Emerging Pulsed Electric Field Treatment for Food and Bio Processing

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The bio-based industry is urged to find solutions to meet the demands of a growing world population. In this context, increased resource efficiency is a major goal. Pulsed electric field (PEF) processing is a promising technological solution. Conventional PEF and the emerging area of nanosecond PEF (nsPEF) have been shown to induce various biological effects, with nsPEF inducing pronounced intracellular effects, which could provide solutions for currently faced challenges. Based on the flexibility and continuous operation of PEF and nsPEF processing, the technology can be integrated into many existing cultivation systems; its modularity provides an approach for inducing specific effects. Depending on the treatment conditions, selective inactivation, continuous extraction without impeding cell viability, as well as the stimulation of cell growth and/or cellular compound stimulation are potential applications in food- and bio processing. However, continuous treatment currently involves heterogeneous energy inputs. Increasing the homogeneity of PEF and nsPEF processing by considering the flow and electric field heterogeneity may allow for more targeted effects on biological cells, further increasing the potential of the technology for bio-based applications. We will give an overview of emerging applications of PEF and nsPEF applications enabled by a thorough process characterization and control.

Process characterization and control

The application of PEF and nsPEF in food- and bio processing requires a comprehensive process characterization. Pulse measurement in the domain of PEF processing can be related to a sole Ohmic response of the load, however for nsPEF processing this relation does not hold any longer and a novel theoretical relation had to be derived integrating the frequency dependent complex impedance of the load, allowing for matched load conditions.

Moreover, in continuous PEF/nsPEF processing, the flow field is of utmost importance in order to induce targeted cellular effects and allow for a scalable system. Therefore, the flow field in continuous PEF/nsPEF processing and its influencing factors were analyzed and energy input distributions in PEF treatment chambers were investigated. The results were obtained using an interdisciplinary approach that combined multiphysics simulations with ultrasonic Doppler velocity profiling (UVP) and rheological measurements of *Arthrospira platensis* suspensions as a case study for applications in the bio-based industry. *A. platensis* suspensions follow a non-Newtonian, shear-thinning behavior, and measurement data could be fitted with rheological functions, which were used as an input for fluid dynamics simulations. Non-invasive validation of multiphysics simulations was enabled integrating UVP. The novel approach to combine multiphysics simulation with rheological measurements and non-invasive UVP validation enabled a comprehensive PEF system characterization and control.

Emerging PEF/ nsPEF applications in food and bio processing

Depending on process parameters, a reversible or irreversible effect can be induced. Most current applications are focused on irreversible electropermeabilization, including non (minimal)-thermal pasteurization, enhanced drying rates, increased extraction yields, tissue softening as well as electrochemotherapy, and tumor ablation. Reversible electropermeabilization is typically used in molecular biology for the introduction of specific molecules, such as plasmids and antibodies, *in vivo.*

Based on the comprehensive PEF/ nsPEF system analysis, promising applications across different sectors (including targeted inactivation, the extraction of bioactive compounds, and the stimulation of cell growth and/or cellular compounds) (Figure 1) were achieved. Furthermore, we note that increasing the homogeneity of energy input may lead to further improvements in efficiency and a wider array of applications and therefore is a key area for future research.

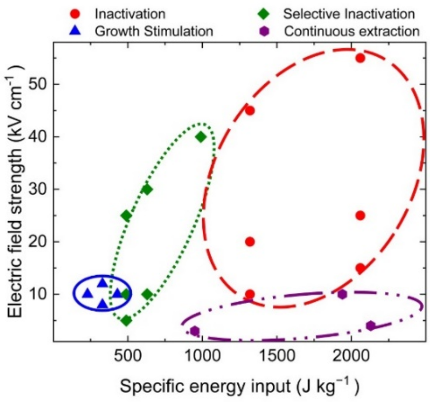

FIGURE 1 | Case study of the microalgae *Chlorella vulgaris* SAG 211-12, illustrating treatment windows for selective inactivation, inactivation of microbial flora and *C. vulgaris*, continuous extraction of high value-added ingredients, and growth stimulation.