Pulse Electric Field Processing: A Sustainable Solution for Food Preservation

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Review Article

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ABSTRACT

Pulse Electric Field (PEF) processing is an innovative technology in food preservation that utilizes high intensity, short duration electric fields to inactivate microorganisms, enzymes and preserve the sensory quality of food products. This technology has the potential to reduce or replace the use of thermal and chemical treatments, leading to healthier and more sustainable food products. Pulse electric field is a non-thermal technology that means it does not require heat for the preservation of food. This is beneficial because heat can cause degradation of the food nutrients, colour and flavour. A review of recent developments and applications of PEF processing in the food industry will highlight its advantages, challenges, and future opportunities. This review paper will provide valuable insights into the current state of the art and future directions for PEF processing in food technology.

Keywords: Micro-organism; Sustainable; High intensity; Short duration; Innovation; Technology

INTRODUCTION

Food processing is any intentional change that occurs in a food before it is ready for consumption. It can be as simple as freezing or drying food to preserve nutrients and freshness, or as complex as formulating a frozen meal with the right balance of nutrients and ingredient. On the one hand, processing foods have a strong influence on food quality, both nutritional quality and food safety. On the other hand, various processing methods can be used. Methods for improving food quality, such as fermentation processes. Nonetheless, the majority of processing methods dilute food's natural properties and nutritional quality. With less processing techniques required for getting the desired outcomes, people nowadays are demanding more and more convenient, high-quality food products with delicious taste, strong flavour, and attractive looks. At the same period, there is increasing concerns regarding reports of breakdowns in food safety systems that result in bacterial contamination, raising production costs because of extra regulatory, reporting, and regulatory activities. Mixed meals, organic eggs and egg items, dessert, liquids, uncooked and processed meats, uncooked and processed seafood, milk products, and fresh and processed eggs are the foods most update and maintain to these bacterial breakouts [1].

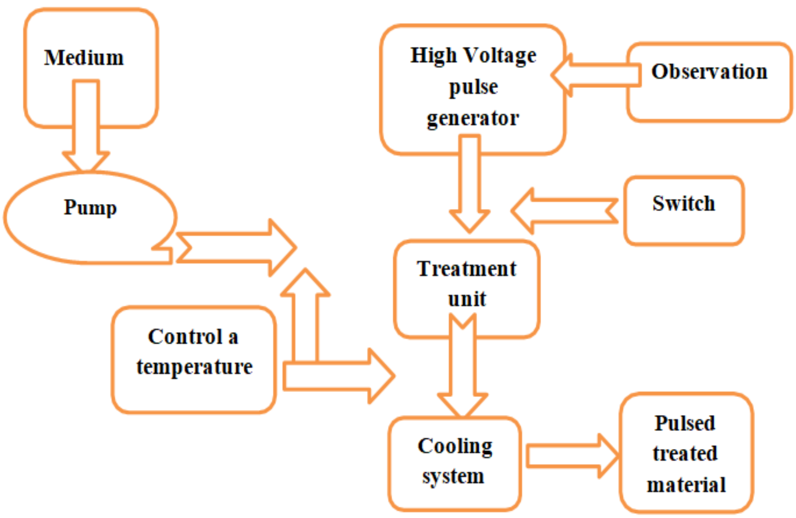
Pulsed Electric Field (PEF) technology is a non-thermal food preservation technique that uses brief electricity pulses to inactivate microorganisms with no negative impact on food quality. The main benefit of this technology is that it can give consumers high-quality food. PEF technology can be used for a variety of foods, including solid and liquid foods. Pulsed electric field is one of the non-thermal ways that is being employed in the manufacturing of liquid/semiliquid food materials. This method is regarded to be an alternative to the pasteurization (thermal) process, improving the drying of food materials, changing the activity of the enzymes, and boosting the liquid extraction of plant cells. A brief application of an external electrical field causes a fast breakdown of the cell membrane and local structural alterations. Many uses of High Intensity Pulsed Electric Fields (HIPEF) have been investigated in recent decades based on this phenomena known as electroporation. Pulsed electric fields are used in the study of plant and microbial genetics to electroporate cell membranes, allowing foreign materials like DNA to enter the cell. One of these subtle preservation methods, known as Pulsed Electric Field (PEF) processing, has been studied over the past few years as a future replacement for thermal processing without losing the flavour or nutritional qualities of food. Although PEF has been shown to be efficient in inactivating vegetative bacterial cells, yeast, and molds, microbial spores are resistant to PEF treatment. Fruit juices are a viable candidate product that's because the dryness of these products controls the germination of microbial spores; as a result, PEF should be considered as a pasteurisation method. The mechanisms of microorganism deactivation by PEF in liquid food products have been the subject of many investigations. The degree of microbial inactivation is extremely dependent on the kind and construction of the instrument, pulse shape, and strength of the pulses in terms of field strength, energy, and number of pulses delivered, which makes it hard to contrast the reported scientific results. Moreover, the characteristics and variety of the (food) medium as well as any capable preservative ingredients have an impact on inhibition [2]. In the sector of food preserving, Pulsed Electric Field electro technology (PEF) is a recent innovation. Electroporation, a biotechnological operation that promotes bacterial DNA exchanges by rupturing microbial cell walls with generated electromagnetic fields, is just where PEF originally appeared. The frequency of the electrical field that is produced determines how effectively this technique works. Whenever membrane potentials are generated, they generally cause cell harm and cell death once they reach a certain value. In sequence to inactivate unwanted microbes in food products, the basic principle that motivates the application of electric fields as a food storage method is to focus on the harmful effect shown in electroporation. For the past ten years, there has been serious research into the inhibition of fermentation and harmful bacteria, as well as of proteins of value to the food industry. With changed for the better, this method is now aiming for manufacturing [3].

