiber, one of which is doyo (*Curliglia latifolia*) leaf fiber. The *C. latifolia* can be found in almost all areas of the island including West Kalimantan. However, optimal utilization has only been carried out in East Kalimantan as traditional clothing (Nur et al., 2021). Morphologically, the fiber produced from *C. latifolia* leaf fiber is long, solid, and long-lasting. This may be caused by the different chemical constituents in the fibers. However, a comprehensive study of the constituent components of *C. latifolia* leaf fibers has not yet been conducted.

The potential of *C. latifolia* leaf fiber is enormous because it can be developed through the rhizome (Farzinebrahimi et al., 2016). Physically, *C. latifolia* leaf fiber is almost identical to pineapple, hemp, and kenaf leaf fiber. This shows that *C. latifolia* leaf fiber also has potential as a raw material for producing cellulose and nanocellulose. However, the characteristics of the nanocellulose produced are based on the characteristics of the raw material (Marwanto et al., 2021b). This is related to the chosen nanocellulose extraction method and the selected method's optimal conditions (Marwanto et al. 2021) showed that the percentage of guayacil and syringil lignin contained in fiber influences the effectiveness of the delignification process. Physical factors of natural fibers also cause differences in nanocellulose results, one of which is the cell wall thickness factor of the fiber source used (Marwanto et al. 2021).

This research analyzes the characteristics of *C. latifolia* leaf fibers based on the functional group, crystallinity index, and chemical components. This characteristic is essential for identifying suitable extraction methods and conditions for producing cellulose and nanocellulose from *C. latifolia* leaf fiber.

B. METHODS

Preparation of Raw Materials

C. latifolia leaf fiber was obtained in the Selakau area, Sambas Regency, West Kalimantan. The chemicals used in this research were sodium chlorite, acetate (glacial), sodium hydroxide, ethanol, benzene, distilled water, and sulfuric acid with PA grade. The collected *C. latifolia* leaves are cut into small pieces and dried in the sun. The dried leaf fibers were ground using a hammer mill to become powder. The powder size is 40-60 mesh.

Analysis of Chemical Components of *C. latifolia* Leaf Fiber

Analysis of the chemical components of *C. latifolia* leaf fiber included water content, cold water dissolved extractive content, hot water dissolved extractive content, ethanol benzene dissolved extractive content, 1% NaOH dissolved extractive content, holocellulose content, α-cellulose content, and acid dissolved lignin content.

The water content of the test sample was determined by drying the sample until it reached a constant mass in an oven at 103 ± 2 ºC (TAPPI T12 os-75). The solubility of the extractive in cold water and hot water was determined using the TAPPI standard number T207 cm-99.

Solubility of the extractive in cold water was carried out by immersing 2 ± 0.1 gram sample powder in 300 mL of distilled water in a 400 mL beaker. Extraction was carried out at a temperature of 23 ± 2 ºC for 48 hours.

The mixture of powder and distilled water was then transferred into a glass filter which had been dried until the mass was constant at a temperature of 105 ± 3 ºC. The extracted powder was washed with 200 mL of cold distilled water and then dried in an oven at a temperature of 103 ± 2 ºC until the mass was constant, the sample was cooled and then weighed.

Solubility of the extractive in hot water was carried out by soaking 2 ± 0.1-gram sample powder in 100 mL of hot distilled water in a 250 mL Erlenmeyer glass. The Erlenmeyer glass was then placed in a water bath filled with boiling water. Soaking in hot water is carried out for 3 hours. The mixture of powder and distilled water was then transferred into a glass filter which had been dried until the mass was constant at a temperature of 105 ± 3 ºC. The extracted powder was washed with 200 mL of hot water and then dried in an oven at a temperature of 103 ± 2 ºC until the mass was constant, the sample was cooled and then weighed.

