IOCG 2025 Conference

The 1st International Online Conference on Gels

03–05 December 2025 | Online

MDPI

Harnessing Nature: Hydrogels Derived from Bacterial Cellulose and Chitosan for Biomedical Applications

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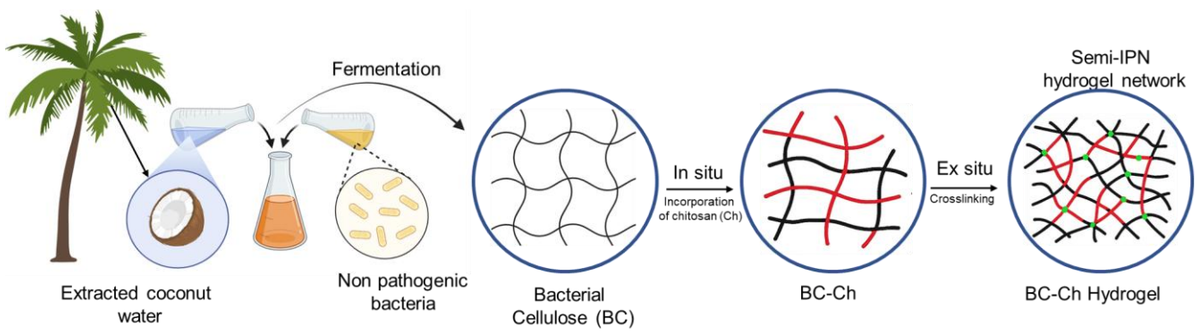
INTRODUCTION & AIM

Bacterial cellulose (BC) is a natural biopolymer known for its purity, mechanical strength and biocompatibility, but its limited reactive groups restrict advanced biomedical use. In this work, bacterial cellulose was produced using coconut water as a sustainable, nature-derived medium, reinforcing the theme of harnessing natural resources for functional biomaterials. Chitosan (Ch) contributes antimicrobial and pH-responsive behaviour, while genipin provides a stable, low-toxicity crosslinking pathway. Combining these materials through in situ incorporation of chitosan followed by genipin crosslinking enables the formation of stable semi-interpenetrating hydrogels with enhanced structural and functional properties.

The aim of this study was to develop and characterize genipin-crosslinked bacterial cellulose–chitosan hydrogels using this dual nature-forward strategy, and to investigate their morphology, water interactions, swelling behaviour, mechanical properties, antibacterial activity and drug-release performance for potential applications in controlled drug delivery and wound-healing systems.



METHOD

Production of Bacterial Cellulose (BC) – Harnessing Nature

BC was produced using **coconut water** as the fermentation medium, enriched with yeast extract, ammonium sulfate, KH_2PO_4 and $MgSO_4$. *Gluconacetobacter xylinus* was cultured at 28°C for 7 days to obtain high-purity cellulose pellicles.

In situ Incorporation of Chitosan (BC/Ch)

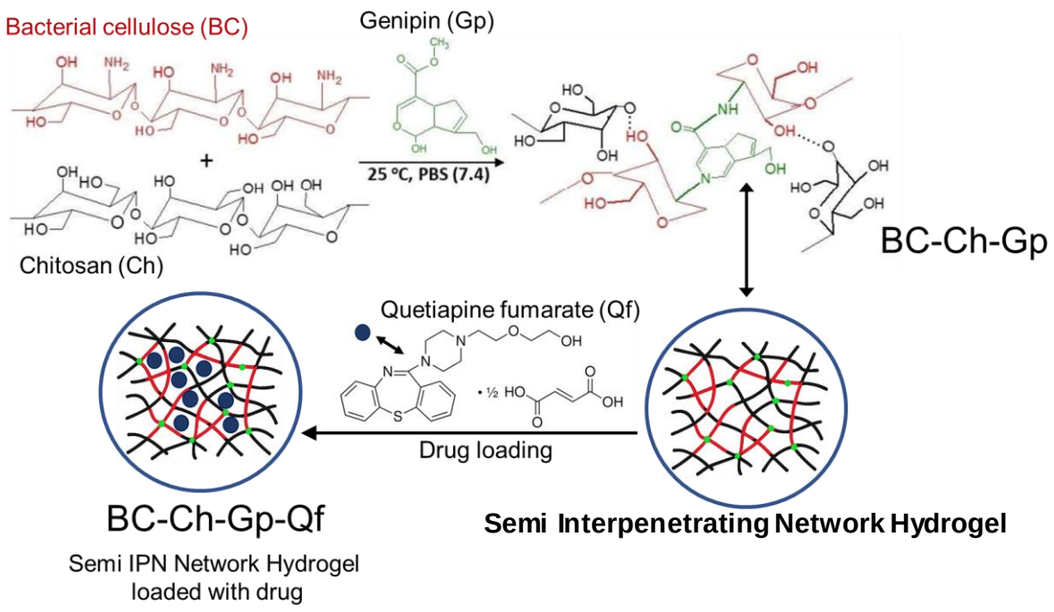
A 2 percent w/v chitosan solution (in 2 percent acetic acid) was aseptically added to the fermenting culture on days 2 and 3. Chitosan became embedded within the growing BC network, forming a composite membrane. Membranes were washed, neutralized and freeze-dried.

