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Review Article

Review on the Application of Pulsed Electric Field in Some Fruit and Vegetable Processing

Rabira Lemessa

Department of Food Engineering, Haramaya Institute of Technology, Haramaya University, Haramaya, Ethiopia

Email address:
rabiralamesa40@gmail.com

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Abstract: Pulsed electric field is a developing non-thermal food processing method that uses high voltage pulses within short time to treat food products. It ruptures the cell membranes of vegetative microorganism by expanding or creating pores results in microbial inactivation and used in tissue softening of food plants. Electric field strength, treatment time, pulse geometry, and treatment temperature are the critical processing parameters in PEF processing. This paper reviews the application of PEF technique in fruit and vegetable processing such as different juice products and potato processing. Pretreatment process by PEF facilitates the release of nutrients from fruit and vegetables during processing, thus increasing the efficiency and extraction yield. Heat sensitive products such as vitamins and bioactive compounds are preserved by PEF treatment. It is generally recognized that PEF processing is environmentally safe and effective to maintain quality and safety of foods without affecting their sensory properties and nutritional value.

Keywords: Electroporation, Fruit and Vegetables, Microbial Inactivation, Preservation, Pulsed Electric Field

1. Introduction

The advancement for nonthermal food processing technology has been one of the most important research areas in the last two decades in terms of searching for alternative energy and efficient applications. To accomplish adequate microbial reduction while maintaining food quality, a number of nonthermal pasteurization techniques have been developed, which includes high pressure processing, irradiation, and pulsed electric fields [1]. PEF processing involves placing the food in a chamber with two electrodes in order to inactivate vegetative microbes and thus improve the shelf life of processed food items without undesirable heat and chemical effects [2].

Pulsed electric field treatment has been applied as a minimally offensive technique for processing plant tissues that avoids a number of adverse changes in food products, vitamins, pigments, and flavoring agents that are distinctive for other pretreatment methods like chemical, enzymatic, and thermal treatments [3]. Furthermore, the PEF treatment is also known for determinations of microbial inactivation. In the past ten years, it has been discovered that the pulsed electric field treatment can improve the pressing, extraction, diffusion and drying process [4].

Pasteurization of a various food products, including juices, milk and dairy products, soup, has been extensively shown using PEF technology. PEF can preserve the sensory and nutritional qualities of food while inactivating pathogenic and spoilage bacteria but not spores or enzymes. As a result, it may be applied as a method for pasteurizing or prolonging the shelf life of liquid food items, particularly acidic ones where spores cannot germinate. The pasteurization of fruit juices is therefore one of the most pertinent uses of PEF, however experiments involving several other food items, including as milks, liquid eggs, and vegetable products, have also been carried out [5].

Despite being a non-thermal technique, PEF processing has temperature as a key processing parameter. Temperature rises caused by joule heating effects during PEF processing might be crucial for the bacteria inactivation as well as for the degradation of heat-labile bioactive substances. Fruit juice can be treated at temperatures from 25 to between 35 - 60°C, which can take benefit of the synergistic effects of mild heat on the effectiveness of the PEF treatment to inactivate E. coli.

Fruit and vegetables processing are essential for producing goods that can be consumed directly or used as food additives. The primary objectives of processing are to maintain the color, flavor, texture, and shelf life of perishable fruits and vegetables as well as their nutritional content [6].

A rapidly expanding sector of the food business, fruit and vegetable product foods and their resulting components play a significant role in international trade and the economies of many nations. Their process techniques involve a varied range of more or less severe techniques, where mass transfer and mechanical treatments are essential. In the industry, mechanical disruption of plant foods from cutting or slicing to juice extraction is a widespread activity [7].

Products made from fruit and vegetables such as juice have gained popularity among people of all ages due to its excellent sensory and nutritional attributes. Numerous health advantages of juice made from fruits and vegetables include antioxidant, anti-microbial, anti-obesity, anti-inflammatory and anti-cancer properties. In addition to the choice of raw materials, the nutrition and functional components are greatly influenced by the technologies used during processing as well as packaging and storage [8].

The objective of this review is to delivers an overview of the present knowledge on the application of PEF in fruit and vegetable processing. The working principles of PEF, the main processing parameters, and the advantage and limitation of PEF processing are also discussed.

2. Literature Review

Nowadays, the use of nonthermal processing technology has exceeded the use of traditional thermal food processing methods. Non-th0ermal technologies for food processing and preservation have the potential to completely or partially replace thermal technologies that use a lot of energy and produce food of low quality. Food products mainly fruit and vegetables are subjected to various thermal processing technologies to preserve its quality and enhance shelf-life. However, these heat processes could cause nutritional content and sensory quality to decline [9].

