



Research Article

Valorization of Nanocellulose Based Composite Membrane Derived from Sugarcane Bagasse for Medical Applications

Mohammad Nayemul Islam^a, Md. Reajul Islam^{a*}

^aDepartment of Yarn Engineering, Bangladesh University of Textiles, Bangladesh

KEYWORDS

Sugarcane bagasse,
Nanocellulose, Chitosan,
Composite membrane,
Antimicrobial activity.

ABSTRACT

The valorization of sugarcane bagasse into high-value biomedical materials is essential for sustainable development. Although nanocellulose has attracted significant interest in medical applications, the utilization of sugarcane bagasse as a cost-effective source for developing nanocellulose-based composite membranes remains insufficiently explored. This study aimed to extract nanocellulose from sugarcane bagasse via acid hydrolysis method and fabricate chitosan incorporated nanocellulose composite membrane on plain woven cotton fabric for antimicrobial activity. The prepared nanocellulose and composite membrane were characterized using scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) to evaluate morphological and chemical properties. FESEM analysis confirmed the successful extraction of nanocellulose and FTIR results revealed its uniform integration with chitosan within the composite structure. Antimicrobial performance of produced composite membrane was assessed against gram-negative bacteria (*Pseudomonas aeruginosa*) and observed 18mm inhibition zone.

*Corresponding Author Email:
reajul@ye.butex.edu.bd

1. Introduction

Agro-industrial residues, particularly sugarcane bagasse, have gained increasing attention as sustainable feedstocks for value-added material development due to their abundant availability and lignocellulosic richness, enabling diverse applications ranging from construction materials to environmental remediation (1,2). The intrinsic physicochemical characteristics of bagasse, including its fibrous morphology and high cellulose content, make it a promising precursor for advanced material synthesis (3) while its utilization as a renewable cellulosic resource has been widely recognized for multifunctional applications (4). Cellulose, as the primary structural component of such biomass, exhibits a highly ordered crystalline architecture and hierarchical organization, which significantly influence its physicochemical and mechanical behavior (5). The versatility of cellulose and its derivatives has driven extensive research toward biomedical applications due to their biocompatibility, biodegrad-

ability, and tunable surface chemistry (6). Furthermore, nanocellulose, derived from cellulose through controlled processing, demonstrates superior properties such as high surface area, enhanced mechanical strength, and excellent biological performance, including promising in vivo compatibility (7,8).

Among various extraction techniques, acid hydrolysis remains one of the most widely adopted approaches for producing nanocellulose with controlled dimensions and crystallinity, where process parameters such as hydrolysis time, pH, and reagent concentration critically govern particle stability and morphology (9,10). Alternative strategies, including oxidative and mixed-acid treatments, have also been explored to optimize yield and dispersion quality (11) while advances in nanocellulose technology continue to refine production efficiency and structural control (12). In particular, sugarcane bagasse has emerged as an effective and sustainable source for nanocellulose production, with several

studies demonstrating successful extraction and characterization of nanocellulosic materials exhibiting desirable physicochemical properties for advanced applications (13,14). Optimization of pretreatment and processing conditions further enhances the quality and yield of nanocellulose derived from bagasse, reinforcing its industrial feasibility (15) while greener production routes are being actively investigated to improve environmental compatibility (16). Chitosan, a naturally derived polysaccharide, has been extensively studied for its remarkable physicochemical and biological properties, including biodegradability, film-forming ability, and inherent antimicrobial activity (17,18). Its effectiveness in biomedical applications is largely attributed to the presence of cationic amino groups, which facilitate strong interactions with negatively charged microbial cell membranes (19) while ongoing advancements have further improved its mechanical and functional performance (20,21).

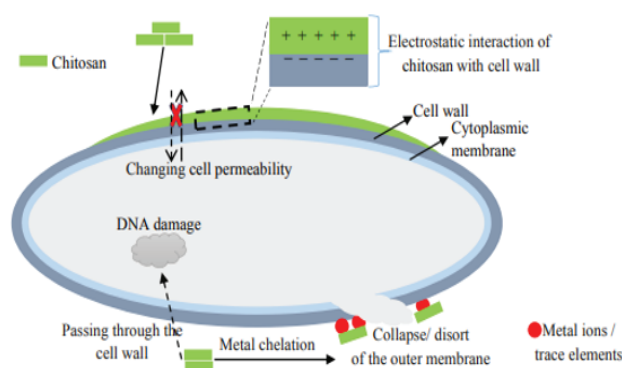


Figure 1 : Schematic representation of chitosan's antimicrobial mechanism involving membrane disruption, metal chelation, and DNA damage (22).

