Shahid Bahonar University of Kerman
Biomechanism and Bioenergy Research
Online ISSN: 2821-1855
Homepage: https://bbr.uk.ac.ir
Iranian Society of Agricultural Machinery Engineering and Mechanization

Effect of Non-Thermal Methods on the Reduction of Pesticide Residues and Harmful Microorganisms in Food Products (A Review)

**Mohammad-Hosein Shojaei[1], Kazem Jafarinaeimi[1]✉, Hamid Mortezapour[2]
Mohammad-Mehdi Maharlooei[1,3], Mahdiye Asadi[4]**

[1] Department of Biosystems Engineering, Faculty of Agriculture, Shahid Bahonar University of Kerman, Kerman, Iran.
[2] Department of Mechanical Engineering, Faculty of Engineering, Bozorgmehr University of Qaenat, Qaen, Iran.
[3] Department of Mechanical Engineering, School of Engineering, University of California-Merced
Merced, CA, USA, 95348.
[4] Department of Plant Protection, Faculty of Agriculture, Shahid Bahonar University of Kerman, Kerman, Iran.
✉ Corresponding author: jafarinaeimi@uk.ac.ir

ARTICLE INFO

Article type:

Review Article

Article history:

Received 11 October 2024

Received in revised form 18 November 2024

Accepted 10 December 2024

Available Online 31 March 2025

Keywords:

Non-thermal, Pesticide residues, Electrical field, Non-destructive, Food safety.

ABSTRACT

Pesticides play a significant role in food production and cannot be avoided. Pesticides are widely employed to improve production efficiency and extend the shelf life of food products. However, the presence of pesticide residues in food items raises global concerns due to varying impacts on human health, which are largely dependent on exposure levels. The primary route of exposure for individuals is through the consumption of contaminated food products. It is important to note that certain pesticide residues can still be present in foodstuffs as a result of common food processing practices. Over the past three decades, research and commercialization of non-thermal technologies have been carried out rapidly within the scientific community as well as in the food processing industry. For eliminating pesticide residues according to their type and processing parameters, new technologies have been used which include Cold Plasma, Pulsed Electric Fields, Radiations, Ultrasound, etc. The purpose of this article is to give a summary of how new technologies are used to eliminate pesticide residues and harmful microorganisms from different food items.

Cite this article: Shojaei, M. H., Jafarinaeimi, K., Mortezapourb, H., Maharlooei, M. M., & Asadi, M. (2025). Effect of Non-Thermal Methods on the Reduction of Pesticide Residues and Harmful Microorganisms in Food Products (A Review). *Biomechanism and Bioenergy Research*, *4*(1), 1-18. https://doi.org/10.22103/bbr.2024.24212.1094

Publisher: Shahid Bahonar University of Kerman
DOI: https://doi.org/10.22103/bbr.2024.24212.1094

INTRODUCTION

The use of pesticides has been widespread to improve production efficiency and extend the shelf life of foodstuffs. In agriculture and the non-agricultural sector, pesticides play an essential role in controlling pest and disease infestation. Especially in urban areas, e.g. lawns, gardens, and impermeable surfaces, some pesticides like herbicides, insecticides, fungicides, rodenticides, etc, may be accidentally applied at high concentrations. This contamination is a serious threat to the environment, living organisms, and food safety as a result of their uncontrolled use. Although a full understanding of the fate and ecological effects of pesticides and their residues is not yet available. The presence of these residues in food products is a global issue, as their negative effects on human health can be affected by the methods and levels of exposure. Consumption of food products is a major way in which humans are exposed to pesticides reducing the presence of pesticide residues in food items is crucial to minimize human exposure to pesticides. Several methods have been created for the elimination of pesticide residues from food items. To reduce pesticide residues, a wide variety of household and industrial processes such as washing, blanching, or heating have been used successfully. The removal of pesticide residues can be effectively achieved through the application of innovative techniques such as cold plasma, pulsed electric fields, radiation, or ultrasound, which are contingent upon the specific type of pesticide and the relevant processing parameters. To improve the quality of various food products, this article aims to provide insight into how emerging technologies are being used to remove pesticide residues and harmful microorganisms from foods (Meftaul et al., 2020; Mir et al., 2022).

Methods to improve the quality of farm and animal products

The traditional methods result in the loss of nutritional value changes to taste characteristics, and adverse effects on consumers' health. Consequently, traditional processing and storage methods are increasingly being supplemented by nontraditional techniques. Moreover, the interest in using nonthermal methods to process food has increased as a result of consumer demand for more natural and healthy foods that are safer. The term "nonthermal methods" refers to a group of technologies that preserve food without heating, so that the quality of the product is not altered by heat (figure1). Non-thermal preservation technologies include high-pressure processing, pulsed electric field processing, ultrasound processing, alternating magnetic field processing, irradiation, microwave processing, and radio waves. In most products, irradiation increases the quality of the products. Non-thermal processes and enzymes are employed to deactivate microorganisms and modify the functional properties of food through alternative methods, ensuring that there is no significant increase in the product's temperature (Tabilo-Munizaga & Barbosa-Cánovas, 2005).

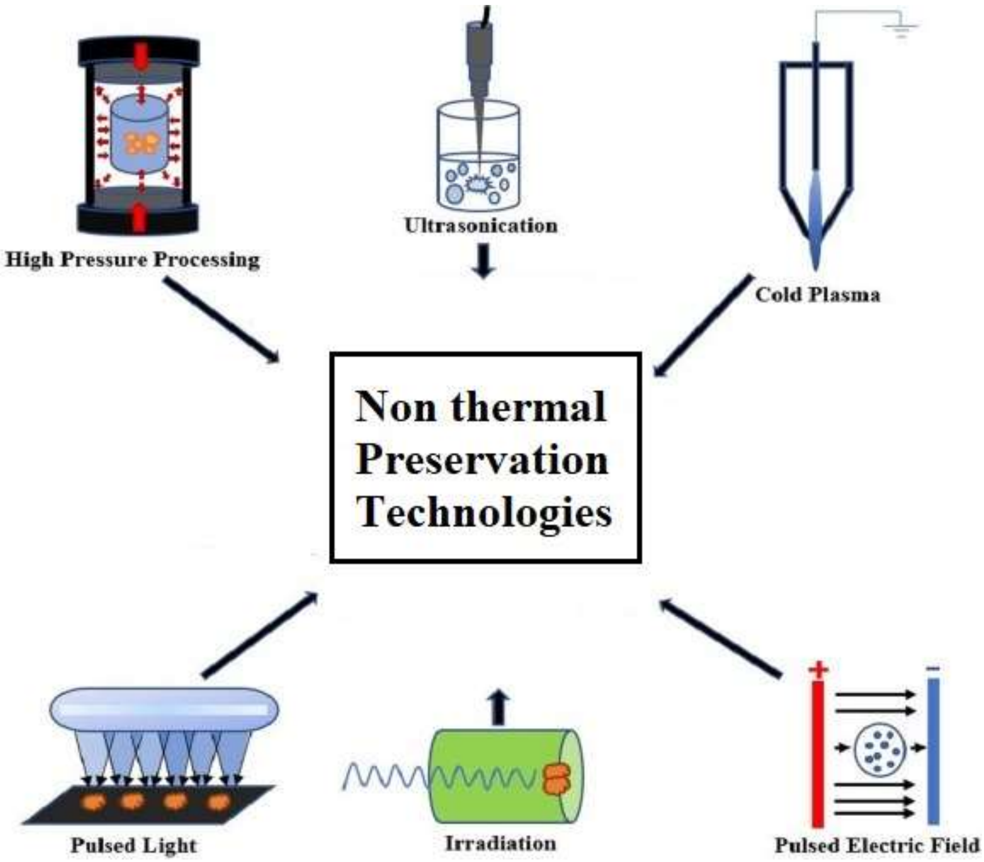

Figure 1. Non-thermal methods of food product preservation(Barbhuiya et al., 2021)

Irradiation

The process of exposing food to ionizing radiation serves to eliminate microorganisms and viruses responsible for foodborne illnesses, including Salmonella, Campylobacter, and Escherichia coli, as well as to disinfect food from insect contaminants. Currently, there are over 40 countries in the world allowing food irradiation and it is expected to rise to 500,000 tonnes of food per year. Food irradiation, like pasteurization, cooking, or other thermal treatments, has a similar effect on food by using electron beams, X-rays, or gamma rays, but with less impact on appearance and texture. Irradiation is an established technique for improving the longevity and quality of food, which in turn impacts the food's structure (Ahmed, 2018).

