**Cold Plasma Technology in Food Processing**

**Ratnesh Kumar1, Suresh Chandra1 and SK Goyal2**

1Department of Agricultural Engineering, SVPUAT, Meerut (UP) India

2KVK, RGSC (BHU Varanasi), Mirzapur (UP) India

**ABSTRACT**

*For the sake of all people, increased agricultural food production and the following preservation of harvested food are critical issues. The use of cold plasma (CP) technology as a substitute technique for food disinfection and shelf-life extension has shown to be quite successful. For CP to be accepted as a substitute for traditional food processing methods, the influence it has on food quality is absolutely essential. Because CP treatments are non-thermal, they have had little to no effect on the physical, chemical, nutritional, and sensory characteristics of numerous items. Microorganisms and pathogens that cause spoiling are a significant issue for the food processing sectors since they negatively affect the public's health and economy. Thermal inactivation procedures, such as pasteurization, autoclaving, ohmic heating, canning, and steam sterilization, are used to kill a variety of bacteria, diseases, and spores. All of these techniques are useful and efficient, but they also have a number of negative side effects, including nutrient loss, altered sensory qualities, and diminished functional qualities of the meal. The primary food processing method still employed in the food industries is thermal processing, which has been around for more than 200 years. Extreme heating has undesired outcomes, including nutrient loss, texture changes, and color changes. Pathogenic and spoilage microbes may be rendered inactive by CP, leading to minimally processed, safe food products with longer shelf lives. However, most of the published research has been focused on microbial decontamination, with limited studies on the impact of CP processing on quality attributes.*

Food-borne illnesses have a long history of association with various foods. One of the main issues facing the food industry, regulatory agencies, and consumers is food safety. Due to their detrimental effects on the general public's health and economics, pathogenic microbes are a big headache for the food processing industry. Pathogenic bacteria are eliminated using procedures like steam sterilization, pasteurization, autoclaving, and canning. However, they have a number of negative side effects, including nutritional loss, changes to the food's sensory qualities, and deterioration of its functional qualities. Different cold processing strategies have been devised to combat these negative effects.

The advancements in food processing technology have come from the application and denial of heat, the use of microbes, natural and artificial preservatives, and the application of electromagnetic fields for preservation. Canning occupies a special place among the many methods of food preservation that humanity has created over the ages. This technology has withstood the test of time, helped humanity during both times of peace and conflict, and is still extensively utilized in the food sector. Canning expanded into retort pouch technology and became much more well-known during the twentieth century revolution brought on by the arrival of polymers. Plasma is a collection of various excited atomic, molecular, ionic, and radical species that coexist with a variety of other particles, such as electrons, positive and negative ions, free radicals, gas atoms, molecules in the ground or excited state, and electromagnetic radiation (UV photons and visible light).

**Plasma**

Ionized gas known as plasma is a mixture of ions, electrons, and high-energy species that can start chemical reactions. In the year 1928, physicist Irving Langmuir made the initial discovery of this. The term plasma is divided into thermal and nonthermal plasma based on the ionization degree of the gas, which ranges from 100% (completely ionized) to very low values (partially ionized). In thermal plasma, the temperature of all gas species, such as the electrons and ions, is the same and ranges from 4000 K to 20000 K. On the other hand, non-thermal (cold) plasma can be created with less energy and has a significantly higher electron temperature than the gas's bulk molecules. One technique to include the advanced oxidation process (AOP) into the process is the existence of these high energy species that can produce the chemical reaction. Due to its lower temperature, cold plasma is of particular relevance to the food sector.

Electronics, polymer processing, and material processing are just a few of the industrial uses for non-equilibrium plasmas. In recent years, the field of cold plasma applications has rapidly grown to include the treatment of biomedical devices and biological materials, including food. A variety of microorganisms and enzymes may be inactivated using cold plasma technology, which has recently attracted the interest of many food scientists and researchers.

In addition to decontamination, cold plasma produced at atmospheric pressure has demonstrated promising potential for a number of novel applications, such as improving the surface hydrophobicity of biscuits, altering the rheology and mixing characteristics of dough and modifying the functionality of whey proteins.