Polyphenol-rich sugarcane extract exhibits significant bioactivity, including modulation of carbohydrate metabolism and antibacterial effects (23). The integration of nanocellulose with chitosan has led to the development of advanced biocomposites with enhanced mechanical, barrier, and antimicrobial properties, owing to synergistic interactions such as hydrogen bonding and electrostatic attraction between the two biopolymers (24,25). These composites have demonstrated significant potential in membrane-based systems and environmental applications, including pollutant removal and adsorption processes (26,27). More importantly, nanocellulose–chitosan composite materials have shown remarkable promise in biomedical applications, particularly in wound dressing systems, where their combined properties contribute to improved antibacterial performance, moisture retention, and structural integrity (28,29). Advanced nanocellulose-based dressings have also been developed with multifunctional capabilities such as real-time monitoring and enhanced healing efficiency (30) while bioactive nanocellulose membranes further contribute to infection prevention and tissue regeneration (31). The growing body of research highlights nanocellulose as a key biomaterial for next-genera-

tion wound care applications due to its adaptability and functional tunability (32).

Previous studies have demonstrated the effective valorization of sugarcane bagasse into nanocellulose and its successful integration with chitosan to develop functional composite materials (33). Bagasse-derived cellulose has also been utilized to fabricate eco-friendly membranes with notable performance in wastewater treatment applications, highlighting its versatility (34). Furthermore, the incorporation of nanocellulose into chitosan matrices has been reported to enhance mechanical properties and impart significant antibacterial activity (35). Moreover, the development of antimicrobial materials from bagasse using chitosan-based modifications further underscores the potential of such biopolymer systems for sustainable and high-performance applications (36).

Despite extensive research on nanocellulose and chitosan-based biomaterials, most studies focus either on nanocellulose extraction or chitosan functionality separately, with limited emphasis on their synergistic combination in a structurally reinforced format. Additionally, although sugarcane bagasse is a promising and sustainable cellulose source, its conversion into uniform, biomedical-grade nanocellulose is not sufficiently optimized. Furthermore, existing nanocellulose–chitosan composites are primarily developed as stand-alone films, lacking the mechanical strength, flexibility, and practicality required for real-world applications, particularly in textile-supported systems. The correlation between nanoscale structural features and functional outcomes such as antimicrobial and hemostatic performance also remains inadequately explored. In this study, develop a sustainable, well-integrated nanocellulose–chitosan composite reinforced with a textile substrate, with systematic evaluation of its structural and biomedical properties for antimicrobial applications.

2. Materials and Method

Sugarcane bagasse was collected from renowned sugar factory of Bangladesh named as “Carew & Co Bangladesh Ltd” located at darshana, chudanga. All the chemicals used in this study are listed in Table 1 A plain-woven bleached fabric with a construction of (20×16)/(110×75) was selected as the reinforcing substrate for membrane fabrication, considering its structural uniformity and mechanical compatibility with the nano-cellulosic matrix. *Pseudomonas aeruginosa* (ATCC 9027) strain was used for the antibacterial study. A commercially available antibiotic disc of Cefepime (CEP 30) was used as a standard reference to compare the antibacterial activity of the developed composite membrane.

Table 1: List of chemicals with their origin.

Name	Brand	Origin
Ethanol	Winnex	Thailand
Toluene	Merck	Germany
Sodium Hydroxide	Merck	Germany
Sodium Carbonate	Merck	Germany
Detergent	Procter & Gamble	USA
Sodium Chlorite	Merck	Germany
Distilled Water	G Lab	Bangladesh
Sulfuric Acid	Merck	Germany
Chitosan	SRL	India
Acetic Acid	Merck	Germany

Firstly, collected sugarcane bagasse were washed repeatedly with water to remove soil and dirt. Then it was dried under sun for 1 week. Dried sugarcane bagasse was chopped into 10 mm cut length and washed repeatedly with distilled water and finally dried in an oven dryer at 70 degree celsius for 10 hours. The dried sugarcane bagasse was mechanically reduced to fine powder using a blender to enhance surface area and facilitate subsequent chemical treatments.