The wavelength between 0.78 and 1000 micrometers is the wavelength of infrared waves (Rastogi, 2012), which are part of the electromagnetic spectrum, as described below. When these waves hit the surface, they reflect, absorb, or transmit. The energy absorbed by liquid, solid, or liquid food containing solid particles is transmitted within the food material by the heat transfer mechanisms of convection, conduction, or a combination of the two. IR absorption by food depends on thickness and moisture content. The absorption of infrared light varies according to the physical and chemical characteristics of the product. In general, it produces molecules and atoms in the vibration state. The hydrogen-oxygen bond of water molecules absorbs the energy of these waves. Then the water begins to vibrate with the same frequency as the beam, which results in water evaporation (Fu & Line, 1998). This results in an improvement in the effectiveness of infrared for selective water heating, which is not affected by any additional food components. There are also advantages to using these waves compared to conventional heating methods, such as direct heat penetration, no direct contact between the heat source and food, shorter processing time, minimal environmental pollution, or maintaining a higher level of nutrients and physical properties (Rastogi, 2012). In a few studies, the use of noncontinuous infrared heating for the pasteurization of fruit juice has been examined. The use of these waves has been shown to reduce the time of the product's temperature increase compared to the processing of lemon juice in a hot water bath in a study conducted by Aghajanzadeh et al. In comparison with the effects of these two heating methods on Orange juice processing, Vikram et al. also achieved similar results (Aghajanzadeh et al., 2016; Vikram et al., 2005).

Ultraviolet radiation in the UV-C range has become more commonly utilized as a non-thermal technique for fresh fruit juice irradiation. The UV ray can effectively reduce the loss of quality related to sensory and quality attributes. Moreover, it results in a reduction of the microbial load without any chemical residues being left behind (Fenoglio et al., 2020). Previous research has indicated that ultraviolet radiation can effectively reduce the microbial load in various fruit juices while preserving the product quality (Fenoglio et al., 2019; Gouma et al., 2020; Kaya & Unluturk, 2019). Mortezapour et al. experimented with a continuous IR dryer and UV to produce foods with moderate moisture content for mushrooms. The results showed that the use of UV light for food with medium moisture content can be recommended based on fair final moisture, energy consumption, and an appropriate color index (Mortezapour et al., 2023). There have been reports regarding the effectiveness of ultraviolet rays in increasing durability and reducing spoilage in agricultural products at the post-harvest stage for different products. A study was conducted to examine how UV rays impact peanuts, and the findings indicated that the rays improved the resilience of the peanuts (Garg et al., 2013).

Disadvantages & Advantages of Utilizing Irradiation in the Food Industry (Yang et al., 2024)

- Radiation exposure can result in certain fruits and vegetables becoming soft and losing their structural integrity.
- Additionally, fats may generate free radicals as a result of radiation, leading to fat oxidation and rancidity.
- High doses of radiation can produce strong and undesirable flavors.
- Certain food items are particularly sensitive to radiation.
- Furthermore, the irradiation process may affect the stability of specific vitamins, such as E, K, and B vitamins, in some dairy products, potentially resulting in an oxidative taste.
- Irradiation can also alter the color of meat.
- It is important to note that low doses of radiation may not eliminate all bacterial spores effectively.
- One notable limitation of the irradiation process, when compared to thermal processing, is its inability to inhibit enzyme activity.

Advantages

- Enhanced preservation of nutritional value and sensory quality of food in comparison to alternative methods.
- Elimination of secondary pollution through the possibility of utilizing radiation post-packaging, ensuring no harmful residues remain in the food.
- Maintenance of food quality over extended periods.
- Efficacious in the control of microorganisms responsible for spoilage.
- Removal of pathogenic bacteria, yeast, molds, and insects from food products.
- Regulation of ripening, aging, and sprouting processes in fresh fruits and vegetables.

Electrical Field

A technology often used in food is high electric field voltage (HVEF), which is a nonthermal technology. The use of the electric field method offers the benefits of minimal energy usage, strong environmental safeguards, and economic viability. It can preserve the natural color, scent, and taste of food, and it does not negatively impact nutritional elements. This method has significant potential for the sterilization and preservation of food ingredients (El Kantar et al., 2018; Van Wyk et al., 2019). The primary voltage application modes include direct current, pulsed, and high-voltage alternating current, and the type of plate electrode affects the electrical filing characteristics. A high-voltage alternating electric field (HVAEF) is an electrical field that is not uniform, and its intensity and on/off state change periodically. The application of a low-voltage alternating electric field does not result in electroporation effects and does not generate free radical oxidants. It is capable of inhibiting bacterial growth by disrupting bacterial division during cytokinesis, thus impeding their reproduction (Giladi et al., 2008; Wellman et al., 1996). The HVEF exhibits uniformity and greater stability compared to HVAEF and PEF; minimal electrical current is present during the processing of the HVEF, resulting in very low energy consumption. Hasieh et al. showed that the treatment of stored carrot juice with HVEF at 100 kV resulted in better physicochemical characteristics and longer shelf life (Hsieh & Ko, 2008). The study conducted by Shojaei et al. demonstrated that HVEF usage led to a reduction in pesticide residues. It was also confirmed by the results of the analysis of FTIR charts and images taken with thermal imaging (Shojaei et al., 2023).

Electrical pulse process

The electric pulse process (PEF) has been reported for the first time in the processing of fruit juices in Germany, the Netherlands, and England. As a nonthermal technology that can replace or complement thermal pasteurization. For pumpable liquid foods, this process is used. Acceptable achievements have been results concerning the inhibition of microorganism and enzyme activity, as well as the preservation of organoleptic properties. The electrical pulse causes biological membranes to be permeable. Upon being exposed to an electric field, cells' plasma membrane becomes increasingly permeable to small molecules. The reduction or elimination of the microbial load, along with penetration and leakage, leads to swelling and eventual breakdown of the cell membrane (Mirzaii et al., 2015).

The process of electroporation involves using electrical energy to produce a breach in the cell membrane. Cell membrane permeability consists of two stages. Initially, the electric field applied must trigger the formation of pores, and subsequently, the pores must remain stable enough. The food is typically positioned between two electrodes and subjected to a strong electric field through brief pulses lasting a few microseconds and high voltage kV. One of the electrodes is linked to a high-voltage switch, while the other is connected to the ground. By dividing the applied voltage U by the distance between the electrodes d, one can determine the estimated electric field strength generated from pairs of electrodes ($E = U/ d$). The key processing parameters that influence the degree of microbial and enzyme inactivation encompass electric field strength, treatment temperature, duration, and specific input energy (Álvarez et al., 2006). Pulsed electric fields are the most extensively researched treatment and have demonstrated a potent antibacterial effect (Mendes-Oliveira et al., 2020; Yang et al., 2016). Zhao et al. Studies have indicated that employing a Pulsed Electric Field (PEF) at voltages ranging from 25 to 40 kV per centimeter can lead to a decrease in spoilage and pathogenic bacteria (Zhao et al., 2012). Tanino et al. research has indicated that utilizing PEF with carbon material as an electrode effectively inactivates the inhibition of Escherichia coli. To enhance passivation efficiency, it is effective to decrease the electric field intensity while increasing the intensity of the electric field (Tanino et al., 2020). Kumar et al. according to the report, subjecting mango nectar to a pulsed electric field at a strength of 38 kV/cm for 24 microseconds and a frequency of 100 Hz did not show a significant impact on the levels of ascorbic acid and the color of the nectar. Conversely, treating the nectar with heat in a hot water bath at 95 °C for 10 minutes led to a reduction in the vitamin content and an adverse alteration in the product's color (Kumar et al., 2015). In addition, it has been found that the treatment of broccoli juice with PEF for 1 minute at 90 °C results in more retention of ascorbic acid content than conventional heat treatment (Sánchez-Vega et al., 2015). Wibowo et al. have reported that the PEF process is one of the most efficient methods to preserve ascorbic acid in apple juice samples as opposed to fresh orange juice. In addition, the quantity of ascorbic acid in samples that have been subjected to oxidative degradation reactions has declined considerably when stored. The amount of ascorbic acid in fruit juice processed with PEF and fresh samples did not show any significant changes (Wibowo et al., 2019).

