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Pulsed electric field technology in food preservation: As an active competitor of thermal treatments

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Abstract
Pulsed electric field technology is a novel non-thermal technology in food preservation to improve the quality and shelf life of the food product. There are many thermal and non-thermal technologies for food preservation like traditional methods including freezing, refrigeration, blanching and non-thermal technologies like pulsed electric field technology, ultrasound technique, irradiation, high pressure processing etc. Among this pulsed electric field technology advantageous compared to others. It is claimed as superior to any other techniques of food preservation because it reduces the detrimental changes in food quality and keeps the physical and sensorial attributes of food. And this technique can be used mostly in the case of liquid foods and semi-solid foods. In this technique, high electric pulses should be applied through the electrodes to the food which is kept between the electrodes in the treatment chamber. And the external electric field leads to breakdown of the cell membrane of microorganisms by the process called electroporation. In this review, importance of pulsed electric field technology, its major components, microbial inactivation process, and the factors responsible for inactivation, major applications of PEF, etc. are discussed.

Keywords: Pulsed electric field, electroporation, thermal and non-thermal technique, microbial inactivation

1. Introduction
Food processing is the process of conversion of one form of food into another valuable form of food according to the consumer interest. Cooking, freezing, refrigeration and blanching are popular methods of conventional food processing and mostly used by people. Mostly processing is done to extend the shelf life, to maintain sensory and nutritive properties, to increase economic value, and to make more convenient products. Thermal and non-thermal are the two types of food processing. Thermal technique is a food sterilization technique used to reduce microbial enzyme activity by the application of heat into the food for a period of time and at a particular temperature, like in gelatinization, pasteurization, denaturation, sterilization process etc. And non-thermal processing is done without the application of heat like pulse electric field, irradiation, high pressure processing, ultrasound etc. When we comparing both of these techniques, non-thermal is more advantageous due to less energy loss, low effect of temperature, maintaining the quality, flavour, taste of food along with nutrient improvement, inactivation of microorganisms. In non-thermal technique, there is no any formation of unwanted products in food, since it is not exposed to higher temperatures. In the case of thermal processing, there is a loss of nutrients from the food, loss of flavour, texture, and taste in food.
In advanced countries, people are searching for well, secure nutritious diet with a good quality food (Arshad *et al*., 2021) [1]. So, producers are also searching for environmentally friendly techniques for the processing of food for good marketing of produce. So modern food technology deals with the development of different technologies like high pressure treatment, pulsed electric field technology, ultrasound, microwave cooking etc. these techniques mainly focus on reduction of harmful microorganisms by maintaining the quality and nutrient content in food. Among these, most successful & having short treatment time and low temperature effect is pulsed electric field technology. (Reddy & Penchalaraju, 2014) [26].

Pulsed electric field process without the use of heat that is a non-thermal technique in which we are using electric pulses of high voltage to inactivate the microorganisms. It is claimed as superior to any other techniques of food preservation, it reduces impact in food quality and keeps the physical and sensory properties of food. And this technique is mostly used in case of liquid foods and semi-solid food. In this technique, high electric pulses should be applied through the electrodes to the food which is kept between the electrodes in the treatment chamber. And the external electric field leads to breakdown of the cell membrane of microorganisms by the process called electroporation. Pulsed electric field technology have so many applications and mainly focused on the harmful microorganisms & it extends the life of food product in the absence of temperature & it is an energy efficient technique. And this is a better alternative to conventional processing techniques because of these applications.

2. Pulsed electric field (PEF) technology

PEF is a technique as a preservation for foods by applying high voltage pulses into the food for the microbial inactivation while it minimizes detrimental effect on food. Wouters *et al*., suggested that Pulsed electric field technology is an important tool against microbial activity in foods (Syed *et al*., 2017) [29]. It is mainly applicable for liquid foods and semi-solid foods than solid foods. Because, in this technology, electric field is used to process or preserve food. So, if it is liquid foods, then it will be a good conductor of electricity. And it helps to penetrate electric pulses into the food because of the conductivity and results into the death of microorganisms by rupturing the membrane of microorganisms. The 2 most important parameters influencing the PEF processing are, electric field strength and treatment time.

PEF technology requires electric fields of high voltage pulses of 10-80 kV/cm between two electrodes in the treatment chamber which results into microbial inactivation and this process performing only under very low temperature. This technology causes permeabilization or depolarization of cell membrane of microorganisms (Syed *et al*., 2017) [29].

The food industries are interested in innovative non-thermal processing technology like PEF because having the ability to maintain the quality of food, to reduce the nutrient loss and energy loss, when comparing with conventional techniques, (Arshad *et al*., 2021) [1]. And current food systems facing different challenges regarding their sustainability as well as other problems like in food supply, regarding its safety, food quality, and the marketing of that products. So, PEF is a very good choice for them.

