# NON-THERMAL PROCESSING AND PACKAGING REQUIREMENTS: RECENT TRENDS AND APPLICATIONS

## ABSTRACT

Improving food quality and shelf stability of all types of processed and raw foods before packing is motivated by the idea of safe food for customers. This has prompted specialists in food processing to research cutting-edge technologies that are new and different and may be able to extend the shelf life of food by maintaining its nutrients with little to no change. Despite this, a lot of food items are lost since improper processing methods were employed throughout the years in various locations. Innovative non-thermal technologies can inactivate microorganisms at temperatures close to ambient, preventing thermal degradation of the food components and preserving the sensory and nutritional quality of the fresh-like food products. These technologies include cold plasma (CP), high-pressure processing (HPP), pulsed electric fields (PEF) and pulsed light treatment (PL), among others, to increase productivity. Ohmic and microwave heating are categorized as volumetric heating techniques that increase food goods' shelf lives by generating thermal energy inside the meal itself. These technologies seem to give measurable environmental benefits by improving process and overall energy efficiency and by utilizing less non-renewable resources, regardless of how they are presently being utilized. The goal of this study was to analyze non-thermal processing methods that are now in use or under development for the inactivation of microbes, extending the microbiological shelf life of food and identifying potential packaging interactions. Finding the optimum packing materials for commodities that maintain the advantages of increased product quality brought on by preservation technologies is a crucial step that has to be addressed.

## 1. Introduction

Food safety is a top priority in food processing. Traditional methods of food processing involve heating food at high temperatures to reduce microbial contamination, but this can also lead to negative changes in the food, such as the loss of temperature-sensitive nutrients, changes in texture and changes in the taste and smell of food. Prolonged heating during thermal processing can also lead to low-quality food. Additionally, thermal processing can create harmful and cancer-causing chemicals in food which is unsafe for human consumption (Jadhav *et al.* 2021). In today's world, customers expect healthy and nutritious meals that are free from harmful bacteria and provide a great taste. Due to increased awareness of food safety, customers prefer natural foods without any chemical additives. To meet this demand, experts are working on advanced non-thermal technologies that can replace conventional heat treatment and maintain the quality and natural taste of food. The goal is to eliminate the need for chemical additives while keeping all the benefits of traditional heat treatment and avoiding its drawbacks. Non-thermal processing methods are unequivocally superior to conventional heat treatment methods in terms of enhancing food safety while minimizing the impact on nutritional content. The preservation of key nutrients, such as lipids, carbs, proteins, enzymes, vital amino acids, minerals and vitamins, is ensured through dehydration, as exemplified in milk. Moreover, this approach is highly beneficial for nutraceutical applications as it facilitates the preservation of the maximum concentration of beneficial substances sourced from animals and plants. It is no surprise that non-thermal innovation technologies have gained considerable traction in the food processing sector due to their ability to significantly extend the shelf life of food items (Allai *et al.* 2023).

## 2. Non Thermal Technologies and Packaging

Non-thermal processing methods have gained immense popularity in the food industry due to their gentle and effective procedures (Laroque *et al.* 2022). These methods are increasingly being preferred over traditional methods because they involve reduced usage of chemicals or additives, thus preserving the nutritional content of food. High pressure processing, pulse electric field, pulse light therapy, cold plasma, ozone treatment, UVC treatment, ultrasound treatment and other technologies are some of the non-thermal processing methods being used. For a long time, food has been packed for storage, protection and preservation. The key objective of food packaging is to enhance quality control and food handling (Sarkar *et al.* 2020).

### 2.1 High Pressure Processing

High-pressure processing, one of the most advanced techniques, provides several benefits, from the preservation of food to the modification of functional qualities. Technology should be used during food processing to preserve its original quality while minimizing microbiological and chemical alterations. As a result, the food items will be able to live up to customer expectations (Fam *et al.* 2021). With high-pressure processing, a non-thermal technique of food preservation, harmful pathogens and vegetative spoilage germs are rendered inactive under pressure rather than heat (Muntean *et al.* 2016). In the literature, HPP is also known as high-hydrostatic pressure processing (HHP) or ultra-high pressure processing (UHP). One of the finest advancements in food processing in the last 50 years has been credited to this technique (Dunne, 2005). Most foods may be processed with little to no change in flavour, texture, appearance or nutritional value when high pressure is used. The majority of foods require high pressure (between 400 and 600 MPa) and a low process temperature (about 45 $^0$C) which are both used in high-pressure processing. The distinguishing features of the high-pressure process are temperature, pressure and exposure duration. The fundamental components of an HPP system are a pressure vessel, a pressure-transmitting fluid, a pressurizing system for material handling and supporting elements including heating and cooling components (Muntean *et al.* 2016; Khan *et al.* 2019). The Le Chatelier concept is used in HPP or high-pressure processing, to maintain equilibrium and reduce disruptions. Because the package surface complies closely with the ISO static standard, it is dependably dependable and smooth. In contrast to heat processing, HPP distributes pressure swiftly and uniformly from all sides, protecting the food being processed from any damage (Prakash *et al* 2020).

