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Review Article

Pulse Electric Field (PEF) in Food Sectors

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Abstract

Background: The requirement for safe, healthy, and high-quality food items has led to the development of food processing. In order to increase the shelf life and maintain the quality of different foods, PEF has become one of the processing techniques, which can be used as a substitute for conventional techniques. People today have great standards for items' sensory attributes, functionality, and dietary benefit. This article's main objective is to examine the potential benefits of the PEF technique as a preservation method for the growth of bacteria inhibition and to explore the concept in different industrial applications without sacrificing the nutritional value and natural organoleptic qualities of food products **Methodology:** The primary research articles were sourced out from Google Scholar, PubMed, Research Gate and other peer reviewed journals published in English related to the context of discussion. This included fifty papers published before 2024. **Results:** Without significantly compromising the qualitative qualities of foods, PEF technology is a very successful method for the processing and preservation of a range of food products. **Conclusion:** PEF can be used for pasteurization, enhancing procedures like freezing, dehydration, or extraction, but it can also help with the production of foods that are useful and contain other ingredients.

Keywords: pulsed electric field, food processing, food production, food quality

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Review Article

Introduction

The concept of PEF technology is defined as a technique in which pulses are employed with higher electric fields that last only a few microseconds to milliseconds and with electric strength intensities ranging from 10-80kV/cm **(Mohamed & Eissa, 2012)**. The number of pulses applied to the product, which is held between two electrodes, determines the outcome of the process. The space between the set of electrodes is referred to as the treatment chamber's gap **(Abbas Syed, 2017).** The processing time is determined by multiplying the effective pulse duration by the number of pulses **(Pushparaj & Athmaselvi, 2021).** Food can transfer electricity due to the existence of many ions, which provide the material with some degree of electric conduction. Because there are charged ions present in the liquid, when an electrical field is applied, electricity passes through the liquid feed and is sent to every location in the liquid. The high voltage employed generates an electric field of forces that promotes microbial deactivation **(Zhang et al., 1995).**

Methodology

The primary articles were sourced from "Google Scholar", "PubMed", "Research Gate" and "ScienceDirect" sites with keywords including "Pulse Electric Field" and "PEF in Food Industry". Articles published in English before 2024 were taken in this review. A total of 349 studies were found initially based on the keyword combinations used in the databases. Subsequently, the retrieved articles were reviewed, and irrelevant ones were excluded. Afterward, a thorough examination of the remaining literature was performed, leading to the development of a manuscript outline. Finally, the relevant content was extracted from the literature using summarization and induction techniques. This scrutinized to the inclusion of 50 studies in this review.

<u>Inclusion Criteria</u>

Articles that explored on any of the benefits of PEF including preservation methods, processing and as a contributor in food industry and sectors were included.

Electroporation

Electroporation explains the mechanism behind the Pulsed Electric Field (PEF) technology. The electric field strength is one of the most important factors impacting cell membrane electroporation, and the size of the target cell determines the desired field strength. The rupture of the cell wall arises when an electric field is

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provided in the form of pulses, which enhances the permeabilization in the cell wall. This condition is called as electroporation **(Pushparaj & Athmaselvi, 2021).** Electroporation bring out a rise in membrane rupture and permeability, which is termed as electro-permeabilization and depending on the degree of membrane organizational changes that lead to cell death, electro-permeabilization can be reversible or irreversible **(Abbas Syed, 2017).** PEF-based extraction occurs when the applied voltage and associated strength of the electric field are higher than the required critical transmembrane potential **(Barba, Parniakov, et al., 2015)**. The food material which is to be treated and the ultimate purpose determine the critical transmembrane potential. After providing sufficient critical transmembrane potential, pores develop in the membrane of biological cells **(Arshad et al., 2021).** If the electric field strength surpasses a critical limit, elastic characteristics of the cell are unable to sustain the charge attraction forces. Once the pores have developed, it may enlarge along with the applied field strength causing cell disruption, as a result, the reversible breakdown becomes irreversible, resulting in continual mechanical destructions of the cell membrane. After reducing the applied voltage, the cell cannot return to its previous place in irreversible electroporation. **(Xi et al., 2021).**