Soxhlet extraction was performed to eliminate waxes and other impurities from the biomass of sugarcane bagasse, ensuring improved accessibility of cellulose fibers. In this study, 60 gm sugarcane bagasse powder were refluxed with 400 ml mixture containing 1:2 ratio of C_2H_5OH (ethanol) and C_7H_8 (toluene) using soxhlet process at 70 degree celsius for 240 minutes. The extracted solid after filtration were aerated in air for 36 hours to evaporate solvent. It was further washed with distilled water to remove remaining organic solvent until pH becomes neutral and then dried in an oven drier at 70 degree celsius for 8 hours. After dewaxing, 50 gm powder was obtained from initially taken 60 gm sugarcane bagasse.

In the scouring process, 50 grams of dewaxed sugarcane bagasse powder were treated with 60 grams of Na_2CO_3 and 10 grams of detergent at 90 degree celsius for 3 hours for 1000 ml mixture. The scoured bagasse powder is washed with distilled water until pH becomes neutral and then dried in an oven drier at 70 degree celsius for 8 hours. 40 gm powder was obtained after scouring.

At the bleaching stage, 40 grams of scoured sugarcane bagasse powder were bleached with 2 grams of sodium carbonate at 90 degree celsius for 2 hours for 1000 ml mixture. pH level was maintained at 4 by adding acetic acid drop by drop. Finally, the bleached bagasse powder is washed with distilled water until pH becomes neutral and then dried in an oven drier at 70 degree celsius for 8 hours. Alpha cellulose is produced after. 30 gm powder was obtained after bleaching.

Rest of the hemicellulose were eliminated by alkali treatment.

In this stage, 30 grams of bleached sugarcane bagasse powder were treated with 50 grams of sodium hydroxide at 40 degree celsius for 2 hours for 1000 ml mixture. The bleached bagasse powder is washed with distilled water until pH becomes neutral and then dried in an oven drier at 70 degree celsius for 12 hours. 22 gm powder was obtained after alkali treatment.

To synthesize nanocellulose, 1gram alpha cellulose was subjected to acid hydrolysis with 60 wt. % H_2SO_4 at $40^\circ C$ for 10 ml solution with continuous stirring provided by a magnetic stirrer on an electric hot plate. The ratio of fiber to liquor was maintained 1:10. After a duration of 30 minutes, the hydrolysis was terminated by introducing ice-cold water into the reaction mixture. The resulting mixture was then allowed to cool down to room temperature and was subjected to centrifugation. The solid fraction was thoroughly washed with distilled water until a neutral pH was achieved. Finally, a Nano-cellulose suspension was created which was filtered and dried to obtain nanocellulose powder which was confirmed by SEM analysis. One complete cycle gives only 0.5 gm of nanocellulose. The whole process of making nanocellulose is shown in figure 2.

**Figure 2 :** Synthesis of nanocellulose powder.

For the final preparation of membrane, 0.5 gram of chitosan was dissolved in 30 ml of 2% (v/v) acetic acid while continuously stirring for a duration of seven hours. After that, 1.0 gram of nanocellulose was incorporated into the mixture, and stirring continued to achieve a homogeneous solution. Solution casting method was employed to prepare the nano-composite membrane. A round shaped (40 mm diameter) plain woven bleached fabric is placed on petri dish (45 mm diameter). This resulting homogeneous solution was then poured into that petri dish and placed in a hot air oven at $60^\circ C$ for 24 hours. The dried membrane was immersed in 1 N NaOH solution for 24 h to facilitate crosslinking. Following this, the resulting membrane was immersed in distilled water

for 24 hours to eliminate any residual chemicals, after which it was thoroughly washed. The whole process of making composite membrane is shown in **Figure 3**.

