Pulsed Electric Field Technology in Liquid Food Processing Technology - A Review

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Abstract: *Pulsed electric field food processing (PEF) has received considerable attention due to its potential to enhance the food quality and extend the shelf life during the last few decades. The associated PEF parameters in food processing are many and the individual performances of the parameters are not separable. Moreover, there are still many unknown factors involved in PEF food processing of liquid foods and many conflict reports are found in the literature. The purpose of this literature review is to give a general overview of how the parameters of the pulsed electric field affect microorganisms and the quality of milk and orange juice.*

Keywords: **Pulsed electric field, orange juice, microorganisms.**

1. INTRODUCTION

Liquid foods are preserved commercially by using high-temperature short time process [HTST]. Even while the heat treatments increase the liquid food's shelf life, they have an adverse effect on its flavor, chemical makeup, and nutritional value.

So, the non-thermal food processing technology is required and the PEF method finds as a potential method among all the non-thermal food processing methods [1, 2, 3, 4]. The results reported by them prompted the researchers to explore their investigations in the field of PEF technology. Thereafter many reports have been published on inactivation of microorganisms by PEF method. Even if it is somewhat challenging to compare the contrast results from various research teams, the PEF treatment's efficiency can be determined by common metrics.

However, the technical limitations made the PEF method at the research level itself. The lack of reliable industrial equipment was indeed a critical factor to upgrade the system [5] and the other critical aspects are the poor operating protocols, the control and monitoring the treatment conditions. So, the commercial applications of PEF technology require more details to improve the reproducibility of the treatments.

2. MAJOR FACTORS AFFECTING PEF TREATMENT EFFICIENCY

The effectiveness of the inactivation of the microorganism depends on several factors. The factors can be classified as PEF processing parameters, biological factors and the properties of the treatment medium, and also the PEF equipment selected for the treatment.

2.1. PEF processing parameters

The typical process parameters that determine the efficiency of the PEF treatment include the amplitude of the electrical pulse, electric field intensity, treatment time, pulse shape, pulse length, number of pulses, pulse specific energy, and pulse repetition frequency.

Electric field intensity defines the field intensity developed in the food treatment chamber. It depends on the voltage applied to the electrodes, the geometry of the treatment chamber, electrode shape, size, and the distribution of dielectric properties of the liquid food between the materials [6]. Generally, the applied electric field intensity needs to be in the range of 10- 40 kV/cm to inactivate the microorganisms. However, few investigations have reported that electric fields up to 100 kV/cm could be applied to the food for continuous treatment protocol [7, 9].

Treatment time represents the number of pulses applied multiplied by the pulse length. The pulse length depends on the pulse shape and the commonly used pulse shapes in PEF treatment are either exponential or square, unipolar or bipolar in nature [5, 9]. The pulse length is usually selected in the range of microseconds to milliseconds for food pasteurization. However, few studies have reported the inactivation effect of nanosecond pulses. Pulse repetitive frequency is defined as the number of pulses applied per unit time. Moreover, recently the pulse frequency is identified as a key factor in food technology by PEF method [10, 11, 14].

Energy density is the electrical energy received by the food product per each pulse. The total specific energy input can be calculated multiplying the energy density by the number of pulses applied. Few investigations have suggested the electrical energy density as a suitable parameter to compare the data obtained by the researchers under distinct PEF treatment conditions [13].

Temperature is one more important parameter which influences the inactivation rate of the microorganisms and at the same time, the high temperature destroys the food quality. The electric field intensity, pulse repetition frequency, and pulse length significantly increase the temperature. Therefore, the optimization of these parameters must be studied by minimizing the related heating effect [14].

2.2. Biological factors

According to reports, the size and direction of the cell with respect to the intensity of the electric field determine the critical electric field needed to render the microbe inactive [5, 13, 15, 16]. The cell outer membrane structure is most important in PEF treatment because the cell outer membrane is the resistant part of it and it protects the cell from PEF. Gram-positive microorganism has thicker and rigid wall than Gram-negative microorganism and so Gram-positive microorganisms are more resistant to the PEF.

The microorganisms in exponential growth phase are more susceptible to PEF than their stationary phase [13, 17]. The microorganism's concentration in the food to be treated also affects the efficiency of the PEF treatment. The high concentrations decrease the PEF lethal effect and if the transmembrane potential is higher across clusters of cells than across an individual cell for the same electric field strength.