The findings indicated that employing pulsed electric fields results in high-purity sugar syrup and enhances cell membrane permeability, leading to improved sugar extraction efficiency from sugar beets. In their study, Rezaei et al. evaluated the sugar syrup quality derived from sugar beets using PEF (Rezaei et al., 2021).

Advantages of Utilizing the Pulsed Electric Field Process (Brito & Silva, 2024)

- Preservation of Food Quality
- Retention of Color, Taste, Aroma, Texture, and Nutritional Value
- Effective Applications in the Pasteurization of Products Including Fruit Juice, Milk, Yogurt, Soup, and Eggs
- Implementation in Drying Processes
- Enhancement of Oil Efficiency from Oilseeds
- Improvement of Sugar Extraction from Sugar Beet

The electrical radio frequency process

The electrical current is known as electric radio frequency (ERF) in the radio frequency range, which spans approximately 3 Hz to 300 GHz. As a non-thermal pasteurization technique, this process has been suggested for the inactivation of bacteria in juice. The radio frequency process closely resembles the electric pulse process, except that in the electric pulse method, the pulse generator receives a high voltage, while in the radio frequency method, the current generator continuously receives the voltage (Geveke et al., 2007). The population of Saccharomyces cerevisiae in water decreased by log 3.8 (99.98%) at 35 ˚C with ERF treatment at 30 kV cm and 20 kHz (Geveke & Brunkhorst, 2003). The ERF inactivation of E.coli K12 in apple juice by log 1.9 (98.7%) compared to control was performed at 21 kV cm and 55 ˚C (Eveke & BRUNKHORST, 2004). Deactivation increases as the temperature rises. The frequencies of 15 and 20 kHz are more effective than 30 to 70 kHz in the activation of E. coli. The RF power source reduced the flow rate to 0.55 liter per minute. Using an innovative pilot plant with 80 kW of power supply and a new matching network, the ERF process has been successfully extended from 0.55 liter per minute to 1.4 liter per minute (Geveke et al., 2007). In the same conditions, RFEF processing decreased E. coli in apple juice by 2.7 log for 60 ˚C and 3s of storage time while traditional heating did not have any effect at all. The electric field strength, frequency, duration of treatment, and temperature shall determine the thermal inactivation of E. coli K12.

High-pressure processing

High hydrostatic pressure (HPP) is a non-thermal technology whereby solid or liquid food products are exposed to elevated pressure levels, typically ranging from 100 to 800 MPa, while maintaining low temperatures. The temperature of the process may be below zero or above 100 ˚C. The time of applying pressure on a commercial scale can be with short pulses (fraction of a second) up to 1200 seconds (20 minutes). There are two ways of applying pressure: high pressure above 400 MPa and very high pressure, and the pressure range between high and very high pressure has not yet been determined (San Martin et al., 2002).

High-pressure technology is a new, non-thermal economic phenomenon in which food is exposed to high pressure, generally in the range of 100 to 800 MPa, at a typically low temperature. Similar to how elevated temperatures render microorganisms inactive, the deactivation of microorganisms, spores, and enzymes can also occur through high pressure (HPH) or ultra-high pressure (UHPH), either alongside temperature variations or independently. This technique is effective in prolonging the shelf life of dairy products (San Martin et al., 2002). A non-thermal technology for food storage is High-Pressure Technology. Water is generally used as a medium to transmit pressure in this technique. This method effectively inactivates a wide range of bacteria, microorganisms, and enzymes, thereby decreasing the reliance on synthetic or artificial additives that are often linked to reduced consumer acceptability (Chen & Stokes, 2012).

Tendering of meat may be carried out using high-pressure processing, but mainly at lower pressures (~200 MPa). Many studies have been done on calpains and other proteases, and how they are affected by high pressure. To obtain the effect of tenderizing meat, preparatory pressure processing should be applied in particular. It has been shown that the effect of meat tenderization is directly related to the amount of shrinkage during processing (Chen & Stokes, 2012). The processing of milk using high-pressure technology has been shown to dissociate casein micelles, alter whey proteins, and change the appearance and rheological properties of milk.

Ultrasonic process

For a variety of purposes, ultrasound or US may be applied for emulsification, crystallization, homogenization, cutting, dehydration, extraction, and microbial elimination. This technology has both positive effects (such as changing the viscosity and homogenization parameters) and negative effects (negative effects on flavors, and unwanted physical parameters) on food processing. These changes have been caused by the conditions of pressure and critical temperature, allowing radicals to form in acoustic cavitation. The propagation of ultrasound in a liquid environment causes cavitation of bubbles due to pressure changes. The increase in temperature and heat is caused by the collapse of these little bubbles. Therefore, the pasteurization process is carried out without significantly increasing the temperature by increasing pressure and energy (Bhargava et al., 2021).

Ultrasound energy is the term used for sound waves with frequencies exceeding 20,000 Hz. Nondestructive testing utilizes high frequencies ranging from 0.1 to 20 MHz, operates in pulses, and employs low power levels of 100 mW. Ultrasound has multiple uses such as rheology, texture analysis, and measuring the concentration of solids or liquids. Evaluating the composition of eggs, meat, fruit, vegetables, and dairy products is important for monitoring various aspects such as thickness, flow level, and temperature using nondestructive inspections. Ultrasound, characterized by frequencies exceeding the human hearing threshold of 20 MHz, finds application across three distinct areas within the food processing industry. Low-intensity ultrasound typically operates at power levels below 1 watt per cm^2 within the frequency range of 5 to 10 MHz. These lower power levels ensure that low-intensity ultrasound does not cause any physical or chemical alterations in the properties of the material through which the wave is transmitted. This method enables the precise measurement of various food characteristics, including texture, composition, viscosity, and concentration. In high-intensity ultrasound, power levels are much higher, typically ranging from 10-1000 W/cm^2, at 20-100 kHz (Dobraszczyk & Morgenstern, 2003).

A wide range of food products, with their rheological and functional characteristics, are subject to the widespread use of ultrasound. Some effects of ultrasound, e.g. improving the stability of juice, increasing meat tenderness, and rheological properties have been shown for milk and dairy products. The effects of ultrasound are strongly influenced by outside control parameters, e.g. frequency, amplitude, velocity, treatment duration, and temperature. Ultrasonic irradiation presents a valuable approach for partial polymerization and the synthesis of medium-sized macromolecules from larger molecules. The implications of these studies could foster further research and development, promoting an increased application of ultrasound technology in food processing operations (Dobraszczyk & Morgenstern, 2003).

The impact of ultrasound on the rheology of food occurs as a result of cavitation phenomena. Cavitation refers to the creation, expansion, and, in certain cases, rupture of bubbles in liquids. Sound waves can lead to two types of cavitation phenomena, known as inertial and non-inertial. Inertial cavitation involves significant changes in bubble size (in comparison to its natural size) throughout several sonic cycles, where rapid expansion ends in the collapse of the bubble with varying degrees of force. Fluctuations of small amplitude, with the bubble radius, are associated with stable cavitation in a non-inertial context. The intense ultrasound results in thermal, mechanical, and chemical impacts, associated with the quick creation and dismantling of cavity bubbles, producing considerable normal and shear stresses. In localized high-temperature environments, where temperatures can ascend to 5,000 ˚C and pressures reach 100 MPa, the phenomenon of cavitation bubble explosions leads to significant energy accumulation. Under these conditions, water molecules are capable of breaking down and generating highly reactive free radicals (Dobraszczyk & Morgenstern, 2003).

