frontiers in Soft Matter

TYPE Review
PUBLISHED 19 August 2026
DOI 10.3389/frsfm.2026.1881300

OPEN ACCESS

EDITED BY
Daniela Lamas,
Institute of Marine and Coastal Research (IIMyC), Argentina

REVIEWED BY
Alkatuzzakia Akhi,
Bangladesh Agricultural University, Bangladesh
Ge Xu,
Nanjing Normal University, China

*CORRESPONDENCE
Owais Yousuf,
mirowais33@gmail.com

RECEIVED 14 May 2026
REVISED 15 July 2026
ACCEPTED 17 July 2026
PUBLISHED 19 August 2026

CITATION
Majeed N, Younis K and Yousuf O (2026) Multiscale structural modulation of plant proteins via ultrasound and electro-physical processing: from extraction to functional food matrices.
Front. Soft Matter 6:1881300.
doi: 10.3389/frsfm.2026.1881300

Multiscale structural modulation of plant proteins via ultrasound and electro-physical processing: from extraction to functional food matrices

Noorain Majeed[1], Kaiser Younis[2] and Owais Yousuf[1]*

[1]Department of Food Technology, Islamic University of Science and Technology, Pulwama, Jammu and Kashmir, India, [2]Department of Bioengineering, Integral University, Lucknow, Uttar Pradesh, India

The transition toward sustainable food systems has increased interest in plant proteins as alternatives to animal-derived proteins due to their lower environmental impact, including reduced greenhouse gas emissions, land use, and resource demand. However, their broader application is constrained by structural characteristics that limit solubility, interfacial behaviour, digestibility, and sensory performance. Many plant proteins exhibit compact globular structures stabilized by strong intermolecular interactions, restricting their functionality in complex food systems. These structural constraints operate across a hierarchy of scales, from the molecular conformation of secondary and tertiary structures to the micro- and macro-structural organisation of protein aggregates, interfacial films, and gel networks, and it is this multiscale organisation that ultimately governs functional performance in complex food matrices. Non-thermal processing technologies, namely, ultrasound, pulsed electric fields (PEF), and cold plasma, together with the electro-thermal technique of ohmic heating, offer promising approaches for modifying protein structure without causing extensive thermal damage. These methods can induce partial unfolding, alter aggregation behaviour, and enhance the exposure of functional groups, thereby improving solubility, emulsification, and gelation properties. This review adopts an explicit multiscale framework to link molecular-level conformational changes to microstructural aggregation and macroscopic structure–property relationships. It summarizes the mechanisms, functional impacts, and industrial relevance of these technologies in plant protein processing. Building on this analysis, the review evaluates the principal technical bottlenecks, the economic and industrial scalability, and the priority directions for future research on non-thermal and electro-thermal processing of plant proteins.

KEYWORDS
cold plasma, electro-thermal processing, non-thermal processing, plant proteins, pulsed electric fields, structure–property relationships, sustainable food systems, ultrasound