A Novel Electrospun Probiotic Delivery Platform for Enhanced Gut Microbiota Modulation

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Introduction

Emerging evidence suggests the crucial role of the gut microbiota in maintaining intestinal homeostasis, with gut dysbiosis often linked to metabolic, inflammatory, and neurological diseases. Thus, modulating gut microbiome represents a promising therapeutic avenue [1].
Oral probiotic supplementation offers a non-invasive way to restore microbial balance. However, the complexity of the gastrointestinal (GI) tract poses significant challenges, including low bioavailability, limited intestinal colonization, and poor treatment adherence due to repeated dosing [2]. To overcome these issues, novel encapsulation strategies are being explored to improve probiotic viability and prolong their retention at colon site. Within this context, electrospinning represents a cost-effective technique for fabricating micro- and nano-fibrous carriers with high surface area and tunable porosity, which support effective cargo encapsulation [3].
This study investigates the production and characterization of probiotic-laden sodium alginate (SA) and corn starch (S_c) electrospun fibers as a potential platform for sustained colonic release of probiotics. SA provides a mucoadhesive and pH responsive matrix, while S_c acts as a prebiotic supporting bacteria viability.
This approach offers a promising strategy for efficient probiotic delivery and long-term colon-targeted action, potentially enhancing gut microbiota modulation.

Materials and Methods

SA/S_c-based solutions were prepared by incorporating S_c into a SA/Poly(ethylene oxide)(PEO) aqueous solution at different concentrations. These formulations were electrospun under optimized conditions and crosslinked in a $CaCl_2$ ethanol/water bath. Rheological characterization was conducted to assess viscosity, while Fourier Transform Infrared Spectroscopy (FTIR) evaluated chemical composition before and after crosslinking. Fiber morphology was examined using scanning electron microscopy (SEM).
The optimal SA/S_c-based formulation, selected based on electrospinnability and fiber morphology, was loaded with commercial lyophilized probiotics. SEM analysis was repeated for probiotic-laden fibers, with probiotic encapsulation assessed via DAPI staining, while probiotic viability post-encapsulation was evaluated using a modified AlamarBlue test, specifically adapted for bacterial metabolism assessment.

Results

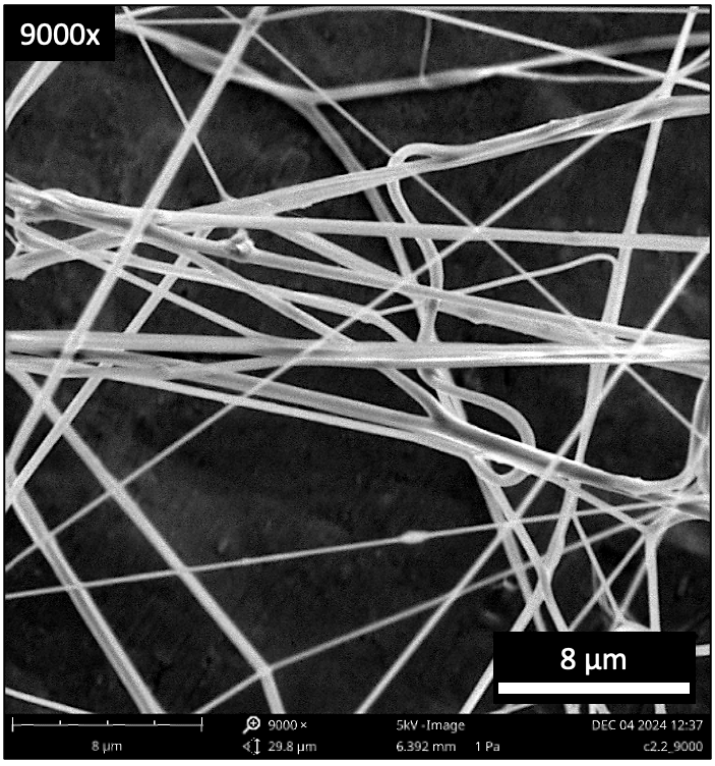
SA/S_c-based solutions were successfully electrospun, with the optimal formulation yielding continuous ultrafine fibers, with a diameter of 402 ± 90 nm. Rheology revealed a weak shear-thinning behavior, favoring fiber formation. Crosslinking increased fiber diameter to 515 ± 127 nm and removed PEO, resulting in pure SA/S_c fibers, as confirmed by FTIR. Probiotic-laden fibers were successfully produced with a diameter of 217 ± 85 nm, which increased to 452 ± 125 nm, after crosslinking. SEM imaging demonstrated effective probiotic incorporation, further validated by DAPI staining, while AlamarBlue assay confirmed that probiotics remained metabolically active within fibers after processing.

Discussion

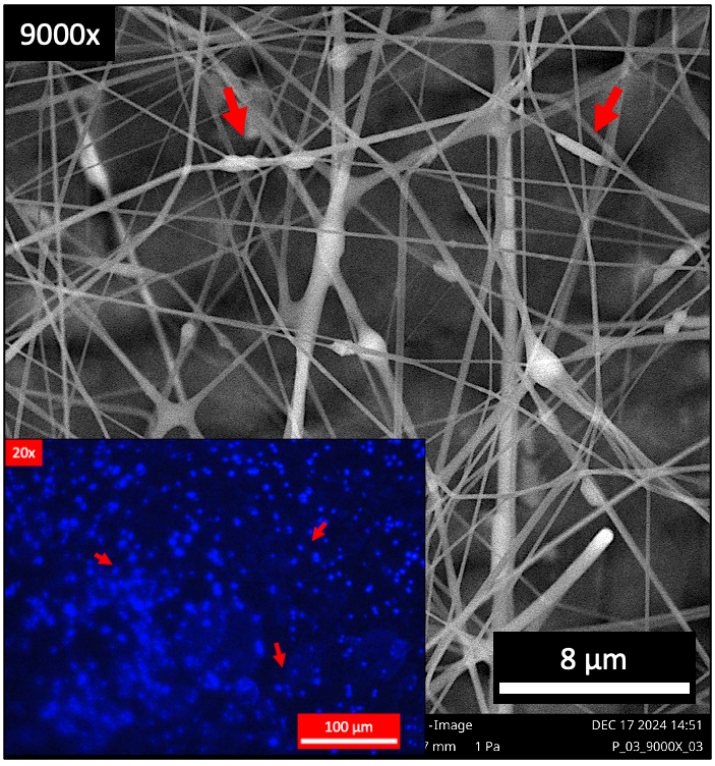
Electrospinning enabled the fabrication of continuous, ultrafine SA/S_c fibers, with crosslinking ensuring their structural integrity. Probiotic encapsulation did not hinder fiber formation, and crosslinking effects remained consistent across formulations, supporting the feasibility of this carrier for targeted probiotic delivery. Fluorescence analysis verified the successful incorporation of probiotics into fibers, while metabolic activity assay demonstrated that encapsulated bacteria were still viable after processing, highlighting the platform's potential for maintaining probiotic functionality.

Conclusions

This study demonstrates the successful fabrication of ultrafine probiotic-laden SA/S_c electrospun fibers, as a novel biomaterial-based platform for colonic delivery and sustained release of viable probiotics. Future research should evaluate the long-term probiotic viability and explore their therapeutic efficacy in gut microbiota modulation.



SEM micrograph of SA/S_c fibers, acquired at magnification 9000× and 15 kV.



SEM micrograph of probiotic-laden SA/S_c fibers, acquired at 9000× magnification and 15 kV; optical microscope insert (in lower left) shows DAPI staining of probiotics within SA/S_c fibers at 20× magnification. Red arrows indicate probiotics.

References

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