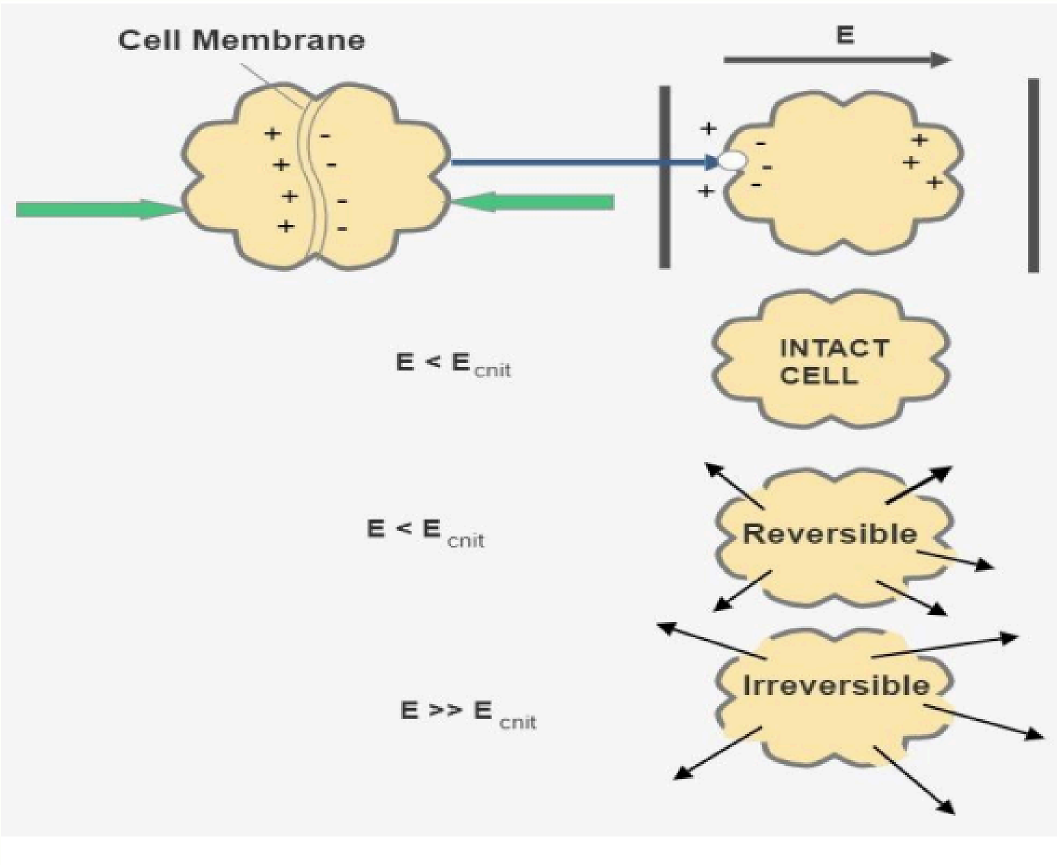

Figure 1: Electroporation Cell Process

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Working of PEF

A typical PEF unit consists of many basic components, including a high-voltage generator, a treatment chamber unit, control and monitoring systems, and a fluid-handling system. The voltage pulse generator creates the desired shape, duration, and intensity of high voltage pulses (**Nowosad et al., 2021**). Food is processed in the treatment chamber, which can be static or continuous, and the produced pulses are given to a set of electrodes used in the procedure, where the connection between two electrodes using a nonconductive material to stop the flow of electricity from one place to another. A force per unit charge is applied to the food item, which is called as an electric field, it is implicated in bacteria for the permanent breakdown of cell membranes. Continuous and batch are the two types of treatment chambers based on the kind of treated product, which can be solid, semisolid, liquid, or semiliquid. A central computer controls the process by establishing the settings, managing the pump's operation, and collecting data from probes positioned within the chamber **(Zimmermann and Benz, 1980, Abbas Syed, 2017).**

Factors affecting PEF

The mortality variables that contribute to the efficiency of PEF technology may be divided into three categories: technical, media and biological factors. Every category of deciding factors are associated with the kind of equipment, processing conditions, the microorganism being targeted, and the kind and state of the medium.

Technical Factors

The most common process variables that describe PEF technology include electric field intensity, pulse shape, pulse width, treatment duration, , pulse-specific energy, number of pulses and frequency.

