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Closing the Loop in Food Protection: Reimagining Packaging with Nano-Enabled Bacterial Cellulose Films

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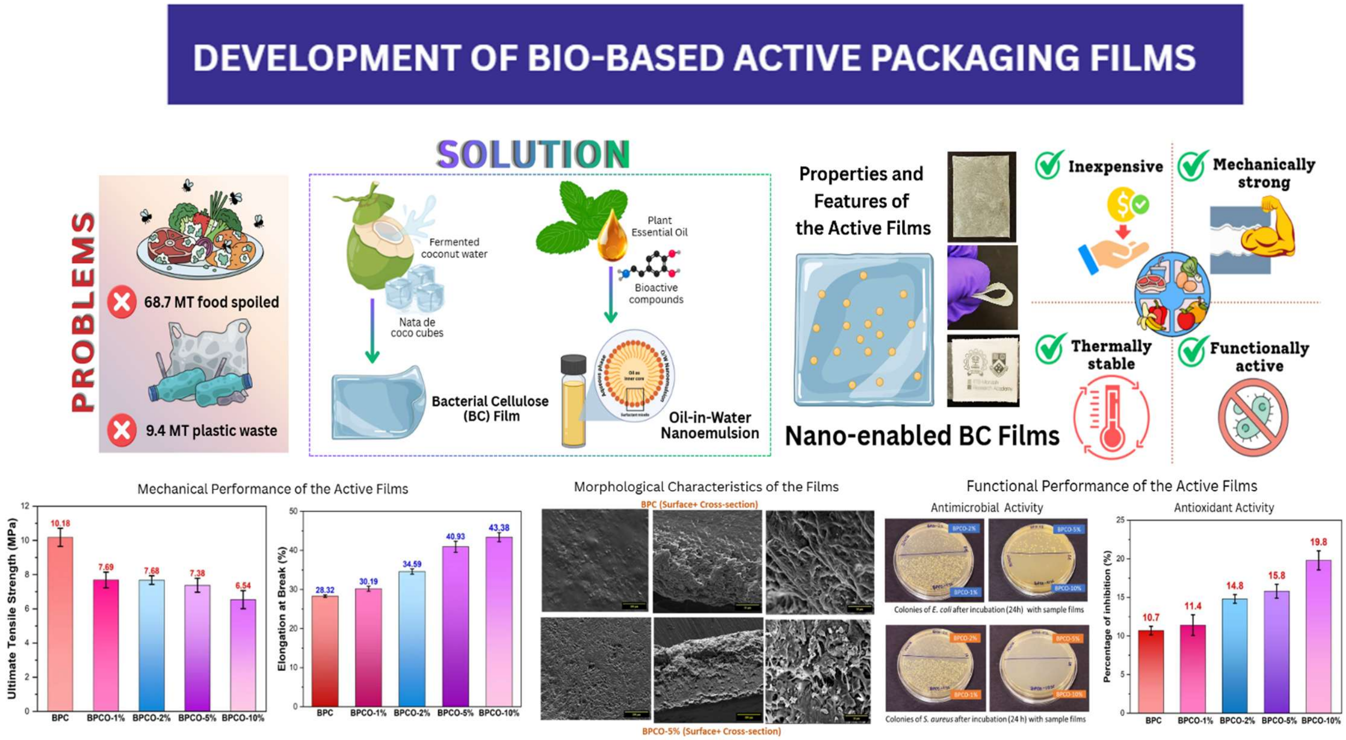
ABSTRACT

Food loss and plastic waste are interlinked global challenges, with a substantial fraction of food spoilage arising from inadequate packaging, while petroleum-based solutions remain major contributors to environmental pollution and resource inefficiency [1,2]. Developing sustainable packaging materials that integrate mechanical integrity with active functionality is therefore essential for advancing sustainable food protection systems.

In this work, we report the development of nanoenabled bacterial cellulose (BC) films incorporated with plant essential oil (EO) nanoemulsions. BC is a promising biopolymer with high purity, excellent mechanical strength, biocompatibility, and rapid biodegradability, but it lacks inherent antimicrobial activity [3]. Plant EOs, widely recognised for their antimicrobial bioactives such as polyphenols and flavonoids [4], were formulated into stable oil-in-water nanoemulsions exhibiting uniform droplet sizes with narrow distributions (PDI < 0.3), high encapsulation efficiency, prolonged physical stability and intrinsic antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*. These optimised nanoemulsions were subsequently incorporated into BC matrices reinforced with food-grade, green plasticisers and reinforcement agents to enhance flexibility and strength.

The resulting active films were characterised using structural (ATR–FTIR, Raman spectroscopy, X-ray diffraction), morphological (Cryo-SEM), thermal (TGA, DSC), and mechanical (tensile testing) techniques. The composites retained the characteristic cellulose I crystalline structure while exhibiting strong intermolecular interactions and megapascal-range tensile strength with high flexibility. Importantly, the films retained effective antibacterial and antioxidant activities confirming successful transfer of bioactivity from the nanoemulsions to the solid film matrix. Overall, this work demonstrates a materials-driven strategy for closing the loop in food protection through mechanically robust, bioactive, and sustainable packaging barriers.



Graphical abstract: Development of nanoenabled bacterial cellulose (BC) films via essential oil nanoemulsion integration, demonstrating enhanced mechanical strength, flexibility, and antibacterial functionality.

KEY WORDS

Biopolymers; Food Packaging; Cellulose-based materials; Plant Essential Oils; Active films; Biodegradable packaging; Food protection; Sustainability

BIOGRAPHY

I am a third-year joint PhD scholar at the Indian Institute of Technology (IIT) Bombay, India and Monash University, Australia, under the IITB-Monash Research Academy. During my Master's, my fascination with biology gradually evolved into a deeper interest in biomaterials and sustainable innovation. Through my research, I explore how biological systems can inspire the design of environmentally responsible food packaging alternatives to petroleum-based plastics. I am particularly interested in biopolymeric nanocomposites, active ingredient delivery, and developing functional materials that not only protect food but also contribute to a more sustainable future.

REFERENCES

[1] O. Olabode, N. Kumar, and D. De, “Food loss and waste management in the retail food supply chain: Methods and framework to achieve environmental sustainability,” *J. Environ. Manage.*, vol. 387, p. 125718, Jul. 2025, doi: 10.1016/j.jenvman.2025.125718.

[2] A. Lahiri, S. Daniel, R. Kanthapazham, R. Vanaraj, A. Thambidurai, and L. S. Peter, “A critical review on food waste management for the production of materials and biofuel,” *J. Hazard. Mater. Adv.*, vol. 10, p. 100266, May 2023, doi: 10.1016/j.hazadv.2023.100266.

[3] L. Bhadra, K. Tuck, J. Tanner, and V. Gundabala, “Strengths, opportunities, challenges and future outlook of bacterial cellulose in cosmeceuticals: A review,” *Int. J. Biol. Macromol.*, vol. 331, p. 148139, Nov. 2025, doi: 10.1016/j.ijbiomac.2025.148139.

[4] R. Tao, J. Sedman, and A. Ismail, “Antimicrobial activity of various essential oils and their application in active packaging of frozen vegetable products,” *Food Chem.*, vol. 360, p. 129956, Oct. 2021, doi: 10.1016/j.foodchem.2021.129956.

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