**Packaging:** For food to be processed at high pressure effectively, packaging materials are essential (Cheftel, 1995; Balasubramaniam *et al.* 2015). Barrier qualities are important in avoiding oxygen access that alters probiotics in yogurt and maize grain chemistry (Talwalkar *et al.* 2004; Shabana *et al.* 2015). They have an influence on product quality, shelf life and preservation. HPP reduces thermal exposure to protect bioactive and its pressure treatment kills bacteria to extend shelf life even at room temperature or below. Studies on mechanical features, water vapor permeability and scent behavior show that HPP's contact with packaging affects their mechanical and barrier qualities (Le-Bail *et al.* 2006; Balaban & Puka 2022). Although packing doesn't directly affect microbe inactivation, it can shape food properties and material choice should be based on how pressure affects proteins, enzymes and reactions (Patterson, 2005). To provide the best performance, mechanical and barrier qualities must be carefully examined for HPP compatibility. Overall, the material of the packaging has an indirect impact on HPP efficacy by affecting the chemical and physical characteristics of the food, microbiological resistance and the pressure-resistance of the packaging (Balasubramaniam *et al.* 2015; Balaban & Puka, 2022).

**Application:** For preserving a wide variety of foods and drinks, HPP is the best option. Both liquid and solid foods with a lot of moisture can be processed using HPP (Muntean *et al.* 2016). In the meat and fish industries, fruits and vegetables and dairy industries, HPP is greatly used. Fruits, vegetables, meat, fish, dairy products and other foods have longer shelf lives as a result of HPP. HPP stops quality-degrading enzymes and microorganisms in their tracks. Without the use of artificial preservatives and additives, it increases food safety while improving its sensory, functional and nutritional qualities. A wide variety of fruit and vegetable products can be processed using HPP, including puree, coulis, sauces, juices, smoothies, chunks, ready-to-eat items, etc. Currently, preservative-free guacamole (avocado puree with spices) is one of the most popular commercial applications of HPP. As a result of the process, avocados retain their flavor, texture and green color while still remaining safe to eat and having a shelf life of up to 6 weeks when kept cold. Easy shell opening of molluscs, simple meat extraction from crustacean products and a boost in yield of up to 45% are some of the most effective commercial applications of HPP today (Matta, 2015). HPP lowers the microbiological hazards associated with eating raw seafood (Sarika K.). On acidic dairy products like yogurt, HPP performs very well. The viscosity of yogurts is increased and synergism is greatly decreased by processing milk before fermentation. Additional benefits for extending the shelf life of yogurt come from using HPP after fermentation. When compared to the products manufactured from pasteurized milk, HPP treatment of the milk enhanced the yield of Cheddar (Drake *et al.* 1997) and semi-hard goat cheese (Trujillo *et al.* 1999) without affecting the cheese flavor (Ozer *et al.* 2023). Additionally, HPP is utilized to enhance milk's ability to coagulate and can increase fresh cheese's ability to retain moisture (Chawla *et al.* 2011). Due to modifications made to the functional qualities of whey protein, HPP may also find use in the egg industry. HPP is a desirable alternative to heat pasteurization for enhancing the microbiological safety of eggs and goods derived from eggs (Srinivas *et al.* 2018).

**Advantages:** HPP provides various benefits over other processing methods, such as shorter processing times, fewer heat damage issues and the preservation of food products color, flavor and freshness. In comparison to conventional thermal procedures, HPP would increase shelf life, use less energy and have the best processing efficiency for foods that can be pumped. There is also no loss of vitamin C and other functional changes are reduced. Due to minimizing microbial contamination, HPP also reduces the requirement for chemical preservatives. Therefore, consumers today are interested in food products made with HPP technology (Fam *et al.* 2021).

**Disadvantages:** There are some drawbacks to this technology. Not all types of food can be preserved using HPP. When in spore form, spore-forming organisms' are extremely resistant to HPP. Delicate foods like strawberries or leafy cereals might potentially suffer visual harm from too much pressure (Shechter, 2016). The cost of HPP is by far its biggest drawback. HPP's equipment is expensive and requires a large investment. Other disadvantages of HPP include a lack of practical understanding of how various food ingredients interact, problems with packing, shelf life and high pressure. (Fam *et al.* 2021)

**Conclusion:** Although there is no denying that HPP foods are beneficial to food processors, consumers and the environment, more scientific proof is needed to be sure of their chemical safety. Food laws specifically addressing non-thermal food processing methods are inadequate in many nations. This eventually caps HPP's level of industrialization (Agriopoulou *et al.* 2023).

### 2.2 Pulse Electric Field

The pulse electric field approach which uses short electrical pulses to eradicate unwanted microorganisms while reducing the influence on other crucial elements of food quality, is a very efficient way to prepare and preserve food. By assisting in preventing or significantly reducing detrimental changes to the sensory and physical characteristics of food, such as color, flavor, texture and nutritional content, this cutting-edge technology, also known as PEF, has been shown to outperform conventional thermal processing techniques (Mohammed *et al.* 2012). This idea has been around for more than 50 years (Von *et al.* 2012) and typical components include a treatment chamber, fluid management systems, high-voltage pulse generators and control and monitoring equipment. The utilization of brief, strong electric field pulses with durations between microseconds and milliseconds and intensities between 10 and 80 kV/cm is the core tenet of PEF technology. By dividing the number of pulses by the actual pulse duration, the processing time may be determined. A product is placed between two electrodes and is subjected to the application of pulsed electrical current in the process. The result of the high voltage that was used was microbial inactivation (Mohammed *et al.* 2012).

