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Impacts of pulsed electric field (PEF) technology in different approaches of food industry: A review

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Abstract
Pulsed Electric Field (PEF) is a process that high voltage electric field is applied at very short term. This technology is mainly used for the food preservation by inactivating microorganisms and enzymes. PEF technology is replaced by traditional preservation methods due to its ability to maintain a preferred food quality. In addition, the main phenomena behind this technique is the ejecting of cell contents by inactivating cell membrane functions. Many studies have depicted that application of PEF can enhance different food processes apart from preservation. Recently, many studies have executed to find out new approaches of using PEF in food industry. Different assessments have highlighted that this technology is applicable in increasing the juice yield, decreasing freezing- thawing time duration, enhancing meat quality, reducing oil absorption in deep frying and etc. Application of PEF treatment for different food processes has a drastic impact over enhancing food quality. The aim of this study is to analyze the impact of using PEF treatment for the development of food industry.

Keywords: pulsed electric field, food, applications, quality, treatment

Introduction

Demand for the high quality nutritious foods encourages for development of novel food processing technologies. Nowadays people are interest in consuming nutritious foods with minimum hazards. Pulsed electric field (PEF) is an innovative and non-conventional treatment which enhances cell membrane permeabilization and the electroporation phenomenon is the main cause [1]. PEF has become a popular technique in different segments due to its ability to inactivate microorganisms and its ability to enhance the efficiency of extracting intracellular chemical compounds.

PEF is a key treatment since it requires short time, minimizes heating effects, gentle food processing and environmental friendly. This can be used to inactivate wide range of microorganisms with minimal changes with preserving nutritional and sensory values. The main components of a PEF system are high voltage direct current power supply, signal generator, capacitors for energy storage, continuous or static treatment of chambers with two parallel or several electrodes, measurement devices and a central control unit [2, 3].

Conventional preservation methods fail to develop microbiologically stable foods at the desired quality level. High intensity pulsed electric field processing can be used as an alternative to produce safe and shelf-stable food products [4]. In PEF technique, short pulses of electric field is used to inactivate most microorganisms and enzymes at room temperature. Further, the biological membrane is affected by PEF which leads to enhance the mass transfer through membrane [5]. The transmembrane potential is induced when an external electric field is applied to a cell. The cell lysis occurs when the applied electric field produced a potential difference of 1V across the cell membrane of the microorganisms. This leads to the irreversible loss of membrane's function. However, strong polarization of viable cells by an external field leads to increase cell membrane conductance and permeability [6]. By applying short electric pulses, the cell membrane causes for rearrangements and this results pore formation. This method is mild for the molecules that should be released as they are subjected to a limited temperature increase and a limited shear forces during the treatment [7].

At a particular voltage, the arrangement of phospholipid molecules changes and this is known as "electroporation" or "electropermeabilization". External field strength, pulse shape, pulse duration, number of pulses applied and specific treatment energy are the key factors. The membrane ruptures promotes the release of intracellular matter and this leads the solvent to access into the cell [8].

Applications of PEF in extracting of bioactive compounds

When a critical electrical potential is introduced along the cell membrane, it leads towards some mechanical changes. These changes forwardly increase the permeability of cell membrane. This enables the transfer of cell content on the outside or cell destruction due to the formation of pores in the membrane. Previous studies have found that Total Polyphenol content, total flavonoid content are increased after applying PEF treatment. The reason for the enrichment is the location of metabolites in different cell compartments and PEF treatment leads to increase the permeability of the membrane and thus this allows the release of the content. Assessment on the bioavailability of polyphenols and flavonoids in PEF treated Muscat Ottonel grape variety depicted that total polyphenol content and total flavonoid content was increased 2.28 & 7.17 times respectively [9].

A study on the effectiveness of applying PEF treatment on sour cherries had shown that total phenolic content increased by 12-19% compared to untreated sample and the total monomeric anthocyanin content of sour cherry juices after PEF treatment was increased by 43-58%. In this experiment different electric field strengths were used and it was reported that 3 kV/ cm and 5 kV/ cm did not contribute a significant effect towards the extraction and the above results were reported by applying 1 kV/ cm intensity [10].

It was found that PEF as the pre-treatment foe potato peels followed by solid-liquid extraction with methanol has a significant effect on recovery of steroidal alkaloids. The recovery percentage was 99.9% higher than that of untreated peels with a field strength less than 0.75 kV/cm and less than 150-1500 µs [11].

Applications of PEF in juice extraction

Hydraulic pressing is used in the food industry to improve yield in the production of fruit juices and oils. Conventional pretreatments such as heating, osmotic dehydration, dehydration, alkaline breakage and enzymatic treatment are done to achieve plasmolysis. Due to high energy usage nutritionally and physiologically molecules could be significantly lost and PEF treatment can be used instead as it is performed at room temperature in a short period [12].

Application of PEF with 3 kV/cm field strength had increased the sour cherry juice yield by 45% and untreated samples were given 26- 37.7 g per 100 g of sour cherries [9]. The effect of PEF as a pre-treatment was analyzed with blueberries and 55.5% juice yield was given by applying 1 kV/cm field strength while untreated sample had 42.7% average juice yield [13].