Genipin Crosslinking (BC/Ch/Gp Hydrogels) BC/Ch membranes were immersed in 1 percent w/v genipin solution in phosphate buffer (pH 7.4) for 24 h to achieve low-toxicity crosslinking. The resulting semi-IPN hydrogels (bluish-green) were rinsed and dried.

Drug Loading

Hydrogels were loaded with quetiapine fumarate by equilibrating samples in a drug solution under controlled conditions. Loaded hydrogels were blotted and weighed before analysis.Antimicrobial

Evaluation Antibacterial activity against Staphylococcus aureus and Escherichia coli was assessed using agar diffusion and contact-based assays. Zones of inhibition were recorded to evaluate antimicrobial performance attributed to chitosan and the modified network.



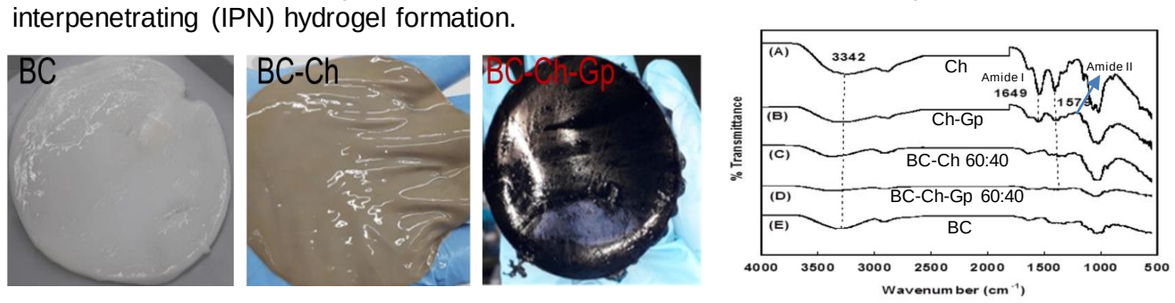
Characterization

- ✓ **FTIR:** Identification of amide I/II bands and C–N vibrations.
- ✓ **SEM:** Morphology and fibril network structure.
- ✓ **Swelling & Moisture:** Water uptake under controlled pH conditions.
- ✓ **Water Interaction:** Free, bound and intermediate water assessed by DSC.
- ✓ **Mechanical Properties:** Tensile strength and stiffness using tensile mode.
- ✓ **Antibacterial Tests:** Activity against *E. coli* and *S. aureus*.
- ✓ **Drug Release:** Quetiapine fumarate loading and release kinetics (UV-Vis), fitted to Higuchi and Korsmeyer–Peppas models.

RESULTS & DISCUSSION

Chemical and Structural Confirmation

FTIR spectra showed clear evidence of chitosan incorporation and genipin crosslinking. The appearance of **amide I and II bands** and **C–N stretching** confirmed successful modification of the BC matrix. These changes were absent in untreated BC, demonstrating effective semi-interpenetrating (IPN) hydrogel formation.

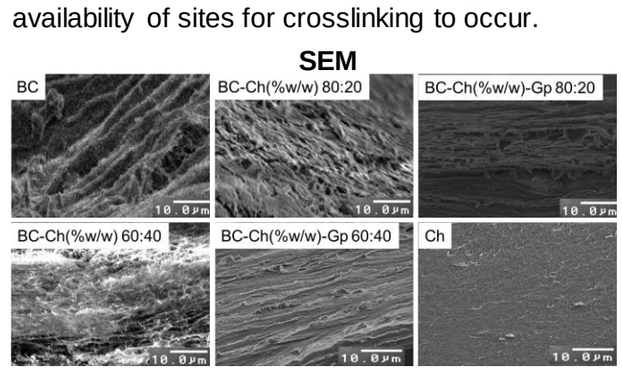


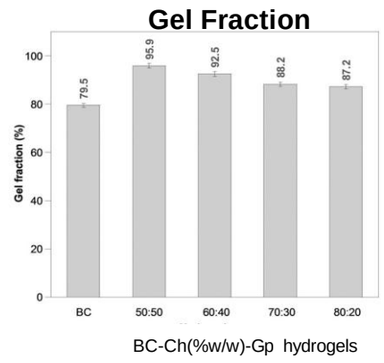
Morphology and Network Organisation

SEM revealed that pure BC had a loose nanofibrillar structure.

- **BC/Ch** became denser due to chitosan deposition within the cellulose network.
- **BC/Ch/Gp** showed the most compact fibril arrangement with visible junction points, indicating stable crosslink formation and enhanced structural integrity.

