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Pulsed Electric Fields: Emerging Technology in the Fish Processing Industry

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SUMMARY

The food industry and researchers are interested in investigating novel processing techniques like pulsed electric fields because of the market need for innovative meat and fish products with improved physicochemical and nutritional qualities (PEF). PEF is a new technology that modifies the structure of tissues without causing harm by applying electrical currents between two electrodes to cause electroporation effects. This article summarises the most recent research on using PEF processing in meat and fish to improve physicochemical and nutritional changes as a means of preservation and to enhance the extraction of high-added-value chemicals. PEF treatment improved several processes, including preservation, tenderization, and aging. Furthermore, PEF treatment could be used to improve the water-holding properties of fish products as well as for fish drying. Finally, because of its ability to enhance the extraction of high-value-added compounds, PEF could increase the value of by-products in meat and fish foods. More research is needed, however, to fully define specific treatments that can be universally applied in the industry.

INTRODUCTION

Pulsed electric fields (PEF) is one of the emerging electrical-based novel technology in the food processing sector. However, compared to thermal electrical-based techniques like ohmic heating (Gavahian et al., 2018) and moderate electrical field, the application of short electrical pulses at high voltages enables the control of thermal effects to remain low. These characteristics make PEF a promising technique for disrupting biological cells in the food matrix while having no negative impact on the attributes of food products. It has been described as a unique preservation technique that can result in foodstuffs with excellent nutritional and sensory quality as well as long shelf life (Gomez et al., 2019). Improving mass transfer through cell disruption and non-thermal microbial inactivation are two primary applications of this approach on which research is now concentrated. These applications are carried out under various processing circumstances because, while mass transfer events typically entail the breakdown of larger structures, such as the glands of fragrant herbs, microbial inactivation acts on microscopic cells (Gavahian et al., 2018). The effect of the electric field on cellular and tissue levels can be examined using several methods. The level of cell permeabilization needs to be assessed and measured. Turgor and texture tests can assess the degree of tissue damage and cell ruptures, such as stress deformation and relaxation assays of complex tissue (Lebovka et al., 2004). Membrane permeabilization affects the turgor of the cell. The release of plant pigments has also been aided by additional techniques for assessing cell rupture or membrane disintegration (Barba et al., 2015).

What is PEF

PEF is a non-thermal cell membrane permeabilization method, is distinguished by its low energy consumption, continuous maintenance and operation with rapid processing intervals, and waste-free process (Gomez et al., 2019). These characteristics allow the development of innovative, economic, and sustainable processing concepts in the food and beverage sector and the biotechnology and pharmaceutical industries (Barba et al., 2015; Puertolas et al., 2016). Numerous researchers are interested in treatments that use high-voltage electric field pulses with very short durations (1-100 s) because they make it possible to inactivate bacteria without compromising the flavour or taste of food (Puertolas et al., 2016)

The PEF apparatus comprises a pulse generator, a treatment chamber properly made to prevent electrolysis, a control and data acquisition system, and electrodes. Figure 1 provides a graphic representation of these fundamental parts. The pulse generator can be used in various ways (Pourzaki and Mirzaee, 2008). The basic electrodes are located inside the treatment chamber, between which is a spot where the food to be treated can be placed. The capacitor stores energy from the power supply, which is then released through the treatment chamber to create an electric field in the food item (Gomez et al., 2019).

Several process parameters must be defined when constructing a PEF process, in addition to the setup of the complete device and the EFS. These include pulses' quantity, breadth, length, form, specificity, frequency, and number (Puertolas and Barba, 2016). Evaluation of the effectiveness and economic effects of PEF treatment, particularly for up-scaled use, should consider the abovementioned variables and the length of the PEF treatment. The particular energy input of the process, expressed as kJ/kg and depended on the input voltage, the ohmic resistance of the treated products, and the processing duration, was previously described as directly related to the financial cost and environmental impact of a PEF process (Gomez et al., 2019). After the PEF treatment, the material is chilled, if necessary, packed aseptically, and then stored at chilled or ambient temperatures depending on the type of food and its future use/s. The initial capital investment is a concern for the industrialization of the application of PEF in food processing. Nevertheless, numerous benefits have been compiled in Table 1 despite some restrictions. PEF technology offers several benefits, including process stability, good nutrition and vitamin retention, and high organoleptic quality of the final product. PEF technology can be more effective with other techniques, such as high hydrostatic pressure, ultrasound, and upstream and downstream temperature control technologies (Gomez et al., 2019).

