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# PULSED ELECTRIC FIELD PROCESSING OF FOODS - A REVIEW

**Satyendra Kumar*, Dr. Nidhi Agarwal** & Dr. Pramod K. Raghav*****

* Lecturer, Department of Food and Biotechnology, Jayoti Vidyapeeth Women's University, Jharna Mahla Jaipur, Rajasthan

** Assistant Professor, Department of Food and Biotechnology, Jayoti Vidyapeeth Women's University, Jharna Mahla Jaipur, Rajasthan

*** Associate Professor, Department of Food and Biotechnology, Jayoti Vidyapeeth Women's University, Jharna Mahla Jaipur, Rajasthan

## Abstract:

*Pulsed electric field (PEF) used short electric pulses to preserve the food. It is suitable for preserving liquid and semi-liquid foods, removing harmful micro-organisms and producing functional constituents. The main objective of PEF processing is to inactivate microorganisms present while minimizing changes in physical, sensory and nutritional properties. PEF technology involves the application of pulses of high voltage to liquid or semi-solid foods placed between two electrodes.*

**Key Words**: Pulse Electric Field (PEF), Electrodes, Liquid and Semi-Solid Foods & Microorganisms

## Introduction:

Pulsed electric field (PEF) use short electric pulses to preserve the food. It is suitable for preserving liquid and semi-liquid foods, removing micro-organisms and producing functional constituents. PEF has not yet been used in Europe on industrial scale although it has been used in the US for orange juice and it has considerable potential for improving quality and taste of pasteurized foods compared with traditional preservation techniques.

Pulsed electric field (PEF) processing is a novel, non-thermal preservation method that has the potential to produce foods with excellent sensory and nutritional quality and shelf-life. High intensity pulsed electric field (HIPEF) processing involves the application of pulses of high voltage (typically 20 - 80 kV/cm) to foods placed between 2 electrodes. PEF treatment is conducted at ambient, sub-ambient, or slightly above ambient temperature for less than 1 s, achieved by multiple short duration pulses typically less than 5 μs and energy loss due to heating of foods as well as undesirable changes in the sensory properties of the food is minimized. For food quality attributes, PEF technology is considered superior to traditional heat treatment of foods because it avoids or greatly reduces the detrimental changes of the sensory and physical properties of foods (Quass, 1997). Although some studies have concluded that PEF preserves the nutritional components of the food, effects of PEF on the chemical and nutritional aspects of foods must be better understood before it is used in food processing (Qin *et al.*, 1995b).

PEF technology has been presented as advantageous in comparison to, for instance, heat treatments, because it kills microorganisms while better maintaining the original color, flavor, texture, and nutritional value of the unprocessed food. PEF technology involves the application of pulses of high voltage to liquid or semi-solid foods placed between two electrodes. Most PEF studies have focused on PEF treatments effect on the microbial activation in milk, milk products, egg products, juices and other liquid foods (Qin et al., 1995). However, whereas a considerable amount of research papers have been published on the microbial aspects of food preservation by PEF, a lesser amount of information is available about the effect of this technology on food constituents and overall quality and acceptability. Recently, the interest in application of pulsed electric fields (PEF) for food processing has revived. The PEF treatment was shown to be very effective for inactivation of microorganisms, increasing the pressing efficiency and enhancing the juice extraction from fruits and vegetables and for intensification of the food dehydration and drying (Gulyi *et al.,* 1994; Barbosa-Cánovas *et al.,* 1998; Barsotti and Cheftel, 1998, 1999; Estiaghi and Knorr, 1999; Vorobiev *et al.,* 2000, 2004; Bajgai and Hashinaga, 2001; Bazhal *et al.,* 2001; Taiwo *et al.,* 2002).

Consumer demand has increasingly required processed food to have a more „natural flavour and colour, with a shelf life that is sufficient for distribution and a reasonable period of home Storage before consumption (Fellow, P. J., 2000).

The use of an external electrical field for a few microseconds induces local structural changes and a rapid breakdown of the cell membrane. Based on this phenomenon, called electroporation, many applications of high intensity pulsed electric fields (HIPEF) have been studied in the last decade. In the area of plant and microbial genetics pulsed electric fields are applied to cause an electroporation of cell membranes to infuse foreign material such as DNA into the cell (Neumann, 1996; Zimmermann, 1996). This process of reversible pore formation has to be controlled to maintain viability of the organisms during the application of the PEF. Due to the reversible permeabilization, the cells repair their membranes through resealing the electropores immediately after the PEF treatment. At higher treatment intensity PEF can be utilized for the inactivation of microorganisms by an irreversible breakdown of the cell membrane.