Electric Field Intensity: The intensity of the electric field is defined by the distance between the set of electrodes in the treatment chamber's and the supplied voltage, which is generally reported in kVcm-1 . The electric field intensity between the set of electrodes in treatment chambers with parallel electrode configurations is uniform, but in colinear layouts, it is not uniform and varies with the position **(Raso et al., 2014).** The electric field strength changes with the potential difference **(Peleg, 1995).** If the electric field intensity surpasses a critical limit, electroporation of the cell membranes occurs, and the intracellular content is liberated **(Donsı, Ferrari, and Pataro 2010).** The intensity of the electric field is a significant factor in determining the degree of active component extraction. Many physical characteristics, such as viscosity, diffusivity, solubility, and surface tension, might be affected by it **(Xi et al., 2021).** It is found that higher the field intensity results in a further improvement in treatment efficiency **(McDonald et al., 2000).**

Treatment Time: The time span during which microorganisms are treated with the applied field strength could be referred as the treatment time. It is determined by the pulse numbers and its width of the pulse. PEF treatment time is estimated by multiplying the pulse duration by the pulse number **(Jayaram et al., 1991;Sale and Hamilton, 1967).** In pulses with exponential decay, the approved effective pulse width is the time required for the input voltage to fall to 37% of its peak value, however in pulses with square waveforms, the effective pulse width is the time required for the pulse to last **(Raso et al., 2014)**. Rise in pulse duration may also result in a rise in the temperature of the material, which is undesirable.

Pulse Shape: Rectangular, exponential, oscillatory, and a combination of wide and narrow pulses duration are usually used in monopolar and bipolar amid various modes possible in waveforms for processing of different food. The shape of the applied pulse is controlled by the impedance properties of the discharge circuit pulse creating network and treatment chamber containing food sample. The sample conductivity governs the resistance of the chamber. As a result, replacing the foods sample with variable conductivity has an impact on the shape of the pulse **(Qin et al., 2015; Kumar, Arshad et al., 2020).** Two of the most widely used waveforms are square waves or exponentially decaying waves. High-power switches with a single-on capability generate exponential decay pulses, which liberate the entire amount of energy carried in the capacitor bank. Surging rate of these pulses is fast but decaying rate is slow, resulting in a long tail portion that is ineffective at destroying microbes but produces excess heat. An inadequate discharge of a capacitor by an on/off switch or a more complicated pulse-forming network can produce square waveform pulses. Because they create a consistent peak voltage for the pulse duration, square pulses is better suited for PEF microbial inactivation. Square waves are more lethal and energy-efficient than exponential waveforms since they have a longer peak voltage duration **(Raso et al., 2014 ; Barbosa-Canovas et al. 2004).**

Width of the Pulse: The discharging circuits also the resistivity of the material being treated determine the pulse width. The treatment time depend on both the parameters, pulse width and the applied frequency of the pulses in any application. Depending on the geometry of the sample cells, enhancing the treatment intensity by increasing frequency or pulse width will boost the development of pores for constant field strength **(Mannozzi et al., 2019).**

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There is an inverse connection between pulse width and field strength ,thus a less field intensity with a wider pulse width can produce the same results as a higher field strength with a shorter pulse width **(Arshad et al., 2020; Korolczuk et al., 2006)**.

Pulse Number: The pulse number is another key characteristic that is affected by both fluid velocity and frequency. The increase of flow velocity could result in decrease of the thickness of boundary layer **(He et al. 2014).** While the material flow velocity is too high to attain the extraction equilibrium in the border layer of both phases, the yield of active components has decreased. When the frequency exceeded a critical point, the materials content increased, and then the growth rate levelled out **(Xi et al., 2021)**.

Pulse Frequency: This parameter represents the number of pulses delivered per unit of time and is expressed in Hz (pulses per second). Compared to the quick, high-energy discharge of the capacitors, the generation of pulsed electric fields necessitates relatively slow system charging, which frequently needs greater time intervals between the pulses than the width of the pulse itself. As a result, in the industrial treatment of liquid foods, PEF processing at a frequency of a kilohertz is usually needed, and a multiple of 10 Hz is requisite for the extraction or drying process to be enhanced **(Raso et al., 2014).** Foods moving rapidly require more average power (energy per unit of time), which increases system expenses. Without raising width of the pulse, the only solutions is to increase peak energy of each pulse or frequency of pulses. High frequency is a solution for this high energy requirement, but it also causes the high voltage pulse generator's switching losses to increase. There is a conflict between frequency and maximum current due to the heating of the power switching devices **(Arshad et al., 2020; Tokusoglu et al., 2014).**

Specific Energy of the Pulse: This parameter is affected by applied voltage, pulse width, and treatment chamber resistance, all of which are affected by the conduction and geometry of the material being processed. This metric assists in quantifying the energy costs associated with the PEF process and compares the effectiveness of PEF treatment to other technologies. It's usually expressed in kJ kg-1 . This parameter enables measuring the increase in temperature of the food as a result of the treatment since all of the electrical energy used to create PEFs in the treatment unit is converted to heat and the residence time of food materials in the treatment chamber during a PEF treatment is less than 1 s **(Raso et al., 2014).**

Biological Factors

Biological characteristics such as the specific qualities of target microorganism, along with their physiological and development phases, influence PEF treatment.