Nonthermal technologies have several benefits for the food industry, including the ability to accelerate mass and heat transfer, reduce time of processing, control reactions like maillard reaction, deactivate enzymes, enhance quality and functionality, protect against environmental stresses, and increase shelf life. The most important currently emerging non-thermal processing technologies are high hydrostatic pressure, pulsed electric field, microwave, cold atmospheric plasma, and ionizing radiation technologies [10].

In order to determine the safety of food, processing unit operations that aim to inactivate harmful microorganisms are of the greatest significance. Pulsed electric fields are particularly appealing to the food business as a nonthermal pasteurization procedure because they may inactivate vegetative cells of bacteria at temperatures lower than those employed in heat processing [11].

Through the introduction of new products to the market, the improvement of product quality, and the reduction of production costs, the development of novel food processing procedures may boost the industry's competitiveness. Pulsed electric field technology was introduced into food production as a result of rising consumer interest in foods with high nutritional content, the need for products that resemble freshness, and the need for food produced with consideration for the environment [3].

High temperatures have been used in conventional food processing methods to confirm food safety and a prolonged shelf life. Thermal processes, however, are constrained by the principles of heat transport, resulting in an incline of temperature exposure from the exterior of food to the inside and excessive processing seriously harms the food's sensory, nutritive, and functional qualities [12].

An innovative non-thermal food processing technique called pulsed electric field offers certain benefits over traditional thermal food processing methods. By the phenomenon known as electroporation, it damages cell membranes owing to mechanical impacts, mostly employed to improve the extraction of chemicals by cell break and to prevent microbial development, thus extending the shelf life of food [13].

For a relatively brief period of time, PEF applies a high electric field to pumpable foods in order to kill vegetative cells. Foods are exposed to critical field intensities of approximately 15000 V/cm, whereas PEF is utilized as a disinfectant at 35000 V/cm. PEF causes reversible or irreversible development or enlargement of cell membrane holes. Pores influence membrane permeability by allowing outside material to enter, which results in a loss of cellular content and ultimately results in cell death [14].

2.1. Principles of Pulsed Electric Field (PEF) Processing

PEF technology makes a use of brief (a few microseconds to milliseconds) pulses with greater electric fields of intensity from 10 - 80kV/cm. The number of pulses applied to the product, which is held between two electrodes, determines how the process operates. The area between these electrodes known as the treatment chamber is where the product is subjected to the electric field. High voltage is used during pulsed electric field processing, which renders any microbes present in the food sample inactive.

Food has a number of ions that give the food product a certain level of electrical conductivity, which is the theory behind the transfer of electrical pulses from food stuff. Since electrical current flows into liquid meals more quickly and the transmission of pulses in liquid is fairly simple due to the presence of charged molecules in foods, this approach is often favored for liquid foods. For a liquid food, PEF processing treats by applying high voltage pulses (20–80 kV/cm) with duration of positioned between two electrodes to treat liquid foods [15]. The pulses are provided at high replication rates (up to 3,000 pulses per second) to foods, so that the whole size of the sample can be treated under such repetition of pulse.

Pulsed electric field processing ruptures the cell membranes of vegetative microbes by expanding existing pores or forming new pores. This process is known as electroporation. The ruptures result in harm to cellular metabolic processes like growth and division, which renders microorganisms inactive [3].

The three main parts of a PEF system used in the processing of food are a treatment chamber, high voltage pulse generator, and control monitoring system. Other components include a cooling system, measuring devices such as voltages and current.

2.1.1. High Voltage Pulse Generator

Pulse generator produces high voltage pulses for the system with the required duration, pulse width, shape, and electric field intensity. A pulse forming network (PFN) is used by the high voltage pulse generator to produce electrical pulses with the desired voltage, shape, and duration. A PFN is an electrical circuit made up of a number of parts, including DC power supply, a charging resistor, switches, a bank of capacitors made up of two or more units linked in parallel, and inductors and resistors for shaping pulses. Typically, the capacitor bank is charged and the energy is stored using a high voltage power supply [16].

2.1.2. Treatment Chamber

The treatment chamber is one of the most important and complex parts of the PEF processing system. Although the treatment chamber's primary function is to hold the treated product during pulsing, the uniformity of the process is highly dependent on the treatment chamber's distinctive design. The breakdown of food occurs as a spark if the strength of applied electric fields surpasses the electric field strength of the food product treated in the chamber. Treatment chambers can be operated in a batch or continuous with parallel plate and coaxial type. Coaxial designs have usually been utilized in continuous modes, while parallel plate chambers have typically been employed in batch modes where the medium is pumped at a set flow rate and known pulse frequency while pulses are delivered [16].