HIPEF consists of a number of components including a power source, capacitor tank, a switch, treatment chamber, voltage current and temperature sensors and aseptic packaging equipment. Generation of different voltage waveforms in PEF: exponential pulses, square pulses, bipolar pulses and oscillatory pulses.

Among all emerging nonthermal technologies, high intensity pulsed electric fields (PEF) is one of the most appealing technologies due to its short treatment times and reduced heating effects with respect to other technologies. PEF is commonly understood as a nonthermal food preservation technology that involves the discharge of high voltage electric pulses (up to70 kV/cm) into the food product, which is placed between two electrodes for a few microseconds (Angersbach et al., 2000).

## Applications of Pulse Electric Field in Food Processing:

### Inactivation of Microorganisms:

PEF treatment has lethal effects on various vegetative bacteria, mold and yeast. Efficacy of spore inactivation by PEF in combination with heat or other hurdles is a subject of current research.

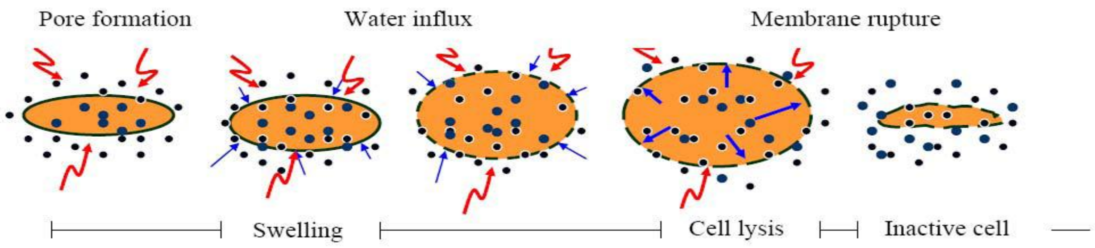

**Figure 1:** Stages of electroporation in a cell membrane through osmosis. The red arrows show the field intensity and blue dots are water molecules

A series of short, high-voltage pulses break the cell membranes of vegetative microorganisms in liquid media by expanding existing pores (electroporation) or creating new ones. Pore formation is reversible or irreversible depending on factors such as the electric field intensity, the pulse duration, and number of pulses (Fig-1). The membranes of PEF-treated cells become permeable to small molecules; permeation causes swelling and eventual rupture of the cell membrane.

**Table 1:** Inactivation of Microorganisms and Enzymes by Pulsed Electric Fields (PEF)

| Source | Microorganisms | Suspension Media | Log Reduction (max) | Treatment Vessel[a] | Process Conditions[b] |
|---|---|---|---|---|---|
| Fernandez-Molina and others (1999) | *Listeria innocua* | Raw skim milk ( 0.2% milkfat) | 2.6 | coaxial, 29 ml, d = 0.63, | 15 to 28°C, 0.5 l/min 100 pulses, 50 kV/cm, 0.5 µF, 2 µsec, 3.5 Hz Exponential decay |
| Reina and others (1998) | *Listeria monocytogenes* (scott A) | Pasteurized whole milk (3.5% milkfat) 2% milk (2% milkfat), skim milk (0.2%) | 3.0-4.0 | C, cofield flow, 20 ml | 10 to 50°C, 0.07l/s, 30 kV/cm, 1.5 µsec, 1,700 Hz, bipolar pulses, t = 600 µsec |
| Dunn and Pearlman (1987) | *Lactobacillus brevis* | Yogurt | 2 | B, parallel plates | 50°C, 1.8 V/ µm |
| Vega-Mercado and others (1996a | B. *subtilis* spores ATCC 9372 | Pea soup | 5.3 | C., coaxil, 0.51 / min | <5.5°C, 3.3 V/ µm, 2 µsec, 0.5 µF, 4.3 Hz, 30 pulses, exponential decay |

**Processing of Milk**:

Fernandez-Molina *et al.* (1999) studied the shelf-life of raw skim milk (0.2% milk fat), treated with PEF at 40 kV/cm, 30 pulses, and treatment time of 2 µs using exponential decaying pulses. The shelf-life of the milk was 2 wk stored at 4 °C; however, treatment of raw skim milk with 80 °C for 6 s followed by PEF treatment at 30 kV/cm, 30 pulses, and pulse width of 2 µs increased the shelf-life up to 22 d, with a total aerobic plate count of 3.6-log cfu/ml and no coliform. The processing temperature did not exceed 28 ° C during PEF treatment of the raw skim milk.

