

Development of pH-Responsive and Antioxidant Bio-Based Aerogels for Smart Packaging Applications Incorporating Passion Fruit Pericarp Extract

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Abstract

Smart packaging is an emerging system that provides real-time information on food freshness and quality through visible color changes during transportation and storage [1]. Growing concerns over the safety of synthetic colorants (e.g., polyaniline, methyl red, and chlorophenol red) have accelerated the development of intelligent packaging materials incorporating natural pigments [2]. In this study, a multifunctional bio-based aerogel was developed using sodium alginate (SA), chitosan (CS), and nanocellulose (NC) as the structural matrix, cross-linked with sodium tripolyphosphate (STPP), and incorporated with purple passion fruit pericarp extract (PFPE) at varying concentrations. The addition of PFPE significantly altered the optical properties of the aerogels, resulting in decreased lightness (L^*) and increased redness (a^*), blueness (b^*), and total color difference (ΔE), with changes positively correlated to anthocyanin content. Thermogravimetric analysis revealed a three-stage degradation process, including moisture evaporation (30–230 °C), polymer decomposition (230–350 °C), and carbon skeleton breakdown (350–900 °C). PFPE incorporation enhanced thermal stability, yielding a residual mass of approximately 24% at high temperatures. The aerogels exhibited distinct pH-responsive color transitions, consistent with PFPE behavior: red under acidic conditions (pH 2–3) due to flavylum cations, pale pink at pH 4–6 from carbinol base formation, and brown to green hues at pH 7–12 due to quinoidal and chalcone structures. These properties demonstrate strong potential for real-time freshness monitoring. Additionally, the aerogels showed improved color stability at 4 °C compared to 25 °C. The PFPE-15 formulation exhibited notable antioxidant activity, with DPPH and ABTS scavenging rates of 12.74% and 19.60%, respectively. Overall, the developed CS/STPP/SA/NC/PFPE aerogel demonstrates excellent stability, sensitivity, and bioactivity, indicating strong potential as a smart indicator for fish freshness in intelligent packaging applications.

References

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