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عنوان مقاله :

**Development of eco-friendly chitosan films enhanced with bioactive citric acid-based deep eutectic agents for sustainable food packaging and fish preservation**

چکیده :

This study explores the development of chitosan (CS) films enhanced with citric acid-based deep eutectic agents (CA-DEA) to address the dual challenges of sustainable food packaging and effective fish preservation. CA-DEA was synthesized using citric acid (CA) and choline chloride (ChCl) in molar ratios of 1:1, 2:1, 3:1, and 4:1, with the synthesis confirmed through FTIR analysis. Among these, the 4:1 M ratio, identified as the most effective formulation for its superior antibacterial properties against *E. coli* ( $17.3 \pm 0.78$  mm) and *S. aureus* ( $23.625 \pm 0.09$  mm), was further evaluated at varying concentrations (0.5 %, 1 %, 1.5 %, and 2 %) to examine its effects on the structure and functional properties of CS films. Mechanical testing revealed that films with 0.5 % CA-DEA achieved the highest tensile strength (TS;  $47.98 \pm 2.40$  MPa), while higher concentrations led to decreased TS ( $13.59 \pm 1.37$  MPa), likely due to over-plasticization. The incorporation of CA-DEA enhanced the films' antibacterial, antioxidant, and UV-barrier properties, significantly improving their bioactivity. As a bioactive coating on tilapia fillets, the incorporation of CA-DEA formulation effectively reduced water loss, preserved protein, controlled TVB-N levels, and extended shelf life, showing the most effective preservation results. This study highlights CA-DEA's multifunctionality as a bioactive plasticizer, offering a sustainable alternative to conventional packaging and advancing eco-friendly preservation technologies for perishable aquatic products.