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PEF inactivation of microorganisms is dependent on microbiological parameters such as the kind of microbe, cell envelope characteristics (Gram-positive or negative), cell size, and shape **(Mohamed & Eissa, 2012)**. In determining microbial sensitivity to PEF, it shows that intrinsic microbial resistance is more essential than the influence of microbial properties. PEF tolerance in Gram-positive vegetative cells is stronger than in Gram-negative bacteria, although yeast susceptibility is higher than bacteria (**Stefan Toepfl et al., 2014).** The PEF resistivity of distinct bacterial species can vary greatly, according to several research. As the PEF resistance of various strains was dependent on the pH of the treatment medium, the target microorganisms for determining PEF pasteurization treatment parameters for foods may be altered based on their pH **(Raso et al., 2014).** Also the quantity of microorganisms in food may influence their ability to be inactivated by an electric field. Logarithmic phase cells are more stress sensitive than lag and stationary phase cells. The logarithmic phase of microbial growth is distinguished by a large number of cells undergoing division, after which the cell membrane is more vulnerable to the applied electric field **(Barbosa-Canovas et al., 2000)**.

Media Factors

The PEF system and the properties of liquid food are concerned with the influence of PEF on the food system. A key variable in PEF is the medium's electrical conductivity, which is defined as its capacity to conduct electric current. Because the conductivity of most food items is determined by their intrinsic characteristics or recipe, the only way to mitigate this impact and optimize voltage distribution in the discharge circuit is to use electrode design and geometry with high-load resistivity **(Stefan Toepfl et al., 2014).** During treatment, rising temperatures will also cause changes in conductivity. PEF treatments often become more destructive as operating temperature rises, it's important to have a strong cooling system to ensure temperatures are within acceptable ranges so that impact on the nutrition, sensory, functional characteristics of foods are maintained **(Wouters et al., 1999).** The physical and chemical properties of foods have a considerable effect on microbial deactivation effectiveness during PEF treatment. **(Wouters et al., 2001)**. Proteins and enzymes are less responsive to electric field strength and pulses than microorganisms. More research is needed, particularly on the effects of pH, temperature, resistivity, and the composition of the enzyme or protein-containing media or food system. Though PEF implementation is purely a non-thermal processing technique, the synergistic impact of temperature on products (due to changes in cell membrane properties) gets stronger when foods material is treated to high pulsed electric fields strength **(Mohamed & Eissa, 2012).**

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Applications of PEF

Drying

PEF has been explored as a replacement for thermal pre-treatment in drying of fruits and vegetables since it is suggested that PEF can improve efficiency of drying by enhancing the moisture transfer and heat transfer rates via cell permeabilization **(Onwude et al., 2017).** PEF involves building a potential difference between two electrodes and delivering short pulses for μs at high voltages (<50 kV), which was then given to foodstuff at mild electric fields (200–1000 V/cm) to improve cell disintegration and permeability by electroporation **(Arshad et al., 2020)**. Although PEF is often used to treat liquid or semi-liquid products with low electrical conduction, solid product treatment have been recently investigated, with solid samples food submerged in a liquid during the process **(Bassey et al., 2021).** To support these claims, (**Rahaman et al., 2019)** evaluated the results of convection drying after PEF pre-treatment leads to increased chroma and lightness, disintegration index of the cell enhanced from 0.147 to 0.572 in comparison to untreated plum, resulting in a lower moisture ratio and higher consumption of specific energy when the field strength was raised from 1 to 3 kV/cm. Increased cell disintegration improves the drying process and reduces drying time **(Shynkaryk et al., 2008)** discovered the same thing that by using PEF pre-treatment drying temperature was reduced by 20–25℃ and causes more tissue shrinkage, resulting in a longer rehydration time. The temperature progression and moisture content inside the drying samples, as well as the spectrum data, demonstrate the advantages of PEF pre-treatment for drying at moderate temperatures, which protects colorants. It was also reported that applying the PEF pre-treatment at 10 kV/cm and 50 pulses decreased drying time by up to 12%, and the dimensionless moisture ratio for PEF-treated samples was 0.18 after 60 minutes of drying, compared to 0.26 for untreated apples **(Wiktor et al., 2013).** As a result, PEF enhanced the cell disintegration index in the studied range of values, which influenced the process kinetics. A comparable study found that PEF treated carrot slices reduced drying time by 6.9–8.2 percent when compared to untreated carrot slices, indicating that PEF reduced drying time by improving carrot slice drying. After PEF treatment, the electroporation procedure and the release of intracellular material decreased particle lightness by up to 25.3 percent **(Wiktor et al., 2016).**

Enzyme Inactivation

PEF is a non-thermal preservation technology that inactivate enzymes by employing high voltage and generate microbiologically safe meals with taste and fresh-like flavor without considerable nutritional loss.

