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Palm Sap Innovation as Bacterial Cellulose Material

Wardatul Husna Irham[1*], Sri Wahyuna Saragih[2], Saroha Manurung[1], Christine Gabriela[3], Ariel Ramadani[3], Trisna Anggraeni[1]

[1] Department of Plantation Cultivation, Institut Teknologi Sawit Indonesia, Medan, Indonesia.
[2] Department of Plantation Product Processing Technology, Institut Teknologi Sawit Indonesia, Medan, Indonesia.
[3] Department of Chemical Engineering, Institut Teknologi Sawit Indonesia, Medan, Indonesia.

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Corresponding Author:
Wardatul Husna Irham
wardatulhusnairham@itsi.ac.id

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Abstract: Old palm oil trunk waste produces sap water which is currently being developed only for the production of brown sugar. Palm oil trunk waste sap has great potential as another material. This study conducted the synthesis of bacterial cellulose from palm sap and conducted a characterization test of bacterial cellulose from the palm sap. This study is classified as qualitative research with laboratory research methods. The results of the study showed the success of palm sap as a bacterial cellulose material, with an optimal formation time on the 10th day with a thickness of 2.5 cm and an absorption capacity of 137.5 g/g. The FTIR test results showed specific functional groups of cellulose, namely OH at the peak of 3290 cm^{-1}, aromatic C-C bonds at the peak of 1561 cm^{-1}, CO bending bonds at the peak of 1399 cm^{-1} and H stretching vibrations with CO bonds at the peak of 1072 cm^{-1} and a closed chain was seen at the fingerprint peak. The SEM test showed a branched pellicle morphology that was bound long and strong. Mechanical tests showed an elongation at breaking load of 25.841%. XRD tests showed specific characteristics of pure cellulose at diffraction peaks of 14.20 and 15.40.

Keywords: Bacterial cellulose; Characteristics; Innovation; Material; Palm sap

Introduction

The government issued Minister of Finance Regulation (PMK) Number 62 of 2024 to increase the competitiveness of Indonesian palm oil products in the global market. The replanting process will be carried out on oil palm plants whose productivity has declined (Harsono et al., 2021; Romiyadi et al., 2024). This old oil palm trunk waste is usually only stockpiled to be used as fertilizer or even wasted (Veronika et al., 2019; Selamat et al., 2019). Technological developments have begun to utilize palm trunk waste as furniture material (Agustira et al., 2019). Since 2018, approximately 489,214.56 hectares of oil palm plantations have undergone the replanting process annually. This produces approximately 48.9 million m3 of oil palm trunks per year (Wulandari et al., 2019; Efendi et al., 2017).

In addition to being used as fertilizer and wood material, palm oil waste also has other great potential that is still little utilized, namely the sap produced by the palm oil trunk (Rinaldi et al., 2022). Palm oil trunk waste produces sap water which is currently being developed only for the production of brown sugar. The sap water from palm oil trunk waste has great potential as another material. The sap produced from palm oil trunks is usually used to make brown sugar, even though the sap produced is quite a lot. One palm trunk that is over 15 years old produces 3-15 L of sap per day for 2-3 months. This result depends on the quality of the palm trunk (Widyaningsih et al., 2023). The palm sap produced by the apical meristem (tip of the trunk) contains water (88.4%), protein (0.41%), fat (0.71%), ash content (0.38%), and sugar (10%) and organic acids. The sugar content of palm sap consists of sucrose (27%), glucose (71%), and fructose (2%) (Indraningtyas et al., 2023). Palm sap has a pH of 6.0-6.5, has a fragrant, sweet and colorless odor (Dutta et al., 2019). With its characteristics, this palm sap can be processed into a material for making fermented products and a growing medium for Acetobacter

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xylinum by polymerizing glucose into cellulose which forms a thick pellicle on the surface (nata) (Irham et al., 2023; Muddasar et al., 2022).