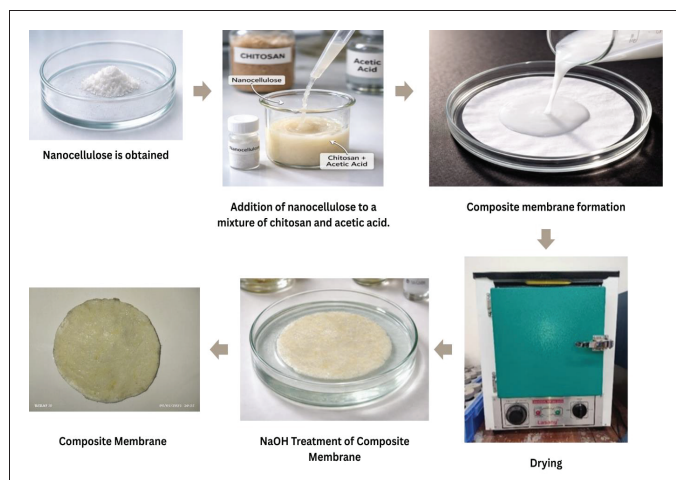


Figure 3 : Composite membrane preparation.

3. Characterization Techniques

3.1 Field Emission Scanning Electron Microscopy (FESEM)

The surface morphology and structural features of the developed composite membrane were analyzed using a field-emission scanning electron microscope (FESEM) (ZEISS Sigma 300). The analysis was conducted at an accelerating voltage of 5 kV. Prior to imaging, the samples were sputter-coated with a thin layer of gold to minimize charging effects and to obtain high-resolution micrographs. The obtained images were further used to evaluate the dispersion and size distribution of nanocellulose within the composite matrix.

3.2 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier transform infrared (FTIR) spectroscopy was employed to investigate the chemical structure and functional group interactions within the composite membrane. The spectra were recorded using a Nicolet iS20 FTIR spectrometer over a wavenumber range of 500–4000 cm^{-1} . The analysis was carried out to confirm the presence of constituent materials and to identify possible intermolecular interactions between cellulose, chitosan, and nanocellulose.

3.3 Antibacterial Activity Test

The antibacterial activity of the composite membrane was evaluated against *Pseudomonas aeruginosa* (ATCC 9027) using the standard disc diffusion method. The samples were placed on agar plates inoculated with the test organism and incubated under appropriate conditions. The antibacterial performance was assessed by measuring the diameter of the zone of inhibition around the samples. A commercially avail-

able antibiotic disc, Cefepime (CEP 30), was used as a positive control for comparison.

4. Results And Discussion

4.1 FESEM Analysis of Composite Membrane

The morphological characteristics of the developed composite membrane were investigated using FESEM. The micrographs given in figure 4 reveal the inherent structure of the plain woven cotton substrate, where well-defined inter-fiber pores are clearly visible. The organized alignment of cellulosic fibers along both warp and weft directions confirms that the fundamental textile architecture remains intact after composite formation.

Moreover, the FESEM images indicate the successful incorporation of nanocellulose particles onto the surface of the cotton fibers. The nanoparticles are observed to be uniformly distributed throughout the matrix, suggesting effective interfacial adhesion between the nanocellulose and the substrate. The particle size was found to range between 58 and 77 nm, confirming the nanoscale nature of the reinforcement. Such uniform dispersion and nanoscale dimensions are expected to enhance the surface functionality and overall performance of the composite membrane.

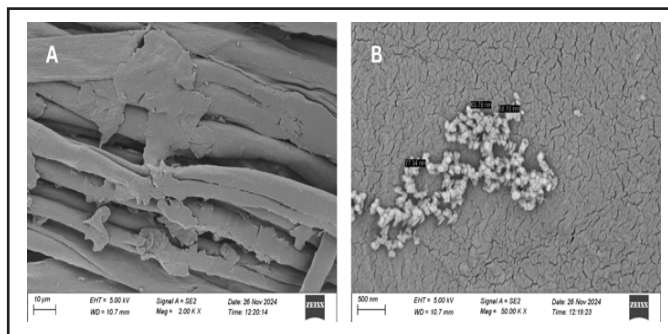


Figure 4 : Microstructural analysis of nanocellulose-based cotton composite membrane by FESEM. (A) inter-fibre pore structure, (B) distribution of nanoparticle and their size.