Cold plasma process

The atmospheric pressure plasma is another non-thermal new technology. This process is related to the Quasi Neutralized Gas composed of very high-energy species. Particles like photons, positive and negative ions, Free Electrons, or Radicals are some of those types. Because they're capable of responding to almost any cell component and deactivating the bacteria. It can be applied in a variety of fields, such as textiles, electronics, biological sciences, and packaging taking into account the properties of cold plasma. However, in the food industry, cold plasma is usually used for microbial cleaning and sterilization of food. In the food industry, low-temperature plasma can be used as an alternative to conventional sterilization methods. The changes in color, taste, and nutrient loss will be reduced by this process (Niemira, 2012).

The electrons have a much warmer temperature in the non-thermal plasma than their lighter counterparts. Because of the difference in electron mass, non-thermal plasma is also known as non-equilibrium plasma. The gas is decomposed into a variety of reactive substances and ionization reactions are carried out when the energy passes (Cai & Du, 2021; Ekezie et al., 2017). Before that, electric fields with alternating or pulsed and direct current were used for the production of nonthermally charged plasmas; different types of energy sources such as capacitor-coupled Plasma, Inductively Coupled Plasma, or Direct Current are used to produce these discharges. Today, however, the discharge of plasma jet with air pressure, coronas discharge, radio frequency, plasma created by microwaves, dielectric arc discharges, and parabolic barriers generated by working gases N2, O2, and Ar emissions are widely used to produce non-thermally discharged Plasma (Ordudari & Rismanchian, 2023; Cong et al., 2021). A significant electrical potential difference of two or more electrodes is created by the power source, microwave, and radio frequencies (Aggelopoulos, 2022). A noble gas with a small mixture of gaseous sources is the most commonly used source for non-thermal plasma discharges. However, it is possible to use these in the air with no gas at all (Fernandes & Rodrigues, 2021). In summary, the non-thermal plasma process can be described with three stages: in the first stage, numerous active species are produced (highly energetic electrons, ozone OH radicals, excited species containing (O and N)) Following a specific path, they play a dominant role in the destruction of organic materials that enhance the chemical reactions of the plasma. The next step is to penetrate the surface of the target material with active species. To remove the pollution, the third step is the chemical reaction of active species and organic pollutants (Ordudari & Rismanchian, 2023).

Two categories of cold plasma, according to the atmospheric pressure, are classified as nonthermal or cold plasma: Low-Pressure Cold Plasma and Cold Atmospheric Plasma. Under low pressures or even a vacuum, low-pressure plasma can be produced. Atmospheric plasma operates at radio frequency, generating ionization by rapid electrical impulses at short intervals, voltages, and power (Ferreira et al., 2020). Atmospheric cold plasma is an enhanced oxidation process (Ordudari & Rismanchian, 2023). Cold atmospheric plasma has emerged as a highly competitive and effective approach for the remediation of pollutants in water and gaseous environments, particularly when compared to alternative methods (Ucar et al., 2021). The advantages of Cold Air Plasma are estimated to be low energy consumption, strong pollutant elimination efficiency, quick purification time, and minimal residual contamination. The absence of a high temperature is one of the most important advantages of the cold atmospheric plasma method, which results in a reduction in energy consumption (Ordudari & Rismanchian, 2023). The use of cold plasma at atmospheric pressure can improve the efficiency and safety of decontamination and removal of organoleptitious qualities in products (Zhan et al., 2020). Non-thermal plasma can effectively prevent the growth of bacteria, molds, and yeasts, so it has been widely used to sterilize food products. Reactive oxygen species, such as OH, O3, and hydrogen peroxides produced in plasma, which can be indirectly oxidized and effectively destroy the chemical bonds of organophosphorus molecules, are responsible for the plasma effect on the decontamination of pesticide residues Cold plasma has benefits such as greater efficiency, better disinfection without the use of chemicals and at low temperatures to ensure bacterial safety, shelf life and freshness for agricultural products compared with other oxidative destruction techniques (Cai & Du, 2021). Bacterial cells and inactivated microorganisms as well as spores and viruses may interact with plasma (Umair et al., 2022).

To enhance quality and extend the shelf life of food products, plasma technology serves as an effective method for deactivating microbiological organisms within food packaging. The ability of cold plasma to effectively inactivate foodborne viruses from different surfaces and foodstuffs has been demonstrated in existing literature (Bae et al., 2015; Lacombe et al., 2017; Pexara & Govaris, 2020). Yong et al. used cold plasma to disinfect Escherichia coli, Salmonella typhimurium, and monocytogenes on shredded cheddar cheese with a DBD device at a voltage of 250 V and a frequency of 15 kHz, and the results showed that the population of all three pathogens, respectively, within The time was reduced by 60 seconds, 45 seconds and 7 minutes (Yong et al., 2015). A study was conducted on the use of cold plasma to sterilize milk at a voltage of 3 kV for 3 minutes at a frequency of 500 Hz. The plasma is very effective in killing bacteria in raw milk (Aslan, 2016). For the surface treatment of fennel seeds and mint leaves, cold plasma from a dielectric barrier has been used in research. The experiments were designed on two different variables: the plasma delivery time of 5 to 15 minutes, and voltage from 17 to 23 kVA. The use of plasma pretreatment has enhanced the extraction performance of basic oils (Rezaei et al., 2021).

In research, the effect of different frequencies of cold plasma stimulation (500, 200, and 800 Hz) was investigated as a pre-treatment for drying Tacoma. Samples treated with 200 and 800 Hz frequencies have shown variations in the color of the edges, as well as a decrease in time to dry (Rouzegar et al., 2021). The chemical properties of date fruits were examined using Cold Plasma treatment. The results showed a significant decrease in the weight of the plasma-treated samples compared to the control samples throughout the storage period. The impact of cold plasma on Mazafati date fruits throughout storage has demonstrated a decrease in pH and an increase in the total amount of insoluble solids. The average total phenolic compound value was the lowest and the highest for samples treated with 2,182 mg per kg of oxygen gas and 4007 mg per kg of argon gas, respectively, with a plasma treatment time of 240s. The sugar reduction ranged from 38.76% to 65.54% for the control and samples treated with air with a plasma treatment time of 240s (Maghsoudi et al., 2023).

Advantages of Cold Plasma in the Food, Agriculture, and Packaging Industries (Kumar et al., 2024)

- Cold plasma technology offers several noteworthy advantages, including high and sustained effectiveness, ease of use in the process, and significant savings in water and energy.
- Additionally, it contributes to the reduction of greenhouse gas emissions, aligning with high environmental standards.
- This technology enables surface treatment under ambient pressure (atmospheric conditions) and operates as a dry process, eliminating the need for toxic or polluting chemicals.

Ohmic heating process

Another non-thermal process is ohmic or OH heating. Ohmic heating is the heating of food through the passage of electrical current, converting electrical energy into thermal energy. Therefore, compared to the traditional thermal process in which heat is transferred from the outer part of the food item to the inner part, it produces heat inside the food element. As a result, the food is uniformly heated and at the same speed, which increases the quality and preserves the basic characteristics of the materials processed by this method. For the pasteurization of a large number of foods such as juice and purees, blanching vegetables, and meat preparations it is recommended to use the Ohmics method.

Ohmic heating is a modern heat application technique utilized in thermal processes. Food is placed between two electrodes that function as electrical resistors, while a varying electric current flows through the system. The generated heat within the food's structure is consistent and volumetric due to its electric resistance. The conversion of electrical energy into heat results in a temperature increase that is significantly influenced by the electrical conductivity of the product. The electrical conductivities of specific fluids' solid and liquid phases can be appropriately matched to enable particles to heat up faster than liquid during ohmic heating in theory. This unique feature has drawn interest from industry, academia, and regulators as it allows Ohmic heating to serve as an alternative source of filtration in the septic process for particulate fluids. When creating and using ohmic heating systems, the rheological characteristics of hydrocolloids play a crucial role. Adding salt to hydrocolloids can enhance the effectiveness of ohmic heating. Rheological properties have an impact on the velocity profiles of the system. The continuous ohmic heating column in a traditional tube or holding tank can be likened to an electrical current. The study of fluid rheological properties is essential for analyzing the flow characteristics in fluid mechanics. When fluid moves through a continuous Ohmic heating system, it is important to understand its flow regime (whether it's laminar, transitional, or turbulent). Determining the flow regime involves calculating the Reynolds number, which compares the inertial force to the internal friction force (viscosity) (Joyner, 2018).

