Next-Generation Active Packaging: zein-based biocomposites functionalized with antioxidants from agrifood wastes

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In a global context where sustainability, food safety, and waste reduction are increasingly urgent priorities, the development of innovative packaging systems plays a pivotal role. Modern food packaging is no longer limited to passive containment; it is evolving into an active, functional interface capable of interacting with the product and its environment to extend shelf-life, preserve quality, and minimize environmental impact. Among the most promising solutions are active packaging systems incorporating natural compounds that can exert antioxidant or antimicrobial effects. These systems offer dual benefits: improving food preservation and promoting circular economy strategies through the valorization of agro-industrial by-products. This study focuses on the development of biodegradable active packaging based on zein, a hydrophobic prolamin protein extracted from corn. Zein-based films were produced using solvent casting and electrospinning and functionalized with antioxidants extracted via non-conventional extraction techniques from agricultural waste, including fruit peels and spent coffee grounds, high-added value substances rich in polyphenols and other bioactive molecules. The resulting materials were characterized in terms of morphological properties (via SEM), surface wettability (contact angle), mechanical performance (tensile strength, Young's modulus), and gas barrier behavior (O_2 and CO_2 permeability). The results demonstrated that the incorporation of natural antioxidants significantly influenced the microstructure and functional properties of the packaging, enhancing flexibility, hydrophobicity, and gas barrier efficiency. In particular, electrospun zein structures showed potential for controlled release applications due to their high surface-area-to-volume ratio. This work highlights the potential of combining biodegradable polymers with waste-derived antioxidants to develop next-generation active food packaging materials that are both environmentally and functionally advanced.

Keywords: *Electrospinning; Solvent casting; Polyphenols; Barrier properties; Biopolymer films; Circular economy*