Most enzymes are almost totally inactivated dependent on the enzyme's type, the suspension medium, and the PEF treatment conditions, while others demonstrate resilience to PEF processing **(Martín-belloso & Elez-martínez, 2005).** After PEF processing of bovine whole milk at 15.9-26.1 kV cm-1 for 34-101 s in conjunction with pre-heating to 55˚C for 24 s, the populations of L. innocua 3024 and inoculated E. coli 916 were successfully lowered to below the detection limit of 2 log cfu mL-1. When compared to raw whole milk, the activities of plasmin and xanthine oxidase, as well as lipolytic activity, was lowered by 32 percent, 12 percent, and 82 percent, respectively, following PEF treatment at 26.1 kV cm-1 for 34s **(Sharma, Oey, et al., 2014).** Electro-permeabilization resulted in significant variations in pectinolytic enzyme activity that is reductions in polygalacturonase and increases in pectinmethylesterase , despite no evident patterns seen during storage for oxidative enzyme activity. The results of antioxidant and pectinolytic enzymes during storage might indicate that metabolismof carrot was stimulated to adapt to and recovered from PEF stress **(López-Gámez et al., 2020)**. The local pH change brought on by PEF treatment is represented by the polyphenol oxidase (PPO) that is dissolved in this medium influenced microbial or enzyme resistance to PEF, a pH reduction in the NaCl solution inside the treatment chamber next to the anode from 7.1 to roughly 3.5 resulted in significant local PPO inactivation, while the cathode and the treatment chamber's center showed no signs of PPO inactivation **(Meneses et al., 2011)**. Investigation to inactivate grapefruit PME, PEF was used with mild preheating of fresh grapefruit juice. PEF treatment lowered grapefruit PME activity substantially. Under the most extreme circumstances, a PEF treatment period of 100 lsat40 kV cm-1 in addition to preheating to 50 ˚C, the highest amount of inactivation (96.8%) was achieved **(Riener et al., 2009).**

Extraction of Bioactive Compounds

Another application of PEF is as a pre-treatment technique before extraction, since it enhances the permeability of the cells, resulting in a higher rate of extraction of the targeted ch1emicals also PEF reduces the amount of energy and organic solvent needed to extract the required compounds **(Naliyadhara et al., 2022).** Short processing time (nanoseconds to milliseconds), better efficiency , less energy input with structure preservation, and higher outcome of the final products are all main advantages of PEF over other techniques **(Toepfl et al., 2006).** Cell disintegration index was higher in custard apple leaf extract (CALE) and extraction yield was higher (+5.2%) than the untreated counterpart when PEF was 6 kV/cm, 300 pulses, and 142 kJ/kg for 5 min **(Shiekh et al., 2021).** After PEF application and water extraction, the yield of onion's water-soluble flavonoid compounds (FC) and phenolic compounds (PC) was considerably improved. Under the optimum conditions of 2.5 kV/cm, 90 pulses, and 45°C for both FC and PC extracts, the PC and FC content increased by 2.2 and 2.7 times, respectively, compared to the control **(Liu et al., 2018).** The juice from PEF-treated berries also exhibited considerably greater total phenolic content (+43%), total antioxidant activity (+31%) and anthocyanin content (+60%). A higher intensity PEF process improved the extractability of bioactive components from press cake of blueberry. In comparison to the untreated sample, the press cake extracts contain greater levels of total anthocyanin (+78%), total phenolic (+63%), and antioxidant activity (+65%) **(Bobinaitė et al., 2015).** When compared to untreated samples, properly selected The extractability of bioactive substances can be improved by using PEF-assisted extraction parameters that are unique to each matrix in cocoa bean shell (CBS) and coffee silver skin (CS) samples by up to 20% and 21.3 percent, respectively, and can be used to create extracts with rich nutritional characteristics for phytochemicals **(Barbosa-Pereira et al., 2018).** PEF treatment affected the beetroot tissue red colour, which was connected with improved pigment extraction as a result of electroporation when compared to the control, the application of PEF with an intensity of 4.38 kV/cm and 20 impulses and an energy expenditure of 4.10 kJ/kg increased the yield of vulgaxanthin and betanin extraction from beetroot cylinders by 244 and 329 percent, respectively **(Nowacka et al., 2019).**