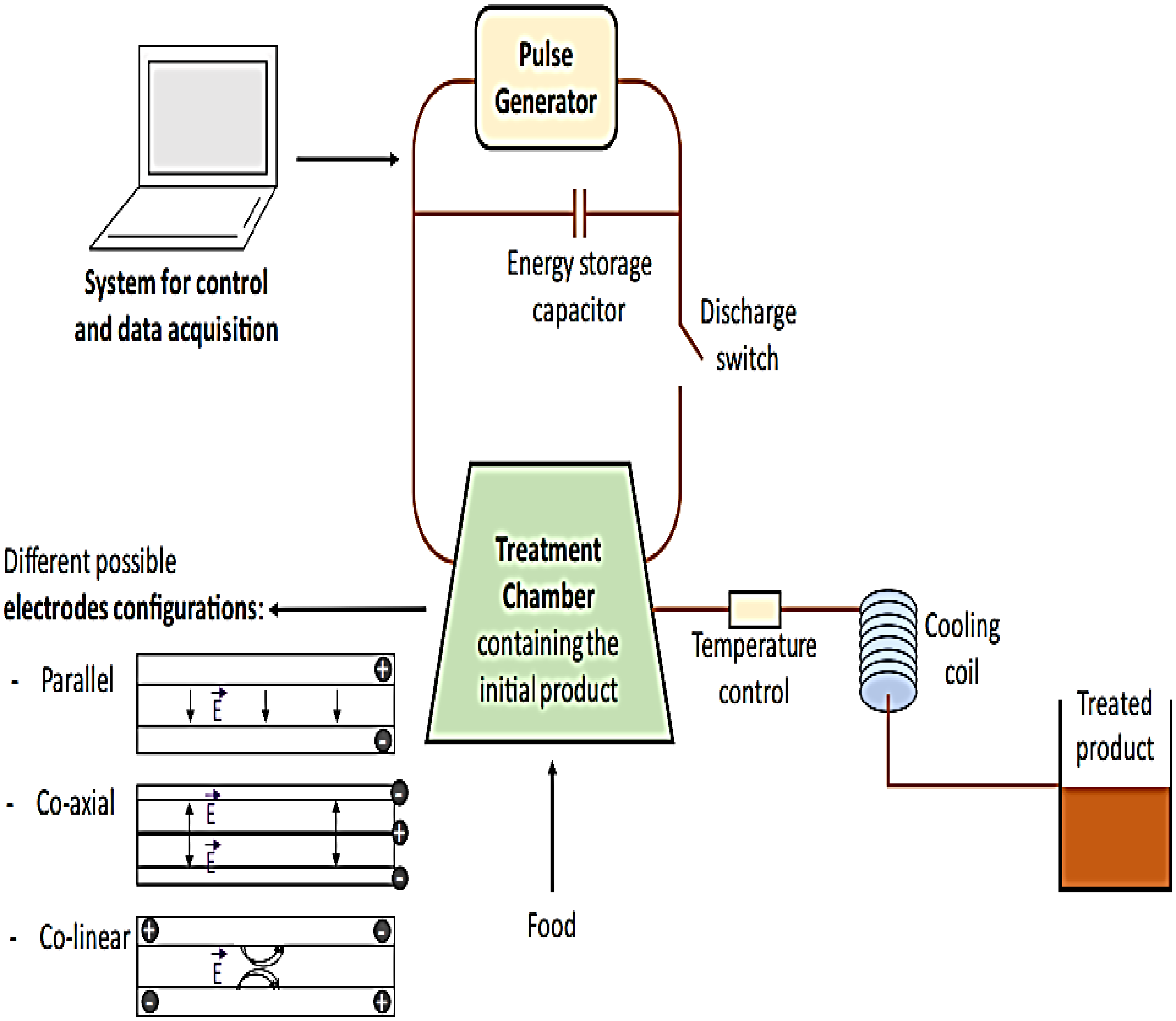

Fig. 1. Schematic diagram of a pulsed electric field (PEF) processing system including different configurations of electrodes (parallel, co-axial and co-linear)

