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Food Processing by Pulse Electric Field: A Review

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The aim of the present study is to know about the effects of pulse electric field on food and compare it with other thermal methods of food processing. Food quality, food safety, convenience, freshness, healthy food, natural flavor and taste with extended shelf-life are the main criteria for the demand made by today's consumers. Thermal methods of food preservation gives low quality food as compare to non-thermally treated food product. Pulse Electric Field processing (PEF) is a non-thermal processing technology to kill microorganism present in food by the application of short pulses of high electric fields for micro-seconds to milliseconds. It preserves the flavor of foods, vitamin content, and color of foods. PEF technology aims to offer consumers high-quality foods product. PEF technology is considered superior to traditional thermal processing methods because it greatly reduces detrimental changes in the sensory and physical properties of foods. It can be used in replace of thermally processed food because it produces the foods that have the good quality as compare to thermally processed food.

Keywords: Pulse electric field processing; food safety; food quality; shelf life; food processing.

1. INTRODUCTION

The spoilage microorganisms may cause the spoilage of food product and reduce the quality of the food product [1]. Any food preservation technique for food product is evaluated by the ability to inactivate pathogenic microorganisms. So to improve the shelf-life of the food and to

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enhance the product's safety, it is necessary to inactivate the spoilage microorganisms [2]. Now a day's consumer prefers convenience, fresh and healthy food, natural flavor and nutritive food after processing. The extended shelf-life of food product is also important criteria for consumers demand [3].

Pulsed electric field (PEF) is one of the non-thermal methods of food preservation. The basic principle of the PEF technology is the application of short pulses of high electric fields for micro-seconds to milliseconds. The food is then packaged aseptically and stored in refrigerated condition [4]. It uses short pulses of electricity for microbial inactivation and causes minimal effect on food quality. It is considered superior to traditional thermal processing methods because it greatly reduces changes of the sensory and physical properties of foods. So the basic aim of this technology is to offer high-quality foods [5]. It is a mild technology as compared to thermal processing because a lower temperature is used during processing which leads to a better retention of the quality of the food product. It can be used for the inactivation of microorganisms and hence for preservation of food products. It can be used for the preservation of various food products like milk and milk products, fruits and vegetables, meat and poultry products etc [6].

2. PROCESSING TECHNIQUE

A Pulse electric field system generally consists of three basic components i.e. a treatment chamber, a high voltage pulse generator and a control system for monitoring the process parameters as shown in Fig. 1 [7]. The PEF is applied in the form of short pulses of high electric fields intensity in the order of 10- 80 kV/cm with duration of micro-seconds to milliseconds. The product placed between a set of electrodes known as PEF or treatment chamber and the pulsed electrical currents is delivered to product [4]. Food products can be placed either in a static or continuous design in treatment chamber. Two electrodes are connected together with a nonconductive material to avoid electrical flow from one to the other. The food product experiences a force per unit charge called as electric field, which is responsible for the cell membrane breakdown in microorganisms [8]. The applied high voltage results in an electric field and then electrical current flows into the liquid food and is transferred from one point to another in the liquid because of the presence of charged molecules in the food. This electric field causes the inactivation of microbes. Foods have a certain degree of electrical conductivity because of the presence of several ions, which is responsible for transferring electricity [9].

3. APPLICATIONS IN FOOD PRODUCTS

A large number of applications exist for pulse electric field processing including fruits and vegetables, milk product, meat product etc. Some of these applications are discussed as below:

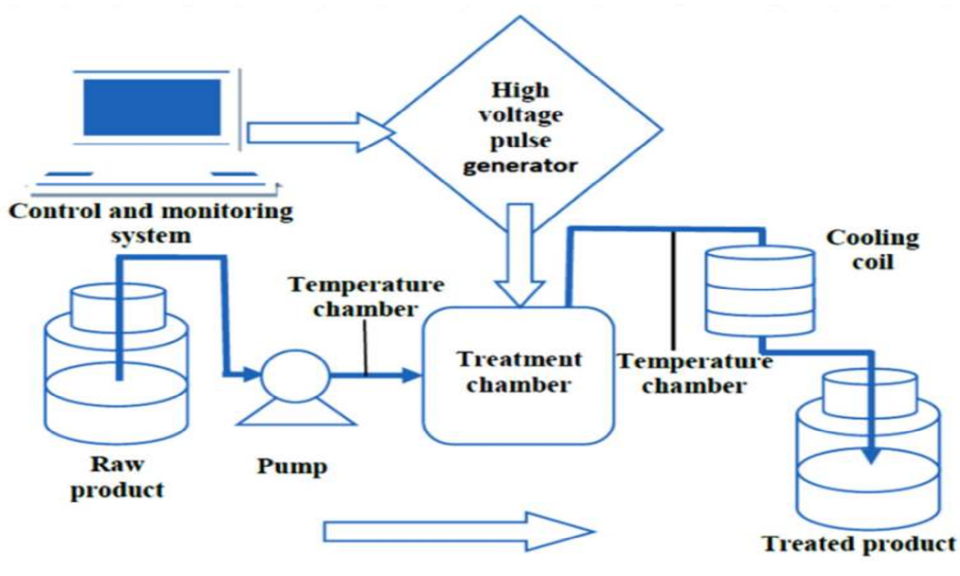

Fig. 1. PEF food processing system with basic component

3.1 Inactivation of Microorganisms and Enzymes

Inoculation of *E. coli* and *B. subtilis* in pea soup and treatment at PEFs of 25–33 kV/cm (10–30 pulses of 2 s) results in a limited inactivation of 1.5D at process temperature below 53℃, while microbial inactivation is 4.4D at process temperatures between 53℃ to 55℃ [10]. In continuous-flow PEF system at electrical field strength of 20 kV/cm with variable frequencies of apple, orange and watermelon juices, the *S. cerevisiae* is the most sensitive micro-organism, followed by *S. panama* and *E. coli*. *L. monocytogenes* is the most resistant micro-organism at the same treatment conditions. Less energy is required at higher temperatures for inactivation of micro-organisms [6]. The PEF treatment of 20 kV–900 μs causes the reduction of 4 log cycles of the initial cell population (10^8 cfu/mL) of *S. typhimurium*. When the PEF pre-treated *S. typhimurium* population is subjected to subsequent incubation in the presence of mandarin and cauliflower by-product [10% (w/v)] infusions, the microbial inactivation is faster. There is reduction of the initial load from 4 $\log_{10}$ cycles to undetectable levels in 2 hours [11].

PEF processing could be successfully used to process a carrot juice based beverage with significant amount of microbial reduction. There is a significant reduction on the total aerobic mesophilic bacteria, total mold and yeast, total *Enterobactericeae* and *Escherichia coli* O157:H7 counts resulting with 4.30 ± 0.26, 3.4 2 ± 0.40, 4.46 ± 0.36, and 3.57 ± 0.32 log cfu/mL, respectively ($p \leq 0.01$) [12]. Polyphenoloxidase activities were reduced up to 3.15% and 38.0% from initial value in apple extract at 24.6 kV/cm and pear extract at 22.3 kV/cm both for 6 ms total treatment time, respectively. Apple and pear polyphenoloxidase exposed to pulsed electric field processing diminishes their activities following first order kinetics [13]. The microbial inactivation increased with the electric field strength, the treatment time and temperature. PEF treatment caused 3.39 and 4.44-log cycles reduction of coliforms and total plate counts, respectively, when pulse duration was 3 μs, the electric field strength 30 kV/cm, the treatment time 520 μs and the water bath temperature 15℃. A 3.7-log cycles reduction of the total yeast and mould counts was obtained by applying 390 μs of 30 kV/cm at 15℃. Yeast and mould cells were less resistant to PEF process than bacteria cells. The effect of heat generated during the PEF treatment was limited on microbial inactivation [14]. The membranes of PEF-treated cells become permeable to small molecules; permeation causes swelling and eventual rupture of the cell membrane (Fig. 2).