Dunn and Pearlman (1987) conducted a challenge test and shelf-life study with homogenized milk inoculated with *Salmonella* Dublin and treated with 36.7 kV/cm and 40 pulses over a 25-min time period. *Salmonella* Dublin was not detected after PEF treatment or after storage at 7 - 9 ° C for 8 d. The naturally occurring milk bacterial population increased to $10^7$ cfu/ml in the untreated milk, whereas the treated milk showed approximately $4x10^2$ cfu/ml. Further studies by Dunn (1996) indicated less flavor degradation and no chemical or physical changes in milk quality attributes for cheesemaking. When *Escherichia coli* was used as the challenge bacteria, a 3-log reduction was achieved immediately after the treatment.

Qin and others (1995b) reported that milk (2% milk fat) subjected to 2 steps of 7 pulses each and 1 step of 6 pulses with an electric field of 40 kV/cm achieved a shelf-life of 2 wk at refrigeration temperature. There was no apparent change in its physical and chemical properties and no significant differences in sensory attributes between heat pasteurized and PEF treated milk

Calderon-Miranda (1998) studied the PEF inactivation of *Listeria innocua* suspended in skim milk and its subsequent sensitization to nisin. The microbial population of *L. innocua* was reduced by 2.5-log after PEF treatments at 30, 40 or 50 kV/cm. The same PEF intensities and subsequent exposure to 10 IU nisin/ml achieved 2-, 2.7- or 3.4-log reduction cycles of *L. innocua*. It appears that there may be an additional inactivation effect as a result of exposure to nisin after PEF. Reina and others (1998) studied the inactivation of *Listeria monocytogenes* Scott A in pasteurized whole, 2%, and skim milk with PEF. *Listeria monocytogenes* was reduced 1- to 3-log cycles at 25 ° C and 4-log cycles at 50 ° C, with no significant differences being found among the 3 milks. The lethal effect of PEF was a function of the field intensity and treatment time.

## Processing of Eggs:

Some of the earliest studies in egg products were conducted by Dunn and Pearlman (1987) in a static parallel electrode treatment chamber with 2-cm gap using 25 exponentially decaying pulses with peak voltages of around 36 kV. Tests were carried out on liquid eggs, on heat-pasteurized liquid egg products, and on egg products with potassium sorbate and citric acid added as preservatives. Comparisons were made with regular heat-pasteurized egg products with and without the addition of food preservatives when the eggs were stored at low (4 ° C) and high (10 ° C) refrigeration temperatures. The study showed the importance of the hurdle approach in shelf-life extension. Its effectiveness was even more evident during storage at low temperatures, where egg products with a final count around 2.7 log cfu/ml stored at 10 ° C and 4 ° C maintained a low count for 4 and 10 d, respectively, versus a few hours for the heat pasteurized samples.

Other studies on liquid whole eggs (LWE) treated with PEF conducted by Qin and others (1995) and Ma and others (1997) showed that PEF treatment decreased the viscosity but increased the color (in terms of b -carotene concentration) of liquid whole eggs compared to fresh eggs. After sensory panel evaluation with a triangle test, Qin and others (1995b) found no differences between scrambled eggs prepared from fresh eggs and electric field-treated eggs; the latter were preferred over a commercial brand.

In addition to color analysis of eggs products, Ma and others (1997) evaluated the density of fresh and PEF-treated LWE (indicator of egg protein-foaming ability), as well as the strength of sponge cake baked with PEF-treated eggs. The stepwise process used by Ma and others (1997) did not cause any difference in density or whiteness between the PEF-treated and fresh LWE. The strength of the sponge cakes prepared with PEF-treated eggs was greater than the cake made with non-processed eggs. This difference in strength was attributed to the lower volume obtained after baking with PEF-treated eggs. The statistical analysis of the sensory evaluation revealed no differences between cakes prepared from PEF processed and fresh LWE

## Processing of Various Food Products:

### Green Pea Soup:

Vega-Mercado and others (1996a) exposed pea soup to 2 steps of 16 pulses at 35 kV/cm to prevent an increase in temperature beyond 55 ° C during treatment. The shelf-life of the PEF-treated pea soup stored at refrigeration temperature exceeded 4 wk, while 22 or 32 ° C were found inappropriate to store the product. There were no apparent changes in the physical and chemical properties or sensory attributes of the pea soup directly after PEF processing or during the 4 wk of storage at refrigeration temperatures.

