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Development and application of Humidity-Responsive Controlled Release Active Packaging Based on Electrospinning Nanofibers and In Situ Growth Polymeric Film in Food preservation

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Abstract : Fresh produces especially fruits, vegetables, meats and aquatic products have limited shelf life and are highly susceptible to deterioration. Essential oils (EOs) extracted from plants have excellent antioxidant and broad-spectrum antibacterial activities, and they can play as natural food preservatives. But EOs are volatile, water insoluble, pungent, and easily decomposing under light and heat. Many approaches have been developed to improve the solubility and stability of EOs such as polymeric film, coating, nanoparticles, nano-emulsions and nanofibers. Construction of active packaging film which can incorporate EOs with high loading efficiency and controlled release of EOs has received great attention. It is still difficult to achieve accurate release of antibacterial compounds at specific target locations in active packaging. In this research, a relative humidity-responsive packaging material was designed, employing the electrospinning technique to fabricate a nanofibrous film loaded with a 4-terpineol/β-cyclodextrin inclusion complexes (4-TA/β-CD ICs). Functioning as an innovative food packaging material, the film demonstrated commendable attributes including pleasing appearance, thermal stability, mechanical properties, and effective barrier properties. The incorporation of inclusion complexes greatly enhanced the antioxidant and antibacterial activity of the film, particularly against Shewanella putrefaciens, with an inhibitory efficiency of up to 65%. Crucially, the film realized controlled release of 4-TA under 98% high relative humidity conditions by inducing the plasticization of polymers caused by water molecules, swelling of polymer chains, and destruction of hydrogen bonds within the cyclodextrin inclusion complex. This film with a long-term antimicrobial effect successfully extended the shelf life of Litopenaeus vannamei shrimp to 7 days at 4 °C. To further improve the loading efficiency and long-acting release of EOs, we synthesized the γ-cyclodextrin-metal organic frameworks (γ-CD-MOFs), and then efficiently anchored γ-CD-MOFs on chitosan-cellulose (CS-CEL) composite film by in situ growth method for controlled releasing of carvacrol (CAR). We found that the growth efficiency of γ-CD-MOFs was the highest when the concentration of CEL dispersion was 5%. The anchoring of γ-CD-MOFs on CS-CEL film significantly improved the surface area of CS-CEL film from 1.0294 m2/g to 43.3458 m2/g. The molecular docking and 1H NMR spectra indicated that γ-CD-MOF has better complexing and stabilizing ability for CAR molecules than γ-CD. In addition, the release of CAR reached 99.71±0.22% on the 10th day, while under 22% RH, the release pattern of CAR was a plateau with 14.71 ± 4.46%. The inhibition rate of this film against E. coli, S. aureus and B. cinerea was more than 99%, and extended the shelf life of strawberries to 7 days. By incorporating the merits of natural biopolymers and MOFs, this active packaging offers great potential as a substitute for traditional packaging materials.

Keywords : active packaging, antibacterial activity, controlled release, essential oils, food quality control
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