Assessment on the effect of PEF on juice yield was analyzed in raspberries and 47.0 ± 2.14% juice yield was recovered by treating 3 kV/cm electric field intensity and 12 kJ kg^{-1} total specific energy. The juice recovery from untreated samples was 37.6 ± 4.49% while the highest increase in juice content was achieved by applying 3 kV/cm field strength and 12 kJ kg^{-1} total specific energy and it was 47.0 ± 2.14% [14].

A study on sugar processing aid of PEF treatment and the yield of pretreated samples was 74.5% at 5 kV & 20 pulses. Untreated sugar cane was given a yield of 65.5%. Further the purity of sugar yield of PEF treated sugar cane was higher than the untreated samples which were 96-98% and 90-93% respectively [15].

Effects of PEF on food preservation

Two mechanisms are proposed for the mode of action in food preservation. They are electroporation and electrical breakdown. In electroporation, the cell is exposed to high voltage which temporarily destabilizes the lipid bilayer and proteins of the cell membranes. A drastic increase in permeability leads to make an electric potential differences of the cell plasma and the extracellular medium forming a Donnan equilibrium. The neutralization of the transmembrane gradient across the membrane irreversibly weakens the osmoregulation of the cell and consequently cell death occurs. In electrical breakdown when the cell is exposed to an external electric field it electroporates through the leakage of ions and small molecules and thus the membrane becomes permeable to water that causes swelling and eventual rupture and lysis of the cell. The primary electroporation with small pores on the cell membrane followed by a secondary electroporation with larger pores which finally causes electrical breakdown and cell lysis. Large pores are obtained by increasing the intensity of electric field pulse duration or reducing the ionic strength of the medium [4, 16].

p^H of the food has a significant effect towards the inactivation of microbes and an assessment had depicted that higher inactivation of *Salmonella* was observed in the foods having neutral or basic p^H values. In high acidic foods L. monocytogenes were reduced after applying the PEF treatment [17, 18, 19]. In addition the water activity of the food has a direct relationship with the preservation while the foods having high electrical conductivity depicts less inactivation of microorganisms [17].

In an assessment regarding the milk preservation it was reported that PEF treatment had a greater effect towards the inactivation of moulds, yeasts and vegetative cells. When treatment was applied to samples inoculated with E. *coli* reductions of 6 and 9 log cycles were achieved, respectively, after applying 50 pulses of 60 kV/cm or 80 pulses of 70 kV/cm. In other hand some studies have depicted that PEF as only pre-treatment has less effectiveness microbial inactivation. This highlighted in the PEF treatment with exponential decaying pulses, field intensities of 30 to 50 kV/cm, pulse frequency of 4 Hz and treatment temperature of 40 to 65ºC in combination with organic acids had a greater effect on inactivation of microorganisms than PEF alone or combined with mild temperature. After inoculating *Salmonella dublin* (3.8±103 cfu/ml) along with a PEF treatment of 40 pulses at 36.7 kV the treated samples showed no of S. *dublin* and less than 20 milk bacteria of the background microflora [20, 21]. Further, studies have shown that Gram –positive and Gram-negative bacteria in whole milk were inactivated at 22-28 kV/ cm for 17-101 µs at 50^0C with 5-6 log reduction in bacterial number [17].

Recent findings of PEF in food industry

A study was carried out to analyze the effect of PEF on potatoes which intended for deep frying. In that study, potatoes were subjected to 18.9 kJ/kg electric field strength with applying 9000 pulses and 0.75 kV/cm electric field and 810 pulses at 2.50 kV/cm electric field. With compared to blanched and water dipped samples, PEF treated samples depicted a lower oil absorption in frying, increased the moisture content and softened the texture. Further, PEF treated samples accounted for lower browning in frying and found that these effects were enhanced with electroporation [22].

An assessment was carried out to determine the effects of freezing and PEF treatment as pretreatments on the quality of beef semitendinosus muscles. Applying of square-wave bipolar pulses at electric field strength 1.4 kV/cm, 20 µs pulse width, 50 Hz frequency and total specific energy 250 kJ/kg PEF treatment caused considerable microstructural changes of meat tissue than freezing and significantly increased the purge loss. However combination of freezing, thawing and PEF delivered a tremendous improvement in tenderness [23].

As a novel approach, a comparative study between PEF and ohmic heating prior to osmotic treatment was used to assess the effects on the structure of apple tissues for their freezing/ thawing behavior. An electrical field strength of 800 V/cm (isothermal regime) was treated for apple discs and they were exposed to osmotic treatment in the aqueous solution of glycerol. At the same time another sample was subjected to electric field strength of 40 V/cm (ohmic heating, non-isothermal regime) and it was subjected to same osmotic treatment. Then each sample was subjected to freezing-thawing experiment. The results were depicted that the osmotic solution was homogenous inside PEF treated apple than ohmic heating treated samples. Further, both freezing and thawing time were reduced in PEF treated samples than other method [24].

These examples highlight that there are several ways of using PEF as a treatment in enhancing the food quality and consumer acceptance rather than using conventional methods. Nowadays researches are eager to find out new approaches of using PEF with the combination of other technologies in order to improve the quality after different food processing techniques.

Conclusion

Apart from the food preservation, PEF technology can be applied in different aspects in food industry. This technology can be used to make different improvements in terms of food quality and studies proved that PEF treatment can make considerable developments in yield, texture, concentration of bio-active compounds and other quality parameters.

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