It has so many applications in food industry like in fruit processing, pasteurization of milk, juices, and to improve meat quality etc. PEF is more acceptable and successful technique in food sector.

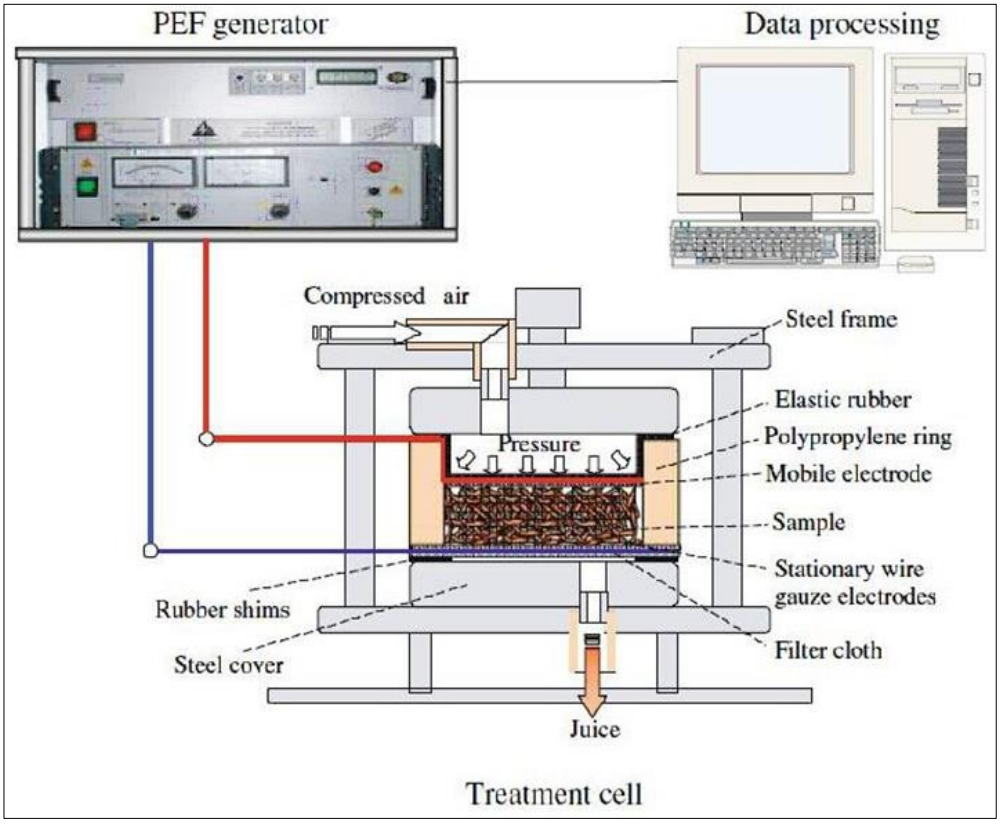

Fig 1: PEF technology in food processing (Mohammed & Eissa, 2019) [19]

2.1 Emergence of Pulsed electric field technology

Due to rising energy cost and rising of interest of people for healthy and nutritious food, during 1950s a new technology introduced primarily into the society having objective as inactivation of microbes & leads to an invention to a process called electrohydraulic treatment. Before the emergence of PEF, Europe and United States emerged a technique called electropure in the 1920s, which is a first attempt in milk pasteurization by using electricity at 220V directly produced into the treatment chamber consists of two carbon electrodes. Doevenspeck reported that PEF made

disturbance in cells of microorganisms in the food material & he explained its further uses (Toepfl *et al*., 2014) [9].

Pulsed electric field technology first introduced by Sale and Hamilton and its impact on microbial inactivation. Sale and Hamilton declared, there are two factors take part in the destruction of microorganisms that is electric field strength and treatment time. In this technique, microorganisms become treated in gel which is impermeable to electrolytic products, and it demonstrated that how electrolysis has no bearing on the deadly consequences of direct current pulses. And it results into functionless cell membrane. After the treatment, there is loss of ions & cytoplasmic constituents, change in cell membrane morphology and destruction of cell were reported due to electroporation happen while application of high pulsed voltages to the chamber (Toepfl *et al*., 2014; Jeyamkondan *et al*., 1999) [9, 10].

Sale and Hamilton conducted so many experiments, and they found out that there is no any influence of temperature on the complete process because only a rise of 10 degree Celsius was there so Sale and Hamilton reported that the deactivation of microorganisms is not due to the temperature producing there (Jeyamkondan *et al*., 1999) [10]. They observed approximately 2 log reduction in various microorganisms by using this process. And they found out that the emergence of PEF technology caused the loss of microorganisms along with the inhabitation of synthesis of enzymes in microorganisms. The first commercial operation of PEF on fruit juice started at Europe on 2009 by installing a 1500l/h juice preservation line. And its application in various fields is increasing day by day due to its efficiency and of low cost for installation.