**Packaging:** Surfaces, packaging and food may all be successfully decontaminated using Pulse Electric Field (PEF) technology, a non thermal technique. The shelf life is safe and extended since it inactivates bacteria without sacrificing nutrition, flavour or taste. The choice of packaging material affects the stability of flavour compounds, colorants and nutrients in foods that have undergone PEF treatment (Ayhan *et al.* 2001). Based on the packing material, storage circumstances and time, orange juice research found changes in scent components, color and vitamin C retention. According to research on pulsed light therapy (Kramer & Muranyi, 2013), PEF affects bacteria like *Listeria* and *E. coli* by causing DNA damage and oxidative stress. It demonstrates that DNA damage and oxidative stress may be mediating factors in packaging's impact on PEF results. The preservation of sensory and nutritional properties during PEF-processed food storage depends on careful packing material selection (Pal 2017). The nutritional value and organoleptic qualities of liquid meals are maintained when PEF processing is done at ambient temperatures. The durability of taste, color and nutrients in PEF-treated meals can ultimately be considerably impacted by the packaging material chosen (Sujatha *et al.* 2021). It suggests that packaging's impact on PEF results may be related to DNA damage and oxidative stress. PEF-processed foods must be stored and packaged in the best possible ways to maintain their freshness and nutritional content.

**Applications:** The needs of consumers in terms of food are changing. PEF is a very helpful method for satisfying the demands of customers who want foods that are both natural and fresh without compromising the quality of the food. PEFs are employed in the fields of genetic engineering and biotechnology for cell hybridization and electro fusion. In order to electro orate the cell membrane; PEF is administered to microbial cells. After processing with PEF, it has also been demonstrated that apple, cranberry and orange juices, apple sauce and salad dressing retain a fresh quality with increased shelf life. Pea soup, tomato juice, carrot juice and other liquid egg products are some further PEF-processed foods. A significant portion of PEF applications concern dairy products such as skim milk, whole milk and yogurt. PEF is used to improve the extraction of sugars and other biological components from plant cells, including sugar beet cells. Reduced solid volume in wastewater is another application for PEF (Mohamed *et al.* 2012). PEF technology has recently been used in sectors such as wastewater treatment, increasing drying, modifying enzyme activity and preserving solid and semisolid food items as an alternate pretreatment method for improving metabolic extraction. By utilizing to enhance mass and heat transport, plant tissue drying can be helped. Applications of PEF are most likely to assist the citrus sector (Mohamed *et al.* 2012). PEF is a fantastic method for enhancing the extraction of many intracellular substances, including sugar from sugar beet and phytosterols from maize germ. In the ice cream-making Lactobacillus rhamnoses B442, Lactobacillus rhamnoses 1937 and Lactococcus lactis JBB 500 cells, PEF is used to enhance the bioaccumulation of magnesium ions; additionally used to enhance the bioaccumulation of calcium and zinc in Lactobacillus rhamnoses B 442 cells (Nowosad *et al.* 2020).

**Advantages:** PEF has a number of advantages over other food preservation techniques. This approach makes it feasible to reduce or even do away with the need for heat processing which is important since it can degrade the food's nutritional value and overall sensory experience. It can improve the extraction of beneficial chemicals from food ingredients, such as antioxidants. It can enhance the texture, of specific food items like cheese, meat or fruits.PEF requires fewer heating, cooling and processing processes, it can save time, water and energy( Toepfi.,2022)PEF can take the place of enzymatic maceration or high intensity mechanical disintegration(Seimer *et al.* 2020)

**Disadvantages:** The use of PEF processing is limited to foods with low electrical conductivity and no air bubbles.PEF is not appropriate for solid food items that cannot be pumped (Mohammed *et al.*2012). The main challenge to the idea of using this method in industry is the high initial cost of setting up the PEF technology (Jeyamkondan *et al.*1999). The fact that PEF exclusively inactivates yeasts and vegetative bacteria is another disadvantage. With the aid of PEF, inactivating enzymes is challenging.PEF kills microorganisms, however spores can survive because of their hard outer shells and dehydrated cells, hence cooling is necessary to increase shelf life (Yadav., 2018).

**Conclusion:** In the field of food processing, PEF is a crucial technology. All across the world, PEF research is being done. To obtain products in a more energy-efficient and environmentally responsible way, this technique can be utilized alone or in conjunction with other approaches. This method can be used to accelerate pasteurization, drying, freezing and extraction operations, as well as to promote the production of functional foods that contain easily absorbed ions of elements crucial for healthy human body operation (Nowosad *et al.* 2020).

### 2.3 Pulse Light Treatment

In addition to other relevant novel technologies, pulse light treatment is a non-thermal method for food preservation. It is a method for quickly killing microorganisms that are present on food surfaces, equipment and packaging materials. It is founded on the use of brief, intense light pulses with a broad spectrum to ensure microbial inactivation and reduce pests and pathogens in food (Oliu *et al.* 2008).When microbial DNA is exposed to UV light, it undergoes physiochemical changes that harm the genetic material, slow down gene replication and ultimately cause the microbial cell to die (Mahendran *et al.* 2019). The principle involve in pulse light treatment ,in order to assure microbiological decontamination on the surface of foods and food packaging is the formation of pulsed light with gradually increasing from low to high energy and then releasing the highly concentrated energy as broad spectrum bursts. The electromagnetic energy is stored in the capacitor within a fraction of second and released as light in a billionth of a second, resulting in power amplification with minimal additional energy use. The intensity and quantity of delivered pulses affect the effectiveness of inactivation by pulsed light (Rayees *et al.* 2014).