2.3. Treatment medium properties

Medium conductivity is also considered in few research articles as a key factor in PEF food technique which is a function of food medium temperature. The presence of ions increases the transmembrane potential. However, the low conductivity medium increases the conductivity differences between the cell and medium and thus increases the pressure on the cell membrane which enhances the electroporation. The food matrix is also very important because it is very difficult to increase the inactivation level of the microorganism when the microorganism is suspended in complex food material such as milk than in buffer solution or simple food material [19]. The recent studies report that the pH value also affects the sensitivity to all kinds of treatments. The acidic and alkaline pH values induce additional stress on the cell membrane which increases the inactivation level [20]. Similarly, a decrease in water activity also lowers the inactivation level of microorganism by PEF method [28].

2.4. PEF equipment and treatment chamber

There are different kinds of PEF generators used in the past few decades. Anyway, the basic PEF generator consists of a high voltage supply, an energy storage system, pulse converter and treatment chamber. The treatment chamber consists of two electrodes that form an enclosure to the food. The electrodes may be a parallel plate or co-linear configurations. Parallel plate configuration is simplest in design and produces uniform electric field distribution in the treatment zone. The co-linear configuration consists of tubular electrodes and provides non-uniform electric field across the treatment zone.

2.5. PEF inactivation of microorganisms in juices

Of all the liquid items, apple juice, orange juice, milk, liquid eggs, and brine solutions have been treated using PEF technology the most. The investigations carried out so far have shown adequate inactivation levels for a number of pathogenic microorganisms [17, 21, 31] and studies show that PEF has a minimal effect on the quality and nutritive value of juices [23, 24, 25, 26]. The inactivation of vegetative bacteria and yeasts by PEF is probably due to the applied electric field intensity and not due to electrolysis products/temperature alone [27, 28].

Additionally, the color change in fruit juices was less in juices treated by PEF [24]. The selected published articles on microbial inactivation in liquid foods by PEF are summarized and presented in chronological order in Table 1.

Table 1. Summary of inactivation of microorganisms by pulsed electric field

PEF conditions (E, t, T)[a]	Microorganism	Medium	Log_{10} reduction	Source
30 kV/cm, 12 ms, 54°C	*Eschericia coli and Listeria innocua*	Orange juice	5 - 6	[22]
30-50kV/cm, 2ms, 30°C	*Leuconostoc mesenteroides*	Orange juice	5.0	[22]
41 kV/cm, 10 to158 µs at 3 Hz, 37°C	*Eschericia coli*	SMUF	2.3 to 4.5	[29]
22-34kV/cm, 166µs, nd	*Eschericia coli*	Apple juice and cider	4.5	[30]
80kV/cm, 60µs, 42°C	*Eschericia coli*	Apple Cider	5.35	[31]
16.7 kV/cm, 150 µs,30°C	*Bacillus cereus*	Buffer Milk	> 4.0	[32]
35.8 kV/cm, 46.3 µs, nd	*Lactobacillus plantarum*	Orange-carrot blend	2.5	[33]
28to 29 kV/cm; 30 to 400 µs , 25 to 45°C	*Listeria innocua*	Skim milk	0.2 to 1.5	[34]
5-11 kV/cm, nd, nd	*Eschericia coli*	SMUF	5.0	[35]
10 – 28 kV/ cm, 16 µs, 20 – 30°C	*Saccharomyces cerevisiae*	Apple juice	4.0	[36]
80 kV/cm, 100 µs, 52°C	*Total microorganisms*	Milk	7.0	[7]
40 kV/cm, 97 µs, 60 ◦C	*Total aerobic count*	Orange juice	6.2	[37]
35 kV/cm, 47 to 188 µs , 52°C	*Lactococcus lactis*	Skim milk	0.5 to 2.2	[38]
35 kV/cm, 47 to 188 µs, 52°C	*Bacillus cereus*	Skim milk	0.1 to 0.3	[38]
8-40 kV/ cm, 6-230 µs, 35-70°C	*Escherichia coli*	Apple juice	> 6.0	[28]
5-40 kV/cm, 120 µs, nd	*Eschericia coli K12*	milk	5.0	[39]
90 kV/cm, 100 µs, 45°C	*Salmonella typhimurium*	Orange juice	> 5.0	[8]
35 kV/cm, 188 µs, 52-22°C	*Pseudonomona fluorescens*	Raw skim milk	2.5	[38]
20 - 40 kV/ cm, nd, 20°C,	*Eschericia coli K12*	Apple juice	5.0	[40]
20 kV/cm, 270 µs, 60°C	*Eschericia coli*	Apple juice	2.7	[41]
12.5 kV/cm, 800 µs, 10 ◦C	*Saccharomyces cerevisiae*	Orange juice	5.8	[42]
35 kV/cm, 1ms, 39 ◦C	*Saccharomyces cerevisiae*	Orange juice	5.1	[43]
35 kV/cm, 450 µs, < 40°C	*Staphyloccocus aureus*	Skim milk	3.7	[44]
15 to 30 kV/cm, 16 to 163 µs, n.d.	*Listeria. monocytogenes*	Skim milk	0.03 to 4.5	[45]
25–40 kV/cm, 40-300 µs, 30°C	*Escherichia coli*	Orange - carrot juice	2.6	[46]
35 kV/cm, 460 µs, 40°C	*Staphylococus aureus*	Skim milk	3.0	[44]
25–40 kV/cm, 40- 300 µs, 30°C	*Lactobacillus plantarum*	Orange - carrot juice	1.3	[46]
24-31 kV/cm,	*Eschericia coli*	Apple juice	2.63	[47]

