Advanced Multifunctional Waste-Derived Biodegradable Nanocomposite Film for Enhanced Postharvest Fruit Preservation and Volatile Aromatic Compound Retention

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Postharvest losses of fresh fruits are primarily driven by physiological processes, including respiration, transpiration, and ethylene release, which accelerate ripening and quality deterioration, particularly through the degradation of carotenoids that directly affect market value. While petroleum-based plastic packaging can extend shelf life, it poses significant environmental concerns, and current biodegradable films remain limited by insufficient mechanical strength and moisture stability. This study developed a multifunctional biodegradable nanocomposite film derived from agricultural and food-processing waste materials. Cellulose and carboxymethyl cellulose (CMC) were extracted from rice straw, chitosan oligosaccharide (COS) from shrimp shells, and inositol hexakisphosphate (IP6) from rice bran to form a crosslinked polymer matrix. Zinc oxide nanoparticles (ZnO NPs), potassium permanganate ($KMnO_4$), and micro-activated carbon (MAC) were incorporated to enhance carotenoid preservation, ethylene adsorption, and moisture regulation. The optimal formulation (Cellulose:CMC:COS = 37.5:37.5:25 w/w) exhibited enhanced mechanical properties and structural stability, with ZnO NPs = 1.0 wt%, $KMnO_4$ = 1.0 wt%, and MAC = 2.0 wt% maintaining functional performance without compromising film integrity. Under real storage conditions, the developed film effectively delayed fruit ripening and reduced quality degradation compared to commercial plastic packaging. These findings highlight the potential of waste-derived multifunctional films as a scalable and sustainable alternative for postharvest fruit preservation, contributing to reduced food loss and advancing circular economy approaches in food packaging systems.

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