### Apple Juice:

Simpson and others (1995) reported that apple juice from concentrate treated with PEF at 50 kV/cm, 10 pulses, pulse width of 2 µs and maximum processing temperature of 45 ° C had a shelf-life of 28 d compared to a shelf-life of 21 d of fresh-squeezed apple juice. There were no physical or chemical changes in ascorbic acid or sugars in the PEF-treated apple juice and a sensory panel found no significant differences between untreated and electric field treated juices. Vega Mercado and others (1997) reported that PEF extended the shelf-life at 22 - 25 ° C of fresh apple juice and apple juice from concentrate to more than 56 d or 32 d, respectively. There was no apparent change in its physicochemical and sensory properties

### Grape Juice:

Juice extraction from Chardonnay white grape using pulse electric field with two pressure conditions was studied. A PEF treatment of 400 V/cm was applied. The PEF pretreatment increased the juice yield by 67 - 75% compared to the control sample without any treatment (Grimi, 2009).

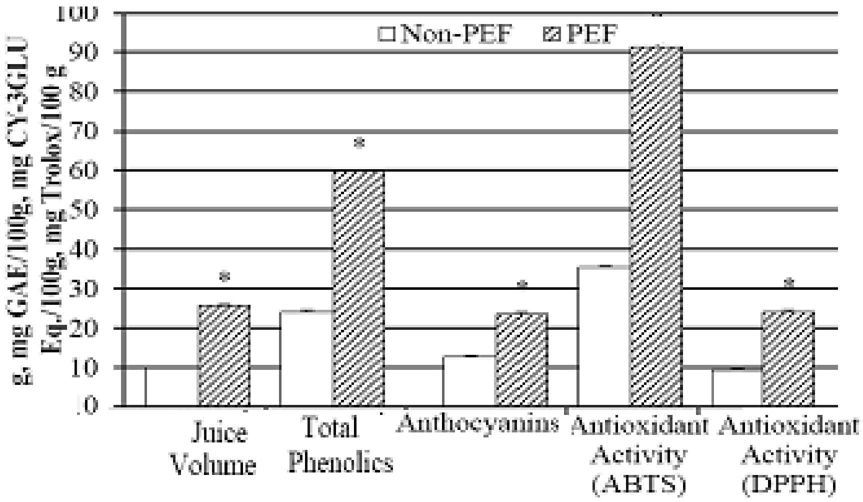

**Figure 2:** Juice volume of PEF treated

### Sugar:

The juice yield of pretreated samples was higher (74.5% at 5kV, 20 pulses) than heat treated (73.2%) and untreated sugar cane (65.5%). The energy consumption for disintegration of sugar cane (17 kJ/ kg at 5kV and 20 pulses) was 10 times less when compared to heat treatment (171 kJ/ kg). Additionally the cell disintegration using occurred faster (less than 2 min with 1Hz pulses frequency and 80 pulses) than thermal disintegration (20 min at 70° C) (Jarupan Kuldiloke et al., 2008). PEF was used as an intermediate in the cold juice extraction from sugar beet cossettes using a pilot scale multi-plate and frame pressing equipment and a pulse generator. A yield of about 80% in juice per initial mass of cossettes was achieved before washing. Purity of juices was higher following PEF treatment compared to those juices without to PEF treatment (96-98% and 90-93% respectively (Jemai and Vorobiev, 2006).

**Meat and Fish:**

The electro-permeabilization of cell membranes, leading to a drastic increase in mass transfer rates, can be utilized to enhance drying rates of cellular tissue. An increase in mass transfer rates, resulting in faster water transport to the product surface and therefore reduction of drying time after a pretreatment will lead to drastic saving of energy and better utilization of production capacities during convective air drying. Taking into account the low energy input required for a PEF treatment of plant or animal tissue (2-20 kJ/kg), it is evident that there is a potential to reduce the total energy input for product drying.

**Conclusion:**

PEF inactivates vegetative micro-organisms including yeasts, spoilage micro-organisms and pathogens, and it can be used to pasteurize fluids such as juices, milk and soups without using additives. This technology can substitute for conventional heat pasteurization or it can operate at room temperature to retain quality and heat-sensitive vitamins. PEF can be used as continuous process but, after processing, products have to be packaged hygienically and kept cool during storage. Using some of antimicrobial substances prolongs the shelf life of foods within pulsed electric fields. An application of PEF for food preservation provides the tremendous potential to preserve high quality products at lower temperatures and short residence time to retain the fresh-like character and nutritional value of the products.

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