141-202 μs, 29°C				
24-31 kV/cm, 141-202 μs, 29°C	*Eschericia coli*	Milk	1.96	[47]
25 kV/cm, 150 μs, 32 ◦C	*Lactobacillus brevis*	Orange juice	1.4	[48]
35 kV/cm, 1 ms, 32 ◦C	*Lactobacillus brevis*	Orange juice	5.8	[48]
25 kV/cm, 280 μs, nd	*Aerobic microorganisms, yeasts, and molds*	Orange-carrot blend	> 3	[49]
35 kV/cm, 1.2 ms, nd	*Staphylococcus aureus*	Milk	4.5	[50]
15 - 40 kV/cm, 700 μs, 55°C	*Lactobacillus plantarum*	Orange juice milk beverage	5	[51]
35 kV/cm, 27 ms, 40°C	*Listeria monocytogenes*	Melon juice	4.3	[52]
35 kV/cm, 27 ms, 40°C	*Listeria monocytogenes*	Watermelon juice	3.8	[52]
35 kV/cm, 1.7 ms, 40°C	*Salmonella enteritidis*	Orange juice	5.2	[52]
35 kV/cm, 1.7 ms, 40°C	*Salmonella enteritidis*	Strawberry juice	4.4	[53]
35 kV/cm, 200 μs,38°C	*Salmonella enteritidis*	Tomato juice	4	[54]
20-30 kV/cm, 140-420 μs, 60°C	*Escherichia coli K12*	Apple cider	4.8	[55]
40 kV/cm, 150 μs, 56 ◦C	*Staphylococcus aureus*	Orange juice	5.5	[56]
35 kV/cm, 1.4 ms, 32°C	*Listeria innocua*	Fruit juice soymilk beverage	5	[57]
40 kV/cm, 100 μs, 56 ◦C	*Listeria innocua*	Orange juice	3.8	[58]
40 kV/cm, 100 *μ*s, 56 ◦C	*Escherichia coli k12*	Orange juice	6.3	[58]
22 kV/cm, 59 *μ*s, 45 ◦C	*Eschericia coli* *Salmonella typhimurium* *Lactobacillus plantarum* *Lactobacillus lactis* *Lactobacillus fermentum* *Lactobacillus casei*	Orange juice	1.59 2.05 2.57 4.15 2.11 0.43	[59]
20 kV/cm, 75 *μ*s, 55 ◦C	*Eschericia coli*	Orange juice	2.02	[59]
28 kV/cm, 75 *μ*s, 55 ◦C	*Eschericia coli*	Orange juice	3.79	[59]
20 kV/cm, 70 *μ*s, 55 ◦C	*Salmonella typhimurium* *Lactobacillus plantarum* *Lactobacillus lactis* *Lactobacillus fermentum* *Lactobacillus casei*	Orange juice	2.8–3.54 3.07 4.53 3.22 0.60	[59]
40 kV/cm, 100 μs, 56 ◦C	*Pichia fermentans*	Orange juice	4.7	[57]
50 kV/cm, 62μs,<30ºC	*Escherichia coli*	Skim milk	2.5	[60]
40 kV/cm, 547 μs, nd	*Escherichia coli* *Staphylococcus aureus*	Soymilk	5.2 3.51	[61]
24 kV/cm, nd, 52.5 °C	*Escherichia coli*	strawberry puree	7.3	[62]
10 kV/cm, nd, nd	*Escherichia coli* *Staphylococcus aureus*	Low-fat milk	4.3 - 5.2 6	[63]

Gurtler [59] demonstrated the effect of PEF to inactivate Escherichia coli O157: H7 suspended in orange juice and reported 1, 2.4, and 3.4 log10 reductions for 75 μs at [11].1, 19.7, and 23.7 kV/cm at 55°C, respectively.