Measuring viscosity helps to understand how a substance behaves when in motion, showing the level of internal resistance or friction experienced when it moves through another layer of fluid. Researchers investigated to assess the viscosity and electrical conductivity of juices from apples, pineapples, oranges, or tomatoes under different conditions utilizing an ohmic heating system. Tomato and pineapple juice were found to have the lowest and highest viscosity levels among the fruit juices that were examined. As the temperature increased, the flow of all juices decreased. A consistent relationship between viscosity and temperature was established for the juices under examination. The effects of ohmic heating on the rheological properties of carrageenan, pectin, starch, and xanthan solutions were investigated across various temperatures, concentrations, and shear rates, with the inclusion of 1% salt in the study. The rheological properties were influenced differently by concentration, temperature, and shear rate based on the hydrocolloid type. The flow curves of starch and pectin were effectively characterized by a power law model. The apparent viscosity of starch, carrageenan, pectin, and xanthan exhibited minimal variation in response to changes in concentration. The viscosity of the fluid phases is also a crucial element for ohmic heating. Sufficient viscosity of the fluid is necessary for absorbing and transporting it in a food system with significant quantities of soluble solid particles (Joyner, 2018).

Sabansi et al. explored the chemical and qualitative characteristics of pomegranate water using the ohmic method and observed that raising the ohmic voltage led to an increase in the levels of antioxidants and phenols in the pomegranate water (Sabanci et al., 2019). In their study, Darvishi et al. examined the impact of the ohmic process on the characteristics of blackberry juice. They found that a higher voltage gradient led to a noteworthy rise in total phenol and vitamin C content, while the pH value of the samples decreased (Darvishi et al., 2020). According to Mokhtarian et al., the reduction of the heating time and the uniformity of the temperature in the various parts of the material through this process has resulted in the least amount of wasted exergy and the production of entropy, which means an increase in the exergy efficiency of the system and possibly make changes in exergy a well, Because of the temperature difference between the system's boundary and its surroundings. At high voltages, because the temperature of the product rises quickly, the amount of temperature exchange with the surrounding environment decreases due to the high speed of temperature inside the sample and causes the amount of exergy to be reduced (Mokhtarian et al., 2016).

Darvishi et al. have shown that the increase in energy efficiency and specific wasted energy can be attributed to increasing the voltage gradient and shortening the process by experimenting with the power and exergy of tomato production during an ohmic procedure. The researchers also reported that the amount of exergy efficiency and wasted exergy increased with the increase in the duration of the process at constant voltage (Darvishi et al., 2015). Zell et al. have examined the effects of electrode types in ohmic heating and determined that they play an important role in terms of thermal efficiency, energy consumption as well as the length of this process (Zell et al., 2011). In the same context, Suik et al. investigated the electrical conductivity and performance evaluation of the fruit juice concentration process using the ohmic heating method and showed that by evaluating the effects of ohmic heating conditions applied on the total process time, total energy consumption and process efficiency, the voltage gradient 19 V/cm can be recommended as the optimum evaporation condition for juice concentration in case of reducing the process time (Cevik, 2021). Another study by Surmeh et al. investigated the use of ohmic heating for milk vapourization and assessed electrical conductivity and performance analysis, finding that with increasing voltage, gradient energy efficiency and exergy are increased. In the conventional approach, the lowest energy yields and exergy values were recorded. The ohmic method can be utilized as an efficient technique for the valve (Ariç Sürme & Sabancı, 2021). Amiyali et al. investigated the electrical conductivity of agricultural products using the ohmic heating method and the results showed that the thermal conductivity coefficient of fruit juice such as apples, oranges, and pineapple increases linearly with temperature (Amiali et al., 2006).

The disadvantages associated with ohmic heating are as follows (Astráin-Redín et al., 2024):

- The initial investment required for the installation of ohmic heating systems is higher than that of conventional heating methods.
- Foods containing fat granules may not be effectively heated using ohmic heating, as these granules lack the necessary conductivity due to their low water and salt content.
- Pathogenic bacteria present within fat granules may be less effectively exposed to heat treatment compared to bacteria located outside of these fat particles.
- The system's electrical conductivity increases as the temperature rises within the food and solution, leading to enhanced movement of electrons.
- The application of ohmic heating may result in increased corrosion of the electrodes, stemming from electrochemical reactions, which can consequently raise operational costs.

The advantages of ohmic heating include (Sain et al., 2024):

- Ohmic heating promotes enhanced retention of food elements and minimizes alterations in the sensory properties of the food.
- It effectively inactivates bacteria not only through its thermal effects but also through the non-thermal effects of electrical current.
- Ohmic heating serves as an alternative heat treatment that exerts a reduced impact on biologically active compounds compared to conventional thermal processes.
- Additionally, ohmic heating facilitates the inactivation of enzymes present in food.

Various methods have been used to remove pesticide residues from food products. Cleaning, blanching, peeling, and applying thermal processes have been effective in decreasing pesticide residues in both household and industrial environments. Table 1 provides an overview of the use of innovative technologies like cold plasma, pulsed electric field, radiation, and ultrasound for the destruction of pesticide residues, the effectiveness of the pesticide is influenced by both the type of pesticide utilized and the processing conditions applied.

Table 1. Effect of the use of some non-thermal techniques on reduction of pesticide residues.

Food material	Type of nonthermal technique	Type of pesticide	Reference
Tomato	cold plasma	Chlorpyrifos	(Ranjitha Gracy et al., 2019)
Mango	cold plasma	Chlorpyrifos	(Phan et al., 2018)
Lycium barbarum	cold plasma	Cypermetrin	(Zhou et al., 2018)
White wine	pulsed electric field	Cyprodinil Pyrimethanil Procymidone Vinclozolin	(Delsart et al., 2016)
Tomato	High voltage electric field	malathion	(Shojaei et al., 2023)
Strawberry	irradiation	Azoxystrobin Carbendazim	(Ciarrocchi et al., 2021)
Pea	irradiation	profenosfos	(Rodrigues et al., 2020)
Tomato	cold plasma (ozone)	Azoxystrobin, Chlorothalonil Difenoconazole	(Rodrigues et al., 2019)
Tomato	cold plasma (ozone)	Chlorfenapyr	(Al-Antary et al., 2018)
Tomato	cold plasma (ozone)	Cypermethrin	(Al-Dabbas et al., 2018)
Carrot	cold plasma (ozone)	Difenoconazole Linuron	(De Souza et al., 2018)

CONCLUSIONS

The residual of pesticides and harmful microorganisms in fruits and vegetables has been gradually improving. However, some highly toxic pesticides are still present in fruits and vegetables, and these pesticide residues in crops are subject to environmental influences. Removing pesticide residues from agricultural products has been achieved using new technologies like cold plasma, irradiation, and electric fields. An overview of different methods for producing Non-thermal Technologies as described in recent literature was presented in the paper during this review. Generally speaking, information on the fate of pesticides and microorganisms is limited when food is processed without heat. Although research progress on the subject is still in its infancy, it has shown that high pressure, high voltage electrical field and pulse processing of electricity can be used effectively to remove pesticide residues from fruits, vegetables, and other products. Plasma and PEF, based on the prolonged processing times necessary to achieve effective pesticide degradation, are likely to be more suitable for liquids like fruit juice than ultrasound. HPP, plasma, and cold plasma are promising alternatives to whole solid foods such as fresh fruits and vegetables.