Microbial Inactivation

The food and beverage industries concentrated on expanding the technology for nonthermal antimicrobial treatment in order to optimise microbe inactivation while reducing unwanted effects on the treated sample. Pulsed electric fields (PEFs) generate nano-meter sized membrane breaches in microorganisms, causing cell death when the PEF duration and intensity are adequate such that the pores cannot reseal after the PEFs through irreversible electroporation **(Garner & Garner, 2019)**. Thermal pasteurisation (TP) and pulsed electric fields (PEF) treatments for inactivation of aerobic bacteria, coliform bacteria, and mold in carrot juice were given and compared by B. Xiang and S. Sundararajan, and it was discovered that the TP treatment decreased aerobic bacteria counts and coliform counts by 80 and 100 percent, respectively, while PEF decreased aerobic bacteria counts by 80 percent and coliform counts by 95 percent also molds were efficiently eradicated by TP and PEF (Xiang et al., 2014). When green tea beverage samples were treated with a bench scale PEF system at 38.4 kV/cm for 160 and 200 ms, Escherichia coli and Staphylococcus aureus were efficiently inactivated, resulting in 5.6 and 4.9 log reduction, respectively while the nutritional composition of the tea was also maintained **(Zhao et al., 2008).**

PEF period and electric field strength considerably enhanced inactivation of E. coli and S. aureus, with the optimum of 5.20, 3.51 log10 cycles reduction at PEF time 547 s and 88 percent inactivation of SLOX at 1,036 s when treated at 40 kV/cm PEF.

PEF-treated soymilk effectively inactivates E. coli, S. aureus, and SLOX and had no considerable influence on soymilk quality parameters **(Li et al., 2013)**. The preliminary counts of aerobic bacteria, yeast, and lactic acid bacteria in red wine were 5.56, 5.61, and 5.22 log CFU/mL, respectively. There was a 1.8 log reduction in initial counts of aerobic bacteria when the field strength was 40 kV/cm and the total treatment period was 270s. After PEF, yeast was shown to have a greater inactivation rate than aerobic and lactic acid bacteria. The mortality rate at a low field intensity of 20 kV/cm was almost double that of aerobic bacteria and four times that of lactic acid bacteria **(Puligundla et al., 2018).**

Freezing

One of the most extensively utilized strategies for preserving the quality of food stuffs during prolonged storage periods is but due to the creation of ice crystals, freezing causes tissue damage; cell membranes are disrupted, and the food product turns soggy on thawing **(Delgado and Sun 2000 ; Dymek et al. 2016)**. In the presence of cryoprotectants such as trehalose, sucrose, glucose, and fructose, PEF was applied via vacuum impregnation. The combination of these strategies resulted in leaf cells being functional and leaves retaining turgor following the freezing and thawing cycle. As a result, it has been shown that pulsed electric fields may be employed to increase the freezing resistance of baby spinach leaves **(Demir et al., 2018).** The research was done to see how freezing as a pre-treatment before pulsed electric field (PEF) treatment affected the quality of beef semitendinosus muscles. And it was found that the PEF induces substantial microstructural changes in meat tissue, combining freezing-thawing and PEF enhanced tenderness as seen by decreased shear force, dramatically increased purging loss but not cooking loss, influence oxidative stability of frozen‐thawed meat, and enhanced oxidation process **(Faridnia et al., 2015).** The effect of a pulsed electric field on the freezing of rice flour gels was investigated, and it was observed that PEF treatment with an output voltage of 15 kV or higher accelerated the freezing rate, influenced the phase transition duration, and resulted in enhanced freezing rates, decreased the size of the ice crystal formed. Furthermore, salt has been shown to be a useful additive for enhancing relative permittivity and reducing the impact of the external PEF on freezing **(Zhang et al., 2022).**

Starch Modification

PEF modification is a safer technology than standard acetylation since it does not involve the use of chemical solvents. As a result, it is more eco- friendly and has a lower processing cost. By lowering relative crystallinity, gelatinization temperatures and enthalpies, viscosity, and pasting temperature, pulsed electric fields (PEF) can enhance starch extraction and change starch characteristics (**Castro et al., 2021).**