2.2 Principle of PEF technology

Basic principle of pulsed electric field technique is the discharge of high electric pulses having the voltage intensity of 10-80 kV per centimeter up to microseconds to milliseconds. This process is working according to the execution of pulsed electricity into the food product placed in the PEF chamber consisting of two electrodes. The applied high voltage causes high electric field in the chamber and that causes microbial inactivation (Mohammed & Eissa, 2019) [19]. The success of technology will depend upon, how many pulses were applied into the chamber. During PEF processing, the applied electric field appearing as in wave form, bipolar waves or in the form of oscillatory pulses at a medium temperature (Syed *et al*., 2017) [29]. When applying pulsed electric field to the food, actually the science behind is the passing of electricity into the sample product is that, the product containing several ions and it helps to conduct electricity by the product. That's why it is mostly preferable for aqueous foods due to the quick passing of current more effectively through these types of foods, when comparing it with other solid type of foods and there is quick transfer of pulses those, we are applying into the food placed in the chamber, from one point to another due to the influence of ions in the product. According to Zimmerman *et al*, the system of performance of pulsed electric field technique is the application of high voltage electric pulses into the chamber to inactivate the microorganisms in the food (Syed *et al*., 2017; Mohammed & Eissa, 2019) [29, 19] by activating the process of electroporation.

2.3 PEF System and its major components

PEF system includes a power source of high voltage, capacitor to store energy, a resistor to resist more current flowing, & a switch for the passing of current from the capacitor to the sample food product. An instrument name oscilloscope is used to identify the pulse waves. A DC generator is used to convert the utilizing current into high voltage AC current. And energy that we are applying through DC is getting deposited in capacitor & it gets passed through electrodes placed in the chamber to be treated then generating an electric field in the chamber. The current gets deposited in the capacitor will be equal to the current applying from the power source. And discharging the energy into the food item is gets started after we put on the switch. A chamber cooling system is also there to maintain the temperature during the treatment. And this system mainly; 3). Consists of three main components, (Mohammed & Eissa, 2019) [19] that is a pulse generator of high voltage, a treatment area, and to control the whole process, there will be a monitoring system (Fig 2).

