Synthesis of a Chitosan–Carrageenan-Based Bigel Using Aquatic Lipid as a Sustainable Liquid Phase for Fat-Reduced Chocolate

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Abstract

Fat reduction in chocolate confectionery can be achieved by partially replacing cocoa butter with structured systems such as bigels. Bigels are biphasic systems consisting of hydrogel and oleogel domains, which form interpenetrated networks to deliver both aqueous and lipid functionalities. In this study, a bigel system based on chitosan and kappa-carrageenan hydrogels incorporated into an oleogel matrix was synthesized and applied as a sustainable fat substitute in chocolate products. The oleogel was prepared using an aquatic lipid phase derived from a freshwater aquaculture by-product, characterized by low polyunsaturated fatty acid content and favorable sensory attributes. Compared to commercial plant-derived oils, this lipid source exhibited no detectable fishy odor, making it highly suitable for incorporation into sweet confectionery systems. Three ratios of hydrogel-forming agents (chitosan:kappa-carrageenan = 25:75, 50:50, and 75:25) were evaluated in terms of oil binding capacity (OBC), thermal behavior, viscoelastic properties (frequency sweep), and proximate composition of the final chocolate formulation. The color, total fat content, and total energy were also assessed to determine the functional performance of the bigel system. Among all tested formulations, the 50:50 chitosan–kappa-carrageenan ratio exhibited the highest oil binding capacity (98.75%) and stable thermal characteristics, as indicated by a melting point shift on the thermogram, suggesting strong internal structuring and oil entrapment. The incorporation of this bigel (contain chitosan) into the chocolate matrix resulted in a significant reduction in total fat content compared to commercial chocolate, while maintaining acceptable physical properties. These findings demonstrate the potential of sustainable hydrogel-in-oleogel systems as functional fat replacers in chocolate products. Furthermore, the valorization of aquatic by-products as alternative lipid sources offers a promising strategy to enhance the sustainability and nutritional profile of confectionery formulations.

Keywords: chocolate, indirect gelation, hydrogel-in-oleogel, pangasius oil.