Holocellulose and α-cellulose content levels were determined according to the Browning method (Browning, 1967). The lignin content, expressed as Klason lignin, was measured according to TAPPI 222 om-88 (TAPPI 2002a) and TAPPI UM 250 (TAPPI 2000). Cold and hot water-soluble extractives, ethanol-benzene soluble extractives, and 1% NaOH soluble extractives were determined according to TAPPI T-207 om-88 (TAPPI 1999), ASTM D1107-96 (ASTM 2013), and TAPPI T-212 om-2 (TAPPI 2002b), respectively. Samples were tested with three replications

Functional Group Analysis of Doyo Leaf Fibers

Functional group analysis of *C. latifolia* leaf fiber was carried out using FTIR ABB MB 3000 (Reliable FTIR Laboratory Analyzer, Kanada). Dry samples were prepared and observed using the standard KBr method. The percentage ratio between the use of KBr pellets and the test sample is 10:1. The mixture of KBr pellets and test samples was compressed using a 10-ton pressure FTIR press for 5 seconds. The wavelength used to analyze functional groups is 4000-400 cm^{-1} with 16 scans at a resolution of 4 cm^{-1} and a data interval of 1 cm^{-1}.

Crystallinity Index Analysis of *C. latifolia* Leaf Fibers

Crystallinity index analysis was carried out using a Shimadzu XRD-7000 MaximaX (Japan). Nickel-filtered CuKα radiation (wavelength, 0.154 nm) was used at 40 kV and 30 mA. Diffraction intensity profiles were collected in the range 2θ = 10–40°.

The crystallinity index is calculated using the Segal formula (Segal et al., 1959):

$$CI = \frac{I_{200} - I_{am}}{I_{200}} \, x \, 100$$

Where:

I_{200} = maximum peak intensity at 2θ

I_{am} = minimum intensity between the (200) and (100) planes.

C. RESULTS AND DISCUSSION

Source of *C. latifolia* Leaf Fiber

The fiber is sourced from the leaves of the *C. latifolia* plant. *C. latifolia* leaf fibers can be found growing in sandy podzolic. *C. latifolia* leaf fiber is used as a weaving material from East Kalimantan (Nur et al., 2021). However, in West Kalimantan, this plant has not been utilized. Figure 1 shows the plants used as raw materials in this research.

The chemical component of *C. latifolia* leaf fibers

The dissolved extractive levels of cold water, hot water, ethanol benzene, and 1% NaOH in *C. latifolia* fiber were 12.5%, 16.16%, 9.39%, and 35.83%, respectively. The extractive content of *C. latifolia* leaf fiber is greater when compared to several other lignocellulosic materials such as balsa fruit fiber, bamboo, and nyatoh wood (Table 1). The chemical components contained in fibers from leaves contain many extractives when compared to other sources, such as fibers for balsa fruits fiber, kapok fruits fiber, nyatoh wood, andong, and betung bamboo. This is caused by the physiological function of leaves, as a medium for plant photosynthesis so that they are dominated by extractive content. The dominant extractive content is water solvent extractive.

Figure 1. Source of *C. latifolia* leaf fiber

The holocellulose content of *C. latifolia* leaf fiber is 60.47%. The holocellulose content of *C. latifolia* leaf fiber is lower compared to other lignocellulosic materials (Table 1). However, the percentage of a-cellulose content is high compared to balsa, kapok fruit fibers (Purnawati et al., 2018), and bamboo (Maulana et al., 2018).

Table 1. Chemical components of *C. latifolia* leaf fiber

Chemical component (%)	*C. latifolia* leaf fibers	Balsa (1)	Kapok (1)	Nyatoh (2)	Andong (3)	Betung (3)
Moisture content	10.41	11.23	11.45	10.2	-	-
Solubility						
a. Cold water	12.5	2.7	3.21	2.08	8.11	7.75
b. Hot water	16.16	4.42	6.04	1.31	7.47	9.87
c. Ethanol Benzene	9.39	-	-	5.32	7.41	4.82
d. NaOH 1%	35.83	30.2	26.02	13.21	21.71	23.84
Holocellulose	60.47	83.73	81.97	77.57	69.41	75.22
α-cellulose	53.5	38.09	44.62	58.15	31.83	45.24
Klason Lignin	19.65	14.1	16.6	32.75	28.07	29.08