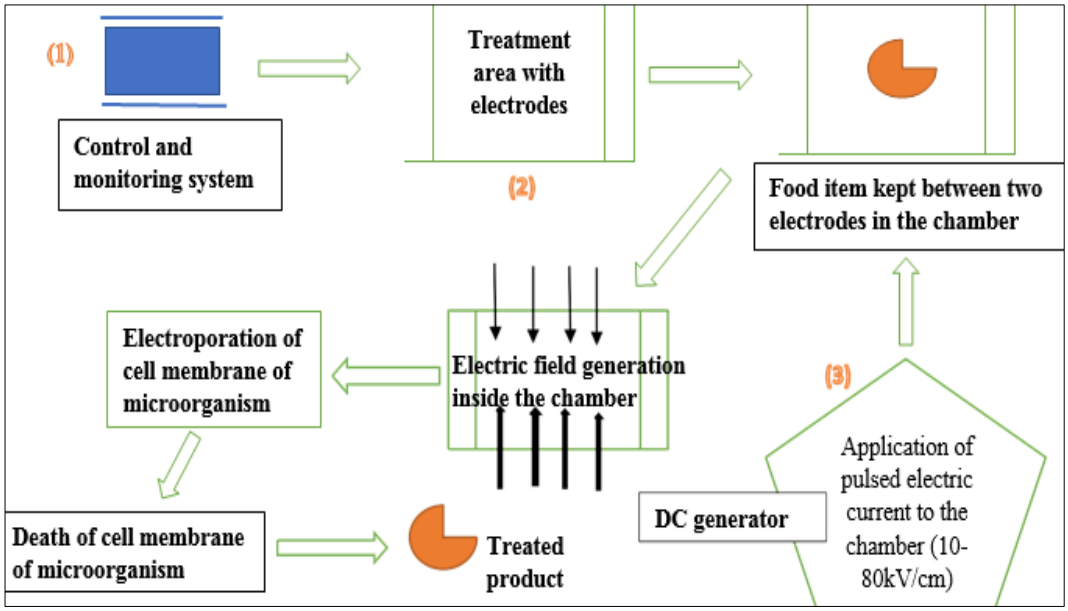

Fig 2: PEF system and its components

3. Influence of Pulsed Electric Field technique in microbial inactivation

Pulsed electric field technology has the ability to sustain the quality of food along with the safety provided by the technology is the one of the major positive things of the PEF technique (Buchmann & Mathys, 2019) [3]. During PEF processing, due to the application of electric field a transmembrane potential created on the cell membranes and it causes the alteration of cell wall. According to the applied voltage intensity, the electromotive force over the cell membrane proportionally rises and when it reaches a threshold value an irreversible origination of pores in membrane takes place and the process can be called as electroporation. (Fig: 3(c). Due to the increase of permeability or the electroporation, finally results into the death of affected cells of microorganisms (Kantar & Koubaa, 2022; Koubaa *et al.*, 2018) [12, 14]. And the cell membrane of the microorganisms become penetrable to the tiny particles results expansion and breaking of plasma membrane.

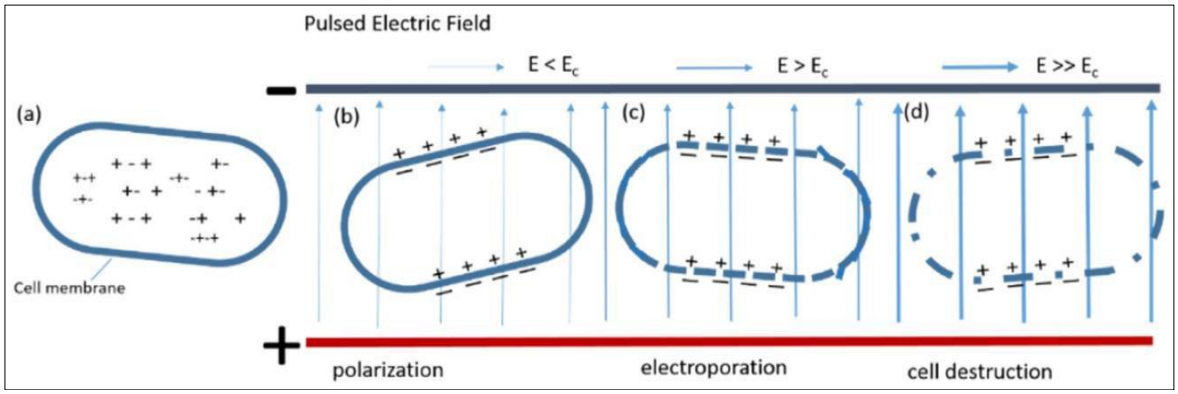

Fig 3: microbial inactivation by destroying cell membrane, (a) cell membrane, (b) polarization, (c) electroporation, (d) cell rupturing, (Capodagilo, 2021), E-Applied electric field, Ec- critical threshold value of required electric field

3.1 Factors influencing inactivation of microorganisms

The major two factors responsible for inactivation of microorganisms are electric filed strength and treatment time. Field strength can be calculated as the potential difference in the middle of 2 electrodes divide by space between the electrodes. And this is one of the reasons of rupture of cell membrane of microorganisms and causing death and also the high electric strength results dielectric breakage of liquid those already made. cell size and the orientation of electric field are the two parameters influencing on the strength of electric field or its critical value (Toepfl *et al.*, 2014) [9]. Electric field strength and treatment efficiency is directly proportional parameters, because if we increase the electric field strength inside the chamber then there will be an increase in efficiency of the process happening there.

Apart from the electric field strength, there is another important parameter which provides the inactivation of microorganisms is, treatment time. We can calculate the treatment time through multiplying pulse duration or the width with the number of pulses discharged to the chamber reported that, when we increasing the treatment time then it results to increase the microbial inactivation. Rising of number of pulses to discharge into the chamber results to rise treatment time, then it causes to increase the microbial inactivation ratio. Except these two, there are many other parameters influenced in PEF inactivation of microorganisms like pulse shape, frequency, electrical conductivity of microorganisms, type of microorganisms etc. (Fig; 4).