The use of hydrogel in agriculture is a potential technology currently in achieving superior agricultural yields. Plant cellulose is commonly used as a hydrogel constituent (Saragih et al., 2025). Bacterial cellulose has a higher level of purity than plant cellulose because bacterial cellulose has an Iα structure compared to plant cellulose which has an Iβ structure. Bacterial cellulose is purer because it does not contain lignin, pectin, and hemicellulose as found in plant cellulose (Irham et al., 2021). In addition to having pure cellulose, bacterial cellulose from palm sap also has biocompatible, biodegradable, porous properties (Santosa et al., 2022; Irham et al., 2020), nano-sized, namely 100-40,000 nm, hydrophilicity, toxicity (Irham et al., 2023), has high tensile strength and is easy to store (Jelita et al., 2024; Gun'ko et al., 2017). With its characteristics, this palm sap-based bacterial cellulose can be used as a superior material in the manufacture of slow-release potassium fertilizer (SRKF) hydrogel (Priya et al., 2024; Nuraini et al., 2020).

Method

The stages of this research can be described in the following diagram.

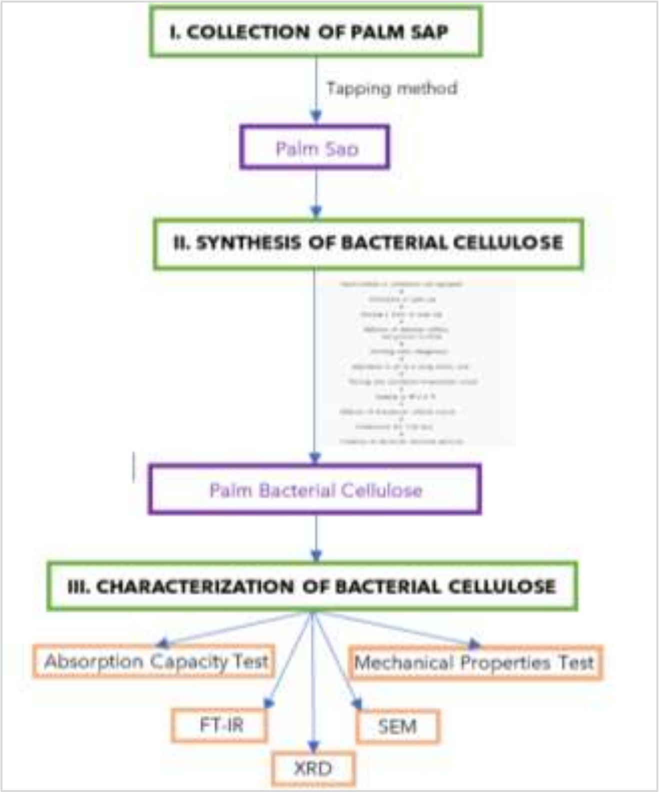

Figure 1. Flow of the research conducted

Collection of Palm Sap

After the palm tree has been felled for 3-7 days, the growing point of the stem (tuber) is cleaned. The shoots are crushed and holes are made for the sap to escape. A collection bucket that has been treated with metabisulphite solution is placed under the buds of the oil palm trunk. Closed to prevent dirt from entering during the sap collection process. The sap obtained is collected for research material.

Synthesis of Bacterial Cellulose

The container used for bacterial cellulose synthesis was sterilized. The palm sap was filtered. 1 liter of palm sap was heated. Add 10 g of ammonium sulfate. Add 20 g of glucose and stir until homogeneous. Add acetic acid to reach a pH of 4. Pour into a sterilized container. Cool to 30 ± 2 °C. Add 200 mL of Acetobacter xylinum starter. Store for 7-13 days. The formed bacterial pellicle/cellulose was rinsed with running water. The bacterial cellulose was soaked in a 1% NaOH solution for 24 hours. Bacterial cellulose can be used for the next stage (Choi et al. 2022; Sulaeva et al., 2020).

Characterization of Bacterial Cellulose

After the cellulose has been successfully synthesized, the next step is to characterize the bacterial cellulose, including absorption capacity testing, morphology testing (SEM), functional group analysis (FTIR), crystallinity testing (XRD), and mechanical testing (tensile testing) (Irham et al., 2025).

Result and Discussion

Collection of Palm Sap

Palm sap was obtained from the oil palm plantation of PT. Havea Indonesia in Dolok Masihul District, Serdang Bedagai Regency, North Sumatra, which is undergoing replanting. The sap collection process was carried out using a tapping method.

After the oil palm trees were felled for 3-7 days, the growing points of the trunks were cleaned to allow the sap to collect in the trunks (Rinaldi et al., 2022). The trunks were tapped and perforated to allow the sap to escape (Widyaningsih et al., 2023). A collection bucket filled with metabisulfite solution was placed under the trunks of the oil palms. This metabisulfite solution was intended to slow the sap fermentation process. It was covered to prevent contamination during the sap collection process. The obtained sap was collected for research. The stages of this research are shown in Figure 2.

