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Spirulina Protein-Carrageenan Gel Systems as Green Structuring Platforms for Sustainable Food Design: Emulsion Gel and Hydrogel

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Abstract

Developing sustainable food products requires ingredients that are not only nutritious but also able to perform well in complex food systems. *Spirulina platensis* protein is a promising microalgal protein source [1], while carrageenan can help build gel networks through protein–polysaccharide interactions. This work brings together three related studies to show how spirulina protein can be extracted, structured, and applied in different food matrices. Ultrasound-assisted extraction was first used to improve the recovery and functionality of spirulina protein. The optimum extraction condition was obtained at 80% amplitude for 30 min with a 60% duty cycle, increasing protein yield from 32.48% to 76.83% [2]. The extracted protein also showed better in vitro digestibility, increasing from 16.08% to 33.44%. Its functional properties were also improved, including water-holding capacity from 4.39 to 5.97 g/g, emulsifying stability from 21.10 to 98.17 min, foaming capacity from 40.56% to 90.00%, and foaming stability from 35.85% to 79.17% [2]. The extracted spirulina protein was then combined with carrageenan to form hydrogel and emulsion gel systems. In the hydrogel system, a higher carrageenan proportion produced stronger gel characteristics, with a hardness of 58.35 N, cohesiveness of 0.56, gumminess of 32.86 N, chewiness of 25.81 N, springiness of 0.78, and water-holding capacity of 97.40% [3]. Freeze–thaw treatment further altered the gel structure, and two cycles yielded a porous, texturized spirulina hydrogel with a hardness of 69.06 N and a swelling ratio of 241.07% [3]. When used in sausages, 50% substitution with texturized spirulina hydrogel reduced fat content while increasing moisture and ash content. In the emulsion gel system, spirulina protein–carrageenan was used to stabilize red palm oil at oil levels of 30–50%. The emulsion gel containing 50% red palm oil exhibited the highest hardness, 9.5 N [4]. When applied as an animal fat replacer in beef patties, the red palm oil emulsion gels improved emulsion stability, reduced cooking loss and shrinkage, and helped retain fat and water during grilling. The grilled patties contained β-carotene of 69.68–129.77 ppm, peroxide value of 1.55–5.96 mEq O_2/kg, and hardness of 96.56–119.85 N [4]. Overall, these findings show that spirulina protein can be developed into versatile gel-based systems through carrageenan-assisted structuring. The same protein–polysaccharide combination can be directed into hydrogels for texturized food applications or red palm oil emulsion gels for fat replacement. This approach supports the development of clean-label, functional, and sustainable food products using microalgal protein as a green structuring ingredient.

References

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