Pea protein hydrogels: influence of protein concentration, pH and ultrasound-assisted gelation

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Introduction

Increasing sustainability expectations have renewed interest in plant-based foods, but texture and formulation stability remain difficult to achieve. Plant-protein hydrogels are promising, although pea protein frequently forms weak or poorly structured gels [1]. In this research, a comprehensive characterization of pea-protein gelation, varying the concentration and pH was performed, followed by the application of HIU to improve the quality properties of the heat-induced gels.

Methods

Firstly, protein dispersions from pea protein isolate (86.1%) were prepared at varying concentration (5–17.5% *w/w*) and pH (pH 3 or pH 7). Protein dispersions were characterized in terms of flow behaviour using a rheometer (Discovery HR10, TA Instruments) and particle size (Mastersizer 3000, Malvern Instruments). Subsequently, hydrogels were prepared by heat-induced gelation and characterized in terms of structural, mechanical, and functional properties, including rheology, textural properties, water-holding capacity, and microstructure. Secondly, pea protein dispersions at pH 3 and at 10, 12.5, 15, and 17.5% (*w/w*) were prepared and treated with HIU (50% amplitude, pulsed mode, 4 min), and subsequent hydrogels were produced by heat-induced gelation. After HIU treatment, both protein dispersions and the subsequent hydrogels were characterized as previously described.

Results and discussion

Increasing the pea protein concentration enhanced the structural properties of the heat-induced hydrogels, as seen by an increased hardness, with values from 8.28 ± 0.39 g at a protein concentration of 5% (*w/w*) up to 579.75 ± 112.08 g at a concentration of 17.5% (*w/w*). In addition, self-standing pea protein hydrogels were only obtained at concentrations of 15% (w/w) or higher. These findings were in line with other structural properties of the hydrogels. An increase in the pea protein concentration formed hydrogels with higher water-holding capacity and increased complex modulus values (G*), indicating a more solid-like behaviour. This was also confirmed by confocal microscopy images, showing a more compact structure. With regard to the influence of pH, protein suspensions at pH 3 formed harder gels than at pH 7. For instance, at a fixed 17.5% (*w/w*) protein concentration, hydrogels formed at pH 3 had a hardness of 579.75 ± 112.08 g, while those formed at pH 7 had a hardness of 74.75 ± 18.74 g. Hence, these results evidence that protein concentration and pH are crucial factors determining hydrogel properties.

Regarding the suspensions, HIU treatment significantly ($p < 0.05$) reduced the particle size D[3,2] at concentrations from 10 to 15% (*w /w*), indicating aggregate disruption due to the cavitation effect. Furthermore, HIU increased the apparent viscosity in the shear range evaluated (0.01-1000 s^{-1}), which may suggest conformational changes in the protein structure.

With respect to the hydrogels, the HIU treatment lowered the minimum concentration of protein required to form a self-standing hydrogel to 12.5% (*w/w*). Both rheological tests, temperature ramp and frequency sweep, confirmed the formation of gels, where G′> G'', which indicates a more solid-like behaviour. Also, HIU treatment improved the mechanical and functional properties of the gels, as they increased in their hardness (up to 6.8-fold after HIU treatment) and water-holding capacity (up to 1.9-fold after HIU treatment). Microstructural analysis revealed more organized networks with smaller and more homogeneous aggregates.

Conclusions

Stronger gels can be formed at higher pea protein concentrations and at pH 3. In addition, HIU may be an effective strategy to reduce the concentration required for pea protein hydrogel formation and to improve their textural properties and homogeneity. Beyond the factors studied, this work advances the formulation of tailor-made hydrogels with specific mechanical and functional properties for diverse plant-based food applications.

References:

[1] Ma, Y., & Chen, F. (2023). Plant Protein Heat-Induced Gels: Formation Mechanisms and Regulatory Strategies. *Coatings* , *13* (11), 1899.

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