Notes: (-) : not included , (1) (Purnawati et al., 2018), (2) (Augustina et al., 2021), (3) (Maulana et al., 2020)

The differences in chemical components possessed by leaf fibers will determine the use of isolation methods for nanocellulose. This will affect the yield. The high alpha cellulose content will be an advantage as a raw material for nanocellulose, especially to produce crystalline nanocellulose (Marwanto et al., 2021a). Fibers that have a high hemicellulose content also have advantages if these fibers are used as raw material for nanocellulose fibrils. The presence of hemicellulose in the fiber fibrillation process into nanocellulose fibrils will facilitate the fibrillation process (Arola et al., 2013; Chaker et al., 2013).

Functional Group Analysis of *C. latifolia* Leaf Fiber

Analysis of functional groups of *C. latifolia* leaf fiber using FTIR. The FTIR wave numbers of lignin observed at 2942, 1737, 1596, 1252, and 1050 cm^{-1} (Figure 2). Based on this, the peak lignin contained in *C. latifolia* leaf fiber is shown in Table 2. This result is also supported by the chemical component analysis in Table 1. Wave numbers as markers for hemicellulose and cellulose components were also observed at 2849, 1369, 1318, and 1155 cm^{-1}. Detailed data is shown in Table 2.

The Crystallinity Index of *C. latifolia* Leaf Fibers

The XRD results show that there were three peaks at 16°, 22°, and 35° correlating to the (110), (200), and (004) crystal planes of the Iβ cellulose structure (Seta et al., 2020). This shows that *C. latifolia* fiber was included in Cellulose I (Figure 3). *C. latifolia* fiber had a degree of crystallinity of 69.77%, higher than balsa and kapok fruit fibers. The high degree of crystallinity of biomass depends on the cellulose content. This was also supported by the chemical component in Table 1 as well as the FTIR analysis of *C. latifolia* fiber.

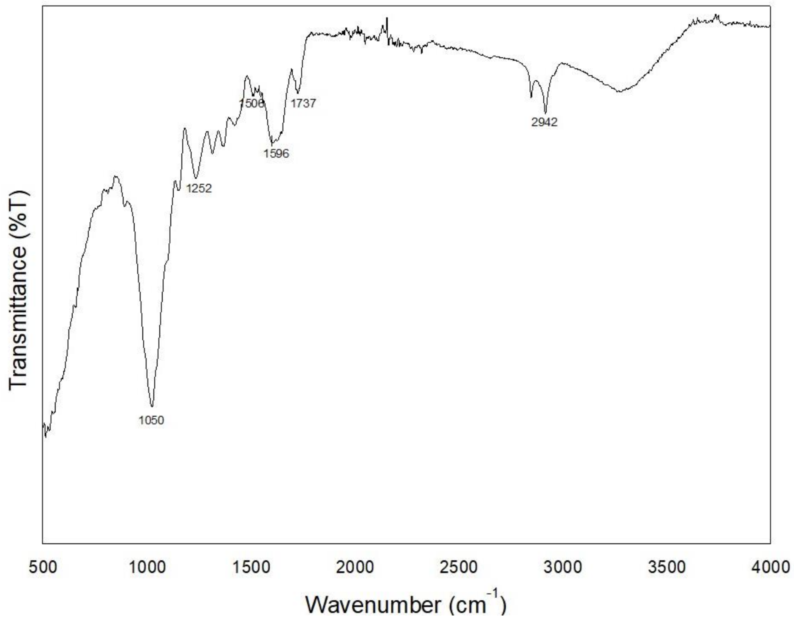

Figure 2. Wavenumber of *C. latifolia* leaf fibers

Table 1. Wavenumber intensity of *C. latifolia* leaf fiber

Peak positions (Wavenumber (cm^{-1})	Transmittance (%T)	Allocations
3334	98.79	OH Stretching
2942	98.39	C-H stretch methyl and methylene groups
2849	98.64	CH symmetric in cellulosic
1737	98.73	C=O stretch, unconjugated ketone, carboxyl, and ester groups
1596	97.95	Aryl ring stretching, symmetric
1421	98.24	Aryl ring stretching, asymmetric
1369	97.92	-C-H deformation in cellulose and hemicellulose
1318	97.80	-CH2 vibration in crystalline cellulose
1252	97.43	Aryl ring breathing with C=O stretch
1155	97.25	-C-O-C asymmetric stretching in cellulose and hemicellulose
1050	94.03	Aromatic C-H in plane deformation