Table 1. Advantages and disadvantages of the application of pulsed electric fields (PEF) in meat and fish industries (Courtesy: Gomez et al., 2019).

Advantages	Limitations
Efficient inactivation of cells	High capital cost
Suitable for processing heat-sensitive foods	Inefficient in spore inactivation
Applicable to many solid and liquid foods	Unavailability of commercial units in many regions of the world
Can perform the pasteurization of a wide range of meat products	
Better retention of color, flavors, and nutrients	The presence of bubbles may lead to non-uniform treatment as well as operational problems
Relatively short treatment time	
Free from health-threatening solvents and Eco-friendly	Limited economic and engineering studies for up-scaled continuous process
Possibility of combination with other processing techniques	

Applications of PEF in the fish industry

The application of PEF in the food sector is attracting attention since it is a non-thermal option that might have more impact on muscle food's microstructure than the emerging heat-based techniques such as ohmic and microwave heating (He et al., 2017; Khan et al., 2017). Additionally, a number of authors have pointed out this technology's effectiveness in maintaining the finished product's physical, organoleptic, and functional qualities, i.e., adding only slight modifications to the tastes, vitamins, and other nutrients (Gomez et al., 2019). The effects of PEF on the microstructure of salmon, chicken, and lumpfish roes were assessed by Gudmundsson and Hafsteinsson in 2001. Their findings showed that salmon is more responsive to light PEF treatment than chicken (2 kV/ cm, 20–40 pulses). Yet, both samples notably changed in texture and microstructure, whereas roes tolerated the treatment.

A different study used the PEF technology a few years later to enhance the water-holding capabilities of fish and improve the texture of shellfish products (Khan et al., 2017). Unfortunately, there were no noticeable improvements in the tenderness of shellfish items such as common whelk and Iceland cyprine, while PEF treatment rendered the structure of fish muscle more porous (He et al., 2017). The authors proposed PEF treatment as a possible method to improve the ability of fish to hold water and as a potential pre-treatment for drying fish. Furthermore, Zhou et al. (2017) and He et al. (2017) investigated the PEF technology's efficacy in extracting protein from mussels. The protein extraction yield was maximized to 77.08% when PEF was applied with a triangular pulse power waveform and a 2 s pulse duration under the predicted ideal circumstances (EFS of 20 kV/ cm, pulse number of 8, and 2 h of enzymatic digestion).

Table 3. Application of pulsed electric fields (PEF) technology in the fish processing industry

Fish product	Operating conditions	Findings/Applications
Salmon and lumpfish roes	Different combinations of electric field, number of pulses and high-pressure treatment.	PEF application had greater impact on salmon than chicken samples. Appropriate technique as pretreatment for lumpfish roes.
Pollock fillets, cod loins frozen, cod fresh fillets, haddock loins frozen, Iceland cyprine and	Electric field strength 1.2–2.0 kV/cm; frequency 1–4 Hz; pulse width 400 µs; pulse number 20, 40, 80	PEF treatment was not effective with <90 pulses and field <2.0 kV/cm. Improvement of the water holding properties and the fish drying.