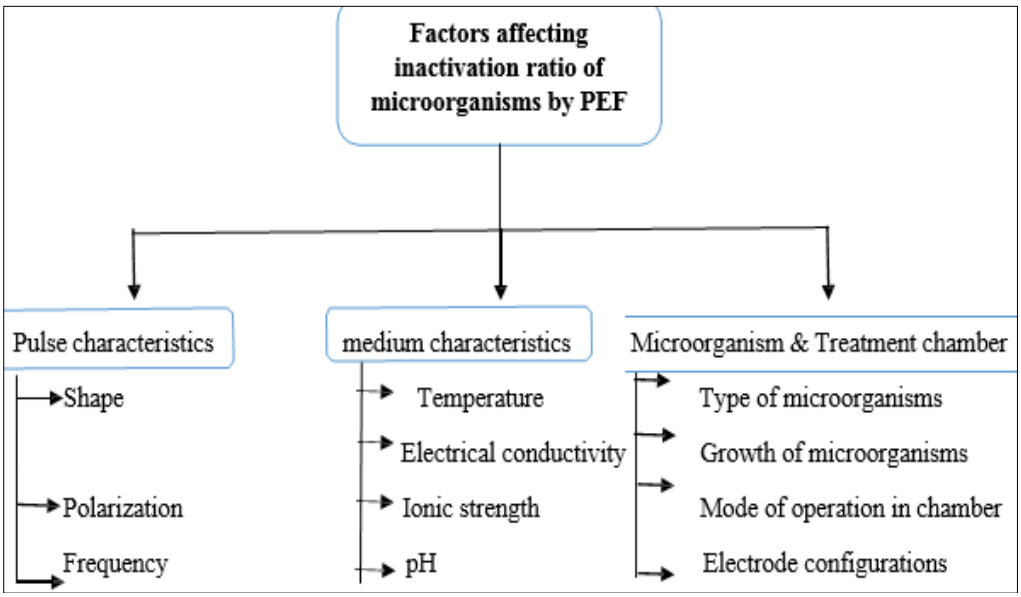

Fig 4: factors affecting inactivation ratio of microorganisms by PEF

4. Advantages and disadvantages of PEF technology

Table 1: Advantages and disadvantages of PEF technology (Kumar *et al*., 2015) [16]

Advantages	Disadvantages
1. It is a simple novel non-thermal technique. 2. Best preservation technique of beverages and other liquid foods. 3. It helps to pasteurize fluid foods such as juices, dairy products, soups etc. without additives. 4. It helps to improve food quality. 5. It kills or inactivate microorganisms up to 4-6 logs. 6. By the process of electroporation of cell membrane, it enables tissue softening and enhanced mass transport. 7. It improves taste, colour, flavor, nutrient quality in the food. 8. Relatively short treatment time. 9. No evidence of toxicity. 10. It makes healthy products last longer. 11. Low treatment temperature 12. Maintain food safety with low processing cost.	1. High initial cost 2. It is not having any effect on enzymes and spores. 3. It is only applicable for liquid foods, not for solid and semi-solid foods. 4. High intensity of electric field sometimes affect food also. 5. After treatment, refrigeration is required to extend shelf life. 6. PEF processing is restricted to products with low electrical conductivity. 7. It is effective for the inactivation of vegetative bacteria only. 8. High energy dissipation 9. To maintain the processing, the food size of food particles must be less than the treatment gap in the treatment area.

Table 2: Effect of PEF on fruit juices

Sample	Voltage applied (kV/cm)	No: of pulses or pulse width (µs)	Effect of PEF on juices/ result	References
Apple juice	50 kV/cm	10 pulses	Increases shelf life of juice	Kumar *et al*., 2015 [16]
30 and 40 kV/cm		200 pulses	Decrease TP content (Total phenolic content)	Ertugay *et al*., 2013 [7]
	40 kV/cm	50 pulses	PPO enzyme activity reduction up to 6.2%	Ertugay *et al*., 2013 [7]
Orange juice	25.3 kV/cm	402.1 pulses	PME enzyme inactivation.	Agcam *et al*., 2014 [33]
Navelia orange juice	35 kV/cm	1500 µs	80% of PME inactivation.	Agcam *et al*., 2014 [33]
Orange-carrot juice beverage.	25 kV/cm	340 µs	81.4% inactivation of PME.	Agcam *et al*., 2014 [33]
Strawberry juice	35 kV/cm	4 µs	73%, 10%, and 66.7%, 15.6% of reduction in PG, PME, LOX & β-GLUC activity.	Roobab *et al*., 2022 [34]
Red raspberry	25 kV/cm	66 µs	98% and 80% of RA enzyme of raspberry were observed.	Roobab *et al*., 2022 [34]
Grape Juice	25-5 kV/cm	1-5 µs	100% PPO & 50% POD inactivation.	Roobab *et al*., 2022 [34]
Mango Juice	35 kV/cm	50-2000 µs	70%, 53%, and 44% PPO, LOX, & POD, inactivation.	Roobab *et al*., 2022 [34]
Orange-carrot juice	24 kV/cm	93 µs	86% RA of PME	Roobab *et al*., 2022 [34]
Watermelon juice	35 kV/cm	1727 µs	1.7%, 85%, 34.8% and 86.4% RA of POD, LOX, PME, and PG.	Roobab *et al*. 2022 [34]
Fruit juices blend (orange, kiwi, mango, and pineapple)	35 kV/cm	4 µs	58.77% and 73.08% RA of PME and PG respectively.	Roobab *et al*., 2022 [34]
Apricot juice	0, 7 and 14 kV/cm	500 µs	Helps to determine phenolic compounds, chemical bond of bioactive compounds present in apricot juice was analysed, PEF treatment increases phenolic content in apricot juice, increased flavonoid content in juice, increases antioxidant activity of PEF treated apricot juice.	Rahman *et al*., 2020 [24]
Carrot-orange juice	25, 30, 35 & 40 kV/cm	30-340 µs	Extending the shelf life of carrot-orange juice stored at 2 degrees Celsius for 50 days.	Salehi *et al*., 2020 [27]
Peach	0-5 kV/cm	30-150 µs	Extraction of bioactive compounds from thinned peach fruits	Salehi *et al*., 2020 [27]
Pomegranate	35 and 38 kV/cm	281 µs	PEF processing didn't significantly impact total phenolic, anthocyanin and antioxidant compounds in pomegranate juice, less impact on colour of pomegranate juice.	Salehi *et al*., 2020 [27]