**Packaging:** High-power light pulses are used in pulsed light (PL) treatment, a nonthermal method, to disinfect surfaces, packaging and food products (Oms-Oliu *et al.* 2008). For this technique to be successfully applied, packaging material compatibility with PL treatment is essential (Junior *et al.* 2020). To ensure the safety and quality of food, often researched materials including polyethylene, polypropylene, polyamide and poly(ethylene terephthalate) must adhere to strict standards (Junior *et al.* 2020). High melting temperatures are not required for PL treatment, despite the fact that it can cause surface heating due to its non thermal nature (Junior *et al.* 2020). It's important to pay attention to how PL treatment affects packaging components. In order to prevent quality deterioration, possible substance migration from packaging to food should be assessed. PL treatment can have a favorable influence on the decontamination of packaging materials (Junior *et al.* 2020). To keep packaging compliant with food safety regulations, migration must be managed (Junior *et al.* 2020). In order to improve the shelf life of a variety of food goods, such as fruits, vegetables, meats, dairy, fish and seafood, PL treatment has been shown to be successful (Junior *et al.* 2020). However, depending on the kind of microbe, the amount of inoculum and the topography of the food surface, it may not always be effective (Proulx *et al.* 2015). The effectiveness of PL treatment in food processing is substantially impacted by the choice of packing material. To undergo PL treatment, packaging materials must have a number of qualities, including heat resistance. To maintain the safety and quality of food, it is also important to take into account the interactions between PL treatment and packaging components as well as the possibility of drug migration.

**Application:** Pulsed light has been successfully used in several applications, including the microbiological cleansing of food surfaces, surfaces in contact with food and packaging surfaces. Pulsed light processing is now used for industrial-scale bottle cap decontamination (Mahendran *et al.* 2019). *Listeria monocytogenes*, *E. coli*, *Salmonella enteritidis*, *Pseudomonas aeruginosa*, *Bacillus cereus*, *Staphylococcus aureus*, *Bacillus subtilis* spores, *Aspergillus nigor* spores and *Listeria monocytogenes* have all been successfully inactivated using this method in model food systems like phosphate buffer, water agar surfaces and stainless steel plates. Additionally, pulse light processing is used to improve the functionality of proteins and other bio molecules. Pulse-light treatment increases the shelf life of freshly cut mushrooms by two to three days compared to untreated samples (Shankar, 2022). In order to extend shelf life and inactivate *Listeria monocytogenes*, ready-to-eat cooked beef products also go under pulse light processing (Abida *et al.* 2014). Applications of pale light processing have been proposed for both water treatment and cold pasteurization of liquid meals (Puertolas, 2015).

**Advantages:** Despite being 20000 times brighter than sunshine for only one second, the light has no temperature effect, preserving its purity and nutritional value. Xenon flash lamps are used in pulsed light processing because they are more ecologically friendly than mercury vapor lamps. Inactivating bacteria with pulsed UV radiation is 4-6 times more effective (Shankar, 2022). The speedy and significant microbial reduction, cheap PL energy cost, lack of leftover chemicals and a high degree of flexibility are a few of the main advantages of pulse light processing (Oliu *et al.* 2010).

**Disadvantages:** The poor efficiency of PL in managing food heating is one of its key drawback. The low penetration power of this technology is yet another drawback .Foods with rough or uneven surfaces, fissures or pores are not good for PLD because germs can live in small spaces. Due to the opaque nature of grains, cereals and spices, PL is not an appropriate approach for them. Food products have also been discovered to have low PL efficiency due to the shadow effect. The shading effect will lower the actual radiation dose (Oliu *et al.* 2008).

**Conclusion:** The food industry has several benefits and new, interesting alternatives thanks to pulse light processing. Some microbial species, meanwhile, are resistant to the pulsed light processing method; as a result, both these organisms and the foods they infect should be studied. Based on the existing degree of success of pulse light processing, a development of this PL industrialization over the future years is predicted (Oliu *et al.* 2008).

### 2.4 Cold Plasma (CP)

Cold plasma, the fourth state of matter, is employed in the food processing industry to improve product shelf life and food safety. It entails heating or electrically irradiating a gas (like noble gas) to produce highly reactive particles that eliminate spoilage germs without the use of chemicals while preserving flavor, texture and nutrition. Cold plasma, also known as low thermal equilibrium (LTE) or non thermal equilibrium (NTE), is a flexible, cutting-edge technique that addresses food safety concerns, optimizes processing and offers consumers safer, higher-quality food products (Nisha and Narayana, 2019; Sashi *et al.* 2018).Under vacuum or atmospheric pressure, cold plasma is often produced by the discharge of air or inert gases like nitrogen, helium and argon. When it is processed, active plasma species (such active nitrides and active oxides) are created that can efficiently destroy microorganisms on the surface of food (Zhang *et al.* 2020).

**Packaging:** With advantages including disinfection, increased shelf life and material modification, cold plasma therapy is a promising technique in the agricultural and food industries (Cullen & Keener, 2018). It preserves nutritional and sensory properties by inhibiting bacteria and enzymes and improving packing materials (Pan *et al.* 2019). Produce quality is maintained by using this non thermal approach to successfully fight against rotting and harmful microbes (Pan *et al.* 2019). The non thermal character of cold plasma retains food properties; it was better than other techniques at retaining ascorbic acid in a tomato beverage (Pan *et al.* 2019). It's employed to destroy pathogens, eliminate poisons, break down insecticides and dyes and alter packaging materials (Pan *et al.* 2019). It improves the antibacterial characteristics of biopolymer-based films while preserving the functioning of bioactive chemicals (Hoque *et al.* 2022). While hardly impacting barrier qualities, cold plasma enhances the surface, mechanical and thermal characteristics of packaging material (Hoque *et al.* 2022). Additionally, this method sanitizes areas that come into touch with food, reducing contamination in the food sector (Niemira *et al.* 2014). As an antibacterial procedure for surfaces in contact with food, cold plasma therapy has promise (Niemira *et al.* 2014). Despite its advantages, in-depth study is required to comprehend processes and maximize the application of cold plasma in the food and agricultural sectors (Cullen & Keener, 2018; Pan *et al.* 2019; Hoque *et al.* 2022).