Palm sap produced by the apical meristem (tip of the stem) contains water (88.4%), protein (0.41%), fat (0.71%), ash content (0.38%), and sugar (10%) and organic acids. The sugar content of palm sap consists of sucrose (27%), glucose (71%), and fructose (2%) [9]. Palm sap has a pH of 6.0-6.5, has a fragrant, sweet and colorless odor [10]. With its characteristics, this palm sap can be processed into a material for making fermented products and a growing medium for Acetobacter xylinum by polymerizing glucose into cellulose which forms a thick pellicle on the surface (nata) (Irham et al., 2023).


(a) (b)

Figure 2. Collection of palm sap (a) freshly harvested from oil palm plants, (b) sap ready for use

Synthesis of Bacterial Cellulose

Synthesizing bacterial cellulose from palm sap, all containers used were first sterilized. This is because cellulose can grow in sterile containers, and conversely, bacterial cellulose cannot grow in non-sterile containers (Zhu et al., 2021; Li et al., 2021). Researchers carried out the sterilization process in two ways: for glass containers, the sterilization process was carried out in an autoclave (figure 3.a), while plastic tray containers were sterilized by heating them over a flame (figure 3.b)


(a) (b)

Figure 3. Container Sterilization Process (a) glass jar container, (b) plastic tray container

The sap collected from the palm trunk is immediately used for bacterial cellulose synthesis within 12 hours, before the palm sap ferments. The resulting palm sap is filtered through a cloth filter to remove any coarse impurities that may have accumulated in the collected sap.

Heat 1 liter of palm sap, add 10 g of ammonium sulfate, 20 g of glucose, and acetic acid to a pH of 4, then stir until homogeneous. Pour into a sterilized container, cool to 30±2°C, add 200 mL of Acetobacter xylinum starter, and store for 7-13 days.

Figure 4. Palm bacterial cellulose synthesis process

The resulting bacterial pellicle/cellulose is rinsed with running water, then soaked in a 1% NaOH solution for 24 hours. The bacterial cellulose can then be used in the next step.

Figure 5. Rinsing of palm bacterial cellulose

In the process of bacterial Cellulose synthesis, Uridine diphosphate glucose (UDP-Glc) acts as a precursor to convert glucose into glucose-6-phosphate (Glc-6-P), and then converts glucose-6-phosphate into glucose-1-phosphate (Glc-1-P) catalyzed by the enzyme cellulose synthase (Vermette et al., 2023; Gorgieva et al., 2022). Next, each β-1-4 glucose molecule rotates 180 degrees to the adjacent molecule, producing intermolecular hydrogen bonds, and polymerizes into a single linear β-1,4-glucan chain inside the bacterial body (Kiflay et al., 2023; Ulfa et al., 2023). The glucan chain is extruded out of the bacterial cytoplasmic membrane through a series of macropores along the cell axis on the surface of the bacterial body. The glucan chain gathers together outside the cell envelope, first gathering into nanofibers with a width within a certain measuring range, then small nanofibers into long nanofibers (Wu et al., 2024).

The surface of the film was found to consist of many intertwined strings that produce a network-like structure formed from overlapping fine fibrils forming layers of randomly oriented cellulose ribbons. Ultrafine ribbons of microbial cellulose, ranging in length from 1 to 9 μm, form a dense reticulated structure, stabilized by extensive hydrogen bonding. The degree of polymerization of bacterial cellulose ranges from 2000 to 6000 and can even reach 20000 while the degree of polymerization of plant cellulose ranges from 13000 to 14000 (Ginting et al., 2023; Aswini et al., 2020). Nata that was formed and had been washed with NaOH and running water, was referred to as bacterial cellulose (sample BC) (Galdino et al., 2020; Guzel et al., 2019).

Characterization of Bacterial Cellulose

Absorption Capacity Test

The absorption capacity test was conducted by weighing the dried bacterial cellulose and recording its mass. The cellulose was then soaked in distilled water for 24 hours. The bacterial cellulose was then weighed again and its mass recorded.