REFERENCES

Aggelopoulos, C. A. (2022). Recent advances of cold plasma technology for water and soil remediation: A critical review. *Chemical Engineering Journal*, *428*, 131657. https://doi.org/10.1016/j.cej.2021.131657

Aghajanzadeh, S., Kashaninejad, M., & Ziaiifar, A. M. (2016). Effect of infrared heating on degradation kinetics of key lime juice physicochemical properties. *Innovative Food Science & Emerging Technologies*, *38*, 139-148. https://doi.org/10.1016/j.ifset.2016.09.027

Ahmed, J. (2018). Advances in rheological measurements of food products. *Current Opinion in Food Science*, *23*, 127-132. https://doi.org/10.1016/j.cofs.2018.10.007

Al-Antary, T. M., Shaderma, A. M., & Al-Dabbas, M. B. (2018). Ozonation treatment effect on spiked chlorfenapyr pesticide on tomato fruits. *Fresenius Environmental Bulletin*, *27*(11), 7822-7826.

Al-Dabbas, M. M., Shaderma, A. A., Al-Antary, T. M., Ghazzawi, H. A., & Hamad, H. J. (2018). Effect of ozonation on cypermethrin and chlorpyrifos pesticides residues degradation in tomato fruits. *Fresenius Environmental Bulletin*, *27*(10), 6628-6633 .

Álvarez, I., Condón, S., & Raso, J. (2006). . Microbial inactivation by pulsed electric fields. *Pulsed electric fields technology for the food industry: Fundamentals and applications*, 97-129. https://doi.org/10.1007/978-0-387-31122-7_4

Amiali, M., Ngadi, M. O., Raghavan, V. G., & Nguyen, D. (2006). Electrical conductivities of liquid egg products and fruit juices exposed to high pulsed electric fields. *International Journal of Food Properties*, *9*(3), 533-540. https://doi.org/10.1080/10942910600596456

Ariç Sürme, S., & Sabancı, S. (2021). The usage of Ohmic heating in milk evaporation and evaluation of electrical conductivity and performance analysis. *Journal of Food Processing and Preservation*, *45*(9), e15522. https://doi.org/10.1111/jfpp.15522

Aslan, Y. (2016). The effect of dielectric barrier discharge plasma treatment on the microorganisms found in raw cow's milk .*Türkiye Tarımsal Araştırmalar Dergisi*, *3*(2), 169-173. https://doi.org/10.19159/tutad.34744

Astráin-Redín, L., Ospina, S., Cebrián, G., & Álvarez-Lanzarote, I. (2024). Ohmic heating technology for food applications, from ohmic systems to moderate electric fields and pulsed electric fields. *Food Engineering Reviews*, *16*(2), 225-251. https://doi.org/10.1007/s12393-024-09368-4

Bae, S.-C., Park, S. Y., Choe, W., & Ha, S.-D. (2015). Inactivation of murine norovirus-1 and hepatitis A virus on fresh meats by atmospheric pressure plasma jets. *Food Research International*, *76*, 342-347. https://doi.org/10.1016/j.foodres.2015.06.039

Barbhuiya, R. I., Singha, P., & Singh, S. K. (2021). A comprehensive review on impact of non-thermal processing on the structural changes of food components. *Food Research International*, *149*, 110647. https://doi.org/10.1016/j.foodres.2021.110647

Bhargava, N., Mor, R. S., Kumar, K., & Sharanagat, V. S. (2021). Advances in application of ultrasound in food processing: A review. *Ultrasonics sonochemistry*, *70*, 105293. https://doi.org/10.1016/j.ultsonch.2020.105293

Brito, I. P. C., & Silva, E. K. (2024). Pulsed electric field technology in vegetable and fruit juice processing: A review. *Food Research International*, *184*, 114207. https://doi.org/10.1016/j.foodres.2024.114207

Cai, X., & Du, C. (2021). Thermal plasma treatment of medical waste. *Plasma Chemistry and Plasma Processing*, *41*, 1-46. https://doi.org/10.1007/s11090-020-10119-6

Cevik, M. (2021). Electrical conductivity and performance evaluation of verjuice concentration process using ohmic heating method. *Journal of Food Process Engineering*, *44*(5), e13672. https://doi.org/10.1111/jfpe.13672

Chen, J., & Stokes, J. R. (2012). Rheology and tribology: Two distinctive regimes of food texture sensation .*Trends in Food Science & Technology*, *25*(1), 4-12. https://doi.org/10.1016/j.tifs.2011.11.006

Ciarrocchi, I. R., Mendes, K. F., Pimpinato, R. F., Spoto, M. H. F., & Tornisielo, V. L. (2021). The effect of radiation in the degradation of carbendazim and azoxystrobin in strawberry. *Radiation physics and chemistry*, *179*, 109269. https://doi.org/10.1016/j.radphyschem.2020.109269

Cong, L., Huang, M., Zhang, J., & Yan, W. (2021). Effect of dielectric barrier discharge plasma on the degradation of malathion and chlorpyrifos on lettuce. *Journal of the Science of Food and Agriculture*, *101*(2), 424-432. https://doi.org/10.1002/jsfa.10651

Darvishi, H., Hosainpour, A., Nargesi, F., & Fadavi, A. (2015). Exergy and energy analyses of liquid food in an Ohmic heating process: A case study of tomato production. *Innovative Food Science & Emerging Technologies*, *31*, 73-82. https://doi.org/10.1016/j.ifset.2015.06.012

Darvishi, H., Salami, P ,.Fadavi, A., & Saba, M. K. (2020). Processing kinetics, quality and thermodynamic evaluation of mulberry juice concentration process using Ohmic heating. *Food and Bioproducts Processing*, *123*, 102-110. https://doi.org/10.1016/j.fbp.2020.06.003

De Souza, L. P., Faroni, L. R. D. A., Heleno, F. F ,. Pinto, F. G., de Queiroz, M. E. L. R., & Prates, L. H. F. (2018). Ozone treatment for pesticide removal from carrots: Optimization by response surface methodology. *Food Chemistry*, *243*, 435-441. https://doi.org/10.1016/j.foodchem.2017.09.134

Delsart, C., Franc, C., Grimi, N., De Revel, G., Vorobiev, E., & Peuchot, M. M. (2016). Effects of pulsed electric fields on four residual fungicides in white wines. 1st World Congress on Electroporation and Pulsed Electric Fields in Biology, Medicine and Food & Environmental Technologies: Portorož, Slovenia, September 6–10, *2015* (pp. 124-127). Springer Singapore. https://doi.org/10.1007/978-981-287-817-5_27

Dobraszczyk, B. J., & Morgenstern, M. P. (2003). Rheology and the breadmaking process. *Journal of cereal Science*, *38*(3), 229-245. https://doi.org/10.1016/S0733-5210(03)00059-6

Ekezie, F.-G. C., Sun, D.-W., & Cheng, J.-H. (2017). A review on recent advances in cold plasma technology for the food industry: Current applications and future trends. *Trends in Food Science & Technology*, *69*, 46-58. https://doi.org/10.1016/j.tifs.2017.08.007

El Kantar, S., Boussetta, N., Lebovka, N., Foucart, F., Rajha, H. N., Maroun, R. G., . . . Vorobiev, E. (2018). Pulsed electric field treatment of citrus fruits: Improvement of juice and polyphenols extraction. *Innovative Food Science & Emerging Technologies*, *46*, 153-161. https://doi.org/10.1016/j.ifset.2017.09.024

Eveke, D. G., & BRUNKHORST, C. (2004). Inactivation of in apple juice by radio frequency electric fields. *Journal of Food Science*, *69*(3), FEP134-FEP0138. https://doi.org/10.1111/j.1365-2621.2004.tb13366.x

Fenoglio, D., Ferrario, M., Schenk, M., & Guerrero, S. (2019). UV-C light inactivation of single and composite microbial populations in tangerine-orange juice blend. Evaluation of some physicochemical parameters. *Food and Bioproducts Processing*, *117*, 149-159. https://doi.org/10.1016/j.fbp.2019.07.005