3.2 Fruits and Vegetables

In 0.2–0.6 kV/cm range of treatment the disintegration degree (*Zp*) value is larger for the treatments applied in the millisecond range as compared to the treatments applied in the microsecond range. The treatment at 0.6 kV gives the *Zp* value higher than 0.95 after 60 ms of treatment and the obtained highest *Zp* value is 0.78 in the microsecond range after 75 μs for the treatment at 6 kV/cm [15]. The anthocyanin content in juices after pulsed electric fields (PEF) treatment shows the contradictory results.

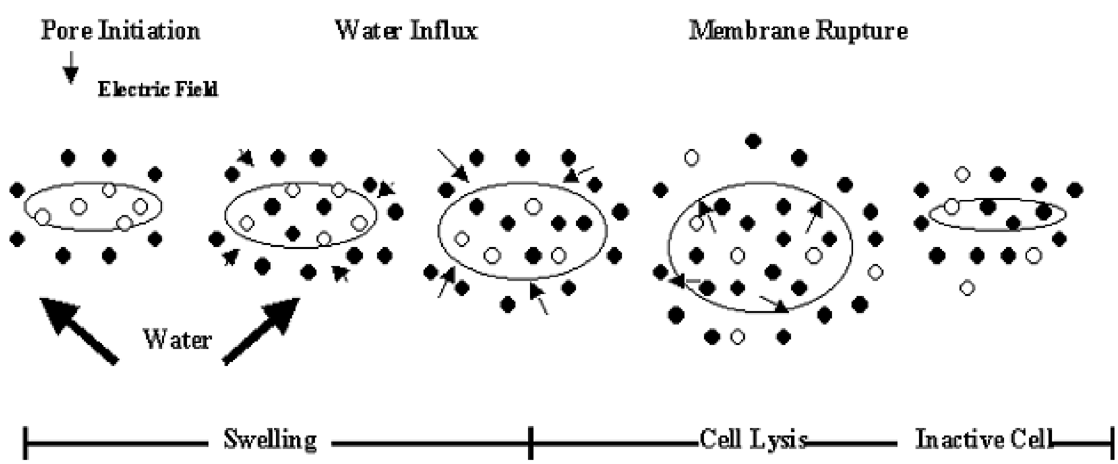

Fig. 2. Stages of electroporation in cell membrane

Some researchers report that there is a minimum effect on the pigment after processing, while others conclude that there is a degradation in anthocyanin content after pulsing effect [16]. The treatment conditions applied in the ms range (0.6 kV/cm; 40 ms) and the μs range (6 kV/cm; 150 μs) increase the betanines extraction yield (BEY_{max}) by 6.6 and 7.2 times, respectively as compared with the control [15]. There are minimal modifications of the metabolism heat and metabolites concentrations when 100 V/cm was applied [17]. PEF processing did not cause any significant change in pH, titratable acidity (TA), °Brix, conductivity, color (L*, a*, and b*), nonenzymatic browning index (NBI), metal ion, and vitamin C concentration ($p > 0.05$) [12]. There is no significant change in pH, Brix, titratable acidity, sugars, total anthocyanins and colour attributes with the increase in pulsed electric strength as compared to control treatment. However, there is significant decrease in non-enzymatic browning (NEB) and viscosity while an increase in cloud value, DPPH, TAC, total phenolics and total carotenoids with the increase in pulsed electric strength as compared to control treatment. It is suggested that PEF at 25 kV cm−1 could improve the quality of grapefruit juice [18].