Table 1. Results of Bacterial Cellulose Absorption Capacity Test

Sample	Wt (g)	Wo (g)	Absorbs (g/g) $\left(\frac{Wt-Wo}{Wo}\right)$
A	18	0.13	137.5
B	17.88	0.14	126.7
C	17.5	0.13	133.62
Mean			133.606

The water absorption capacity of bacterial cellulose is related to its crystallinity and amorphous index. The higher the crystallinity index, the fewer water molecules can physically interact with it. Conversely, the lower the amorphous index, the fewer water molecules can physically interact with it (Campano et al., 2025). To verify the crystallinity and amorphous index, the next step is to conduct X-ray diffraction (XRD) tests on the samples.

Morphology Test

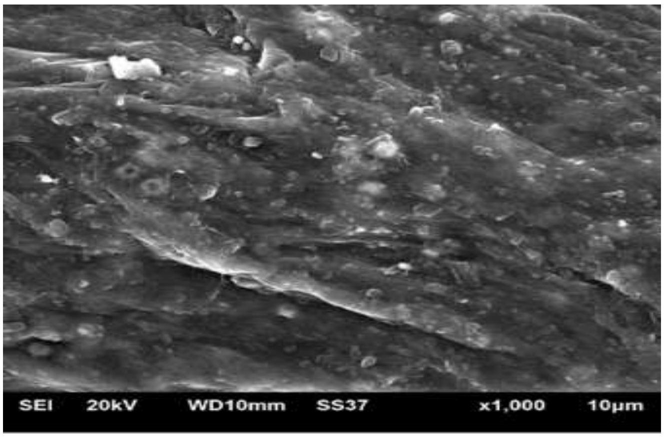

Figure 6. Morphology test of palm bacterial cellulose

Bacterial cellulose pellicles form a network of long, branched fibers that are tightly bound to each other, proving that the bacterial cellulose in this sample contains pure cellulose (Campano et al., 2025). Bacterial cellulose (BC) has pores with a pore diameter that is very useful for controlling chemicals, especially the process of absorbing bioactive substances in the desorption process (Irham et al., 2021).

Functional Group Analysis (FTIR)

FTIR spectra analysis of Bacterial Cellulose (BC sample), can be seen functional groups that are characteristic of the presence of bacterial cellulose, namely the peak at 3290.13 cm^{-1} indicates the hydrogen bond OH. The peak at 1561.05 cm^{-1} indicates the presence of aromatic C-C bonds, the peak at 1398.68 cm-1 indicates the bond C-O bending, and the peak at 1072.28 cm^{-1} indicates the stretching vibration of H with the bond C-O (Irham et al., 2020). In the FTIR test of this bacterial cellulose, an absorption peak is seen in the fingerprint region which indicates that this compound is cellulose that has a closed chain.

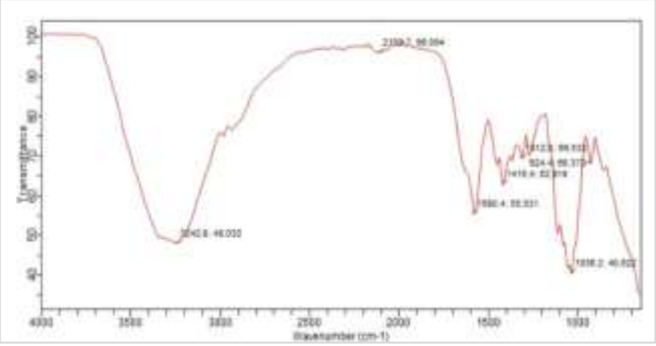

Figure 7. Functional group analysis of palm bacterial cellulose

Crystallinity test

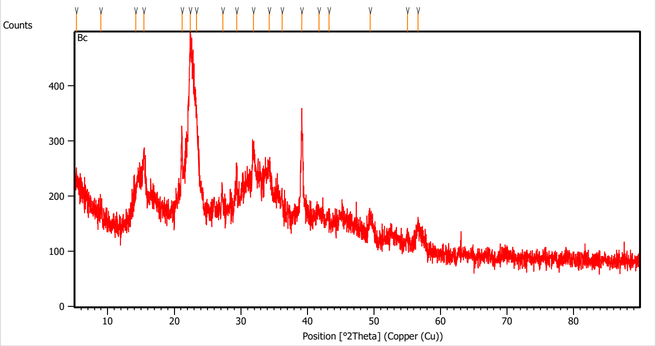

Figure 8. Crystallinity test

The XRD pattern of bacterial cellulose showed a characteristic peak at 2θ around 22°, which corresponds to the (200) crystal plane of the cellulose type I structure. This peak indicates the presence of a crystalline phase in the sample. However, peak broadening and a relatively high background intensity were still observed, suggesting the existence of amorphous regions within the bacterial cellulose structure. The coexistence of crystalline and amorphous phases is commonly found in biosynthesized bacterial cellulose and is influenced by the purification process as well as subsequent material treatments (Irham et al., 2025).