**Applications:** Medical devices, textiles, apparel, automobiles, aircraft, electronics and packaging materials are just a few of the production sectors that have embraced cold plasma technology. The food sector has recently adopted CP to lower microbial counts, decompose mycotoxin, inactivate enzymes, improve the concentration of bioactive enzymes, boost antioxidant activity and lower pesticides and allergens in food items.(Laroque *et al.* 2022).Significant advancements in plasma technology have accelerated the use of cold plasma for surface sterilization of both food products and food packaging materials.( Birania *et al.*2022). The CP approach has the capacity to ensure the safety of meat and meat products, such as chicken, beef and pig, as well as to successfully prevent a variety of microorganisms and food borne pathogens, such as bio-films, a small number of viruses and spores. CP provides the microbiological safety of marine foods (Allai *et al.* 2023)

**Advantages:** In the food industry, cold plasma technology has various benefits including quick processing periods (between a few seconds and minutes), effectiveness at room temperature which is vital for items that are sensitive to heat and low energy requirements (Nikmaram *et al.* 2022).There are tremendous benefits to using cold plasma technology to clean food goods, maintain their safety and increase their shelf lives without compromising their sensory or nutritional attributes. Cold plasma is harmless for the environment and modifies products only slightly (Birania *et al.* 2022). Only the cost of filling oxygen cylinders and the cost of the power supply affect how much it costs to operate. Otherwise its cost is low.

**Disadvantages:** The present impact of CP technology is that it mostly affects product quality during the laboratory stage. The commercialization of CP technology has proven to be difficult due to a lack of precise working conditions and in-depth study on the quality attributes of different meals. The CP processing process involves a wide range of factors and every modification will have a different effect on the food's quality. The hefty equipment costs and difficult operation and maintenance procedures further limit the deployment of CP (Zhang *et al.* 2022). The browning of seafood and the oxidation of fat and protein which change sensory qualities, are some of the additional downsides (Allai *et al.* 2023).

**Conclusion:** As a new and cutting-edge approach to treating food, cold plasma technology has recently attracted a lot of interest. The shelf life of perishable foods may be successfully extended with this technique while maintaining their nutritional content and sensory qualities by exposing food to low or ambient temperature plasma. In contrast to conventional thermal processing, cold plasma enables quick and targeted processing which saves energy while retaining the general caliber of the treated items. Its capacity to fight against food-borne infections and ecologically friendly attributes also help to explain its rising recognition in the food business.

### 2.5 Ozone Treatment

One of the most effective oxidizers on the market is ozone which is made up of three oxygen atoms and is a highly reactive gaseous form of oxygen. Ozone is a potent antibacterial agent when used properly in the processing, storage and treatment of food. Due to its adaptability, it may exist in both gaseous and aqueous phases, making it useful in a variety of food industry applications (Hugh, 2015). Ozone has potent antibacterial characteristics, making it a possible alternative to chemical additives for improving food safety and shelf life (Aslam *et al.* 2020; Aslam *et al.* 2022).

**Applications:** Many different food types can be directly treated with ozone to increase safety and lengthen shelf life. Ozone is used to food processing in both gaseous and aqueous sprays and dips. One of ozone's most promising uses is the hygienic treatment of fresh vegetables. Ozone is also utilized in the preparation of seafood and has been shown to prolong shelf life in addition to improving the safety of the seafood. When used in farming operations, fungicides, insecticides and other chemicals can contaminate food on the surface. Ozone can therefore be used to eliminate the contaminant and make the food acceptable for sale and additional processing. Food contact surface sanitation is another use for ozone. Food processors have the chance to treat manufacturing facility surfaces more effectively and efficiently by including ozone-containing water in clean in place (CIP) cycles. Additionally, aqueous ozone can be utilized as a sanitizing rinse for non-food contact surfaces like floors as well as food contact surfaces like cutting boards. Additionally, aseptic food packing materials can be treated with ozone to disinfect their surfaces. As an alternative to chemical treatment, ozone can be used to treat grains and other foods that have been kept in order to prevent the growth of fungus and mycotoxins as well as to control insects (Hugh, 2015).

**Packaging:** Food, equipment, surfaces and processing environments may all be decontaminated using ozone treatment (Khadre *et al.* 2001). On-site ozone production and fast decomposition leave no trace (Khadre *et al.* 2001). It shows efficiency at low concentrations (1 ppm) and prolonged contact durations which makes it effective in preventing microbial development during storage (Khadre *et al.* 2001). According to Khadre et al. (2001), packaging materials and food-contact surfaces are also treated with aqueous ozone. Its ability to quickly inactivate germs by interacting with internal enzymes, genetic material and cell envelope components is what gives it its antimicrobial agent efficacy (Khadre *et al.* 2001). Advanced oxidation processes (AOPs) can be developed by synergistically combining ozone with other oxidants like hydrogen peroxide to potentially battle resistant microbes. AOP applications in the food industry, however, are still developing (Roy *et al.* 2021). Ozone treatment is effective in decreasing microbial biofilms on packaging and stainless steel surfaces, according to research (Panebianco *et al.* 2022). Comparing stainless steel to multilaminated packaging materials, it is noticeably more effective against biofilms (Panebianco *et al.* 2022). Studies also investigate the ability of ozone treatment to degrade food-borne pesticide residues. This is accomplished both directly by oxygen atoms and indirectly by hydroxyl radicals (Wang *et al.* 2018). Ozone is permitted to be used as an antibacterial agent in both gaseous and aqueous phases for the treatment, storage and processing of food due to regulatory permission from organizations like the US FDA (Botondi *et al.* 2021). In short, ozone treatment efficiently removes contaminants from food and surfaces that come into touch with it while inhibiting microbial development, reducing biofilms and deteriorating pesticide residues. Its features include on-site generation, quick breakdown and residue-free nature justifies its authorized use in food processing. To optimize treatment settings and fully use its potential in a variety of food processing applications, continual research is necessary.

