Preparation, Characterization, and Drug Release Study of Bacterial Cellulose-Based Composite Membranes

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3 GOOD HEALTH AND WELL-BEING | 8 DECENT WORK AND ECONOMIC GROWTH | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | 15 LIFE ON LAND

Abstract

A membrane derived from bacterial cellulose (BC) prepared from nata de coco was developed for use in drug delivery and fluid absorption in wound dressing applications. The BC membrane offers a sustainable and environmentally friendly alternative for wound healing. To enhance its mechanical properties, liquid absorption capacity, and drug release performance, the BC membrane was reinforced with cellulose fibers (CFs) and layered material (LM). The resulting BC composite membrane exhibited improved tensile strength while maintaining flexibility compared to neat BC membrane. Drug release study revealed that the BC composite membrane loaded with model drug A provided sustained release for up to 240 hours, with a cumulative release of 25%, whereas the BC composite membrane loaded with model drug B released only 6% within 2 hours. Additionally, the BC composite membrane demonstrated excellent biocompatibility, with cell viability reaching 99%. The drug A-loaded membrane further exhibited strong antibacterial activity against *Escherichia coli*. In terms of liquid absorption, the BC composite membrane absorbed up to 370% of its weight, while the drug A-loaded membrane absorbed up to 190%. Thermal analysis confirmed the membrane's stability up to ~350 °C. These findings suggest the potential of the developed BC-based composite membrane for use in advanced wound dressings, contributing to both improved biomedical applications and sustainable material development.

Introduction

Currently, many wound dressings are made from petrochemical-based polymers, which are difficult to degrade, causing skin irritation and potential harm to wounds. This research focuses on utilizing bacterial cellulose (BC) derived from coconut jelly, a widely available and edible material, as the primary component for developing an eco-friendly and biodegradable wound dressing. BC offers a safe, low-cost alternative that aligns with sustainable development goals (SDGs).

To enhance the mechanical properties of BC membrane, cellulose fibers (CFs) were incorporated to improve strength and flexibility, while layered material (LM) was used to enhance drug retention and controlled release. These additives were used in minimal, non-toxic amounts. The developed BC composite membrane provides excellent breathability, preventing moisture buildup around the wound. Additionally, it promotes wound healing and bacterial inhibition by incorporating both synthetic drugs and natural antibacterial or anti-inflammatory agents.

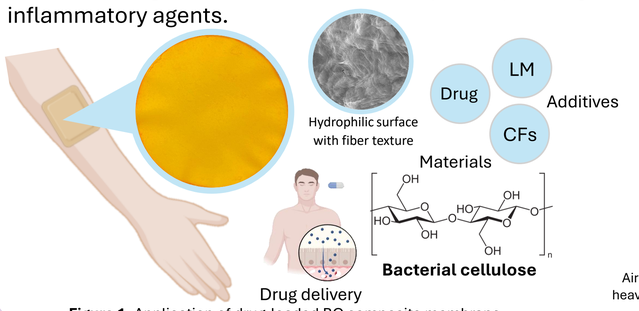


Figure 1. Application of drug-loaded BC composite membrane.

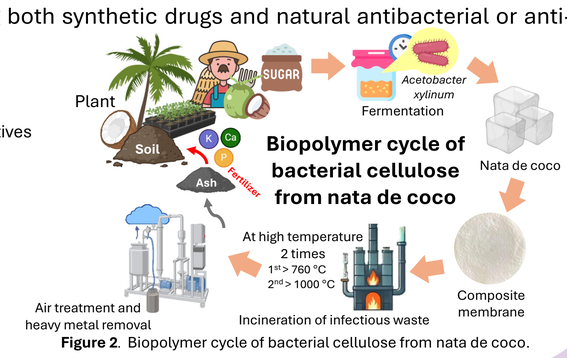
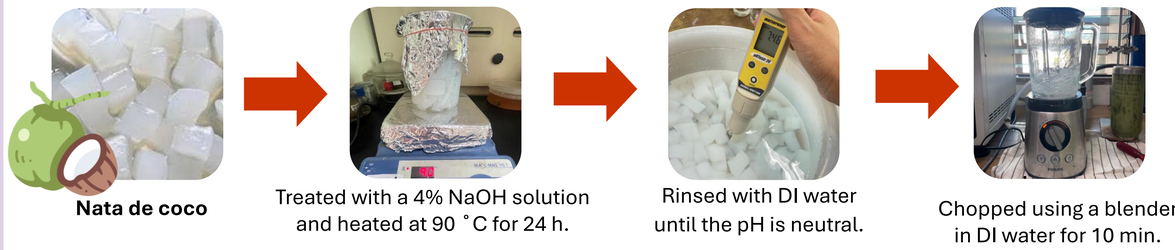


Figure 2. Biopolymer cycle of bacterial cellulose from nata de coco.