The cellulose structure indicated by the diffraction peaks in the range of 220 and 230 is characteristic of native cellulose (cellulose 1) (Saragih et al., 2025). Therefore, it can be concluded that the cellulose produced in this study is native cellulose, or cellulose 1.

Table 2. Interpretation of X-Ray Diffraction (XRD) Data for Cellulose Materials

2θ (°)	Crystal Field	Interpretation	Information
~14–16	$(\bar{1}10)/(110)$	Cellulose structure I	Typical peak of cellulose I
~22–23	-200	Main crystalline phase	BC dominant peak
~34	-4	Ordering Crystal	Low intensity
Broad hump	Amorf	Irregular area	Shows amorphous structure

Mechanical Test

The mechanical test results on the bacterial cellulose samples are shown in Figure 9 and Table 3, which are load-elongation graphs. The graphs show a 25.9% decrease in elongation at break for the Bacterial Cellulose sample (sample PBC). The high tensile strength of bacterial cellulose is a result of intramolecular and intermolecular hydrogen bonding.

Table 3. Mechanical Test of Palm Bacterial Cellulose

	Load kgf		Max point	Elongation at Break	Young's Mpa
	Max avarage	Break ponit avarage	Stress MPa	%	
PBC	6.8	2.75	11.3	25.9	43

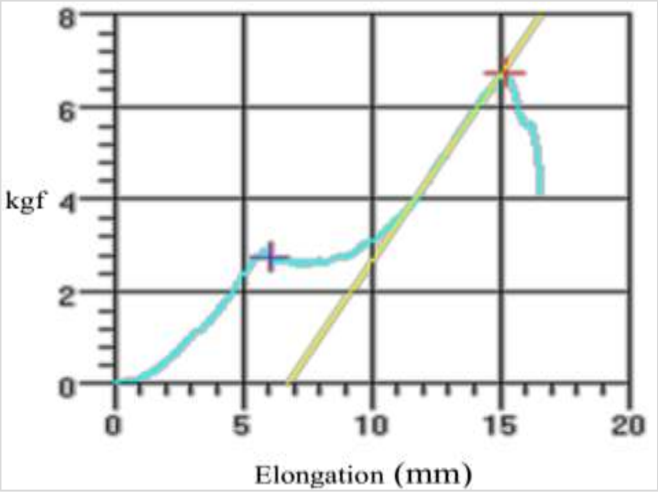

Figure 9. Mechanical test of palm bacterial cellulose

Conclusion

Palm sap was successfully used as a substrate material in synthesizing bacterial cellulose. Bacterial cellulose obtained from palm sap has good characteristics, namely having a thickness of 1-2.5 cm, with an average absorption capacity of 133.6 g / g. The results of the FTIR test proved that this bacterial cellulose has specific cellulose functional groups, namely OH, aromatic C-C bonds, CO bending bonds, H stretching vibrations with CO bonds and closed chains are visible at the fingerprint peak. The SEM test showed a branched pellicle morphology with long and strong bonds. The mechanical test showed an elongation of the breaking load at 25.9%. The XRD test showed Semi-crystalline structure, medium–high crystallinity, dominated by cellulose I, still contains a natural amorphous phase resulting from biosynthesis.