4.2 FTIR Spectroscopy Analysis

The FTIR spectrum of the nanocellulose suspension given in figure 5 displays a broad and intense band centered at $\sim 3296 \text{ cm}^{-1}$, corresponding to O–H stretching vibrations, indicative of extensive intra- and intermolecular hydrogen bonding within the cellulose network. The absorption at $\sim 1642 \text{ cm}^{-1}$ is attributed to the bending vibration of adsorbed water molecules. The band at $\sim 1408 \text{ cm}^{-1}$ arises from C–H bending vibrations of the polysaccharide structure. Prominent peaks at ~ 1150 and $\sim 1020 \text{ cm}^{-1}$ are assigned to asymmetric C–O–C glycosidic linkages and C–O stretching of the pyranose ring, respectively, confirming the integrity of the cellulose backbone. Minor absorptions in the 845–647 cm^{-1} region are associated with skeletal vibrations of the glucopyranose units.

Collectively, the spectral features corroborate the characteristic chemical structure and purity of nanocellulose.

The FTIR spectrum of the composite membrane given in figure 6 confirms the presence of both cellulose and chitosan components and provides evidence of their interaction within the matrix. A broad absorption band around 3281 cm^{-1} is attributed to O–H stretching vibrations, indicating the presence of extensive hydrogen bonding. The characteristic peaks observed at 1643 cm^{-1} (amide I) and 1549 cm^{-1} (amide II) correspond to the functional groups of chitosan, confirming its successful incorporation into the composite structure. In addition, the absorption bands at 1149 cm^{-1} , 1019 cm^{-1} , and 845 cm^{-1} are associated with C–O–C and C–O stretching vibrations, which are typical of polysaccharide backbones present in both cellulose and chitosan.

These spectral features collectively indicate the formation of a compatible composite system, with possible intermolecular interactions such as hydrogen bonding contributing to structural stability.

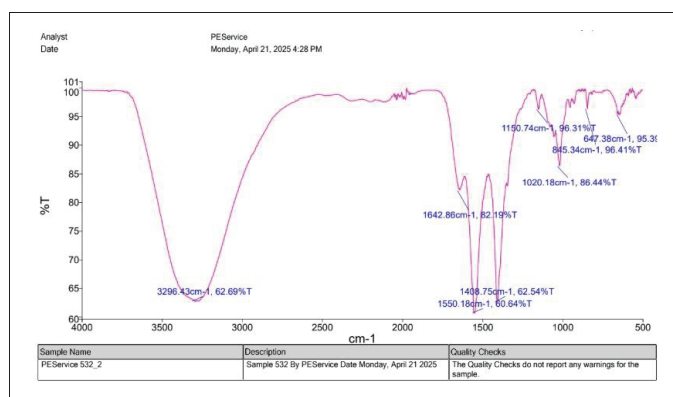


Figure 5 : FTIR spectrum of the nanocellulose suspension showing key functional groups and interactions.

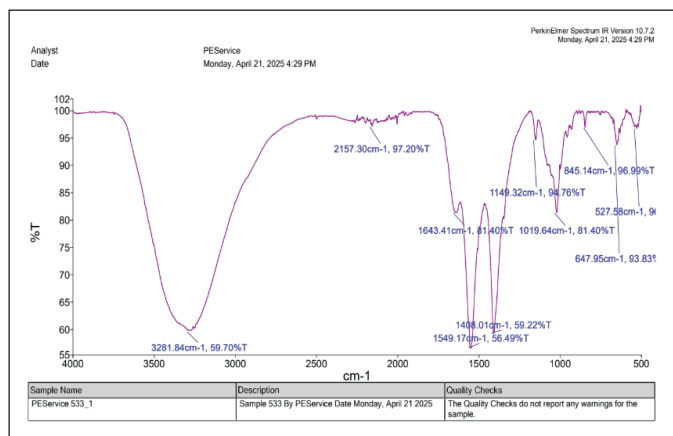


Figure 6 : FTIR of composite membrane showing key functional groups and interactions.