The temperature impact was investigated by Heinz [28] to inactivate Escherichia coli in apple juice for the temperature range of 35 to 70°C. A maximum of 7 log10 reductions of Escherichia coli was achieved at 24 kV/cm if the temperature is increased from 40 to 50°C. It was clearly stated that the temperature rise decreased the energy level required to achieve the same log10 reductions of Escherichia coli in apple juice. Saldana [64] also reported the effect of temperature rise to enhance the inactivation level and achieved 0.5, 1.5, and 2.8 log10 reductions of Escherichia coli in apple juice by increasing the initial temperature to 20, 30, and 40°C respectively. Fleischman [54] observed the inactivation rate of Listeria monocytogenes inoculated in skim milk was increased as 0.3, 1.5 and 4.5 log10 reductions when the inlet temperature was set at 0, 50 and 55°C respectively. So, PEF processing efficiency can be increased by increasing the treatment temperature at not increased electric field strength [20, 65].

Korolczuk [66] enhanced the inactivation level of Salmonella enteritidis by increasing the pulse width from 0.05 to 3 μs at 50 kV/cm and 15°C. In contrast, Korolczuk [66] showed that increasing the pulse width from 1 to 3 μs did not produce any significant increase in the inactivation of Salmonella enteritidis. Similarly, increasing the pulse width from 2.5 to 4 μs did not improve the inactivation level of Lactobacillus plantarum during PEF processing at 40 kV/cm [67]. These contradictory results can be the consequence of using different PEF systems or pulses and operating conditions.

A small number of further studies comparing the effectiveness of various pulse waveforms have shown that microbial inactivation can be achieved with both square wave and exponential decaying pulses. However, square wave pulses require less cooling effort since they save more energy [68, 69, 70]. In contrary, Qin [71] investigated the inactivation of Saccharomyces cerevisiae by applying square, oscillating and non-oscillating exponential impulse waveforms with 67 and 80 kV/cm, and observed that non-oscillating exponential impulses showed better performance with a maximum of 3 log10 reductions. It was also reported that bipolar pulses are more efficient than monopolar pulses regarding the inhibition of microorganisms [26, 52, 57].

Gurtler et al. [59] observed 1.59 log10 reductions of Escherichia coli O157: H7 at 22 kV/cm for 59 μs at 45°C and 2.22 log10 reductions at 20 kV/cm for 70 μs and 55°C. In the same study, 2.8 and 3.5 log10 reductions of Salmonella typhimurium strain UK-1and 14028 were detected in orange juice, respectively.

When low pulse numbers are administered the Gram-positive bacteria and yeasts are more resistant to PEF treatment than Gram-negative bacteria. In contrary, McDonald [31] reported 3.5 and 6 log10 reductions of Listeria innocua at 30 kV/cm for only 5 μs (42°C) or 12 μs (50°C), respectively. He observed the greatest inactivation of Listeria with few numbers of pulses at lowest temperature when compared to other microorganisms considered by him for the investigations. This result was unexpected since Gram-positive organisms are usually less susceptible to PEF treatment than Gram-negative organisms. He also observed a maximum of 2.5 log10 reductions of Saccharomyces cerevisiae at 50 kV/cm, 55°C by applying 6 to 7 pulses. He noticed that fewer pulses and reduced electric field intensity did not show higher inactivation and found less than 1 log10 reductions. This observation was again contradictory that yeast was more susceptible to PEF. In contrast, McNamee [66] only observed 3.9 log10 reductions of Listeria innocua in orange juice at 40 kV/cm and 56°C for 100 μs. This difference in inactivation level might be due to differences in PEF treatment chamber design, pulse shape, chemical properties of the orange juice, and variations of bacteria cultivation methods. Listeria monocytogenes in apple juice was inactivated by 5 and 6.5 log10 reductions at 25 kV/cm for 31.5 μs (50°C) and 37 μs (55°C), respectively but in sour cherry juice, the same microorganism was inactivated by 3 log10 reductions by the application of 27 kV/cm for [11]1 μs (20°C) [72]. When two pulses were delivered and the juice temperature was maintained below 23°C, the population of Byssochlamys fulva conidio spores in tomato juice fell by less than 1

log cycle at 30 kV/cm. When 15 pulses were applied, the inactivation rate climbed to 4 log cycle [72].