common whelk	or 120	
Fishbone	Optimal combination of parameters: EFS 25 kV/cm and pulse number 8	Effective calcium extraction
Fishbone	Processing conditions were optimized and the best yield was achieved using a EFS of 16.88 kV/ cm and pulse number of 9	Extraction of chondroitin sulfate
Fishbone	Combinations of semi-bionic extraction method with PEF (optimum conditions: EFS 22.79 kV/cm and pulse number 9)	Extraction of effective ingredients
Mussel	Best conditions: EFS of 20 kV/cm, pulse number of 8 and enzymolysis time of 2 h	Extraction of protein
Haliotis discus hannai Inoviscera	Treatment time (100–800 μs), Intensity strength 5–20 kV/cm, and the ratio of material to solvent (3:1–10:1)	Extraction of Protein hydrolysate

Source: Gomez et al. (2019)

Valorization of fish by-products

PEF technology can be pretty interesting when used for value-added by-products from the fish processing sectors, just like it can be for meat. It is accurate to conclude that PEF achieved higher extraction efficiency in a shorter time when comparing the findings with the ultrasonic approach. This conclusion was consistent with the findings that power ultrasound could not be used to quicken an extraction procedure (Gavahian et al., 2018). Similarly, a different study employed high-intensity PEF to extract chondroitin sulphate from fishbone as its raw material. This study emphasized the advantages of this technology, such as shorter process times, increased efficiency, and environmentally friendly characteristics (He et al., 2017).

Li et al (2016) and Fang et al. (2016) conducted yet another study on the utilization of fish waste (2016). They designed a PEF enzymatic-assisted extraction to isolate the protein from the viscera of abalones. They investigated the impacts of several PEF parameters, such as treatment duration, intensity, and solvent-to-material ratio. They found that the maximum extraction yield occurred when the solvent to material ratio was 1 to 4, and the PEF was applied for 600 s at an intensity level of 20 kV/cm. When compared to traditional enzymatic extraction techniques, the scientists found that the suggested extraction approach produced a high yield of abalone viscera protein with promising emulsifying capabilities. In contrast, when PEF was used, the extracted product's viscosity and foaming characteristics were reduced.

The biggest obstacle preventing PEF from being used more widely in the fish processing sector is the expensive initial capital investment. One of the drawbacks of this new technology is that it is ineffective in reducing naturally occurring enzymes in fish. The electrical conductivity of the product is a critical element that restricts the application of PEF to materials with moderate conductivity, much like the ohmic heating method (He et al., 2017). Food chemists need more research on the effects of processing variables on the quality and safety of novel products, including temperature, pH, moisture, and fat content. Additionally, various PEF processing variables, meat characteristics, and pre and post-treatment meat conditions (freezing, ageing, etc.) substantially impact the finished product's quality.

Finally, despite numerous papers highlighting the benefits of PEF technology for processing meat and fish at laboratory scales, the industry only uses it in a relatively small number of applications (He et al., 2017). This is due to a number of factors, including the high capital expenditure (which discourages the sector from purchasing PEF equipment), the introduction of changes to the traditional layouts of meat processing plants, and the new technology requirement. There have only been a few research on the customization of PEF treatments and how they affect the various quality aspects of meat and fish. Due to the low energy consumption and quick processing times required by PEF processing, applying PEF technology to the fish and meat industries would be highly advantageous. However, this technology transfer needs more research on the effects of PEF treatment on meat and fish product quality indices (such as tenderness, color, oxidation, weight loss, and water-holding capacity) (Khan et al., 2017).

CONCLUSION

PEF is a cutting-edge processing technology that offers immense potential for food product preservation and structural modification. It is also an environmentally friendly and energy-efficient alternative for processing food. With these benefits, it is anticipated to be successfully used in the industry soon, either as a stand-alone treatment or in combination with other treatments that jointly increase product quality and process yields. However, creating machinery capable of producing high-strength electric field pulses on an industrial scale and with reliability remains difficult. It is difficult to translate the technological requirements into a practical and cost-effective PEF system that complies with legal requirements. For PEF to be fully implemented in the meat and fish industries, user-friendly and affordable PEF solutions must be developed. The electrochemical reactions at the electrode/medium interfaces are another recent issue that hasn't received enough attention. They show that it's difficult to prevent electrode corrosion and the migration of electrode materials into food systems and suggest that other materials might be used in place of commonly used stainless steel electrodes.

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