4.3 Antimicrobial Analysis :

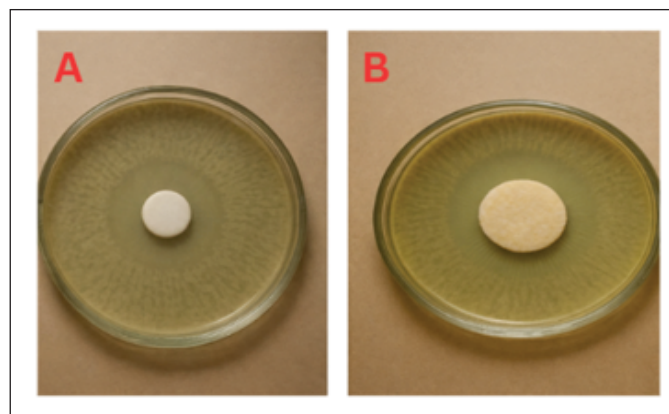


Figure 7 : Comparative antimicrobial activity against *Pseudomonas aeruginosa*. (A) antimicrobial activity of cefepime (CEP 30), (B) antimicrobial activity of composite membrane.

Figure 7 shows the antibacterial activity of the chitosan–nanocellulose composite membrane was evaluated against *Pseudomonas aeruginosa* (ATCC 9027) using the disc diffusion method. The composite membrane exhibited a clear zone of inhibition of approximately 18 mm, indicating notable antibacterial efficacy. In comparison, the standard antibiotic cefepime (CEP 30) produced a larger inhibition zone of 26 mm under identical conditions, reflecting its superior bactericidal performance. Nevertheless, the composite membrane demonstrated significant antimicrobial activity, which can be attributed due to the presence of lignin-derived phenolic moieties in sugarcane bagasse may impart antimicrobial activity through partial disruption of microbial cell membranes. Additionally, the fibrous morphology of bagasse can hinder microbial adhesion via surface-level physical interactions. These findings highlight the potential of the developed composite membrane as an effective antimicrobial material for biomedical and environmental applications.

5. Conclusion

This study demonstrates the successful valorization of sugarcane bagasse, an abundant agro-industrial residue, into a high-value nanocellulose-based composite membrane for potential antibacterial application. Through systematic chemical pretreatment and controlled sulfuric acid hydrolysis, nanocellulose with particle sizes ranging from 58–77 nm was effectively extracted. Structural characterization using FESEM confirmed the presence and uniform distribution of nanocellulose within the composite matrix, while FTIR analysis verified the coexistence of characteristic functional groups of cellulose and chitosan, indicating successful composite formation. The developed composite exhibited notable antimicrobial activity against *Pseudomonas aeruginosa*, demonstrating an 18 mm zone of inhibition, which

confirms its potential as an antibacterial biomaterial. Although its activity was comparatively lower than the standard antibiotic cefepime, the membrane offers a sustainable, biodegradable, and non-antibiotic alternative for infection control in medical textiles. Furthermore, the integration of the composite membrane onto plain woven cotton fabric provides structural stability and flexibility, which are essential properties for wound dressing applications. The biopolymeric nature of both nanocellulose and chitosan suggests additional advantages such as biocompatibility, moisture management, and potential hemostatic activity. Future studies should focus on in vivo biocompatibility studies, cytotoxicity evaluation, mechanical performance optimization, large-scale production feasibility, in-depth hemostatic evaluation and clinical validation to establish the suitability of this biodegradable nanocellulose–chitosan membrane for wound care and related medical textile applications.

Conflicts of Interest

No

Funding

Self

Acknowledgements

The authors gratefully acknowledge the technical support provided by the laboratory staff involved in material characterization and antimicrobial testing. The authors also thank Carew & Co (Bangladesh) Ltd., Darshana, Chuadanga, for supplying sugarcane bagasse used in this study.

