Processing liquid food with hundreds of hertz and tens of kilovolts Comment on “advances in pulsed electric stimuli as a physical method for treating liquid foods” by F. Zare, N. Ghasemi, N. Bansal and H. Hosano

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In their extensive and outstandingly referenced review [1], F. Zare, N. Ghasemi, N. Bansal, and H. Hosano restrict on inactivation of microorganisms by pulsed electric field (PEF) technology for shelf-life enhancement of liquid foods. It excellently provides valuable insights into the current state of the art and potential applications of PEF technology in liquid food preservation and also highlights the need for alternatives to heat-based processing to provide safe and nutritious food at lower costs. The review also includes engineering principles, inactivation models and theories related to electroporation and electro-permeabilization which allows for a detailed and scientifically rigorous exploration of the subject.

Beyond the author’s focus, it should be pointed out, that PEF technology successfully approached market-entry in various other food industry applications, including but not limited to sugar extraction from sugar beets, wine production, potato chip manufacturing and fruit juice or oil extraction [2], which considerably accelerated PEF related technological advances in generator and auxiliaries developments. This in turn favored industrial applications on microbial inactivation. Nowadays high power (>600 kW) facilities operating at pulse repetition frequencies up to 100 Hz are commercially available to satisfy the mass-flow requirements in this sector.

In particular, the review addresses real challenges in PEF assisted liquid food pasteurization, such as providing a target value of 5 log reduction of pathogens (typically *salmonella, listeria*, and *E. coli*) for food safety. It should be mentioned that this value is a guideline value. Some applications require stricter safety criteria due to regulatory requirements [3].

All developments to date have taken place between the different demands of customers, industry and regulatory authorities. Different requirements have shaped the development process. Consumers are primarily concerned with food safety and maintaining food quality, i.e. preservation of sensory and nutritional properties or prevention of harmful field-induced by-products in PEF processed foods. Consumers increasingly favor fresh-like products with preserved sensory and nutritional qualities. However, conventional heat processing for pasteurization, can compromise these qualities, prompting a growing interest in non-thermal preservation technologies [4]. As this comprehensive review has shown, PEF treatment can inactivate micro-organisms with a small increase in temperature, providing fresh-like products with retained flavor and color properties and high nutritional value. This is also due to the fact that PEF exposure does not create additional radical oxygen species [5]. However, if significant amounts of metal ions, especially iron ions, are released from the electrodes a change in flavor, mouthfeel and a metallic taste may occur. This side effect can be minimized by using appropriate pulse protocols, such as bipolar pulses, frequencies above a critical frequency and pulses of short duration [6], and by using chemically inert titanium electrodes.

From the industry’s perspective, several factors play a crucial role in the decision to implement and commercialize a new

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technology. Some of these factors can be shaped by R&D. For instance, reducing maintenance and operating costs by developing pulse generators with solid-state switches that last longer. Treatment chambers are needed, that are resistant to electrical breakdown due to unavoidable gas bubbles in the liquid food. Utilization of less corrosive electrodes extends maintenance intervals. The development of scalable, „push-button" pulse generators offers companies flexibility and reduces the requirement for high-educated maintenance personal.

As bacterial inactivation is dose-dependent, suitable and optimized PEF protocols and combined treatments with heat recovery can help to reduce ongoing operating costs, in particular energy consumption [7]. Finally, the technology's effectiveness in delivering promised results and achieving operational goals, is paramount. The effectiveness of microbial inactivation must be guaranteed by the chosen PEF treatment method to meet the microbiological criteria for food safety, which states that "*foodstuffs should not contain micro-organisms or their toxins or metabolites in quantities that present an unacceptable risk for human health*" [8]. This can be a particular challenge as PEF treatment does not inactivate spores effectively, except in few cases or in combination with other methods [9].

Similar concerns have been raised about the use of PEF technology for environmental applications, e.g. in reducing pathogenic and antibiotic-resistant bacteria in hospital wastewater and preventing the spread of these opportunistic bacteria into the aqueous environment. In comparison to other existing decontamination techniques, the main advantage of PEF technology is, that no electro-tolerant bacteria are developed, and no mutagenic by-products are generated by repeated PEF treatments [10]. In addition, released enzymes, i.e. nucleases, are not denatured by PEF treatment, thus liberated bacterial DNA, carrying antibiotic resistances, will be digested, avoiding horizontal resistance-gene transfer [11]. These special properties of PEF treatment also made this technology attractive for use in the automotive industry for the disinfection of dip coatings and process water as an alternative to the use of biocides, which are suspected of inducing biocide-resistant bacteria and can be harmful to the environment and humans [12].

At current state, PEF technology for environmental applications still exhibits high energy and investment costs. The regulatory authorities are now called upon to initiate a technological change in this area. We are confident that established collaborations between Information Technology, Electrical Engineering, Agriculture, and Food and Environmental Sciences will result in future economic utilization of PEF technology in environmental applications, too.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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