**Advantages:** On produce, ozone is rather moderate. Ozone also has the benefit of reducing the number of spoilage bacteria in wash water as well as on the surface of produce, extending the shelf life of the product while maintaining clean wash water and allowing for reduced water usage. Additionally ozone is eco-friendly and leaving no dangerous chemical residues (Hugh. 2015).Only the cost of power supplies and replenishing oxygen cylinders affects how much it costs to operate. This procedure reduces the expense of storing gas and transporting chemical disinfectants (Crites *et al.* 1998). Unlike other disinfection methods, there is no need to store harmful materials. Ozone is able to quickly and effectively combat a variety of microorganism strains. No heat requirement and no heat generation during treatment reduce the need for energy input (Siddiqui *et al.*2021)

**Disadvantages:** One drawback of ozone treatment is that some viruses, spores and cysts may not be completely inactivated at low doses. Due to its instability and unsuitability for storage, onsite generation is another drawback. In indoor applications, it necessitates routine leak detection monitoring. Ozone is hazardous; when inhaled, it can cause asthma and create difficulties with the nose and throat (Crites et al. 1998).Ozone should be used carefully and delivered to the treatment chamber due to its corrosive nature at concentrations higher than 4 ppm (Siddiqui *et al.* 2021)

**Conclusion:** It can be concluded that ozone treatment can be an appropriate decision for food preservation. The reactive, antibacterial capabilities of a naturally occurring, environmentally benign molecule, such as ozone which is manufactured in a controlled manner, have a lot of potential for use in food based applications. Ozone is gradually taking the place of traditional sanitation methods like chlorine, steam or hot water today. It is gaining popularity in the food processing sector as the most secure, economical and chemical free method of managing food safety (Nath *et al.* 2014).

## 2.6 UVC Treatment

UV irradiation for food preparation has shown to be a promising technique in practical situations. It is typically regarded as a non-toxic type of food processing that stays away from the drawbacks of more traditional procedures (such as heat processing). Because UV light, especially UVC, may harm the DNA of harmful germs, it is widely known that it has germicidal properties. A number of factors need to be taken into account when considering UV light as an alternative method of food processing, including the physical and chemical makeup of the food product to be processed, the UV equipment's characteristics (such as UVC intensity and exposure period), the presence of bacteria and other practical considerations (Singh *et al.* 2021).

**Packaging:** Using UVC-LEDs with a wavelength of 280 nm is one common method for decontaminating surfaces in the food processing industry (Kebbi *et al.* 2020). On a variety of food contact surfaces, including glass, PVC, stainless steel, Teflon and silicon, effective microbial load reduction has been shown to work (Kebbi *et al.* 2020). Surface properties including hydrophobicity and roughness are crucial to the effectiveness of UVC therapy (Kebbi *et al.* 2020). Many packaging life cycle analyses ignore its influence on total environmental consequences, including food waste and logistics, even though decreasing packaging material is advised for decreased environmental impact in food supply chains (Molina-Besch *et al.* 2018). The effect of UVC light on chitosan-based materials treated with phenolic acids for prospective use as food packaging is investigated in research (Kaczmarek *et al.* 2021). The physicochemical characteristics of the films were changed by UVC exposure (Kaczmarek *et al.* 2021). According to Kebbi et al. (2020), UVC LED therapy can disinfect low-water-activity foods without changing their color. The hexagonal-compact nano-packed composite system is one example of an active nano-packed composite system that has made strides and has great prospects for food packaging (Mary & Sinija, 2023). In order to increase the effectiveness of microbial inactivation and reduce processing durations, UVC treatment is being investigated in conjunction with other techniques such as high-pressure processing or continuous-flow microwave systems (Debonne *et al.* 2023; Gomez-Sanchez *et al.* 2020). Although taking into account material particular and wider environmental effects in the supply chain is essential (Kebbi *et al.* 2020; Molina-Besch *et al.* 2018), UVC treatment stands as an efficient method for decontaminating packing materials in the food processing industry. In order to analyze the long-term impacts on packaging and food product quality and improve treatment settings, more study is absolutely necessary.

**Applications:** For a variety of food safety applications, such as pasteurizing juices, treating surfaces that come into contact with food to prolong the shelf life of food items and getting rid of germs on the surface of meats, UVC is being used as an alternative to conventional heat processing. Bacteria's DNA is altered or destroyed by UVC which is commonly delivered by lamps with a wavelength of 254 nano-meters (nm) which limits their ability to spread and proliferate. It is only capable of killing bacteria that are directly exposed to UVC rays since it is a surface decontamination method. In a recent investigation, samples of pork tenderloin were inoculated with *Listeria* mono. The results showed that UV-C treatment significantly reduced the amount of *Listeria* mono by an average of 2.23 log colony-forming units (CFU) per 100 ml, while another study discovered that the technology significantly reduced the amount of E. coli in samples of chicken breast (Whittaker, 2022). Surfaces, wastewater and water and air sterilization have all been accomplished with UV radiation for a very long time. It has been established in the food industry that UVC light treatment is a non-thermal method for treating liquid foods (juices from fruits and vegetables, alcoholic beverages, soft drinks, etc.), sanitizing milk and dairy products, processing ready-to-eat meat products, preserving food and extending the shelf life of fresh goods. In the fish sector, UVC processing is also used. The UV-C sensitivity of the relevant microorganisms is another significant concern in a microbial decrease in food matrices. The use of UV light to produce food items is a relatively new and exciting technology for the treatment of wastewater, air disinfection and surface pollution. Additionally, several technological and processing elements are taken into account that is significant for food scientists working with UV technologies (Singh *et al.* 2021).