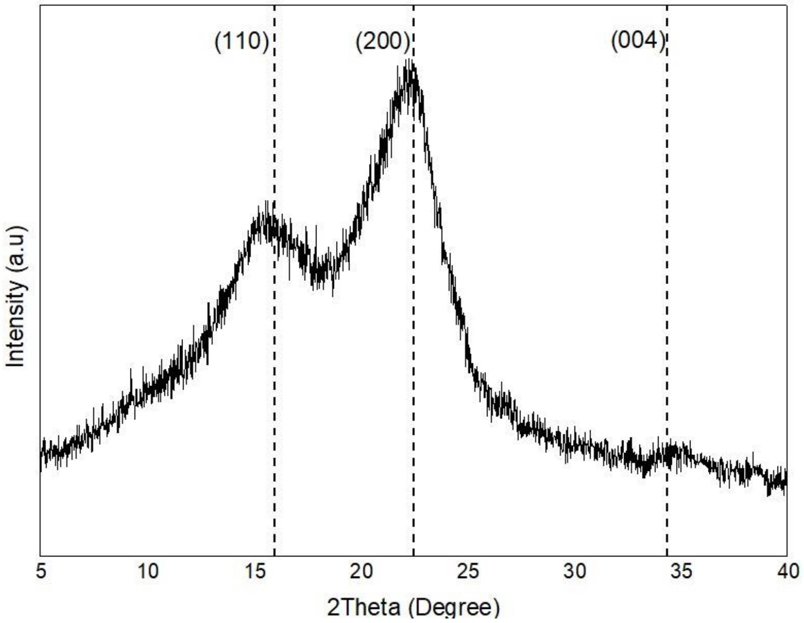

Figure 3 Crystallinity index of *C. latifolia* leaf fibers

D. CONCLUSION

C. latifolia leaf fiber has a high extractive content in water-soluble extractives compared to ethanol benzene soluble extractives. XRD results show that *C. latifolia* fiber has a crystallinity index of 69.77%, and a high alpha-cellulose content of 53.5%. This factor can support *C. latifolia* fiber as a raw material for nanocellulose. The process of removing extractives using a water solvent will also make it easier in the pretreatment process before the delignification process.

ACKNOWLEDGEMEN

The authors acknowledge the Faculty of Forestry Tanjungpura University funding this research with number reference PNBP (DIPA) 023.17.2.677517/2023 with No. SPK Research: 2259/UN22.7/PT.01.03/2023.

REFERENCES

Arola, S., Malho, J. M., Laaksonen, P., Lille, M., & Linder, M. B. (2013). The role of hemicellulose in nanofibrillated cellulose networks. *Soft Matter*, *9*(4), 1319–1326. https://doi.org/10.1039/c2sm26932e

Augustina, S., Wahyudi, I., Darmawan, I. W., Malik, J., Kojima, Y., Okada, T., & Okano, N. (2021). Pengaruh Karakteristik Kimia terhadap Sifat Mekanis dan Keawetan Alami Tiga Jenis Kayu Kurang Digunakan (Effect of Chemical Characteristics on Mechanical and Natural Durability Properties of Three Lesser-Used Wood Species). *Jurnal Sylva Lestari*, *9*(1), 161. https://doi.org/10.23960/jsl19161-178

Brata, A., Tavita, G. E., & Oramahi, H. A. (2022). Etnobotani Bahan Kerajinan Anyaman Dari Hasil Hutan Bukan Kayu Oleh Masyarakat Desa Mekar Raya Kecamatan Simpang Dua Kabupaten Ketapang. *Jurnal Hutan Lestari*, *10*(1), 206. https://doi.org/10.26418/jhl.v10i1.53511

Browning, B. . (1967). *Methods of wood chemistry* (I). Wiley & Sons, Interscience Publishers.