Fenoglio, D., Ferrario, M., Schenk, M., & Guerrero, S. (2020). Effect of pilot-scale UV-C light treatment assisted by mild heat on E. coli, L.

plantarum and S. cerevisiae inactivation in clear and turbid fruit juices. Storage study of surviving populations. *International journal of food microbiology*, *332*, 108767. https://doi.org/10.1016/j.ijfoodmicro.2020.108767

Fernandes, F. A., & Rodrigues, S. (2021). Cold plasma processing on fruits and fruit juices: A review on the effects of plasma on nutritional quality. *Processes*, *9*(12), 2098. https://doi.org/10.3390/pr9122098

Ferreira, A. R., Guedes, P., Mateus, E. P., Ribeiro, A. B., & Couto, N. (2020). Emerging organic contaminants in soil irrigated with effluent: Electrochemical technology as a remediation strategy. *Science of The Total Environment*, *743*, 140544. https://doi.org/10.1016/j.scitotenv.2020.140544

Fu, W. R., & Line, W. R. (1998). Optimization of far infrared heat dehydration of shrimp using RSM. *Journal of Food Science*, *63*(1), 80-83. https://doi.org/10.1111/j.1365-2621.1998.tb15680.x

Garg, N., Aggarwal, M., Javed, S., & Khandal, R. K. (2013). Studies for optimization of conditions for reducing aflatoxin contamination in peanuts using ultraviolet radiations. *International Journal of Drug Development and Research*, *5*(3), 408-424 .

Geveke, D. J., & Brunkhorst, C. (2003). Inactivation of Saccharomyces cerevisiae with radio frequency electric fields. *Journal of food protection*, *66*(9), 1712-1715. https://doi.org/10.4315/0362-028X-66.9.1712

Geveke, D. J., Brunkhorst, C., & Fan ,X. (2007). Radio frequency electric fields processing of orange juice. *Innovative Food Science & Emerging Technologies*, *8*(4), 549-554. https://doi.org/10.1016/j.ifset.2007.04.012

Giladi, M., Porat, Y., Blatt, A., Wasserman, Y., Kirson, E. D., Dekel, E., & Palti, Y. (2008). Microbial growth inhibition by alternating electric fields. *Antimicrobial agents and chemotherapy*, *52*(10), 3517-3522. https://doi.org/10.1128/AAC.00673-08

Gouma, M., Álvarez, I., Condón, S., & Gayán, E. (2020). Pasteurization of carrot juice by combining UV-C and mild heat: Impact on shelf-life and quality compared to conventional thermal treatment. *Innovative Food Science & Emerging Technologies*, *64*, 102362. https://doi.org/10.1016/j.ifset.2020.102362

Hsieh, C.-W., & Ko, W.-C. (2008). Effect of high-voltage electrostatic field on quality of carrot juice during refrigeration. *LWT-Food Science and Technology*, *41*(10), 1752-1757. https://doi.org/10.1016/j.lwt.2008.01.009

Joyner, H. S. (2018). Explaining food texture through rheology. *Current Opinion in Food Science*, *21*, 7-14. https://doi.org/10.1016/j.cofs.2018.04.003

Kaya, Z., & Unluturk, S. (2019). Pasteurization of verjuice by UV-C irradiation and mild heat treatment. *Journal of Food Process Engineering*, *42*(5), e13131. https://doi.org/10.1111/jfpe.13131

Kumar, R., Bawa, A., Kathiravan, T., & Nadanasabapathi, S. (2015). Optimization of pulsed electric field parameters for mango nectar processing using response surface methodology. *International Food Research Journal*, *22*(4), 1353 .

Kumar, N. S., Dar, A. H., Dash, K. K., Kaur, B., Pandey, V. K., Singh, A., Fayaz, U., Shams, R., Mukarram, S. A., & Kovács, B. (2024). Recent advances in Cold Plasma Technology for modifications of proteins: A comprehensive review. *Journal of Agriculture and Food Research*, 101177. https://doi.org/10.1016/j.jafr.2024.101177

Lacombe, A., Niemira, B. A., Gurtler, J. B., Sites, J., Boyd, G., Kingsley, D. H., . . . Chen, H. (2017). Nonthermal inactivation of norovirus surrogates on blueberries using atmospheric cold plasma. *Food microbiology*, *63*, 1-5. https://doi.org/10.1016/j.fm.2016.10.030

Maghsoudi, H., Balvardi, M., Ganjovi, A., & Amir-Mojahedi, M.-S. (2023). Investigating the Effect of Cold Plasma on some Chemical Properties of Date Fruits (Phoenix dactylifera L.). *Biomechanism and Bioenergy Research*, *2*(1), 56-67. https://doi.org/10.22103/BBR.2023.20459.1044

Meftaul, I. M ,.Venkateswarlu, K., Dharmarajan, R., Annamalai, P., & Megharaj, M. (2020). Pesticides in the urban environment: A potential threat that knocks at the door. *Science of The Total Environment*, *711*, 134612. https://doi.org/10.1016/j.scitotenv.2019.134612

Mendes-Oliveira, G., Jin, T. Z., & Campanella, O. H. (2020). Modeling the inactivation of Escherichia coli O157: H7 and Salmonella

Typhimurium in juices by pulsed electric fields: The role of the energy density. *Journal of Food Engineering*, *282*, 110001. https://doi.org/10.1016/j.jfoodeng.2020.110001

Mir, S. A., Dar, B., Mir, M. M., Sofi, S. A., Shah, M. A., Sidiq, T., . . . Khaneghah, A. M. (2022). Current strategies for the reduction of pesticide residues in food products. *Journal of Food Composition and Analysis*, *106*, 104274. https://doi.org/10.1016/j.jfca.2021.104274

Mirzaii, M., Alfi, A., Kasaeian, A., Norozi, P., Nasiri, M., Darban Sarokhalil, D., Khoramrooz, S. S., Fazli, M., & Davardoost, F. (2015). Antibacterial effect of alternating current against Staphylococcus aureus and Pseudomonas aeroginosa. Russian Open Medical Journal, 4(2), 0203. https://doi.org/10.15275/rusomj.2015.0203

Mokhtarian, M., Tavakolipour, H., & Kalbasi-Ashtari, A. (2016). Energy and exergy analysis in solar drying of pistachio with air recycling system. *Drying Technology*. *34*(12), 1484-1500. https://doi.org/10.1080/07373937.2015.1129499

Mortezapour, H., Rezvani, Z., Rashedifar, M., & Hajimohammadi-Farimani, R. (2023). Assessment of an ultraviolet-Assisted Continuous Infrared Dryer for producing intermediate moisture food from mushroom slices. *Iranian Journal of Chemistry and Chemical Engineering*. https://doi.org/10.30492/IJCCE.2023.2006960.6128

Niemira, B. A. (2012). Cold plasma decontamination of foods. *Annual review of food science and technology*, *3*(1), 125-142. https://doi.org/10.1146/annurev-food-022811-101132

Ordudari, Z., & Rismanchian, M. (2023). A review of the application of plasma technology in air pollution control. *Occupational Medicine Quarterly Journal*, *15*(3), 78-93. https://doi.org/10.18502/tkj.v15i3.13782

Pexara ,A., & Govaris, A. (2020). Foodborne viruses and innovative non-thermal food-processing technologies. *Foods*, *9*(11), 1520. https://doi.org/10.3390/foods9111520

Phan, K. T. K., Phan, H. T., Boonyawan, D., Intipunya, P., Brennan, C. S., Regenstein, J. M., & Phimolsiripol, Y. (2018). Non-thermal plasma for elimination of pesticide residues in mango. *Innovative Food Science & Emerging Technologies*, *48*, 164-171. https://doi.org/10.1016/j.ifset.2018.06.009

Ranjitha Gracy, T. K., Gupta, V., & Mahendran, R. (2019). Influence of low-pressure nonthermal dielectric barrier discharge plasma on chlorpyrifos reduction in tomatoes. *Journal of Food Process Engineering*, *42*(6), e13242. https://doi.org/10.1111/jfpe.13242