5. Significance of pulsed electric field technology in food processing

PEF can be applied as a tool for food processing, and act as a better alternative to traditional thermal processing techniques and its gaining popularity due to the major applications of PEF technology, is reported by (Kumar *et al*., 2015) [16]. The utilization of PEF technology is mainly in pasteurization technique of various liquid foods.

5.1 Application of PEF in juice processing

According to the researchers conducted by scientists in the context of juice industries, saying that PEF provide good result for the deactivation of microbes present in different fruit juices like apple, strawberry, orange, grape, watermelon juices etc. It is executed to maintain the quality of the food material & to increase the mean life of foods. Avoids the contamination in fruit juice and helps to inactivate the microbes present in it after the electroporation technique of PEF technique. Many PEF related experiments were conducted on different juices at particular electric field strength, according to particular number of pulses or pulse width and great result also came after treatments.

5.2 PEF and meat quality

Conservation of quality of meat is important because, nowadays most of the people consume meat by reason of appearance of precious micronutrients and high-quality protein. When PEF technique used to treat meat, it helps for extending the mean life & to maintain the vaporous form of meat during storage. Pulsed electric field technique results to release enzyme and to improve the process of glycolysis which are important for the splitting of proteins into smaller peptide fractions and amino acids for meat softening. For example, when we apply 5-10 kV electric field, on beef

muscles at different frequencies like 20, 50 & 90 Hz, it resulted that, the pulsed electric field treatment brings down the shear force to 19% and increases the softness (Syed *et al*., 2017) [29].

5.3 Microbial inactivation or pasteurization of milk

Raw milk consists of various harmful microorganisms, so the utilization of raw milk & the products get from raw milk is at danger. In raw and pasteurized milk, the microbes which spoiling the quality are mostly by the gram-negative psychotropic microorganism & the pseudomonas species.

E. coli bacteria, it is the major reason for the beginning of diseases from the consumption of raw milk. So, there are many studies conducted over this problem and PEF treatment found to be effective to inactivate *E. coli* in milk. At 24 kV/cm electric field for 141 µs at the range of temperature of 30 degree Celsius causes a depletion of 2 log microorganisms after PEF treatment (Walter *et al*., 2016) [32].

5.4 Extraction of biological compounds by PEF

PEF processing is appropriate for biological applications that call for delicate extraction and disintegration procedures (Buchmann & Mathys, 2019) [3]. Higher mass transfer and higher extraction yields are caused by electroporation or the permeability of electric fields (Toepfl *et al*., 2014) [9]. PEF-based extraction's selective nature enables the cascade processing of various cell-derived substances such carbohydrates, proteins, and lipids (Buchmann & Mathys, 2019) [3]. The notion of reversible and continuous PEF-based extraction may have significant future applications. Reversible PEF permeabilization is particularly beneficial for determining microbial inactivation. It was proven by Buchmann *et al*. (2019) [3], who showed that protein extraction from Chlorella vulgaris cells is feasible without limiting growth. After 24 hours, protein extraction in this system reached its peak. The free protein fraction of *C. vulgaris* was extracted using a PEF-based method with an absolute yield of up to 96.6 4.8%. However, in *C. vulgaris* cultures, increased extraction yields were associated with a decreased capacity to proliferate after treatment.

Two key parameters which lead to relatively low extraction yield. First, the permeable structure, forming after PEF treatment which affects the quality or state of the complete membrane of the cell which was in the perfect condition, and Diffusion gradient-assisted release of cellular substances is made possible by this. Second, while PEF processing can permeabilize cell membranes, the extraction of membrane-bound chemicals is constrained by the incomplete disruption of the membrane. (Buchmann *et al*., 2019) [3].