Chaker, A., Alila, S., Mutjé, P., Vilar, M. R., & Boufi, S. (2013). Key role of the hemicellulose content and the cell morphology on the nanofibrillation effectiveness of cellulose pulps. *Cellulose*, *20*(6), 2863–2875. https://doi.org/10.1007/s10570-013-0036-y

Elanthikkal, S., Francis, T., & Akhtar, S. (2021). Utilization of Areca Nut Leaf Sheath Fibers for the Extraction of Cellulose Whiskers. *Journal of Natural Fibers*, *18*(9), 1261–1273. https://doi.org/10.1080/15440478.2019.1689885

Farzinebrahimi, R., Mat Taha, R., Rashid, K. A., Ali Ahmed, B., Danaee, M., & Rozali, S. E. (2016). Preliminary Screening of Antioxidant and Antibacterial Activities and Establishment of an Efficient Callus Induction in Curculigo latifolia Dryand (Lemba). *Evidence-Based Complementary and Alternative Medicine*, *2016*. https://doi.org/10.1155/2016/6429652

Fitriani, F., Aprilia, S., Arahman, N., Bilad, M. R., Amin, A., Huda, N., & Roslan, J. (2021). Isolation and Characterization of Nanocrystalline Cellulose Isolated from Pineapple Crown Leaf Fiber Agricultural Wastes Using Acid Hydrolysis. *Polymers*, *13*(23), 4188. https://doi.org/10.3390/polym13234188

Gnanasekaran, S., Ahamad Nordin, N. I. A., Jamari, S. S., & Shariffuddin, J. H. (2022). Isolation and characterisation of nanofibrillated cellulose from N36 Ananas comosus leaves via ball milling with green solvent. *Industrial Crops and Products*, *178*, 114660. https://doi.org/10.1016/j.indcrop.2022.114660

Hartono, R., Iswanto, A. H., Priadi, T., Herawati, E., Farizky, F., Sutiawan, J., & Sumardi, I. (2022). Physical, Chemical, and Mechanical Properties of Six Bamboo from Sumatera Island Indonesia and Its Potential Applications for Composite Materials. *Polymers*, *14*(22). https://doi.org/10.3390/polym14224868

Hussin, F. N. N. M., Attan, N., & Wahab, R. A. (2020). Extraction and Characterization of Nanocellulose from Raw Oil Palm Leaves (Elaeis guineensis). *Arabian Journal for Science and Engineering*, *45*(1), 175–186. https://doi.org/10.1007/s13369-019-04131-y

Kathirselvam, M., Kumaravel, A., Arthanarieswaran, V. P., & Saravanakumar, S. S. (2019). Isolation and characterization of cellulose fibers from Thespesia populnea barks: A study on physicochemical and structural properties. *International Journal of Biological Macromolecules*, *129*, 396–406. https://doi.org/10.1016/j.ijbiomac.2019.02.044

Lee, H. V., Hamid, S. B. A., & Zain, S. K. (2014). Conversion of Lignocellulosic Biomass to Nanocellulose: Structure and Chemical Process. *The Scientific World Journal*, *2014*, 1–20. https://doi.org/10.1155/2014/631013

Li, Y., & Li, Q. (2022). Plant Fiber Reinforced Composites. In *Advanced Materials Research*. Springer Nature Singapore. https://doi.org/10.1007/978-981-19-5162-6

Madhushani, W. H., Priyadarshana, R. W. I. B., Ranawana, S. R. W. M. C. J. K., Senarathna, K. G. C., & Kaliyadasa, P. E. (2022). Determining the Crystallinity Index of Cellulose in Chemically and Mechanically Extracted Banana Fiber for the Synthesis of Nanocellulose. *Journal of Natural Fibers*, *19*(14), 7973–7981. https://doi.org/10.1080/15440478.2021.1958428