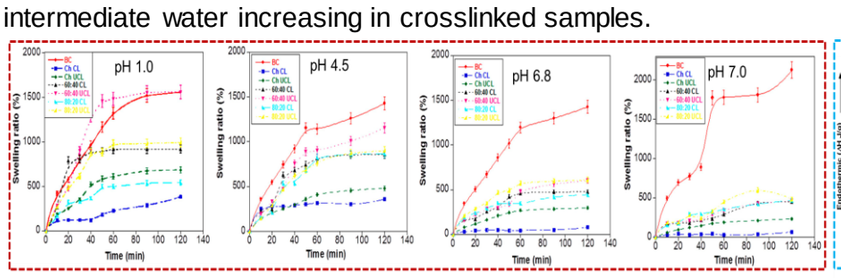
Gel fraction increased with increasing chitosan content in the hydrogel as a result of the availability of sites for crosslinking to occur.



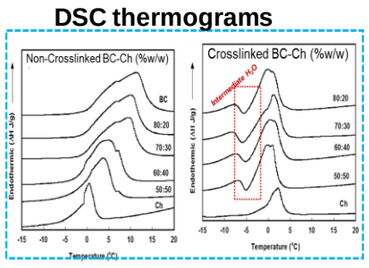


Swelling Behaviour and Water Interactions

Swelling studies showed that BC had the highest water uptake, while BC/Ch and BC/Ch/Gp displayed reduced swelling due to increased network density. All hydrogels exhibited pH-responsive swelling, with significantly higher uptake in acidic conditions owing to chitosan protonation. DSC confirmed distinct proportions of free, bound, and intermediate water, with intermediate water increasing in crosslinked samples.



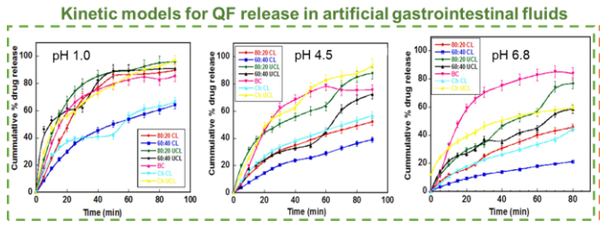
DSC thermograms



Drug Loading and Release Kinetics

Plots Acronyms: CL = Crosslinked; UCL = Non-crosslinked

Kinetic models for QF release in artificial gastrointestinal fluids



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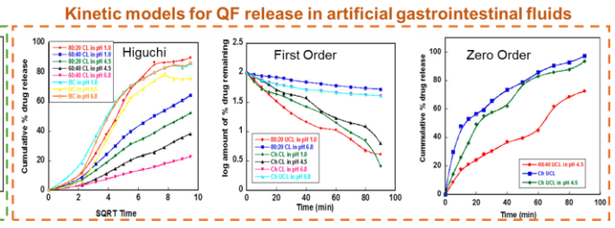
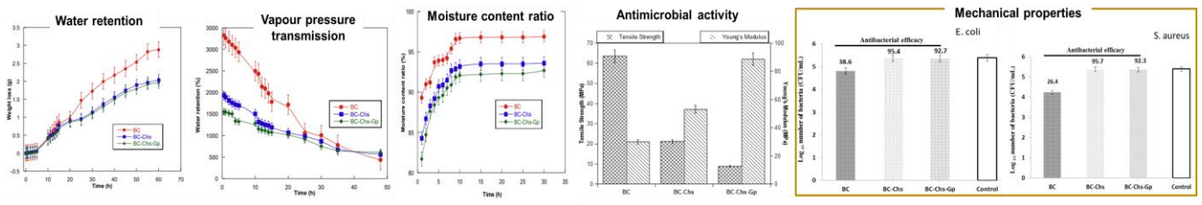


Water Retention, Vapour Pressure Transmission, Mechanical and Antimicrobial Properties



CONCLUSION

This work developed a nature-derived semi-IPN hydrogel by combining bacterial cellulose from coconut water with chitosan and genipin crosslinking. The dual-step modification improved chemical functionality, mechanical stability, pH-responsive swelling and antibacterial activity. Drug-release studies confirmed controlled, diffusion-driven release suited for biomedical use. Overall, the BC/Ch/Gp network provides a simple, safe and tunable platform for wound-healing and sustained drug-delivery applications.

FUTURE WORK / REFERENCES

Future Work

- ✓ Optimise crosslinking and swelling behaviour while expanding drug-loading to additional therapeutics.
- ✓ Evaluate long-term biocompatibility, degradation and scalability using natural feedstocks.
- ✓ Develop multilayer or composite formats for advanced wound-care applications.

References

1. Arikibe et al., J. Appl. Biosci. 2021, 162: 16675 - 16693
2. Arikibe et al., ChemistrySelect 2019 4 (34):9915-9926
3. Arikibe et al., Key Eng. Mater. 2020, 841, 238–242