The study of the release of carbohydrate content from the chlorella vulgaris, reveals that at processing temperatures between 25 and 55 °C without any PEF treatment, only a little portion (YC: 5% of biomass carbohydrate content) of the microalgae's total carbohydrate content was liberated. However, a significant increase in the release of carbohydrates was seen when the temperature was raised further, to 65 °C. This was most likely caused by the cell membranes' thermal disintegration, which produced an extraction yield of more than 35% of the total carbohydrate content the results of the combination PEF- temperature treatments for carbohydrate release. Between 22% and 25% of carbohydrates were yielded when PEF was used at processing temperatures between 25 and 45 °C. However, in this temperature range, there is no evidence of a positive relationship between PEF and temperature. Instead, a further rise in processing temperature to 55 °C revealed a definite synergistic impact of the combination treatment, increasing the carbohydrate yield by up to 39%. This synergistic impact was probably brought on by a less stable cell membrane as a result of the elevated temperature, which made the lipid bilayer of the cell membrane more susceptible to electric pulses and permitted a greater release of carbohydrates.

Different physical approaches, such as electric (PEF and HVED), USN, and HPH procedures, were used to disrupt the intracellular extraction from the microalgae *Nannochloropsis* sp. These physical approaches were used to determine the release efficiency of proteins, pigments (chlorophylls and carotenoids), and ionic components in 1% (w/w) suspensions. In a cylindrical batch chamber with two plate electrodes, PEF treatment was performed. The electrodes' separation was set at 2 cm, and the corresponding electric field's intensity, E, was 20 kV/cm. Application of N consecutive pulses (N = 1-400).

5.5 Extraction of bioactive compounds by the assistance of PEF

To extract compounds or the bioactive compounds pulsed electric field technique is a auspicious method from fruits and vegetables like anthocyanins, betanines, carotenoids etc. There are different parameters have taken part in the isolation of bioactive compounds like the process of isolation, solvent used for the extraction and the staple materials used for the process of extraction. Some traditional methods like hydro distillation, maceration, and Soxhlet require agitation.

For example, by using pulsed electric field technology, can extract anthocyanins from grape juice & is given by Leong *et al*., 2016 [17] under particular electric field power, pulse width and at a frequency by using particular solvent. Likewise, Frontuto *et al*., 2019 [8], extracted polyphenols from potato peels using PEF technology under proper conditions. There are some other bioactive compounds which can be derive through PEF processing technology.

Table 3: PEF assisted extraction of bioactive compounds

Extracted bioactive compounds	Source	Pulse width	Frequency	Electric field power	Solvent used for extraction	References
Anthocyanin	Grape juice	20 µs	50 Hz	1.5 kV/cm	1ml methanol to 1ml of grape juice.	Leong *et al*., 2016 [17]
Polyphenols	Potato peels	3-25 µs	1-450 Hz	1 kV/cm	Water-ethanol mixture Ethanol concemtration-50%	Frontuto *et al*., 2019 [8]
Polyphenols	*Sideritis raiseri*	10 µs & 100 µs	1000 Hz	1.0 kV/cm	100% water, 25% ethanol in water, 50% ethanol in water, 75% ethanol in water, & 100% ethanol.	Athanasiadis *et al*., 2022 [2]
Quercetin	Onion skin	25 µs	50 Hz	2.5 kV/cm	Subcritical water extraction.	Kim *et al*., 2022 [13]
Vitamin C	Orange	4 µs	800 Hz	35 kV/cm	NR	Yilmaz & Evrendilek, 2014 [33]
Phenolic compounds	Blueberry juice	20 µs	10 Hz	1, 3 & 5 kV/cm	50% ethanol & 0.5% HCl	Bobinaite *et al*., 2014
Curcumin	*Curcuma longa*	49 µs	NR	2 kV/cm	Ethanol	Tan *et al*., 2022 [30]
carotenoid	*P. tricornutum*	45Pulses	2 Hz	3 kV/cm	50% DMSO in water	Kokkali *et al*., 2020
Chlorophyll b	*Chlorella vulgaris*	75 µs	2 Hz	20 kV/cm	Pure DMSO	Kokkali *et al*., 2020

5.5.1 Impact of PEF on bioactive compounds

Mostly peoples are searching for consuming healthy and nutritious food, so there is a need to improve the preservation techniques to improve food freshness and to maintain stability of bioactive compounds. Some researchers have already found out the bioactive properties of fresh fruit juices can able to preserve more efficiently after the pulsed electric field processing. It offers greater preservation of polyphenols, isoprenoid compounds, fatty acids, amino acids, vitamin C, vitamin A, and several other water-soluble vitamins. And it was once noted that after 14 days of storage at 4 degrees Celsius, the vitamin c bioavailability in PEF-treated orange juice and gazpacho remained noticeably higher than in untreated samples. PEF increases the number of vitamins and other bioactive substances that may be extracted from fruits and vegetables, increasing their health benefits. Compared to heat processing, PEF treatment increases the *In vitro* bio accessibility of vitamin C and phenolic compounds as well as the antioxidant capacity of fruit juice-based beverages.