Components of pulsed electric field: The high current generator, treatment unit, fluid handling system, and controlling equipment make the pulsed electric field technology. By applying pulse forming technology, the high current generator produces electrical pulses with a variety of voltages, forms, and application time. Electricity supply, charge resistor, capacitor, switches, inductors, and resistors compose the system. High voltage Alternating Current (AC) electrical power is converted to high Direct Current power by a power generator (DC). Capacitors are used to store the generator's output energy, which is then used to generate electric fields [4]. Through the use of a voltage transformer, the voltage of the Alternate Current (AC) is raised until being rectified. Next, a series of resistors in the Direct Current (DC) high voltage supply charge capacitors. By using a rectifier, the circuit works to change the current voltage train that the pulse generator sends to high voltage pulses. With an electric field with a higher intensity, the system produces pulses of short duration (microsecond or millisecond). In some systems, a switch is used to release high energy through food ingredients in the treatment chamber. The materials of switching systems are what link the energy load at the treatment chamber with the storage device (capacitors). How much pulse current and application time is needed is determined by the switch. It serves as a link between high energy providers and treatment facilities [5].

LITERATURE REVIEW

Food products that are liquid or semi-liquid are placed in a treatment unit with electrodes connected to one another with non-conductive material to restrict electrical flow from one electrode to another. Electrodes that conduct the high electrical charge to food ingredients are given a high electrical current. The generator applies the following current intensity and processing times to deliver high electrical currents to the food products. Square wave, bipolar, exponential, and other waveform can all work with the generator's high output current. In the treatment of pulsed electric fields, a wide range of waveforms are reportedly used. Often, either exponential or square wave pulse forms are used. A switch with an off switch or a network that can make pulses is necessary for systems that produce square waves (Figure 1) [6].

Figure 1. Flow chart process of components of pulsed electric treatment field.

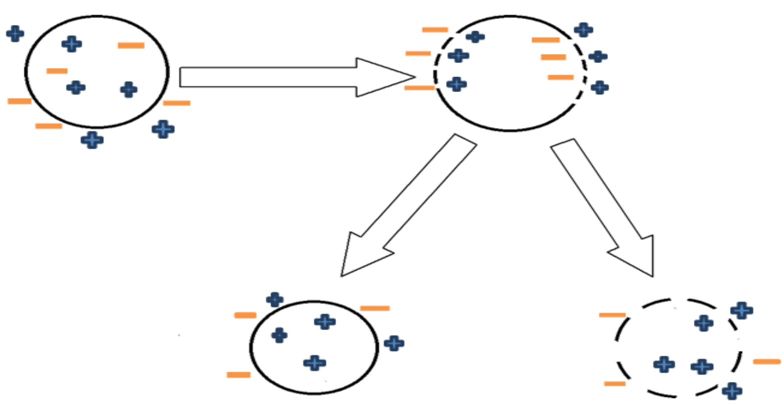


The pulsed electric fields generated by generator are used in treatment unit or chamber. Both batch and type of system are possible with treatment units. Coaxial or similar plate types in the chamber are used to pump semi-liquid or liquid food materials to a specific flow rate. Whereas circular flow systems are used for continuous systems, parallel flow systems are used for batch systems. Both system includes pulsed electric fields that can be produced at any pulse frequency while pumping liquid or semi-liquid materials through at a specific flow rate. A space insulator and parallel plate electrodes are said to compensate the treatment chamber. Electrolyte is used to facilitate electrical conduction between the electrodes and membranes. The electrodes are separate from the fluid materials by ion conductive membranes made of sulfonated polystyrene and acrylic acid copolymers. Another element of the pulsed electric field application is the cooling section. Through a cooling coil section that is connected to the treatment chamber, fluid samples are transferred. In order to cool down, the cooling section is usually submerged in an ice bath [7].

