Sustained Intestinal Release and Enhanced Bioaccessibility of Cinnamon Essential Oil from Cold Plasma-Modified Nanocarriers

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The increasing demand for natural food bioactives necessitates the development of clean-label and efficient carriers. In this study, a plant protein-polysaccharide complex was designed using pea protein isolate (PPI) and sodium alginate (AG) to encapsulate cinnamon essential oil (CEO). Cold plasma (CP) treatment was used as a non-thermal modification technique to enhance functionality. Different PPI:AG ratios (1:1 to 8:1) were tested, and the 3:1 ratio was found to be optimal based on particle size and polydispersity index (PDI). CP treatment (60 W for 4 min) significantly altered the surface properties and structure, as evidenced by SEM and FTIR, promoting higher encapsulation efficiency (EE) and water solubility compared to the untreated samples. The CEO-loaded PPI-AG nanoparticles exhibited improved physicochemical properties, including color, oxidative, and thermal stability. Structural alterations, such as increased β-sheet and β-turn content, support plasma-induced conformational changes. In vitro digestion using the INFOGEST model demonstrated a sustained release pattern of CEO with enhanced release during the intestinal phase from the CP-treated encapsulation systems, indicating improved bioaccessibility of encapsulated oil. The cytotoxicity and biocompatibility of the plasma-treated PPI-AG delivery system were evaluated using the MTT assay, which revealed that the treated delivery system maintained high cell viability, confirming its safety for food and nutraceutical applications. Overall, this study demonstrates that cold plasma serves as a green, non-thermal strategy for the functionalization of protein-hydrocolloid matrices for improved delivery of sensitive bioactives. This approach is promising for developing sustainable, stable, and functional food systems.

Keywords:

Cold plasma, Pea protein isolate, Sodium alginate, Cinnamon oil, Biopolymer encapsulation, Bioaccessibility, Cytocompatibility

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