Marwanto, M., Maulana, M. I., Febrianto, F., Wistara, N. J., Nikmatin, S., Masruchin, N., Zaini, L. H., Lee, S. H., & Kim, N. H. (2021a). Characteristics of nanocellulose crystals from balsa and kapok fibers at different ammonium persulfate concentrations. *Wood Science and Technology*, *55*(5), 1319–1335. https://doi.org/10.1007/s00226-021-01319-0

Marwanto, M., Maulana, M. I., Febrianto, F., Wistara, N. J., Nikmatin, S., Masruchin, N., Zaini, L. H., Lee, S. H., & Kim, N. H. (2021b). Effect of oxidation time on the properties of cellulose nanocrystals prepared from balsa and kapok fibers using ammonium persulfate. *Polymers*, *13*(11). https://doi.org/10.3390/polym13111894

Maulana, M. I., Arif, A. K., Nawawi, D. S., Wistara, N. J., Febrianto, F., & Nikmatin, S. (2018). Change of chemical components content in andong and yellow bamboo due to various steam treatment. *IOP Conference Series: Earth and Environmental Science*, *209*(1). https://doi.org/10.1088/1755-1315/209/1/012044

Maulana, M. I., Marwanto, M., Nawawi, D. S., Nikmatin, S., Febrianto, F., & Kim, N. H. (2020). Chemical components content of seven Indonesian bamboo species. *IOP Conference Series: Materials Science and Engineering*, *935*(1). https://doi.org/10.1088/1757-899X/935/1/012028

Nur, Y., Ishmah, R., Ratnasari, D., & Bunga, I. (2021). Senyawa Metabolit Sekunder dan Aktivitas Antioksidan Ekstrak Metanol Bunga Doyo (Curliglia Latifolia Lend.). *Bivalen:Chemical Studies Journal*, *4*(2), 27–31.

Purnawati, R., Febrianto, F., Wistara, I. N. J., Nikmatin, S., Hidayat, W., Lee, S. H., & Kim, N. H. (2018). Physical and chemical properties of kapok (Ceiba pentandra) and balsa (ochroma pyramidale) fibers. *Journal of the Korean Wood Science and Technology*, *46*(4), 393–401. https://doi.org/10.5658/WOOD.2018.46.4.393

Sasmita, D. F., Diba, F., & Setyawati, D. (2021). Pemanfaatan Hasil Hutan Bukan Kayu Sebagai Kerajinan Anyaman Oleh Masyarakat Di Desa Kuala Dua Kecamatan Kembayan Kabupaten Sanggau. *Jurnal Hutan Lestari*, *9*(1), 1–13. https://doi.org/10.26418/jhl.v9i1.45319

Segal, L., Creely, J. J., Martin, A. E., & Conrad, C. M. (1959). An Empirical Method for Estimating the Degree of Crystallinity of Native Cellulose Using the X-Ray Diffractometer. *Textile Research Journal*, *29*(10), 786–794. https://doi.org/10.1177/004051755902901003

Seta, F. T., An, X., Liu, L., Zhang, H., Yang, J., Zhang, W., Nie, S., Yao, S., Cao, H., Xu, Q., Bu, Y., & Liu, H. (2020). Preparation and characterization of high yield cellulose nanocrystals (CNC) derived from ball mill pretreatment and maleic acid hydrolysis. *Carbohydrate Polymers*, *234*(December 2019), 115942. https://doi.org/10.1016/j.carbpol.2020.115942

Wu, Y., Luo, C., Wang, T., Yang, Y., Sun, Y., Zhang, Y., Cui, L., Song, Z., Chen, X., Cao, X., Li, S., & Cai, G. (2024). Extraction and characterization of nanocellulose from cattail leaves: Morphological, microstructural and thermal properties. *International Journal of Biological Macromolecules*, *255*, 128123. https://doi.org/10.1016/j.ijbiomac.2023.128123