Timmermans et al. [88] experimented on the shelf life of the PEF treated orange juice. The PEF treatment juice under 23 kV/cm, 36 μs resulted in fewer microorganism counts when tested after 58 d which was refrigerated at 4°C after the PEF treatment. Yeom [25] achieved a 112 d shelf life at 4°C for orange juice treated by PEF under 35 kV/cm for 59 μs. Similarly, Min et al. [46] achieved a shelf life of 196 d at 4°C of orange juice at 40 kV/cm for 97 μs at 45 to 65°C in the commercial-scale (500 L/h) PEF treatment.

3. PEF INACTIVATION OF MICROORGANISMS IN MILK

The majority of studies examined the effects of PEF treatment on enzymatic and microbiological inactivation in milk or skimmed milk ultra-filtration (SMUF) and demonstrated the efficacy of this technology. Smith [7] reported a maximum of 1 to 2 log10 reductions of the total flora in raw skim milk when the inlet temperature was 25 and 50°C. Fernandez-Molina et al. [74] reported that the inactivation of Pseudomonas fluorescens in skim milk increased with the increase in energy input and treatment time, and achieved a maximum of 2.6 log10 reductions by applying 38.9 kV/cm, at 33°C, and an energy input of 128 kJ/L.

Smith [7] used PEF treatment (80 kV/cm, 50 pulses), mild heat (52°C), and the addition of both the natural antimicrobials nisin (38 IU/mL) and lysozyme (1638 IU/mL) to produce a maximum of 7 log10 reductions of bacteria in raw skim milk. Bermudez-Aguirre [75] conducted experiments to check the quality of the skim milk and whole milk. The physicochemical parameters (pH, electrical conductivity, density, color, solids nonfat) and composition (protein and fat content) were measured after processing by the electric field of 30.76 to 53.84 kV/cm, at 20, 30, and 40°C for a different number of pulses. The authors observed minor variations in physicochemical parameters. They also reported that there was decreased in fat and protein in PEF treated skim milk and whole milk when the treatment became stronger. PEF treated samples showed higher stability at 4°C with minor variations in pH and it was found as higher than 6 after 33 d. However, the samples treated at 21°C showed faster spoilage and pH reduced to 4 after 5 d itself.

Michalac et al. [47] observed an overall log reduction of 1.0 in PEF-treated raw skim milk when the milk was treated by 35 kV/cm, 64 pulses for the treatment time of 47 μs to 188 s. The authors attributed this difference in microorganism inactivation to the complex composition of skim milk and the presence of proteins. According to Dutreux et al. [29], the less than 1 log difference between the inactivation of Escherichia coli in milk and in phosphate buffer was due to the influence of the physicochemical composition of the medium.

Rowan [76] investigated to reduce the viability of Mycobacterium paratuberculosis cells suspended in 0.1% peptone water and in sterilized cow's milk. The number of viable M. paratuberculosis cells was reduced by 5.3 log10 reductions in 0.1% peptone water and 5.9 log10 reductions in cow milk when treated by electric field intensity of 30 kV/cm, 2500 pulses at 50°C, while the cells were reduced by only 1.6 log10 reductions by PEF at 5°C. The results were compared by thermal method conducted at 50°C for 25 min or at 72°C for 25 s which results in 0.01 and 2.4 log10 reductions, respectively.

Using square bipolar pulses of 1.7 μs and a frequency of 200 Hz, Alkhafaji and Farid [77] reported a maximum of 6.6 log10 reductions of Escherichia coli (ATCC 25922) suspended in SMUF across treatment times ranging from 100 to 900 μs at electric field strengths of 37 and 43 kV/cm and a flow rate of 2.5 mL/s.

