

## Emerging Food Processing Techniques: Applications of High-Pressure Processing and Pulsed Electric Fields in Food Preservation

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### Abstract

Emerging food processing techniques, focusing on the applications of high-pressure processing (HPP) and pulsed electric fields (PEF) in food preservation. HPP and PEF are non-thermal processing methods that have gained significant attention in recent years due to their ability to extend shelf life, maintain nutritional quality, and improve safety of food products. HPP involves subjecting food to high pressures ranging from 100 to 1000 MPa, while PEF applies short bursts of electrical pulses to food materials. Both techniques disrupt microbial cells, enzymes, and other biological structures, thereby reducing spoilage, pathogens, and enzymatic reactions. the principles, mechanisms, and industrial applications of HPP and PEF in various food categories, including fruits, vegetables, meats, seafood, and beverages. Additionally, we examine the advantages, limitations, and future prospects of these emerging food processing techniques in meeting consumer demands for minimally processed, nutritious, and safe food products.

**keywords:** Emerging food processing techniques, High pressure processing (HPP), Pulsed electric fields (PEF), Food preservation

### Introduction

The landscape of food processing is continually evolving, driven by the demand for safer, more nutritious, and minimally processed food products. In recent years, emerging techniques such as high-pressure processing (HPP) and pulsed electric fields (PEF) have garnered significant attention for their ability to meet these demands while extending shelf life and enhancing food safety. HPP involves subjecting food products to elevated pressures ranging from 100 to 1000 megapascals (MPa), while PEF applies short bursts of electrical pulses to food materials. Both techniques are non-thermal in nature, meaning they do not rely on heat to achieve microbial inactivation and preservation. Instead, they work by disrupting microbial cells, enzymes, and other biological structures that contribute to spoilage, pathogenicity, and enzymatic reactions. The appeal of HPP and PEF lies in their ability to preserve the sensory, nutritional, and functional properties of food products while effectively reducing microbial loads and extending shelf life. These techniques are particularly well-suited for treating delicate foods such as fruits, vegetables, meats, seafood, and beverages, where traditional thermal processing methods may compromise quality or nutritional value. the principles, mechanisms, and industrial applications of HPP and PEF in food preservation. We will discuss their effectiveness in various food categories, highlighting their advantages, limitations, and future prospects. By examining the latest advancements in these emerging food processing techniques, we aim to provide insights into their role in meeting consumer demands for safer, fresher, and more nutritious food products in the modern food industry.

### **Overview of High-Pressure Processing (HPP):**

High Pressure Processing (HPP) is a non-thermal food preservation technique that utilizes elevated pressures to inactivate microorganisms, enzymes, and spoilage agents while preserving the sensory, nutritional, and functional properties of food products. HPP involves subjecting packaged food products to pressures ranging from 100 to 1000 megapascals (MPa) for a specified duration, typically a few minutes to several hours, depending on the food matrix and target microorganisms. The principle behind HPP lies in the ability of high pressures to disrupt cellular structures, including cell membranes, proteins, and nucleic acids, leading to microbial inactivation and enzymatic inhibition. Unlike traditional thermal processing methods such as pasteurization or sterilization, HPP does not rely on heat to achieve preservation, thereby minimizing detrimental effects on food quality, taste, and nutritional value. The industrial application of HPP spans a wide range of food categories, including juices, sauces, dairy products, meats, seafood, fruits, and vegetables. HPP is particularly well-suited for treating heat-sensitive foods or those containing live enzymes, probiotics, or bioactive compounds that may degrade under high temperatures. Advantages of HPP include extended shelf life, improved safety, and retention of fresh-like characteristics, color, texture, and flavor. Furthermore, HPP offers environmental benefits by reducing the need for chemical preservatives, additives, and energy-intensive thermal processes. However, challenges associated with HPP include equipment costs, packaging considerations, regulatory compliance, and consumer acceptance. Despite these challenges, HPP continues to gain traction in the food industry as a viable alternative to traditional preservation methods, offering a balance between safety, quality, and sustainability in food processing.