Methodology

- **Preparation of bacterial cellulose fibers**



Nata de coco → Treated with a 4% NaOH solution and heated at 90 ˚C for 24 h. → Rinsed with DI water until the pH is neutral. → Chopped using a blender in DI water for 10 min.

Vacuum filtration. → Heated at 50˚C for 24 h in an oven. → As-prepared neat BC membrane.

- **Preparation of bacterial cellulose composite membranes with a drug**

A dry BC mat (0.5 g) was chopped using a blender in DI water medium (350 mL) for 6 min. → In another container, the additive and drug were dispersed in DI water for 15 min. → Being poured into the blender, the BC and additive dispersions were then blended for 3 min. → The preparation procedure was conducted similarly to that used for the preparation of the neat BC membrane.

Results and discussions

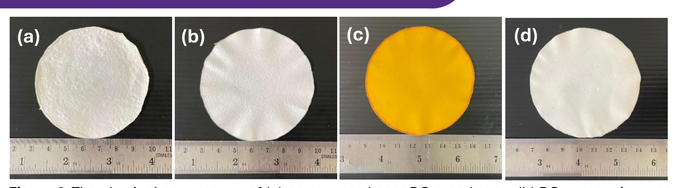


Figure 3. The physical appearance of (a) as-prepared neat BC membrane, (b) BC composite membrane, and (c,d) BC composite membranes with drugs.

- **Sample characterization result**

The physical appearance of (a) the as-prepared neat BC membrane, (b) BC composite membrane, and (c) BC composite membrane with drug. The shape and size (diameter) of the BC-based membranes were controlled by the filter funnel base used. Here, circular membranes were obtained with a mean diameter of 6.5 ± 0.5 cm.

- **The surface characteristics of the BC composite membrane observed using scanning electron microscopy (SEM)**

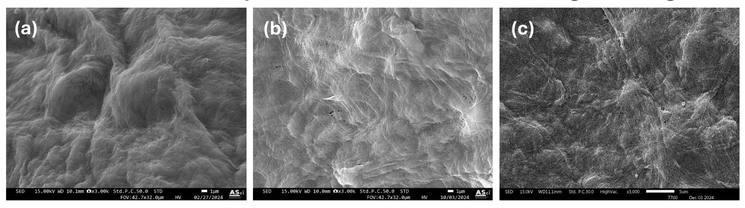


Figure 4. (a) Morphology of the BC membrane at 3000x magnification, (b) morphology of the BC composite membrane at 3000x magnification and (c) morphology of the BC composite membrane with drug A at 3000x magnification.

- **The mechanical and thermal properties of the membrane using tensile test, TGA, and DSC**

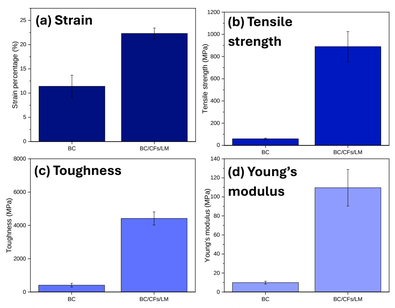


Figure 5. Mechanical properties of BC membrane and BC composite membrane: (a) Strain percentage, (b) tensile strength, (c) toughness, and (d) Young's modulus.

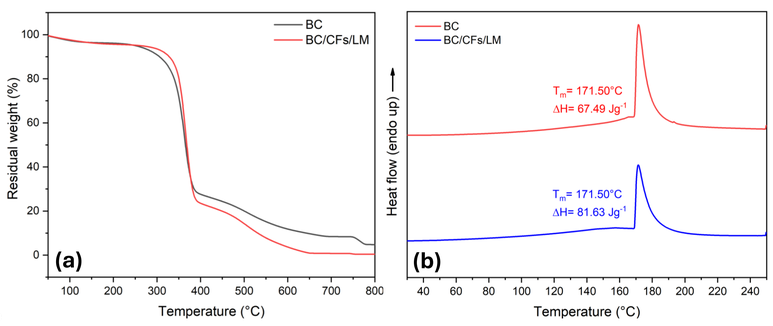


Figure 6. Thermal stability of polymers: (a) TGA thermograms of BC membrane and BC composite membrane, and (b) DSC thermograms of BC membrane and BC composite membrane.