**Advantages:** In contrast to other food processing methods that alter the genetic make-up or structure of food items, UV-C light sterilizes products and the equipment it comes into touch with by eradicating microorganisms. As a result, it is typically regarded as a relatively non-invasive form of food disinfection. Two major benefits are suggested by an analysis of survey and scientific consumer study replies. The first benefits from less food waste during processing, while the second benefits from the nutrients and quality being preserved in the goods produced using this approach. When it comes to shelf-life, research on the impact of UV-C light on the surface of meat products reveals that, in comparison to other approaches, such as thermal processing, just a tiny amount of energy is needed to kill germs and lengthen shelf life (Whittaker, 2022). In addition to these uses, UVC technology has been shown to be more efficient and cost-effective than its traditional equivalent techniques in the food business. The usage of chemical disinfectants which are frequently employed in the food processing chain, can be decreased by using UVC light (Singh *et al.* 2021).

**Disadvantages:** Due to its damaging effects on human skin and eyes, measures must be taken when using UVC radiation to prepare food and beverages (Fetters, 2023). Implementing UVC equipment, however, may be an expensive investment for growers and processors. The method also has drawbacks such as weak penetration power, erratic dosage distribution and protracted treatment periods (Guerrero et al. 2004). Even though UVC treatment is excellent at disinfection, it is crucial to carefully evaluate safety precautions and cost-benefit analyses before applying them to the food business.

**Conclusion:** Novel UVC-based disinfection systems with higher intensity and penetration capabilities for food products have been created as a result of recent engineering developments. Despite these developments, producers must carry out their own validation and due diligence before applying UVC technology to products related to food. It is essential to make sure that the technology won't have a detrimental influence on the reliability or safety of the items. Consumers will be assured of the safe and effective use of UVC treatment through proper validation and testing (Fetters, 2023). This will assist ensure the effectiveness and compatibility of UVC treatment for particular food products.

### 2.7 Ultrasound Treatment

A non-thermal technique called ultrasound (US) has demonstrated potential for accelerating mass and energy transfer operations which might ultimately enhance the quality of food (Raso, 2021). The transducer, the emitter and the electrical power generator make up the three primary parts of a conventional ultrasonic processing system. Three ultrasonic frequency ranges are used in the preparation of food, each of which has specific benefits. The processing and preservation of food can be significantly impacted by low-frequency, high-power ultrasound in the 20-100 kHz range (Hugh, 2016). The extraction, emulsification and preservation processes, among other sectors of the food business, may benefit from the use of this technology.

**Packaging:** The effect of ultrasonic treatment on the barrier qualities of packing materials was examined in a study using food stimulants (Ščetar *et al.* 2022). Changes in barrier properties brought about by ultrasound therapy included changes in water vapor permeability and oxygen transmission rate which were controlled by elements including ultrasound intensity and treatment time. Another work (Peters-Texeira & Badrie, 2005) investigated the application of chitosan to polypropylene films using an ultrasound-assisted coating. Chitosan adherence was enhanced by ultrasound treatment, resulting in a more stable and uniform coating and improving barrier properties including decreased oxygen permeability and higher water vapor resistance. Starch-based films benefited from ultrasound treatment as well, improving mechanical characteristics including tensile strength and elongation at break as well as water vapor barrier qualities. But overtreatment accelerated film deterioration and decreased barriers, highlighting the necessity of exact parameter management. Protein-based films are useful for food packaging because they efficiently suppress microbial growth and lipid oxidation when active chemicals are added to them (Chen *et al.* 2019). Protein-based films are frequently used because they are essential for maintaining food safety and quality. Food packaging choices were highly impacted by consumer perception and although the importance of packaging on quality and performance was acknowledged, complicated nutrition information could have gone unnoticed. The stability of packaging-food interactions can be affected by environmental changes like temperature and storage, potentially increasing material migration rates (Garba, 2023). Different types of packaging react differently to variations in humidity, demonstrating the complexity of enhancing the efficiency and security of food packing.