At final product temperatures of 15°C or 60ºC, Shamsi [78] examined the effects of PEF treated raw skim milk on the inactivation of Pseudomonads, Enterobacteriaceae, and total microflora at field strengths of 25–37 kV/cm, 200 Hz. in 15ºC, the Enterobacteriaceae count was found to be higher than 2.1 log10 decreases, while the total microflora and pseudomonads count decreased by a maximum of 1 log10 in the PEF electric field intensity range of 28–43 kV/cm. PEF treatments at 25–35 kV/cm reduced total microflora by up to 2.4 log10 and Pseudomonads and Enterobacteriaceae counts by at least 5.9 and 2.1 log10, respectively, when the temperature was elevated to 60°C.

4. QUALITY ASPECTS OF PEF TREATED LIQUID FOOD

Yeom et al. [24] studied aroma loss, browning index, color, and variation of soluble solids and pH in freshly squeezed orange juice. The orange juice was treated by applying 35 kV/cm, 59 μs pulses maintaining the temperature at 94.6°C. They observed that PEF-treated juices better retained volatile compounds (a-pinene, myrcene, octanal,d-limonene, and decanal) at 4°C than heat treated juices. However, PEF treated juices exhibited less browning and minimal modification of pH and soluble solids content. Cserhalmi et al. [79] reported no differences on the physical and chemical properties on citrus juice made from grapefruit, lemon, orange, and tangerine between the PEF treated and the untreated samples analyzed the effects of PEF-processing. Interestingly, the volatile compounds of PEF treated juice were essentially equal to those present in the unprocessed juice. Elez-Martinez et al. [80] observed that PEF-treated juice (35 kV/cm, 1000 μs, bipolar 4-μs at 200 Hz) retained better color than heat treated juice with no differences in pH, and acidity. Zarate Rodrıguez et al. [81] reported no differences in soluble solids, pH, and acidity of PEF treated apple juice. Evrendilek et al. [30] also did not find any differences in volatile compounds in PEF treated apple juice. Aguilar-Rosas et al. [83] observed less changes in volatile compounds of apple juice processed by PEF than a heat treated juice.

PEF treated tomato juice was found with better physicochemical and sensory characteristics (color, pH, acidity, soluble solids, viscosity, aromas) than the heat treated juice [84, 85, 85]. Moreover, the overall acceptability of PEF processed tomato juice was better than thermally processed juice [85].

Aguilo Aguayo et al. [86] demonstrated that the viscosity of a strawberry juice was affected by the PEF processing parameters such as pulse frequency, width, and polarity. In addition, they also observed that PEF treated watermelon juices retained better color characteristics than thermally treated juice [87]. The PEF treatment did not affect acidity and pH of milk [88]. Evrendilek et al. [89] conducted experiments to study the changes during storage in color, pH, soluble solids, and conductivity in milk with chocolate by PEF and hurdle PEF-Thermal methods and compared the results with an untreated sample. They did not find any change in the treated milk by both methods.

Mosqueda-Melgar et al. [90] found no significant changes in odor, color, taste and overall attributes in PEF treated melon and watermelon juices but found changes in those attributes after a thermal treatment.

Fernandez-Molina et al. [74, 91, 90] investigated the shelf life of skim milk by conducting various PEF-treatment (30 to 50 kV/cm, 4 Hz, 40 to 65ºC), conventional heating at 60 or 65°C for 21 s and the combination of PEF treatment with heat or organic acids (acetic or propionic acids) and the inactivation level of aerobic bacteria. PEF can be used in conjunction with heat or organic acids to increase the amount of microbial inactivation in milk, according to the results of all three investigations, which showed that the combination of PEF and organic acids had a bigger effect on microorganism inactivation.

The combination of PEF and organic acids had the biggest impact on the inactivation of microorganisms among the three trials, and it was shown that PEF can be used in conjunction with heat or organic acids to increase the amount of microbial inactivation in milk.

5. CONCLUSION

PEF has been investigated as a potential non-thermal technique for food preservation but the microbial inactivation by PEF depends on many factors. Based on all the available studies, an adequate knowledge of the critical factors is necessary to obtain the quality PEF inactivation data. The process of PEF pasteurization is complex because many variables are involved and these parameters have been tested by several research groups. But, it could still impossible to separate the parameter influences over the inactivation level of microorganisms. Anyway, the application of PEF for food preservation provides the tremendous potential to preserve high-quality products at lower temperatures to retain the fresh-like products. Considerable investigations are still required to address the regulatory and commercial concerns.

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