Authors, April, 2026

References

1. Jha P, Sachan AK, Singh RP. Agro-waste sugarcane bagasse ash (ScBA) as partial replacement of binder material in concrete. *Materials Today: Proceedings*. 2021 Jan 1;44:419-27.
2. Bayapureddy Y, Muniraj K. Enhancing material properties of agro-industrial waste sugarcane bagasse ash—Way towards sustainable development. *Sustainable Futures*. 2024 Jun 1;7:100154.
3. Rasul MG, Rudolph V, Carsky M. Physical properties of bagasse. *Fuel*. 1999 Jun 1;78(8):905-10.
4. Mahmud MA, Anannya FR. Sugarcane bagasse-A source of cellulosic fiber for diverse applications. *Heliyon*. 2021 Aug 1;7(8).
5. Glasser WG, Atalla RH, Blackwell J, Malcolm Brown Jr R, Burchard W, French AD, Klemm DO, Nishiyama Y. About the structure of cellulose: debating the Lindman hypothesis. *Cellulose*. 2012 Jun;19(3):589-98.
6. Seddiqi H, Oliaei E, Honarkar H, Jin J, Geonzon LC, Bacabac RG, Klein-Nulend J. Cellulose and its derivatives: towards biomedical applications. *Cellulose*. 2021 Mar;28(4):1893-931.
7. Ho HV, Makkar P, Padalhin AR, Le TT, Lee SY, Jaegyong G, Lee BT. Preliminary studies on the in vivo performance of various kinds of nanocellulose for biomedical applications. *Journal of Biomaterials Applications*. 2020 Feb;34(7):942-51.
8. Cheng Z, Li J, Wang B, Zeng J, Xu J, Zhu S, Duan C, Chen K. Comparative study on properties of nanocellulose derived from sustainable biomass resources. *Cellulose*. 2022 Sep;29(13):7083-98.
9. Pawcenis D, Leśniak M, Szumera M, Sitarz M, Profic-Paczkowska J. Effect of hydrolysis time, pH and surfactant type on stability of hydrochloric acid hydrolyzed nanocellulose. *International Journal of Biological Macromolecules*. 2022 Dec 1;222:1996-2005.
10. Rashid ES, Gul A, Yehya WA, Julkapli NM. Physico-chemical characteristics of nanocellulose at the variation of catalytic hydrolysis process. *Heliyon*. 2021 Jun 1;7(6).
11. Cidreira AC, Hatami T, Linan LZ, Pinheiro IF, Gomes RC, Rocha JJ, Mei LH. Nanocellulose extraction from acai bagasse through mixed acid hydrolysis and oxidative techniques. *International Journal of Biological Macromolecules*. 2024 Jul 1;273:133034.
12. Isogai A. Emerging nanocellulose technologies: recent developments. *Advanced Materials*. 2021 Jul;33(28):2000630.
13. Gond RK, Gupta MK, Jawaid M. Extraction of nanocellulose from sugarcane bagasse and its characterization for potential applications. *Polymer Composites*. 2021 Oct;42(10):5400-12.
14. Waghmare NK, Khan S. Extraction and characterization of nano-cellulose fibrils from Indian sugarcane bagasse-an agro waste. *Journal of Natural Fibers*. 2022 Dec 1;19(13):6230-8.
15. Ramesh S, Doddipatla P, Pamidipati S. Optimization of parameters for biological pre-treatment route for the production of nanocellulose from sugarcane bagasse. *Biomass Conversion and Biorefinery*. 2023 Feb;13(3):2293-303.
16. Pula B, Ramesh S, Pamidipati S, Doddipatla P. A comparative study of greener alternatives for nanocel-