The generation and operation of a pulsed electric field: PEF involves applying a high electric field for a brief period of time to a substance that is placed between two electrodes. This process has the irreversible ability to electroporate cells, which results in the growth of microorganisms.

Electroporation, also known as electro permeabilization or palpitated electric field treatment, is a process that increases the conductivity and permeability of a cell's tube membrane by convincing a trans-membrane possible outcome through the use of an external load, sufficiently powerful electric field. It has been proved through experimental work on lipid bilayers, cells in suspense, monolayers, and healthy napkins that this increase is due to the formation of drying processes, or pores in the lipid bilayer. The electroporation concept had previously been used in medical procedure in the middle of 1900. The idea was also used in food processing and technology to destroy pathogens and microbes. Because of the conception's comparison uniqueness, researchers have been taken to use it in biotechnology and engineering, particularly to produce valuable intracellular substances like lipid and protein from microbes. The miracle of electroporation occurs when the cell wall is presented to a strong electric field for a particular period of time. The cell membrane becomes temporarily unstable during the electric field exposures. The cell membrane will experience either reversible or irreversible electroporation as a result of increasing the electric field intensity. The ability of the cell membrane to recover or reseal is known as reversible electroporation. Whereas irreversible electroporation permanently damages the cell membrane and makes it unable to recover its original shape. Reversible electroporation is a technique used in chemotherapy for cancer treatment that enables the formed treatments to attack the cancerous cells after the cell membrane returns to its original shape (Figure 2) [8].

Figure 2. Process of cell membrane, formation of pores, resealing of pores and cell death.



- Before pulse
- During pulse electric field
- After pulse

Moreover, from an industrial point of view, unrecovered electroporation is preferred for the removal of valuable cell components like lipid and proteins. The representation of the electroporation medium for cell membranes. A cell is given a static state by being placed between two electrodes without applying electricity or when the voltage is zero. Electric fields were exposed to the cell, trying to convince it to become bibulous and irregularly shaped. At this time, the electric field induction broke away the cell membrane motes that are held together by positive ions [9]. Additionally, in this state, reversible electroporation may occur as well as the conformation of pores within the cell wall and membrane. The cell membrane will break as the electric field strength is increased because the number of pores grows. The cell wall will electroporate if the electric field strength is kept above its specific value or z-value. The cell will release valuable substances like lipid, carotenes, chlorophylls, and protein. The membrane won't be able to return to its original shape at this frequency, which is known as irreparable electroporation. The size of the microorganism, for example, has an effect on the efficiency of the membrane that will be electroporated. Smaller microorganisms required a stronger electric field in order to break down their cell walls. This is actually caused by the cell membrane's both mechanical and thermal change situation [10].

High voltage field: High voltage electric fields are applied to food products during the high voltage field electroporation process, which causes temporary pores to form in the cell membranes of microorganisms. Electro permeabilization or electroporation are other names for this procedure. Microorganisms are depicted inactive as a result of the release of cellular content that is made possible by the formation of these pores in the cell membranes. Electric pulses are applied to the food product during the high voltage field electroporation process. The electrical pulses typically have pulse durations of a few microseconds to several milliseconds and have a voltage density per centimetre in the range of 1 to 50 kilovolts. The electric field is applied in a structured way, making sure that the voltage and pulse duration are high enough to damage the food product but not too high to cause pores to form in the cell membranes of the microorganisms. The cell membranes of the microorganisms are effected to a strong electric field when the electric pulses are applied. Because of the temporary increase in cell membrane permeability brought on by this high voltage field, pores start to appear. These pores allow the removal of cellular materials like ions, proteins, and DNA, which makes microorganisms inactive [11].

Low voltage electric field: By applying a weak electric field to food products, low voltage electroporation allows microorganisms to temporarily form pores in their cell membranes. The cell membranes are made permeable by the electric field, allowing molecules like antibiotic or nutrients to be taken up. To enhance the electroporation process efficiency, the length and strength of the electric field can be changed. It has been proved that low voltage electroporation can successfully lower the microbial load in a range of food products, including fruits, vegetables, and meat. Moreover, this process may increase the absorption of beneficial substances like antioxidants, vitamins, and minerals, which may enhance the nutritional value of food products [12].

