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The Power of Pulses: Sustainable Fish Processing with Electric Fields

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Pulsed Electric Field (PEF) technology is an innovative nonthermal processing method gaining prominence for its ability to preserve foods while minimizing the degradation of sensory and nutritional qualities associated with conventional heat treatments. This article reviews the principles, historical development, and specific applications of PEF within the fish processing industry. The technique utilizes short, high-intensity electric field pulses to inactivate microorganisms via electroporation, effectively extending the shelf life of seafood products like shrimp. Beyond preservation, PEF enhances processing efficiency by improving the extraction yields of valuable compounds such as proteins and calcium from fish by-products, contributing to waste valorisation. The effectiveness of PEF is governed by key parameters including electric field strength, treatment time, pulse characteristics, and product conductivity. With advantages such as energy efficiency, minimal environmental impact, and the maintenance of product quality, PEF technology represents a sustainable and cutting-edge advancement for the future of fish processing and preservation.

Introduction

Nonthermal food processing methods are currently prominent worldwide and in recent years, research on them has expanded significantly. Inactivating the harmful bacteria and extending the food items' shelf life are the goals of conventional heat processing. Nonthermal processing was developed to add a fresh perspective to food preparation and preservation methods because of the drawbacks of thermal processing, such as the degradation of color, texture, and flavor. The purpose of the nonthermal approach was to eliminate the extra heat produced during the process, which causes negative consequences in different food systems (Preethi, 2024).

Millions of people globally rely on the seafood business for their food, jobs, and money, making it an essential component of the world's economy. In order to preserve seafood, processing methods are essential since they fulfill a number of purposes that enhance the product's overall quality and safety (Russo et al. 2023). Although there are many different approaches, the pulsed electric field (PEF) is an innovative nonthermal food processing and preservation technique. PEF processing offers significant benefits over conventional thermal processing, including reduced energy use, time savings, and the possibility of being an efficient processing method. Additionally, food products that get PEF treatment can retain their natural texture, flavor, color, and nutritional content (Preethi, 2024).

History of PEF

The historical development of Pulsed Electric Field (PEF) technology in the food processing sector spans over a century, beginning in 1890 when Prochownick and Spaeth investigated the bactericidal effects of electrical current. By 1920, Electropure was introduced in Europe and the USA, marking the first attempts at milk pasteurization. Between 1949 and 1953, Zagoruiko explored the effect of electrical currents on beet tissue, identifying a cell membrane breakdown process termed electroplasmolysis. In 1950, pulsed discharges were considered for electrohydraulic food treatment. By 1960, high electric fields were shown to induce artificial mutations, and PEF was applied for protein suspension using electro flocculation. In 1965, PEF technology was incorporated into canning factories to enhance juice yield and maintain color. The electroplasmolysis of apple mash was reported in 1968 by Flaumenbaum, and from 1980 to the mid-1990s, the Moldavian group developed electroplasmolyzators, with Hulsheper contributing a mathematical model for microbial inactivation using PEF (Preethi, 2024).

In 1980, Sakarauchi and Kondo employed a disk-shaped electrode to show the microbicidal effect of PEF. In 1984, Doevenspeck introduced pulsed electric fields to treat microbial cells in food material, enhancing inactivation effectiveness. In 1987, Dunn and Pearlman advanced microbial inactivation on fruit juices using 10 to 25 kV/cm, patented by PurePulse Technologies in San Diego. In 1988, using PEF led to the breakdown of animal materials like meat and fish in the Elcrack process. Between 1988 and 1990, pilot testing of juice and milk sterilization using PEF was conducted by Krupp. In 1991, Tsong demonstrated that PEF could form hydrophilic pores in phospholipids. By 1995, PurePulse Technologies developed the Cool Pure system for continuous juice processing. In 1996, Sitzmann used high-voltage techniques to study juice cell cracking. Finally, in 2006, large-scale prototypes for juice and sugar processing were developed in Germany, expanding PEF applications in the food industry (Preethi, 2024).