- **The chemical characteristics of the samples were studied using FT-IR in an ATR mode and Raman spectroscopy.**

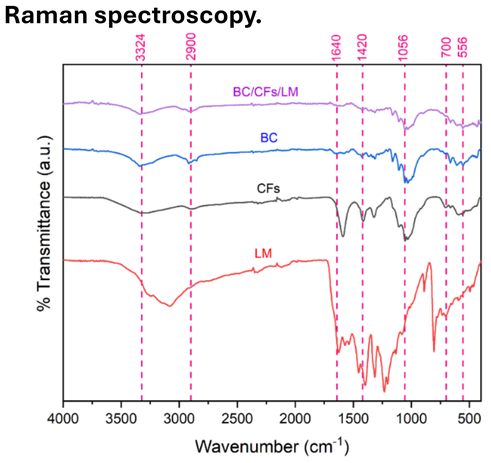


Figure 7. FT-IR spectra of BC membranes and BC composite membranes containing CFs and LM additive loading content for BC and BC/CFs/LM

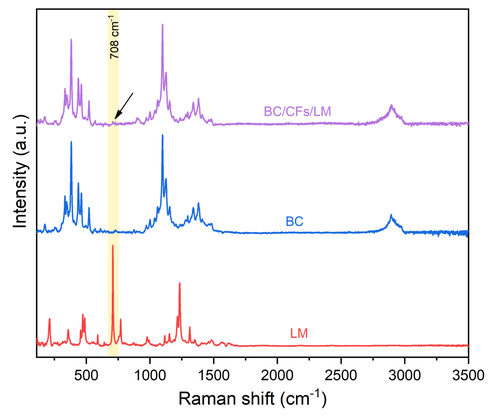


Figure 8. Raman spectra of BC composite membranes containing CFs and LM additive loading content for BC and BC/CFs/LM and LM additive.

- **Drug release study from bacterial cellulose membrane in simulated skin conditions.**

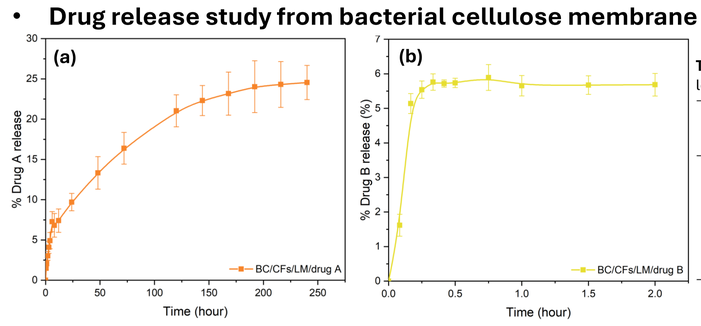


Figure 9. The amount of drug released (a) Drug A reaches its maximum release at 240 h and (b) Drug B reaches its maximum release at 2 h.

Table 2. The R-squared (R^2) values of the BC composite membrane loaded with both drugs in various models.

Kinetic model	R-squared (R^2)	
	BC/CFs/LM/drug A	BC/ CFs/LM/drug B
Zero order model	0.98101	0.15860
Frist order model	0.91718	0.16179
Higuchi model	**0.99941**	0.21593
Hixson-Crowell model	0.94352	0.16073
Korsmeyer-Peppas model	0.99886	**0.30011**

- **Cytotoxicity and growth inhibition assay in simulated cellular environments.**