- lulose production from sugarcane bagasse. *Bioresources and Bioprocessing*. 2021 Dec 19;8(1):132.
17. Li Q, Dunn ET, Grandmaison EW, Goosen MF. Applications and properties of chitosan. In *Applications of Chitan and Chitosan* 2020 Aug 18 (pp. 3-29). CRC Press.
 18. Alemu D, Getachew E, Mondal AK. Study on the Physicochemical Properties of Chitosan and their Applications in the Biomedical Sector. *International Journal of Polymer Science*. 2023;2023(1):5025341.
 19. Li J, Zhuang S. Antibacterial activity of chitosan and its derivatives and their interaction mechanism with bacteria: Current state and perspectives. *European Polymer Journal*. 2020 Sep 5;138:109984.
 20. Wahba MI. Enhancement of the mechanical properties of chitosan. *Journal of Biomaterials Science, Polymer Edition*. 2020 Feb 11;31(3):350-75.
 21. Khan A, Alamry KA. Recent advances of emerging green chitosan-based biomaterials with potential biomedical applications: A review. *Carbohydrate Research*. 2021 Aug 1;506:108368.
 22. Hosseinnjad M, Jafari SM. Evaluation of different factors affecting antimicrobial properties of chitosan. *International journal of biological macromolecules*. 2016 Apr 1;85:467-75.
 23. Gao L, Li L, Zeng A, Fei Y, Zhao W. Antibacterial and anti-biofilm activities of sugarcane polyphenols against dental caries-related bacteria. *Food Bioscience*. 2025 Jul 1;69:106866.
 24. Jannatyha N, Shojaee-Aliabadi S, Moslehishad M, Moradi E. Comparing mechanical, barrier and antimicrobial properties of nanocellulose/CMC and nanochitosan/CMC composite films. *International Journal of Biological Macromolecules*. 2020 Dec 1;164:2323-8.
 25. Talebi H, Ghasemi FA, Ashori A. The effect of nanocellulose on mechanical and physical properties of chitosan-based biocomposites. *Journal of Elastomers & Plastics*. 2022 Feb;54(1):22-41.
 26. Goswami R, Mishra A, Bhatt N, Mishra A, Naithani P. Potential of chitosan/nanocellulose based composite membrane for the removal of heavy metal (chromium ion). *Materials Today: Proceedings*. 2021 Jan 1;46:10954-9.
 27. Matter EA, Hassan AF, Elfaramawy NM, Esmail G. Fabrication of nanocellulose/chitosan nanocomposite based on loofah sponge for efficient removal of methylene blue: thermodynamic and kinetic investigations. *Journal of Inorganic and Organometallic Polymers and Materials*. 2024 Nov;34(11):5620-35.
 28. Ribeiro AS, Costa SM, Ferreira DP, Calhella RC, Barros L, Stojković D, Soković M, Ferreira IC, Figueiro R. Chitosan/nanocellulose electrospun fibers with enhanced antibacterial and antifungal activity for wound dressing applications. *Reactive and Functional Polymers*. 2021 Feb 1;159:104808.
 29. Sultana T, Hossain M, Rahaman S, Kim YS, Gwon JG, Lee BT. Multi-functional nanocellulose-chitosan dressing loaded with antibacterial lawsone for rapid hemostasis and cutaneous wound healing. *Carbohydrate polymers*. 2021 Nov 15;272:118482.
 30. Eskilson O, Zattarin E, Berglund L, Oksman K, Hanna K, Rakar J, Sivilér P, Skog M, Rinklake I, Shamasha R, Sotra Z. Nanocellulose composite wound dressings for real-time pH wound monitoring. *Materials Today Bio*. 2023 Apr 1;19:100574.
 31. Jančič U, Nacu I, Verestiuc L, Rancan F, Gorgieva S. Bioactive bacterial nanocellulose membranes for non-surgical debridement and infection prevention in burn wound healing. *Carbohydrate Polymer Technologies and Applications*. 2025 Jun 1;10:100762.
 32. Aderibigbe BA. Application of nanocellulose for wound dressings. *Nanocellulose: A Biopolymer for Biomedical Applications*. 2024 Mar 6:193-219.
 33. Wu L, Gao S, Cheng H, Wu C, Zhang S, Gao R, Zhu X. Preparation of nanocellulose from bagasse and its application in chitosan composite films. *Royal Society open science*. 2025 Jul 1;12(7).
 34. Alrefaey KA, Sallam NA, Fahim IS. Eco-friendly cellulose-based membranes derived from sugarcane bagasse for efficient industrial paint wastewater treatment. *International Journal of Environmental Science and Technology*. 2026 Mar;23(3):169.
 35. Hisbiyah AY, Nurfadlilah L, Nisyak K. The nanocellulose addition's effect on chitosan composites mechanical properties and antibacterial activity against *S. aureus*. In *AIP Conference Proceedings* 2023 Jan 25 (Vol. 2554, No. 1, p. 070002). AIP Publishing LLC.
 36. Yang Z, Wang X, Cheng H, Kawasaki H, Guo Y, Yao W. Valorizing Sugarcane Bagasse for Sustainable Antimicrobial Paper Using Chitosan-Silver Nanoparticle Enhancement. *Food and Bioprocess Technology*. 2025 Dec;18(12):10841-55.