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Author Contributions

Conceptualization, Wardatul Husna Irham; methodology, Sri Wahyuna Saragih; software, Saroha Manurung; validation, Wardatul Husna Irham and Sri Wahyuna Saragih; formal analysis, Wardatul Husna Irham; investigation, Saroha Manurung; resources, Wardatul Husna Irham; data curation, Sri Wahyuna Saragih; writing—original draft preparation, Christine Gabriela; writing—review and editing, Ariel Ramadani; visualization, Saroha Manurung; supervision, Wardatul Husna Irham; project administration, Trisna Anggraeni. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

References

Agustira, M. A., Siahaan, D., & Hasibuan, H. A. (2019). Nilai Ekonomi Nira Sawit Sebagai Potensi Pembiayaan Peremajaan Kebun Kelapa Sawit Rakyat. *Jurnal Penelitian Kelapa Sawit*, *27*(2), 115–126. https://doi.org/10.22302/iopri.jur.jpks.v27i2.62

Aswini, K., Gopal, N. O., & Uthandi, S. (2020). Optimized culture conditions for bacterial cellulose production by Acetobacter senegalensis MA1. *BMC Biotechnology*, *20*(1), 46. https://doi.org/10.1186/s12896-020-00639-6

Campano, C., Rivero-Buceta, V., Hernandez-Arriaga, A. M., Manoli, M. T., & Prieto, M. A. (2025). Pushing the limits of bacterial cellulose for biomedicine: a review. *International Journal of Biological Macromolecules*, *323*, 146701. https://doi.org/10.1016/j.ijbiomac.2025.146701

Choi, S. M., Rao, K. M., Zo, S. M., Shin, E. J., & Han, S. S. (2022). Bacterial Cellulose and Its Applications. *Polymers*, *14*(6), 1080. https://doi.org/10.3390/polym14061080

Dutta, S. D., Patel, D. K., & Lim, K. T. (2019). Functional cellulose-based hydrogels as extracellular matrices for tissue engineering. *Journal of Biological Engineering*, *13*(1), 55. https://doi.org/10.1186/s13036-019-0177-0

Efendi, F., Pujiharto, & Dumasari. (2017). Analisis Produksi Dan Pemasaran Gula Merah Di Desa Kubangkangkung, Kabupaten Cilacap (Studi Kasus Pada Penderes Gula Merah Di Desa Kubangkangkung, Kecamatan Kawunganten, Kabupaten Cilacap). *Agritech*, *XIX*(2), 110–120. Retrieved from https://www.neliti.com/publications/360136/analisis-produksi-dan-pemasaran-gula-merah-di-desa-kubangkangkung-kabupaten-cila

Galdino, C. J. S., Maia, A. D., Meira, H. M., Souza, T. C., Amorim, J. D. P., Almeida, F. C. G., Costa, A. F. S., & Sarubbo, L. A. (2020). Use of a bacterial cellulose filter for the removal of oil from wastewater. *Process Biochemistry*, *91*, 288–296. https://doi.org/10.1016/j.procbio.2019.12.020

Ginting, D., Na Duma, T., Rahmadani, N., Suryani, Y., & Haryanti, R. (2023). Potential of Cellulose Acetat Separator of Empty Palm Oil Fruit Bunches and Polyvinylidene Fluoride for Energy Storage Applications. *POSITRON*, *13*(1), 51. https://doi.org/10.26418/positron.v13i1.63784

Girard, V., Chaussé, J., & Vermette, P. (2024). Bacterial cellulose: A comprehensive review. *Journal of Applied Polymer Science*, *141*(15). https://doi.org/10.1002/app.55163

Gorgieva, S., Jančič, U., Cepec, E., & Trček, J. (2023). Production efficiency and properties of bacterial cellulose membranes in a novel grape pomace hydrolysate by Komagataeibacter melomenusus AV436T and Komagataeibacter xylinus LMG 1518. *International Journal of Biological Macromolecules*, *244*, 125368. https://doi.org/10.1016/j.ijbiomac.2023.125368

Gun'ko, V., Savina, I., & Mikhalovsky, S. (2017). Properties of Water Bound in Hydrogels. *Gels*, *3*(4), 37. https://doi.org/10.3390/gels3040037

Güzel, M., & Akpınar, Ö. (2019). Production and Characterization of Bacterial Cellulose from Citrus Peels. *Waste and Biomass Valorization*, *10*(8), 2165–2175. https://doi.org/10.1007/s12649-018-0241-x

Harsono, D., Ihsan, H., Miyono, M., & ... (2021). Sifat fisik dan mekanik balok lamina dari batang kelapa sawit berdasarkan jumlah lapisan. *Jurnal Riset Industri*, *13*(1), 51–64. Retrieved from http://bpkimi1.kemenperin.go.id/jrihh/article/view/6157/0