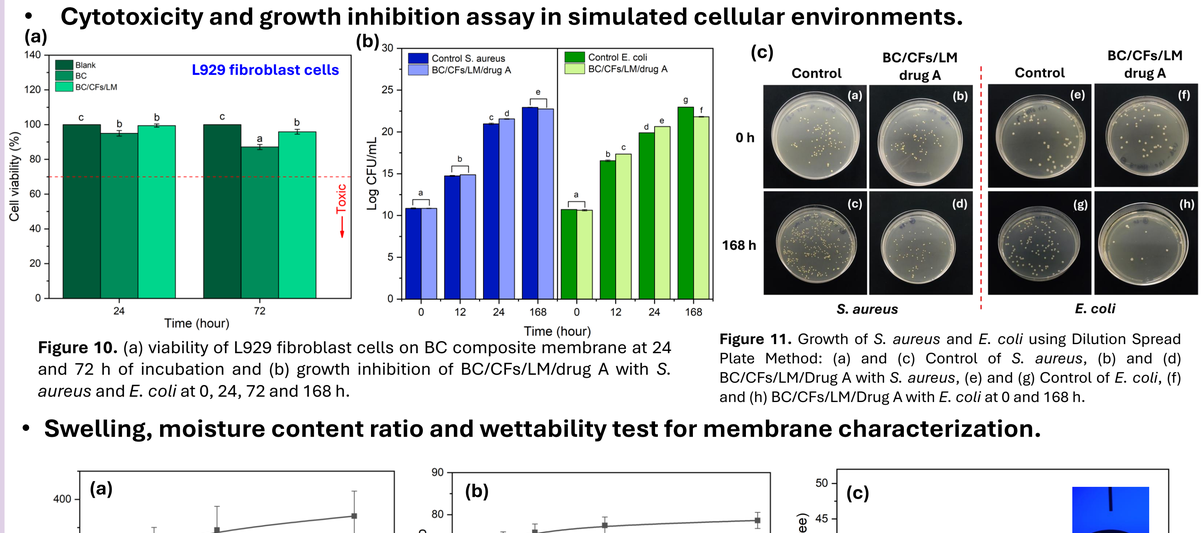


Figure 10. (a) viability of L929 fibroblast cells on BC composite membrane at 24 and 72 h of incubation and (b) growth inhibition of BC/CFs/LM/drug A with *S. aureus* and *E. coli* at 0, 24, 72 and 168 h.

Figure 11. Growth of *S. aureus* and *E. coli* using Dilution Spread Plate Method: (a) and (c) Control of *S. aureus*, (b) and (d) BC/CFs/LM/Drug A with *S. aureus*, (e) and (g) Control of *E. coli*, (f) and (h) BC/CFs/LM/Drug A with *E. coli* at 0 and 168 h.

- **Swelling, moisture content ratio and wettability test for membrane characterization.**

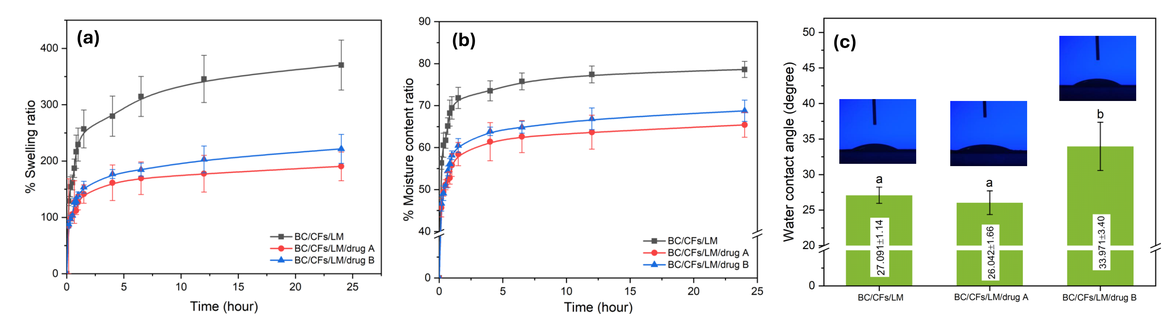


Figure 12. Membrane wettability: (a) Swelling ratio test, (b) moisture content ratio test and (c) contact angle measurement of water on membranes.

Conclusion

- BC/CFs/LM composite membrane exhibited higher mechanical strength than neat BC, with drug loading having no significant impact on mechanical properties.
- **SEM**: The composite membrane (BC/CFs/LM) had a smoother surface and denser fibrous structure than BC.
- **FTIR** and **Raman** results confirmed the presence of additives and drug A in the membrane.
- **Thermal properties**: The melting temperature (T_m) was 171.5 °C for both BC and the composite. However, the enthalpy change (ΔH) increased due to enhanced crystallization. The composite decomposed at 245.4 °C, indicating high thermal stability.
- **Drug release & biocompatibility**: The composite membrane exhibited **24.5% of drug release** over **240 hours** in acetate buffer, was **non-toxic to L929 fibroblast cells**, supported cell growth, and **inhibited *E. coli* for 168 h**.
- The membrane's **hydrophilicity** enabled potential effective **fluid absorption from wounds**.

Acknowledgments

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3. Polymer Research Laboratory, Faculty of Science, Chiang Mai University
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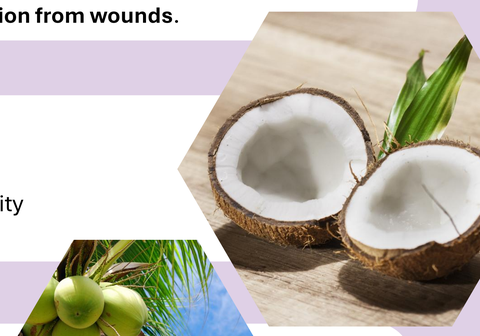

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3. M. Misra et al., *Compr. Biotechnol.*, 2011, 111–119.