RESULTS AND DISCUSSION

Benefits of pulse electric field in food technology

PEF has proven to be helpful in improving food quality, including reducing duplicate uptake, expanding health related nanoparticles, and enhancing protein features and functions. The PEF treatment reduces microorganisms, extending the shelf life of food productions. Moreover, heat sensitive composites, such as those used in aircraft, can be made less weakened by this technology. PEF treatment provides preservation of Vitamin C with relation to freezing, darkening and excessive pressure treatment. PEF technology also provides a brilliant chance for the development of innovative, healthier foods, as it is now used to produce potato chips on an industrial level. PEF creates microscopic holes in the potato cell walls that allow protein and sugars to be washed out, reducing the shape and size of maillard reaction. Future applications of PEF in the potato industry could enhance the blanching, drying, and wastewater treatment methods. PEF can also be beneficial for the production of fried or dehydrated snacks made from other vegetables, tubers, or fountainheads. PEF has also been mentioned as a way to improve other processing conditioning, such as hot air drying, snap drying, frying, bibulous dehumidification, helping with slice/slicing (for example, when making vegetable snacks), or shelling (entire fates and vegetables). PEF action could be used to activate treatments that carry active bio compounds into vegetable essentials, such as an undercover initiative to create active food productions. Moreover, PEF technology is environmentally friendly and specifically helps to promote the growth of a lush, sustainable, indirect thriftiness [13].

Drawbacks of pulse electric field in food technology

Although PEF technology has numerous advantages, some experimenters refocused out that this technology has a many downsides, like high cost of the palpitation creators, absence of well standardized procedures, stability and duration of the systems and bulk capability, electrochemical responses, erosion and the migration of electrode construction accoutrements. There's incomplete trading availability of PEF technology systems due to its great original freight, which is advanced than the other food processing outfit (e.g. refrigeration). Thus, an important chance of the food manufacturers have concluded to exercise the traditional food processing treatments (e.g. canning and refrigeration) as contrary to utilizing PEF technology. Moreover, an effective colour formation from vegetable budgets by PEF has an explosive effect on the artificial process in goods and duration tour packages [14]. Finally, one of the most extreme examples of PEF may be the degradation and displacement of important electrical accessories, which may cause sensitive changes in fluid food productions. Impurity of food and drink with degradation products cannot be allowed in meal ambitious initiatives, as degradation productions produce medical problems for food consumers. Hence, the production of functioning out ions from moisture substances should be developed [15].

Application of pulsed electric field

Fresh fruits, milk, liquids, soups, and fluid eggs can all advantage from the pulsed electric field application, which prevents microbial growth and the interruption of enzymes. Food particles that cannot be squeezed are not appropriate for the pulsed electric field. This method can be used to enhance the liquid phase of cellular systems, for example when removing seeds' oils, sugar from sugar beets, or cane from plant tissue, and to reduce wastewater's starch content. Apple, citrus, and cranberry juices, which are less thick and have less electrical properties, can be processed using PEF technology. The PEF method has also beneficial effects on fruit juice quality parameters. Accordingly, investigated pasteurized and PEF- treated citrus juice during cold storage (4°C) for a duration of 112 days [16]. They observed that the second type had less browning than the original due to ascorbic acid (vitamin) being transformed to phenol during in the PEF treatment. The impact of highly intense pulsed electric fields on the carotenoids character of tomato juice indicated that, in distinction to high temperature and unprocessed tomato juices, the carotenoid amount of juices improved (10–20%) over the duration of preservation (56 days at a refrigerator). Bipolar rectangular shape pulses with a 100 Hz frequency were applied to activate the pulsed electric field at a flow speed of 60 ml/min and an electrical field of 35 kV/cm for 1.5 millisecond [17].

Micro-organism inactivation

PEF has primarily been used to maintain nutritional content, which includes prolonging the useful life of bread, milk, citrus fruits, fluid eggs, and apple juice as well as brewer's yeast's fermentation abilities. One of the most important steps that directly affects the nourishment and security of food material is the deactivation of bacteria. Yet, there is still disagreement over how PEF inactivates germs. It is currently accepted that PEF treatment causes electrical breakdown of cell membranes, or electroporation, which results in cell membrane damage, increase in cell susceptibility, and cell death. This is the main method by which bacteria are currently rendered inactive by PEF therapy [18]. According to the theory of electrical breakdown, the cell is compared to a battery that is filled with a dielectric media. In the cell membrane, a trans membrane potential difference forms in the presence of an external electric field. Electroporation of the membrane is induced when the trans membrane voltage surpasses a crucial threshold value (of about 1 V). Many studies by Chinese researchers investigated the use of PEF to inactivate bacteria in liquid food products according to this process. However According to these investigations, PEF is only applied to low conductivity, air-free products like milk, soymilk, fruit juice, and wine to inactivate germs and prevent dielectric breakdown [19].