Hasanin, M. S., Abdelraof, M., Hashem, A. H., & El Saied, H. (2023). Sustainable bacterial cellulose production by Achromobacter using mango peel waste. *Microbial Cell Factories*, *22*(1), 24. https://doi.org/10.1186/s12934-023-02031-3

Hu, J., Wang, L., Xiao, M., Chen, W., Zhou, M., Hu, Y., Zhang, Y., Lai, M., He, A., & Zhao, M. (2025). Insights into bacterial cellulose for adsorption and sustained-release mechanism of flavors. *Food Chemistry: X*, *25*. https://doi.org/10.1016/j.fochx.2024.102110

Indraningtyas, L., Yuliandari, P., & Anungputri, P. S. (2023). Karakterisasi Nira Sawit Hasil Penyadapan. *Prosiding SENIATI*, *7*(1), 170–176. https://doi.org/10.36040/seniati.v7i1.7889

Irham, W. H., Marpongahtun, & Dur, S. (2023). Improving mechanical properties of bacterial cellulose with supplemented Curcuma Longa Linn extract for wound healing. *AIP Conference Proceedings*, *2431*, 050001. https://doi.org/10.1063/5.0114810

Irham, W. H., Tamrin, Marpaung, L., & Marpongahtun. (2020). Characterization of bacterial cellulose from coconut water supplemented Curcuma Longa Linn and Ziziphus Mauritiana extract. *AIP Conference Proceedings*, *2431*, 020056. https://doi.org/10.1063/5.0023953

Irham, W. H., Tamrin, Marpaung, L., & Marpongahtun. (2020). Characterization of bacterial cellulose from coconut water supplemented Curcuma Longa Linn and Ziziphus Mauritiana extract. *AIP Conference Proceedings*, *2267*, 020056. https://doi.org/10.1063/5.0023953

Irham, W. H., Tamrin, Marpaung, L., & Marpongahtun. (2021). Morphology of bacterial cellulose-Curcuma longa Linn from acetobacter xylinum for wound healing. *AIP Conference Proceedings*, *2342*, 060002. https://doi.org/10.1063/5.0045493

Irham, W. H., Tamrin, Marpaung, L., & Marpongahtun. (2021). Preparation and characterization of bacterial cellulose supplemented centella asiatica l. Urban extract to improve mechanical properties. *Rasayan Journal of Chemistry*, *14*(01), 09–15. https://doi.org/10.31788/RJC.2021.1415810

Irham, W. H., Yusra, S., Gunawan, H., Isra, M., & Dur, S. (2025). Silver Nanoparticle Impregnated Bacterial Cellulose from Oil Palm Frond Juice and Their Antimicrobial Properties. *Jurnal Penelitian Pendidikan IPA*, *11*(12), 81–85. https://doi.org/10.29303/jppipa.v11i12.13390

Irwan, P. (2024). Pemanfatan limbah batang kelapa sawit menjadi bahan baku papan blockboard. *Jurnal Teknik*, *18*(2), 37–45. https://doi.org/10.31849/teknik.v17i1

Jelita, J., Saragih, S. W., & Irham, W. H. (2024). BC-g-PAA: Characterization and Establishment of the IPN Hydrogel. *Jurnal Penelitian Pendidikan IPA*, *10*(5), 2537–2544. https://doi.org/10.29303/jppipa.v10i5.7007

Li, W., Wang, S., Fan, Z., Li, S., Bernussi, A., & Newman, N. (2021). Functionalized bacterial cellulose as a separator to address polysulfides shuttling in lithium–sulfur batteries. *Materials Today Energy*, *21*, 100813. https://doi.org/10.1016/j.mtener.2021.100813

Muddasar, M., Beaucamp, A., Culebras, M., & Collins, M. N. (2022). Cellulose: Characteristics and applications for rechargeable batteries. *International Journal of Biological Macromolecules*, *219*, 788–803. https://doi.org/10.1016/j.ijbiomac.2022.08.026

Nurani, K. C., Budiyanto, S., & Purbajanti, E. D. (2020). Dosis dan Waktu Aplikasi Boron Terhadap Pertumbuhan dan Hasil Kacang Hijau. *Agrosains : Jurnal Penelitian Agronomi*, *22*(2), 64. https://doi.org/10.20961/agsjpa.v22i2.42058

