

Mechanisms Responsible for Gelation during High-Temperature Treatment of Whey Protein Aggregates

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Whey protein nanogel particles are promising functional ingredients for beverage applications due to their lower viscosity dependence on protein concentration compared to other whey protein aggregates. This is of special interest for application in ultra-high temperature (UHT) treated beverages. However, the mechanisms governing interactions between the particles and with other food matrix components such as minerals during high-temperature processing remain uncharacterized, limiting control over their functional properties after processing.

In this study, phase diagrams were established for whey protein nanogel dispersions treated under UHT conditions (143 °C, 5 s), exploring the effects of protein and nutritionally relevant mineral concentrations. Dispersions in the transition region were studied using laser diffraction and confocal laser scanning microscopy (CLSM) to assess structural modifications post-treatment. CLSM revealed spherical particles with consistent morphology and size, with some aggregated particles present after UHT treatment. These observations were supported by laser diffraction data, and no changes in the overall single-particle structure were observed in dispersions that remained liquid.

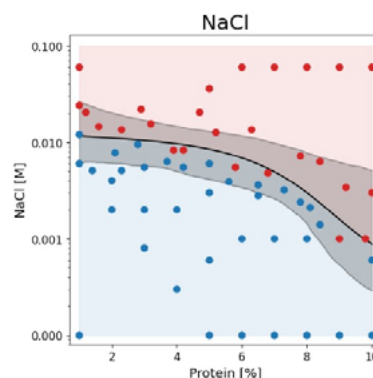
Temperature-dependent structural development was further investigated by diffusing wave spectroscopy (DWS) during heating up to 150 °C. Dispersions with varying mineral concentrations exhibited a transition from liquid-like to solid-like behavior at a mineral concentration-dependent temperature, with structural rearrangements becoming more pronounced with prolonged heating and subsequent cooling. Visual inspection confirmed flocculation at higher mineral concentrations after the temperature cycle.

Additionally, UHT treatment led to an increase in non-native peptide crosslinks formed via a dehydroalanine intermediate, as quantified by liquid chromatography-mass spectrometry. These results correlate with the DWS observations, confirming that structural changes and network formation in the dispersions are strongly dependent on temperature. This indicates that an energy barrier exists for the gelation of the dispersed whey protein nanogel particles.

Collectively, these findings advance the mechanistic understanding of gelation in whey protein nanogel systems under processing-relevant conditions. This knowledge supports the design of protein-rich beverages subjected to high-temperature processing.

Keywords:

whey protein aggregates, UHT treatment, minerals, phase diagrams, gelation, colloidal stability, pH, heat treatment, thiol reactions



Phase diagram of β -lg nanogel particle dispersions after UHT treatment as a function of protein and an added NaCl. Red points represent a gel, and blue points represent a liquid. The grey area represents a 95 % confidence interval for the boundary.