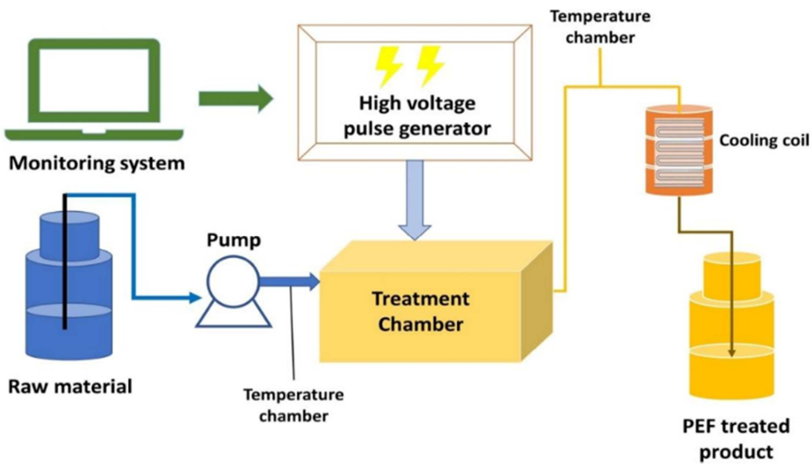

Figure 1. *The diagram of PEF scheme for treating liquid food [17].*

2.2. Main Processing Parameters of PEF

2.2.1. Electric Field Strength

Charges will be produced in the nonconductive microbial membranes if cells suspended in an electrically conductive media are subjected to an external electrical field with sufficient strength. It has been revealed that the size of the cell and their orientation in the electric field have a significant impact on external field strength. Differences in shape of cell can result in significant increases in electricity and the required field strength rapidly rises as the cell size decreases [18].

2.2.2. Treatment Time and Pulse Geometry

In addition to peak electric field strength, the average number of given pulses and the product of pulse width have also frequently been employed to measure treatment intensity. Microbial inactivation increases with longer treatment times. The pulse width is the length of time the peak field is maintained for square wave pulses or the length of time it is maintained for exponential decay pulses until it has declined to 37%. The treatment time is the period of time when range microorganisms are actually exposed to the electric field intensity. It depends on the quantity of pulses and applied pulse width. Classically, the pulse width is fixed by the impulse generator setup, increasing the number of pulses increases the treatment time. Although saturation has occasionally been reported after a particular number of pulses, successful inactivation has often been achieved when treatment duration is extended [19].

2.2.3. Treatment Temperature

When the medium's temperature rises, PEF treatment's lethal effect also rises. The major benefit of increasing the temperature primarily is that it requires less intense PEF treatment to reach the desired inactivation threshold. Li, Zhang [20] reported greater inactivation of Lactobacillus brevis when rising temperature of treatment from 24 to 60°C.

Lebovka, Praporscic [21] have been studied to see how treatment temperature affects the textural characteristics of apple tissue. The findings showed preheating to 50°C temperature more efficiently damaged tissue than treatment by PEF alone and produced higher juice extraction during pressing.

2.3. Advantage and Disadvantage of Pulsed Electric Field Processing

The use of PEF as a non-thermal way of food processing has been one of the primary areas of research in the last ten years in the context of alternative energy-saving methods. As a general view PEF has advantages such as use less energy, less time consuming, low treatment temperature, increase shelf life and maintains food safety. It replaces for conventional heat treatment pasteurization or it can operate at room temperature to maintain quality and heat sensitive vitamins. PEF inactivates vegetative microorganism including yeasts, spoilage microorganisms and pathogens [3].

As reviewed by Nowosad, Sujka [3], pulsed electric field processing have some disadvantages. Pulsed electric field processing treatment is effective for the inactivation of vegetative bacteria only but not spore formers, and dehydrated cells are able to survive. It is limited to treatment of food products those have no air bubbles (air bubbles making the process less effective) and with low electrical conductivity.

Dielectric breakdown will happen in the event that bubbles are present in the PEF treatment chamber. The reason for this is that as the spherical gas bubbles lengthen, the ends develop an electric field that is up to five times stronger. The electric field's intensity overpowers the bubbles' dielectric strength, creating partial discharge, which eventually connects the two electrodes and produces a spark as the bubbles enlarge [14].

2.4. Impact of PEF on Nutrient Content and Bioactive Compounds

The human diet must include fruits and vegetables, and customers are now expecting less processed goods that still keep the organoleptic features of fresh food. Fruits and the products made from them have long been known to have beneficial effects on human health due to their high concentration of vitamin C and bioactive components such phenolic acid, carotenoid, flavonoid, limonoid, and fiber [22].

Recent studies have primarily focused on plant-based foods, particularly juices. They have demonstrated that PEF treatment is safe for bioactive constituents such as vitamins, polyphenols, and carotenoids. There were no noticeable variations in the amount of vitamin C in treatment of apple juice (200, 300, and 400 pulses with intensity of 30 kV/cm), pineapple juice (20, 30, and 40 kV/cm, frequency 10, 20, 30, and 40 kHz), and blueberry juice (350 V) [3].