### **Principles of Pulsed Electric Fields (PEF):**

Pulsed Electric Fields (PEF) is a non-thermal food preservation technique that involves the application of short bursts of electrical pulses to food materials. These pulses typically have high voltage and short duration, ranging from microseconds to milliseconds. PEF treatment disrupts cellular membranes, leading to microbial inactivation, enzyme inhibition, and preservation of food products. The principle behind PEF lies in the ability of electric fields to create pores or temporary openings in cell membranes, allowing for the exchange of ions, molecules, and other cellular components. This disruption of cellular integrity leads to irreversible damage to microorganisms, enzymes, and other biological structures, thereby extending the shelf life and safety of food products. PEF treatment parameters, including pulse intensity, frequency, duration, and waveform, can be tailored to target specific microorganisms and achieve desired preservation effects. Additionally, PEF can be applied to both liquid and solid food matrices, making it versatile for various food processing applications. The industrial application of PEF spans a wide range of food categories, including juices, dairy products, liquid eggs, sauces, soups, and purees. PEF is particularly effective for reducing microbial loads, extending shelf life, and preserving the sensory, nutritional, and functional properties of foods without the need for heat treatment. Advantages of PEF include reduced processing time, energy savings, and retention of fresh-like characteristics, color, texture, and flavor. Furthermore, PEF offers environmental benefits by minimizing the use of chemical

preservatives and additives. Challenges associated with PEF include equipment costs, process optimization, scale-up considerations, and regulatory compliance. Despite these challenges, PEF continues to gain interest in the food industry as a promising alternative to traditional thermal processing methods, offering a balance between safety, quality, and sustainability in food preservation.

### **Mechanisms of Microbial Inactivation:**

- **Cell Membrane Disruption:** High Pressure Processing (HPP) and Pulsed Electric Fields (PEF) both work by disrupting the integrity of microbial cell membranes. In HPP, the application of high pressures causes structural changes in cell membranes, leading to rupture and leakage of intracellular components. Similarly, PEF creates pores or temporary openings in cell membranes through the application of electrical pulses, allowing for the leakage of cellular contents and eventual cell death.
- **Protein Denaturation:** The application of high pressures or electric fields can also lead to the denaturation of microbial proteins. This disrupts essential cellular functions and metabolic pathways, ultimately leading to microbial inactivation. Denaturation of proteins occurs due to the disruption of hydrogen bonds, disulfide bonds, and other non-covalent interactions that maintain protein structure and function.
- **DNA Damage:** Both HPP and PEF can cause DNA damage in microorganisms, leading to the inhibition of DNA replication and cell division. High pressures and electric fields can induce structural changes in DNA molecules, such as strand breaks, cross-links, and base modifications, which interfere with essential cellular processes and ultimately lead to cell death.
- **Enzyme Inhibition:** In addition to microbial inactivation, HPP and PEF can also inhibit the activity of enzymes present in food products. High pressures and electric fields disrupt the structure and activity of enzymes, preventing them from catalyzing biochemical reactions that contribute to food spoilage, browning, and degradation. This helps to preserve the sensory, nutritional, and functional properties of food products.

the mechanisms of microbial inactivation by HPP and PEF involve a combination of physical, chemical, and biological processes that disrupt cellular structures, metabolic pathways, and essential functions in microorganisms. By targeting multiple cellular components, these non-thermal processing techniques effectively reduce microbial loads, extend shelf life, and enhance the safety of food products without compromising their quality or nutritional value.

### **Conclusion**

The application of emerging food processing techniques such as High-Pressure Processing (HPP) and Pulsed Electric Fields (PEF) holds significant promise for enhancing food preservation, extending shelf life, and improving the safety of packaged products. Both HPP and PEF offer non-thermal alternatives to traditional processing methods, allowing for the retention of sensory, nutritional, and functional properties while effectively reducing microbial loads and enzymatic activity. HPP and PEF operate on different principles but share common objectives of disrupting microbial cells, enzymes, and other biological structures to achieve

preservation. HPP utilizes elevated pressures to induce cellular disruption, while PEF applies short bursts of electrical pulses to achieve similar effects. These techniques offer advantages such as extended shelf life, improved safety, and reduced environmental impact compared to thermal processing methods. The industrial applications of HPP and PEF span a wide range of food categories, including juices, dairy products, meats, seafood, fruits, and vegetables. These techniques are particularly well-suited for treating heat-sensitive foods or those containing live enzymes, probiotics, or bioactive compounds that may degrade under high temperatures. By offering alternatives to heat treatment, HPP and PEF provide opportunities to preserve the sensory, nutritional, and functional properties of foods without compromising quality or safety. Despite their potential benefits, challenges remain in the widespread adoption of HPP and PEF in the food industry. These include equipment costs, packaging considerations, regulatory compliance, and consumer acceptance. Additionally, further research is needed to optimize processing parameters, scale up operations, and explore new applications for these emerging techniques. The continued development and integration of HPP and PEF into food processing operations offer opportunities to meet consumer demands for safer, fresher, and more nutritious food products while reducing waste and environmental impact. By leveraging the unique advantages of these techniques and addressing existing challenges, stakeholders across the food industry can unlock the full potential of HPP and PEF in shaping the future of food preservation and processing.

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