Processing of apple juice: In relation to fresh squeezed apple juice, that has a shelf life of 21 days, apple juice with keep focused treated using PEF at 50 kV/cm, 10 pulses, pulse duration of 2 s, as well as a maximum processing degree of 45°C had a storage life of 28 days. The vitamin c and glucose in the PEF-treated apple juice did not experience any either chemical or physical changes, and a taste group failed to identify any substantial changes between the juice treated both with and without an electric field.

Processing of milk: Examined the shelf-life of raw skim milk (containing 0.2% milk fat) treated with PEF at 40 kV/cm, 30 pulses, and treatment time of 2 s utilising exponentially decaying pulses. When milk was stored at 4°C, it had a shelf life of 2 weeks. However, when raw skim milk was treated with 80°C for 6 seconds, followed by PEF treatment at 30 kV/cm, 30 pulses, and pulse width of 2 seconds, the shelf life was extended to 22 days, with a total aerobic plate count of 3.6 log cfu/ml and no coliform. During the PEF treatment of the raw skim milk, the processing temperature was kept under 28°C [20].

Processing of egg: Dunn and Pearlman used 25 exponentially decaying pulses with peak voltages of about 36 kV in their earliest experiments on egg products, that were conducted through a static parallel electrode treatment chamber with a 2 cm gap. Liquid eggs, heat pasteurized liquid eggs, and egg products with citric acid and potassium sorbate added as preservatives were evaluated. When the eggs were preserved in low (4°C) and high (10°C) refrigeration temperatures, comparisons with standard heat pasteurized egg products were done, with and without the addition of food preservatives. The study showed the importance of the barrier strategy for shelf-life extension (Table 1).

Table 1. By using the PET treatment for food materials with certain temperature their shelf life is increases for storage.

Food material	PEF (Volt)	Temperature (in Celsius)	Shelf life (days)
Apple juice	50 kV	45 degree	28
Milk	40 kV	4 degree	22
Egg	36 kV	4-10 degree	28

CONCLUSION

Pulse Electric Field (PEF) processing is a promising technology in the food industry that can help preserve the freshness and nutrients of various food products. The process involves applying short and intense electric pulses to food products, which can effectively reduce the microbial load and increase shelf life without using high temperatures or chemicals. PEF processing has shown potential in preserving the freshness and nutritional quality of a variety of food products such as fruits, vegetables, dairy products, and meat. PEF processing has been shown to increase the availability of bioactive compounds such as polyphenols, antioxidants, and vitamins, which can provide health benefits to consumers. This is particularly important because many of these bioactive compounds are heat-sensitive and can be destroyed during conventional thermal processing methods. By using PEF processing, it is possible to preserve these compounds and maintain their nutritional value. One of the main advantages of PEF processing is that it can effectively reduce the microbial load in food products. This is particularly important in products such as fruit juices, where spoilage can occur quickly due to the high sugar content. PEF processing has been shown to be effective in reducing the microbial load of fruit juices, thereby increasing their shelf life and reducing the need for preservatives. PEF processing is also an environmentally friendly process as it does not require the use of chemicals or high temperatures, which can have negative impacts on the environment. Additionally, PEF processing has the potential to reduce food waste as it can extend the shelf life of food products, thereby reducing the need for frequent disposal.

One of the main challenges is the high energy consumption associated with the process. The amount of energy required to generate the electric field can be substantial, particularly for larger scale production. This can increase the cost of production and make it difficult to compete with conventional processing methods. Another limitation of PEF processing is the scale-up issue. While the process has been shown to be effective at a laboratory scale, it is more challenging to apply the technology to a commercial scale. The development of larger and more efficient equipment will be necessary to overcome this challenge. Finally, the cost of PEF equipment is a significant barrier to adoption. The technology is still relatively new, and the cost of equipment is high, which makes it difficult for smaller companies to invest in the technology. However, as the technology becomes more widely adopted, it is expected that the cost will decrease, making it more accessible to a wider range of companies. The technology has shown potential in preserving the nutritional quality of a variety of food products and reducing the microbial load without the use of chemicals or high temperatures. While there are some limitations to the technology, such as high energy consumption, limited scale up, and equipment costs, further research and development can help address these challenges and optimize the technology for commercial use. Overall, PEF processing is a promising technology that can help address some of the challenges faced by the food industry and contribute to a more sustainable and efficient food system.

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