3.3 Meat and Poultry Products

PEF causes the significant micro-structural change in meat tissue as compared to freezing. Combination of freezing–thawing and PEF results in improved tenderness. The PEF significantly increases the purge loss but not cooking loss. PEF not affects the ratio of polyunsaturated/saturated fatty acids and omega 3/omega 6 and the free fatty acid profiles. Freezing with or without PEF greatly affects the volatile profile of the meat [19]. The PEF treatment not effects the tenderisation of hot-boned beef *Musculus longissimus lumborum* muscle for 3, 7, 14 and 21 days ageing treatment times but the 3 × treatment reduce the tenderness [20]. Treatment at electric field strength of 25 kV/cm for 400 μs not changes the protein solution colloidal properties but when the processing time exceeds to 600 μs the small peak of large particle size appears and decreases the soluble protein content (7.84%) and increases the *Z*-average size (36.9%). The free sulfhydryl content increases slightly but there is no increase in protein carbonyl content during PEF treatments [21]. The prolonged storage time and frozen–thawed pretreatment led to increase in volatile compounds due to lipid and protein oxidation. Temporal dominance of sensations (TDS) shows that storage and PEF treatment affects the temporal flavor of the meaty and oxidize the flavor attributes [22].

3.4 Milk and Milk Products

PEF treatment of milk at electric field strengths of 18–28 kV cm^{-1} for 17–235 μs for 24 s at 4℃ did not reduce bacterial numbers, but it increases the effectiveness with increase in temperature. PEF treatments at 22–28 kV cm^{-1} for 17–101 μs at 50℃ give 5–6 log reduction at 55℃. The Gram-negative bacteria are less resistant for PEF as compared to Gram-positive bacteria [23]. Electric field intensities of 30 and 40 kV/cm were applied at selected number of pulses (1–30) and temperatures (20–72 ℃) for less than 10 s. The maximum microbial reduction of 4.3 log cycles can be achieved using 10, 17.5, 20 and 25 pulses, if milk is processed at 30 kV/cm and initial temperatures of 43, 33, 23 and 13℃, respectively. Milk treatment with 40 kV/cm of electric field intensity, few pulses, and initial temperature approximately of 55℃ shows the best balance of *L. innocua* inactivation with energy-consumption [24].

The increase in electric field intensity, temperature, and pulse number significantly affected milk coagulation properties of milk. PEF treatment shows better rennetability as compared to thermally pasteurized milk. PEF combination with mild heat results in a potential pasteurization method for milk destined for cheese production [25]. The combination of PEF with mild temperature treatment extends the shelf life of milk. The use of a thermal regeneration system improves the energy efficiency of PEF preservation process [26]. After processing only minor changes in color, Allura Red concentration, and pH is observed. PEF affects the stability of Allura Red in milk when additional ingredients are not added to the product [27]. Except for milk at pH greater than or equal to 7.5, PEF treatment not affects the size of the milk particles and the amounts of protein in the serum or in the state of the whey proteins. Sodium dodecyl sulphate – polyacrylamide gel electrophoresis (SDS–PAGE) measurements shows that the amount of caseins in the serum increases. This indicates that the decrease in the size of the milk protein is due to the dissociation of the casein micelles [28]. It was also shown that PEF induced interactions between β-lactoglobulin and milk fat globule membrane (MFGM) proteins at 65℃, whereas the phospholipid composition remained unaltered. This work demonstrates the potential of PEF not only the means to produce a microbiologically safe product, but also as a process preserving the biofunctionality of the MFGM [29]. A High intensity pulse electric field treatment of 1,000 μ ensured the microbiological stability of whole milk stored for 5 days under refrigeration. Initial acidity values, pH, and free fatty acid content were not affected by the treatments; and no proteolysis and lipolysis were observed during 1 week of storage in milk treated by high intensity pulse electric field (HIPEF) for 1,000 μ. The whey proteins (serum albumin, *β*-lactoglobulin, and *α*-lactalbumin) in HIPEF-treated milk were retained at 75.5, 79.9, and 60%, respectively, similar to values for milk treated by traditional heat pasteurization [30].

4. CONCLUSION

The pulsed electrical field technology is an emerging technology for food processing. It processes the food and makes safe for consumption. During processing the color, aroma retention and the preservation of nutritive components are most important criteria for food processing industry and consumers which is much higher in pulse treated food compare to the thermal or heat processed food. It allows manufacturer to obtain high and good quality products. It has competition properties over conventional thermal processing and novel thermal. It maintains the properties of food like organoleptic, nutritional and rheological properties of foods. It is used to inactivate microorganisms and enzymes or no effects on nutritional and sensory quality of foods.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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