**Applications:** One of the most often used processes in the food processing sector is the cutting of food using ultrasound. The total cutting force is decreased, cracking and crumbling are prevented and a very smooth cutting surface is created thanks to the method's quick deformation rate and minimal deformation. Ultrasound can be used to inactivate enzymes and microorganisms, preserving food while maintaining its freshness. Because bubbles are quickly formed and deflated by the ultrasonic vibrations, ultra-sonography has an antimicrobial impact. As cells age and cell membranes shrink, free radicals are produced, causing DNA damage. Considering fruit juices, extracts and industrial wastes have all been effectively improved using ultrasonically assisted filtration, frequencies between 20 and 600 kHz are routinely employed. In the high frequency, low power (1–10 MHz) range, ultrasound is used for diagnostic reasons in the food processing industry. This makes these ultrasonic waves perfect for analytical applications like determining a meal's structure, content and physical state. These ultrasonic waves don't change the food they travel through. Examples include figuring out how much protein, water and fat is in food, changing dough consistency, figuring out the make-up and purity of oil, analyzing batters physically, adulterating honey and more. Ultrasound has been used to accelerate the osmotic dehydration of fruits and vegetables. Airborne ultrasonography has also been investigated as a means to improve food drying using hot air. Ultrasound has also been researched as a way to improve the efficacy and quality of meals that are frozen and thawed. In order to manage crystallization via sono crystallization, ultrasound has also been used to produce premium frozen treats like ice cream. Using ultrasound to alter the protein structure and tenderize meats has also been shown to be effective. Ultrasound can aid in extraction processes by enhancing mass transfer and disrupting cells. A few examples of operations where the use of ultrasound has enhanced extraction rates include the extraction of juice from pomace, the extraction of antioxidants from herbs and the extraction of seed oil. Last but not least, ultrasound is widely used to seal sandwiches and other food packaging (Hugh, 2016). In addition, the US is used to get rid of ingredients that are found in food naturally but may be harmful to human health, including oligosaccharides from pulses, heavy metals like cadmium from edible crabs and even carcinogens like acrylamide from fried potatoes (Raso *et al.* 2021)

**Advantages:** The use of ultrasound in the food industry has numerous advantages. Ultrasound waves are safe, chemical-free and ecologically friendly; it is also feasible to combine ultrasonication. This emerging technology has generated a lot of attention because of its environmental friendliness and non-thermal benefits, such as increased throughput, reduced costs, improved final product quality and process simplicity. The phrase "Green Food Processing" describes methods of processing food that use less energy and water and is thus more sustainable and environmentally friendly. One of these technologies is ultrasound. Food does not adhere to the blade when cutting with ultrasonic which is advantageous. Therefore, it is excellent for cutting sticky foods. Foods that are delicate, varied or frozen respond well as well. The main advantage of this approach, according to Hughes (2016), was a reduction in the loss of hydrophilic macro- or micronutrients. Additionally, it may be applied on any object and doesn't require being soaked in water (Ravikumar *et al.* 2017).

**Disadvantages:** Although there are numerous advantages to employing ultrasonic waves, there are also some disadvantages. The free radicals that are produced during cavitations' may affect consumers. Physiochemical reactions may be what create the off-flavour, discoloration and component degradation that ultrasound causes. The US's hefty initial investment is one additional flaw. The frequency of ultrasonic waves may impede mass transmission (Ravikumar *et al.* 2017).

**Conclusion:** Mass and energy transfer processes in the food sector, such as freezing and dehydration, have already greatly improved with the use of the US. Shorter drying timeframes due to the use of US during dehydration lead to dehydrated food that has greater levels of TPC, flavonoids and ascorbic acid as well as improved sensory characteristics like color and better functional qualities (i.e., rehydration). This US application is regarded as a highly advantageous technology in the food processing business due to a variety of advantages (Raso *et al.* 2021).

## 3. Future Aspects and Challenges

Future advancements in food packaging technology have a lot of potential to improve food safety, increase shelf life and lessen the need for chemical additives. High-pressure processing (HPP) provides a non-thermal way to maintain nutrients and increase food safety; however, there are still difficulties in optimizing processing settings and dealing with potential changes in food texture and sensory qualities. By using less energy, pulse electric field (PEF) technology has the potential to enhance food preservation and sustainability. To ensure cost-effectiveness, navigate regulatory issues and achieve widespread acceptance, PEF parameters must be tailored for various food items. The effective pathogen inactivation and shelf life extension provided by pulse light treatment (PLT) make it a desirable alternative for food packaging. The hurdles that must be overcome, however, include enhancing treatment settings, scaling up for industrial usage and guaranteeing customer approval. As an effective and environmentally acceptable approach for food preservation and disinfection, cold plasma technology is still developing. Although it has great potential for the food business, its successful deployment depends on optimizing systems for different food items, assuring cost effectiveness and resolving regulatory and customer concerns. Ozone treatment has the potential to increase food safety and shelf life, but controlling by products and optimizing application for various food matrices are obstacles that must be solved. A potential technique to improve food safety is UVC treatment, but its widespread use will depend on the development of economical methods for large-scale manufacturing, thorough validation and resolving safety issues. However, in order for ultrasound therapy to be widely used in the food industry, it is necessary to optimize the parameters for a variety of food items and address any potential impacts on texture and sensory qualities. Ultrasound treatment has the potential to improve food quality and preservation. In conclusion, these advancements in food packaging technology have a promising future since they provide fresh approaches to enhancing food safety, extending shelf life and reducing the need for chemical additives. The effective integration of each technology into the food sector which will ultimately benefit both producers and consumers, depends on addressing the issues it brings with it.

## 4. Conclusion

Consumer expectations for safe, wholesome and minimally processed food items have prompted the food industry to use non-thermal treatments. These techniques have the advantage of keeping taste, texture and other components that are sensitive to heat while maintaining food safety. The loss of color and flavor as well as lipid oxidation may result from extended exposure or intensive treatment which are undesirable changes in food. Combining non-thermal technology with established techniques like PEF and US can increase the efficiency and quality of food production while maximizing the advantages of non-thermal technologies. For further use in the food sector, it is essential to overcome obstacles including creating bulk processing equipment, setting up processing standards and resolving consumer concerns. The use of non-thermal processing and packaging has the potential to transform food preservation and provide customers all over the world safer, healthier and higher-quality goods via continued collaboration between food scientists, engineers and manufacturers.

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