Priya, E., Jha, A., Sarkar, S., & Maji, P. K. (2024). A urea-loaded hydrogel comprising of cellulose nanofibers and carboxymethyl cellulose: An effective slow-release fertilizer. *Journal of Cleaner Production*, *434*(140215), 140215. https://doi.org/10.1016/j.jclepro.2023.140215

Rinaldi, W., Raja, P. M., Syukri, M., Maharani, R., & Rangkuti, I. U. P. (2022). Optimasi Nira Sawit Dalam Pembuatan Minuman Sinbiotik Dengan Tambahan Inulin Dan Kultur Bakteri Lactobacillus Casei. *Jurnal Agro Fabrica*, *4*(1), 20–28. https://doi.org/10.47199/jaf.v4i1.178

Santosa, B., Tantalu, L., & Sairo, N. W. (2022). Sintesis selulosa bakteri dari jerami kulit nangka dengan penambahan beberapa konsentrasi sukrosa. *AGROMIX*, *13*(1), 67–73. https://doi.org/10.35891/agx.v13i1.2881

Saragih, S. W., Irham, W. H., Yosephine, I. O., Ferza, M., Yulia, B., & Fadhilah, A. (2025). Characteristics of Chitosan from Black Soldier Fly Pupa Shells as a Crosslinking Agent in the Manufacture of Slow-Release Fertilizer Hydrogels. *Jurnal Penelitian Pendidikan IPA*, *11*(1), 558–566. https://doi.org/10.29303/jppipa.v11i1.9692

Selamat, M. E., Hashim, R., Sulaiman, O., Kassim, M. H. M., Saharudin, N. I., & Taiwo, O. F. A. (2019). Comparative study of oil palm trunk and rice husk as fillers in gypsum composite for building material. *Construction and Building Materials*, *197*, 526–532. https://doi.org/10.1016/j.conbuildmat.2018.11.003

Singh, O., S. Panesar, P., & K. Chopra, H. (2017). Isolation and Characterization of Cellulose Producing Bacterial Isolate from Rotten Grapes. *Biosciences, Biotechnology Research Asia*, *14*(1), 373–380. https://doi.org/10.13005/bbra/2455

Sulaeva, I., Hettegger, H., Bergen, A., Rohrer, C., Kostic, M., Konnerth, J., Rosenau, T., & Potthast, A. (2020). Fabrication of bacterial cellulose-based wound dressings with improved performance by impregnation with alginate. *Materials Science and Engineering: C*, *110*, 110619. https://doi.org/10.1016/j.msec.2019.110619

Ulfa, M., Noviani, I., Yuanita, E., Dharmayani, N. K. T., Sudirman, & Sarkono. (2023). Synthesis and Characterization of Composites-Based Bacterial Cellulose by Ex-Situ Method as Separator Battery. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 4647–4651. https://doi.org/10.29303/jppipa.v9i6.3819

Veronika, N., Dhora, A., & Wahyuni, S. (2019). Pengolahan Limbah Batang Sawit Menjadi Pupuk Kompos Dengan Menggunakan Dekomposer Mikroorganisme Lokal (Mol) Bonggol Pisang. *Jurnal Teknologi Industri Pertanian*, *29*(2), 154–161. https://doi.org/10.24961/j.tek.ind.pert.2019.29.2.154

Widyaningsih, F., Irwanto, R., & Br Panjaitan, D. (2023). Karakteristik Nira Kelapa Sawit (Elaeis Guineensis Jacq) Hasil Pengolahan Limbah Berbasis Zero Waste. *Jurnal Kesmas Dan Gizi (Jkg)*, *5*(2), 195–202. Retrieved from https://ejournal.medistra.ac.id/index.php/JKG/article/download/1403/741

Wulandari, A., & Erwinsyah, E. (2020). Distribution of Vascular Bundles and Physical Properties Analysis of Variety DxP Oil Palm Trunk Based on Various Zones and Trunk Heights. *Jurnal Penelitian Kelapa Sawit*, *28*(1), 1–14.

https://doi.org/10.22302/iopri.jur.jpks.v28i1.93

Zhu, C., Zhang, J., Qiu, S., Jia, Y., Wang, L., & Wang, H. (2021). Tailoring the pore size of polyphenylene sulfide nonwoven with bacterial cellulose (BC) for heat-resistant and high-wettability separator in lithium-ion battery. *Composites Communications*, *24*, 100659. https://doi.org/10.1016/j.coco.2021.100659