From the aspect of octenyl succinylated (OSA) potato starch structural characteristics, PEF affected the pasting capabilities of the starch. The granules were significantly structurally disrupted by PEF-assisted esterification, which increased granule accessibility and facilitated the interaction of OSA molecules with starch hydroxyls. The pasting temperature of starch was reduced by approximately 7.6–15.1 C as a result of these adjustments. In addition, the reaction time was lowered from hours to 50 minutes when compared to traditional procedures **(Chen et al., 2021)**. The impact of PEF application on the properties of corn starch was comprehensively investigated. The results revealed that as the electric field strength increased, gelatinization temperatures and enthalpy reduced. PEF treatment after 50 kV cm-1 resulted in the loss of granule structure and a significant decline in crystallinity degree. Meanwhile, increasing the field strength reduced the peak, breakdown, and ultimate viscosity of treated starch. Because of the rearrangement and degradation of the starch molecular structure after PEF treatment, corn starch was susceptible to gelatinization **(Han et al., 2009).** Wheat and cassava were used as starch sources, and three distinct conditions of PEF were tested. When compared to the control starch, wheat starch treated with PEF produced printed samples with a smoother surface and varied textural properties. PEF, on the other hand, had no effect on cassava starch, and the control starch exhibited the same behavior as the modified starch. PEF treatment enhanced the ability of wheat starch hydrogels to be utilized in 3D printing while also improving their shelf life, the texture options available in printed samples **(Maniglia et al., 2021).** Wheat starch (type A), potato starch (type B), and pea starch (type C) are all susceptible to PEF treatment, with potato starch undergoing the most significant changes. Qualitative characteristics such as X-ray diffractive patterns, absorption peak locations on infrared spectra, fractal size, and thickness of semi-crystalline layered structure show no significant changes. PEF alters relative crystallinity, Maltese cross brightness, self-similarities, and molecular weight distribution as a result of quantification **(Li et al., 2019).**

Disadvantages

1. Due to the heat generated by the electric pulses because of Joule heating, cooling is required to keep the treated product at a low temperature during PEF treatment.
2. However, according to the findings of certain research, electrode material contents (e.g. Fe, Cr, Ni, Mn) are released into liquid food samples as a result of corrosion.
3. The appearance of bubbles/impurities, as well as the thermo-physical characteristics of the product itself, both contribute to the non-uniformity of the applied electric field inside the treatment chamber in liquid products treated with PEF.

Review Article

PEF in different Food Sectors

Beverage Industry

PEF processing has potential uses in the citrus sector, particularly in terms of inactivating microorganisms and preventing the development of off-flavors during preservation **(Abbas Syed, 2017)**. **Aadil and colleagues (2018)** noticed that Grapefruit juice treated with ultrasound (US) and pulsed electric field (PEF) improved DPPH activity, TAC, flavonols, TF, TP, and reduced microbial load and also provides more advantages for maintaining quality. The effect of PEF on juice expression efficiency and polyphenol recovery from citrus fruits (orange, pomelo, and lemon) was investigated, and it was discovered that a synergistic effect increased the yield of juice obtained after pressing by 25% for orange, 37% for pomelo, and 59 percent for lemon, as well as optimized extraction of polyphenols in 50 percent ethanol solution from fruit skins **(Kantar et al., 2018).** Sugarcane juice with lemon and ginger addition are treated with PEF in different condition and it is observed that at strength 20 kV cm−1 and 150 pulses the microbial reduction of greater and the juice shelf life was increased up to 7 days **(Kayalvizhi et al., 2016).** For sterilisation the PEF technology is a potential non-thermal technology, can effectively preserved polyphenols, catechins, and natural colour of green tea infusions. Also amino acid is induced due to PEF treatment **(Zhao et al., 2009).**

Meat Industry

PEF method not only offers enormous potential for preservation food product but also for structural modification. Beef jerky was introduced to PEF treatment, it is noticed that direct reduction in the salt without any negative effect on lipid-oxidative stability, sensory attributes, and microbiological resistance. It improves the saltiness naturally by distribution and diffusion of in flesh matrix due to liberation and perception of salt during chewing without affecting the cooking and colour quality **(Bhat et al., 2020).** Within a variety of processing conditions, there is a PEF treatment for beef cuts that is ideal. Ultrastructural modifications in beef LL can result from low and high PEF applications **(Khan et al., 2017)**. Application of PEF has no considerable negative side effects on the lipid oxidation of the turkey meat, nor did they cause any changes in the meat's weight, texture, cook time, lipid oxidation, or color in frozen fresh or frozen item **(Arroyo et al., 2015).**

Oil Industry

The sunflower seed's extraction yield rise by 2.3 percent after PEF treatment, compared to a control, with an field strength of 7 kV/cm and energy usage of 6.1 kJ/kg. Chemically, PEF therapy does not result in a rise in the reactivity of molecule oxygen with triacylglycerine, since it has a detrimental impact on chemical features, but instead raises the level of molecules that are related to human health.