Morales-de la Pena, Salvia-Trujillo [23] who investigated how PEF processing affected the amount of B vitamins in a product made with orange, kiwi, mango, and pineapple juices discovered that the amount of thiamin and niacin in the fruit drinks were not affected. Moreover, PEF also helps improve the extraction rates of food colorants (carotenoids, betanines, etc.) and bioactive substances, reducing solvent feeding, lowering extraction time in the process [18].

In order to maintain bioactive chemicals, PEF pasteurization is preferable to heat treatment. For instance, tomato juice and orange juice treated with PEF had larger amounts of phenolic acids and flavonoids than those thermally treated as usual.

The phenolic compounds of the samples of orange juice treated by PEF and heat pasteurization has been studied and the total amount of phenolic content of juice was increased after treatment. However, the total phenolic contents began degrading after being processed by PEF (with intensity of 21.50-25.26 kV/cm) followed by heat pasteurization (90°C for 20 s). PEF processing improved the flavor quality of strawberry juice for up to 14 days by retaining increased aroma-related enzyme activity and lowering the primary volatile components (methyl butanoate, ethyl butanoate, and linalool) [24].

2.5. Application of PEF in Fruit and Vegetable Processing

In pulsed electric field pretreatment process, it enables the release of nutrients from fruit and vegetables by cell disintegration and tissue softening during processing, results in increasing the process efficiency and extraction yield [25].

Juice processing using a pulsed electric field has been thoroughly studied. Fruit juice is one of the most suitable foods for treatment with pulsed electric fields. It has been revealed that, mechanical pressing combined with PEF treatment together are likely to enhance the quality and yield of juice produced from fruits and vegetables such as oranges, tomatoes, apples, and carrots [26].

It is commonly recognized that PEF processing may produce fruit juices that are safe, chill-stable, and have fresh-like sensory and nutritional qualities. Freshly squeezed juices processed with PEF are commercially available in the UK, the Netherlands, Belgium and Germany.

To assess the effects of PEF on the physicochemical properties of fruit juices, numerous studies have been conducted. Orange juice treated with PEF (29.5 kV/cm for 60 µs) at 30°C temperature and bottled aseptically had shelf life for 7 months with stored at 4°C while untreated juice spoiled after 3 months [27]. Studies have shown that PEF treatments, as opposed to heat pasteurization, are sufficient to kill bacteria in tomato juices without significantly altering their nutritional content and sensory qualities [5].

The potato processing sector has been the principal user of pulsed electric field technology. This method can be used to treat potatoes right after they have been peeled but before they are chopped. PEF treatment induces the electroporation of cell membranes of potato which softens the tissue and enhances cutting process. The smoother cutting surface makes it possible to decrease starch loss, which raises process yield. The smooth surface also reduces oil absorption in addition to the other effects [28]. The amount of acrylamide in cooked or fried potato products is reduced as a result of PEF's alteration of the structural integrity of tissues, which enhances the release of intracellular constituents such reducing sugars or amino acids involved in Maillard reactions [29].

The study by Ben Ammar, Lanoisellé [30] showed how pretreatment with a pulsed electric field affect the freezing of potato, onion, spinach, and other produce at a low temperature, by air-blast freezer (-80°C). The result has been demonstrated that electroporation of multicellular tissues improves the development of intracellular and extracellular constituents, which increases the likelihood of ice nucleation and speeds up ice propagation, thus reduces freezing time.

Liu, Grimi [31] investigated that Potatoes treated with PEF method also have a uniform color and less oil absorption during frying. PEF also gives a softer texture that enables potato processing operation like cutting, and a significant decrease in the drying time of potato discs [32].

3. Conclusions and Future Aspects

Pulsed electric field is a developing non-thermal food processing method that uses high voltage pulses within short time (micro to milliseconds) to treat food products. It can be used for microbial inactivation and replaces for conventional heat treatment pasteurization to maintain quality and heat sensitive vitamins. PEF treatment in combination with mechanical pressing, is likely to enhance the yield and quality of fruit and vegetable processing like juice products made from orange, tomato, and apples result in better juice extraction. PEF treatment induces the electroporation of cell membranes of potato by softening the tissue and enhances cutting process and less oil absorbed during frying.

It is generally recognized that PEF processing is environmentally safe and effective to maintain quality and safety of foods without affecting their sensory properties and nutritional value.

Future research must focus on PEF product and process elements that have not yet been studied and are important for commercial distribution. The results of PEF treatments on products so far have not been sufficient to address issues with their quality, safety, microbiology, nutritional content, or processing conditions. Further research is required to determine how processing variables including temperature, pH, lipid content, and moisture affect the safety and quality of novel products.

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