5.6 Egg pasteurization by PEF

Egg and the products which get after processing of egg are important healthy, strengthening, nutritive food in our diet due to their functional properties, but these will lead to health issues in some cases and results a huge economic loss and affect the well-being of populations. So, to retain the quality of egg, several studies have revealed that PEF application increases the quality, reduce the spoilage causing microorganisms and better retention of nutrients compared with other thermal treatments.

Monfort *et al*., done PEF experiment on extra- large Grade A eggs collected from the market and the eggshells cleaned with 70% ethanol allowed to air dry. Microorganisms treated with a 3 s pulse width at 0.5 Hz frequency in a temperate batch parallel electrode treatment chamber. At 20 degrees Celsius, the electrical conductivity of the egg or sample was 0.67+ 0.03 S/m. They work on the reduction of inactivation of salmonella species present in egg by PEF treatment. They observed highest inactivation values coming at 25 kV/cm and 105 µs and at 35 kV/cm and 45 µs and the reduction is about 3 logs. So, it relies on the length of treatment and the intensity of the electric field, with the inactivation rate rising as treatment length and electric field intensity rise (Monfort *et al*., 2010) [20].

5.7 PEF in biogas production

Biogas production or anaerobic digestion process is an efficient technique to produce clean and renewable energy from organic wastes like plant wastes, animal wastes etc. The hydrolysis stage of the process, where organic substrate is broken down into smaller molecules such amino acids, mono saccharides and disaccharides sugars, fatty acids, etc., is the slowest and rate-limiting step. And PEF is a useful technique for quickening the hydrolysis phase of biogas production. Application of high electric voltages increases bioavailability of compounds by cracking cell structures. And PEF technology faster biogas production process and decrease the retention time (Kovacic *et al*., 2020) [15].

6. Future aspects of PEF technology

PEF technology gaining importance nowadays, because it is one of the cheapest non- thermal techniques than other thermal techniques. So, in future, its demand increases because of the high rate of quality improvement of food and maintaining of shelf life of the product. It is only using the electric energy as energy for the process instead of heat energy. High rate of electric pulses will reach into the food product inside the treatment chamber and causes electroporation of the cell membrane of the microorganisms and inactivate the microorganisms.

At present, most of the people going for nutritious food and healthy food, so the industries also tried to make the healthy food to increase the economic value of the food and to make their selling stable in the market. They will search for environmentally friendly methods for the preservation of foods to increase their value, quality, taste, flavour, and the shelf life of the product. But it is only suitable for liquid foods, but let's except a new application of PEF on solid foods. Through some modifications, the pulsed electric field technology also operated for solid foods conservation as like as the fluid foods. And it also has a great advantage on the improvement of or maintain the stability of quality of food product under storage conditions. PEF process of food preservation will gain more demand in between industries due to the increase in demand of quality food by the people in the future. It will be a having a great advantage over rising of food industries in the future, because it is one of the low cost most demand technique due to its efficiency.

7. Conclusion

PEF is simple novel technique which operated without the use of heat for the food preservation. It is an important non-thermal technique which provides high quality food product without any lack in nutrients, taste, flavour, etc. along with higher shelf life. So, through many findings related to PEF on food quality, most of the results were positive because it is more advantageous over any other techniques.

This review highlighted about all important things that we should know about the PEF technology in food processing to know its value and to increase its demand, like its principle, PEF system and its major components, how it inactivates the microorganisms, its positives and negatives, several applications of PEF on various fields, etc. So, we get to know the importance and need of PEF technology in food preservation.

This technology was introduced by Sales and Hamilton, and they reported that this technology inactivates microorganisms at a level (2 log reduction) but not because of the temperature created inside the working chamber, because only 10 degrees Celsius rise will be there so it is happening because of two important variables like electric force applied & the time required for treatment. When applying high voltages, then the cell membrane of microorganism become destroyed or pores will form on membrane and this process can be called as electroporation, and it increases the permeability of cell membrane and swelling happens at last it will burst and causing the death. So, this process, completely reduces the spoilage causing microorganisms from the treated food.

The PEF treated foods having a lot of advantages over non-treated foods. But it also having one negative side also. But the negatives of PEF can be treated by improving or by keeping more focus on positive side of PEF technology in food processing to increase the stability of food industries and to provide best quality food to consumers.

8. References

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