The diffusion coefficient, micropore volume, and disintegration index were more significant than the control ones by 55.5 percent, 32.2 percent, and 43 percent, respectively, according to extraction parameters acquired using PEF treatment (**Shorstkii et al., 2020).** When the peanut oil is treated with PEF to study its physicochemical and storage properties after application, findings showed that PEF treatment might slow down the rate of the lipid oxidation process, increasing the shelf life of items rich in lipids **(Zeng et al., 2010)**. Application of PEF on cannabis seeds prior to cold press oil extraction is efficient in enhancing and boosting the qualitative and quantitative qualities of the extracted oil. The effectiveness of oil extraction and phenolic compounds also improved along with an increase in PEF strength and rotating press speed. PEF is a viable method for improving cannabis oil efficiency and quality, as well as for pre-treatment- treatment to protect cannabis oil's value without the use of heat or chemicals **(Haji-Moradkhani et al., 2019).**

Dairy Industry

After HTST pasteurization the milk is immediately treated with PEF which shows the extension of shelf life of milk by 60 days, whereas after 8 days of HTST pasteurization milk treated with PEF lasted for 78 days before it reached the maximum allowable bacterial population **(Sepulveda et al., 2005)**. Cheese produced from milk pasteurized by pulsed electric fields had an increase in hardness and springiness, but not statistically different from cheese produced from raw milk in terms of adhesiveness and cohesiveness. Also cheese seems like a workable solution to raise the quality of this crucial dairy product **(Sepúlveda-Ahumada et al., 2000).** To maintain the functional qualities of raw milk while protecting its component parts from heat, PEF offers an analogy to thermal pasteurization conditions. Gram-negative bacteria are more vulnerable to PEF-induced inactivation than Gram-positive bacteria, and preheating milk accelerates bacterial inactivation **(Sharma, Bremer, et al., 2014).** The PEF treatment period of 100s at 40 kV/cm and preheating to 50 ˚C resulted in the maximum amount of inactivation, which was 84.5 percent. The LOX activity was significantly reduced when pulsed electric fields were combined with a little preheating of freshly produced soy milk. More extensive levels of LOX inactivation were brought about by a stronger electric field, extended treatment periods, and greater preheating temperatures **(Riener et al., 2008).**

Waste Utilization

For the sustainable valorization of industrial tomato peel wastes, PEF application prior to solid-liquid extraction using eco-friendly solvents might be an alternative. When compared to untreated tomato peel waste samples, PEF treatment significantly increased the extraction rate (27-37%), the lycopene yields (12-18%), and the antioxidant power (18.0-18.2%) in acetone and ethyl lactate extracts **(Pataro et al., 2020).**

Wastes and by-products of red prickly pear has given the treatment and results demonstrated that when compared to untreated tissues, Pulse electric field and ultrasound improved the extraction of red colorants. After PEF and USN pre-treatments, scanning electron microscopy demonstrated cell denaturation, which can lead to a greater recovery of the intracellular components with lower impurity **(Koubaa et al., 2016).** The findings demonstrated that when dissoluble protein from leftover beer yeasts was extracted by PEF, the protein extraction yield could reach 2.788 0.014 percent. PEF may be considered of as a very effective and energy-saving method for removing bio-components from raw materials **(Mingyuan Liu, 2012)**. Using the PEF technique to extract anthocyanin from blueberry processing by-products (BPBs) may not only enhance the extraction yield of anthocyanin but also drops the extraction period and temperature. Also application of PEF area for BPB's anthocyanin extraction, which may reduce costs and raise the added value of blueberries **(Zhou et al., 2015)**.

Conclusion

A non-thermal alternative to traditional thermal processing, pulsed electric field (PEF) can then be used to preserve food. Without significantly compromising the qualitative qualities of foods, PEF technology is a very successful method for the processing and preservation of a range of food products. There is active worldwide research into pulsed electric field technologies. Most of the research done so far has been in the laboratories or on a small scale in a production plant, and the outcomes have been encouraging. Research studies on the application of PEF technology for treating food at the laboratory scale have produced some incredibly encouraging findings for the scaling up of the system. PEF can be used for pasteurization, enhancing procedures like freezing, dehydration, or extraction, but it can also help with the production of foods that are useful and contain other ingredients.

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Conflict of Interest

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Ethics Approval

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This study did not require any human participation for consent.

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