Principles of PEF processing

The fundamental idea behind PEF technology is the use of brief bursts of strong electric fields with intensities between 10 and 80 kV/cm and durations ranging from microseconds to milliseconds. The processing time is determined by multiplying the total number of pulses by the duration of each effective pulse. As part of the process, a product positioned between a set of electrodes is subjected to pulsed electrical currents; the distance between the electrodes is known as the PEF chamber's treatment gap. The high voltage that is provided creates an electric field that deactivates microorganisms. At ambient, sub-ambient, or slightly above-ambient temperatures, the electric field can be applied as bipolar, oscillatory, square wave, or exponentially decaying pulses. The presence of many ions in food gives it a certain level of electrical conductivity, which allows it to transport electricity (Ali et al., 2024 and Poojitha et al., 2021).

Factors involved in processing parameters

1. Electric field strength

The intensity of the external field for electroporation varies based on cell size, chamber design, and the position of the dielectric characteristics. While small cells require powerful electrical pulses, and the strength may also vary depending on the configuration of the cells, large cells are more susceptible to electric fields (Preethi, 2024).

2. Treatment time, pulse shape, and width

The number, width, and length of pulses may all be used to determine their intensity in addition to their electric power. Treatment time is determined using pulse duration, i.e., the number of pulses multiplied by pulse width. Usually, either exponential or square wave pulses are used; the square wave pulse is more effective in inactivation than the exponentially decaying pulse form. While exponential decay pulses were employed at the industrial level, square wave pulses are commonly used for batch cell inactivation when the electric field intensity and treatment duration are more precise. Another factor affecting microbial inactivation is pulse width. Longer pulses were produced via higher inactivation, but the drawback was an increase in temperature (Preethi, 2024).

3. Frequency and specific energy

PEF has been carried out with a greater pulse frequency and shorter processing time, ranging from 1 to 500 Hz. In certain instances, it can also raise the treatment medium's temperature. Depending on the food items exposed, different amounts of pulses may be used. When the specific energy, or energy delivered per unit mass, is reached, inactivation occurs. Therefore, a stronger electric field with the same specific energy is required to ensure maximal inactivation of the microorganisms (Preethi, 2024).

4. Conductivity

According to the researchers, the impact of electric pulses may be lessened if the extracellular medium's conductivity decreases. However, the whole population enters the lethal stage in a single pulse in a low-conductivity medium, but in the case of a conductivity medium, only 30% of cells are inactivated (Preethi, 2024).

5. pH

The pH change in the treatment might either make electroporation more or less effective on the cells (Preethi, 2024).

6. Impact of air bubbles and particles

Before PEF treatment, air bubbles in the product should be eliminated in order to inactivate the bacteria. Air bubbles in the media disrupt the electric breakdown and interfere with PEF's ability to permeate the medium, resulting in ineffective microbial inactivation (Preethi, 2024).

Pulsed electric field in fish processing

The application of the pulsed electric field (PEF) technique has become increasingly important in fish processing industries for tasks like preservation, extraction, and improving drying efficiency. The PEF technique was used to extend the shelf life of shrimp by inactivating spoilage microorganisms through electroporation and preserving its sensory qualities, such as texture and color. PEF technology presents an opportunity for the valorisation of waste streams in the fish processing sector. High-intensity PEF can be utilized for the extraction of calcium from fish bones. This technique was also employed for the extraction of protein from the mussel (Shiekh and Benjakul, 2020 and Poojitha et al., 2021).

Conclusion

Pulsed Electric Field (PEF) technology has emerged as a promising nonthermal food processing method with significant potential in the seafood sector. Unlike conventional heat-based techniques, PEF ensures microbial inactivation and extended shelf life while maintaining the natural texture, flavor, color, and nutritional quality of fish and fishery products. Its effectiveness depends on processing parameters such as electric field strength, treatment time, pulse shape, frequency, and product conductivity. Beyond preservation, PEF also enhances processing efficiency by facilitating the extraction of proteins, calcium, and other valuable compounds, thereby contributing to waste valorisation in the fish industry. With its energy efficiency, minimal impact on sensory properties, and ability to improve both quality and sustainability, PEF represents a cutting-edge innovation for future fish processing and preservation technologies.

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