Rastogi, N. K. (2012). Recent trends and developments in infrared heating in food processing .*Critical reviews in food science and nutrition*, *52*(9), 737-760. https://doi.org/10.1080/10408398.2010.508138

Rezaei, S., Ebadi, M.-T., Ghobadian, B., & Ghomi, H. (2021). Optimization of DBD-Plasma assisted hydro-distillation for essential oil extraction of fennel (Foeniculum vulgare Mill.) seed and spearmint (Mentha spicata L.) leaf. *Journal of Applied Research on Medicinal and Aromatic Plants*, *24*, 100300. https://doi.org/10.1016/j.jarmap.2021.100300

Rodrigues, A. A. Z., de Queiroz, M. E. L. R., Neves, A. A., de Oliveira, A. F., Prates, L. H. F., de Freitas, J. F., . . . Faroni, L. R. D. A. (2019). Use of ozone and detergent for removal of pesticides and improving storage quality of tomato. *Food Research International*, *125*, 108626. https://doi.org/10.1016/j.foodres.2019.108626

Rodrigues, F. T., Marchioni, E., Lordel-Madeleine, S., Kuntz, F., Villavicencio, A. L. C. H., & Julien-David, D. (2020). Degradation of profenofos in aqueous solution and in vegetable sample by electron beam radiation. *Radiation physics and chemistry*, *166*, 108441. https://doi.org/10.1016/j.radphyschem.2019.108441

Rouzegar, M. R., Abbaspour-Fard, M. H., Hedayatizadeh, M., & Mohamadinezhad, H. (2021). Comparison of drying kinetics of mint leaves by photovoltaic/thermal solar dryer and natural drying. *Journal of food science and technology (Iran)*, *18*(119), 193-204. https://doi.org/10.52547/fsct.18.119.193

Sabanci, S., Cevik, M., Cokgezme, O. F., Yildiz, H., & Icier, F. (2019). Quality characteristics of pomegranate juice concentrates produced by ohmic heating assisted vacuum evaporation. *Journal of the Science of Food and Agriculture*, *99*(5), 2589-2595. https://doi.org/10.1002/jsfa.9474

Sain, M., Minz, P., John, H., & Singh, A. (2024). Effect of Ohmic Heating on Food Products: An In-Depth Review Approach Associated with Quality Attributes. *Journal of Food Processing and Preservation*, *2024*(1), 2025937. https://doi.org/10.1155/2024/2025937

San Martin, M., Barbosa-Cánovas, G., & Swanson, B. (2002). Food processing by high hydrostatic pressure. *Critical reviews in food science and nutrition*, *42*(6), 627-645. https://doi.org/10.1080/20024091054274

Sánchez-Vega, R., Elez-Martínez, P., & Martín-Belloso, O. (2015). Influence of high-intensity pulsed electric field processing parameters on antioxidant compounds of broccoli juice. *Innovative Food Science & Emerging Technologies*, *29*, 70-77. https://doi.org/10.1016/j.ifset.2014.12.002

Shojaei, M.-H., Jafarinaeimi, K., Mortezapour, H., Maharlooei, M.-M., & Asadi, M. (2023). Investigating the Effect of High Voltage Electric Field on the Pesticide Residue in Tomatoes Using the Thermal Imaging Technique. *Russian Journal of Nondestructive Testing*, *59*(10), 1074-1082. https://doi.org/10.1134/S1061830923600521

Tabilo-Munizaga, G., & Barbosa-Cánovas, G. V. (2005). Rheology for the food industry. *Journal of Food Engineering*, *67*(1-2), 147-156. https://doi.org/10.1016/j.jfoodeng.2004.05.062

Tanino, T., Hirosawa, M., Moteki, R., Matsui, M., & Ohshima, T. (2020). Engineering of pulsed electric field treatment using carbon materials as electrode and application to pasteurization of sake. *Journal of Electrostatics*, *104*, 103424. https://doi.org/10.1016/j.elstat.2020.103424

Ucar, Y ,.Ceylan, Z., Durmus, M., Tomar, O., & Cetinkaya, T. (2021). Application of cold plasma technology in the food industry and its combination with other emerging technologies. *Trends in Food Science & Technology*, *114*, 355-371. https://doi.org/10.1016/j.tifs.2021.06.004

Umair, M., Jabbar, S., Ayub ,Z., Muhammad Aadil, R., Abid, M., Zhang, J., & Liqing, Z. (2022). Recent advances in plasma technology: Influence of atmospheric cold plasma on spore inactivation. *Food Reviews International*, *38*(1), 789-811. https://doi.org/10.1080/87559129.2021.1888972

Van Wyk, S., Silva, F. V., & Farid, M. M. (2019). Pulsed electric field treatment of red wine: Inactivation of Brettanomyces and potential hazard caused by metal ion dissolution. *Innovative Food Science & Emerging Technologies*, *52*, 57-65. https://doi.org/10.1016/j.ifset.2018.11.001

Vikram, V., Ramesh, M., & Prapulla, S. (2005). Thermal degradation kinetics of nutrients in orange juice heated by electromagnetic and conventional methods. *Journal of Food Engineering*, *69*(1), 31-40. https://doi.org/10.1016/j.jfoodeng.2004.07.013

Wellman, N., Fortun, S. M., & McLeod, B. R. (1996). Bacterial biofilms and the bioelectric effect. *Antimicrobial agents and chemotherapy*, *40*(9), 2012-2014. https://doi.org/10.1128/AAC.40.9.2012

Wibowo, S., Essel, E. A., De Man, S., Bernaert, N., Van Droogenbroeck, B., Grauwet, T., . . . Hendrickx, M. (2019). Comparing the impact of high pressure, pulsed electric field and thermal pasteurization on quality attributes of cloudy apple juice using targeted and untargeted analyses. *Innovative Food Science & Emerging Technologies*, *54*, 64-77. https://doi.org/10.1016/j.ifset.2019.03.004

Yang, N., Huang, K., Lyu, C., & Wang, J. (2016). Pulsed electric field technology in the manufacturing processes of wine, beer, and rice wine: A review. *Food Control*, *61*, 28-38. https://doi.org/10.1016/j.foodcont.2015.09.022

Yang, J., Pan, M., Han, R., Yang, X., Liu, X., Yuan, S., & Wang, S. (2024). Food irradiation: An emerging processing technology to improve the quality and safety of foods. *Food Reviews International*, *40*(8), 2321-2343. https://doi.org/10.1080/87559129.2023.2272961

Yong, H. I., Kim, H.-J., Park, S., Kim, K., Choe, W., Yoo, S. J., & Jo, C. (2015). Pathogen inactivation and quality changes in sliced cheddar cheese treated using flexible thin-layer dielectric barrier discharge plasma. *Food Research International*, *69*, 57-63. https://doi.org/10.1016/j.foodres.2014.12.008

Zell, M., Lyng, J., Morgan, D., & Cronin, D. (2011). Minimising heat losses during batch ohmic heating of solid food. *Food and Bioproducts Processing*, *89*(2), 128-134. https://doi.org/10.1016/j.fbp.2010.04.003

Zhan, J., Zhang, A ,.Heroux, P., Guo, Y., Sun, Z., Li, Z., . . . Liu, Y. (2020). Remediation of perfluorooctanoic acid (PFOA) polluted soil using pulsed corona discharge plasma. *Journal of Hazardous Materials*, *387*, 121688. https://doi.org/10.1016/j.jhazmat.2019.121688

Zhao, W., Yang, R., & Zhang, H. Q. (2012). Recent advances in the action of pulsed electric fields on enzymes and food component proteins. *Trends in Food Science & Technology*, *27*(2), 83-96. https://doi.org/10.1016/j.tifs.2012.05.007

Zhou, R., Zhou, R., Yu, F., Xi, D., Wang, P., Li, J ,. . . .Ostrikov, K. K. (2018). Removal of organophosphorus pesticide residues from Lycium barbarum by gas phase surface discharge plasma. *Chemical Engineering Journal*, *342*, 401-409. https://doi.org/10.1016/j.cej.2018.02.107