According to **Misra et al. (2018),** plasma is a collection of various excited atomic, molecular, ionic, and radical species that coexist with a variety of other particles, such as electrons, positive and negative ions, free radicals, gas atoms, molecules in the ground or excited state, and electromagnetic radiation (UV photons and visible light). By using thermal energy (heating) or electromagnetic fields (electric field or high energy light), the ionization of a specific gas can be determined. The most common technique for using plasmas for technical purposes at ambient temperature and under atmospheric pressure is the deployment of an electric field. However, it is generally acknowledged that plasma sources operating at temperatures under 60°C, close to ambient, can be categorized as cold plasmas. According to physicists, the term "cold" denotes a lower temperature of the heavy species (ions, radicals, and neutrals) in the ionized gas as opposed to the electrons. The asymmetric momentum transfer that occurs during collisions when an electrical potential difference is present is what causes the thermodynamic disequilibrium between electrons and heavy species.

**Cold Plasma Technology**

Using energetic, reactive gases, cold plasma technology is a contemporary non-conventional method for inactivating contaminating bacteria on meats, poultry, fruits, and vegetables. It is an environmentally friendly method that is utilized as an alternative to conventional methods for food preservation and other possible uses. In the post-harvest, meat, packaging, and other food processing industries, this technology is crucial. According to **Salim et al. (2018),** cold plasma is crucial in the production of packaging materials, active packaging, and the slowing of browning reactions in addition to decontaminating food and packaging materials from microbes.

Antibiotics do not effectively kill germs as cold plasma. When treating wounds with cold plasma, a variety of nutrients are produced, including NO, O3, OH-, O2-, H2O2, and UV radiation, which kill pathogenic bacteria and the poisonous byproducts of their life. Cold plasma is used to disinfect wounds and sterilize medical equipment since it has been clinically demonstrated to be an efficient method of inactivating bacteria. The necessity for numerous beneficial solutions for cold plasma generators is determined by the variety of medical applications for cold plasma. There is and will always be a need for highly specialized plasma equipment, not the "universal" plasma generator.

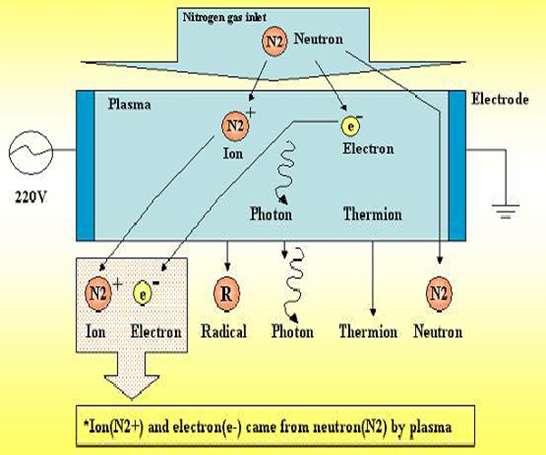
Foods can become spoiled by natural food enzymes or become infected by other microbes. Due to their serious hazards to public health and negative effects on the economy, pathogenic and spoilage microorganisms are a challenge for the food sector. As a result, it is crucial and critical for the food business to control unwanted bacteria. A number of techniques for eliminating these microorganisms, including non-thermal ones like high hydrostatic pressure, pulsed electric fields, and high voltage arc discharge as well as thermal ones like sterilization, pasteurization, and ohmic heating.

**GENRATION OF COLD PLASMA (CP)**

A fully ionized gas made up of atoms in an excited state with a neutral charge, photons, free electrons, and other varying components is referred to as plasma. Due to the equal numbers of positive and negative ions in plasma, there is no net charge. Both light (photons) and heavy (the other constituents) species make up plasma. Plasma is thought to be the fourth state of matter, following solid, liquid, and gaseous states before reaching plasma, for maintaining this particular feature.

Cold plasma discharges can be generated with stationary and pulsed (DC) and alternating (AC) electrical fields. Various electrical power supplies can be used to generate the cold plasma discharges such as pulsed (DC), Inductively Coupled Plasma (ICP) and Capacitive Coupled Plasma (CCP). Besides, nowadays, many researchers are attempting to develop the configuration of atmospheric pressure plasma discharges such as Arc Discharge, Corona Discharge, Dielectric Barrier Discharge (DBD), Uniform DBD, and Atmospheric Pressure Plasma Jet (APPJ) (**Zainal *et al.,* 2015**).

Cold plasmas can be found at low pressure or at atmospheric pressure, including low pressure DC and RF discharges (silent discharges), discharges from fluorescent (like neon) illuminating tubes, and DBDs. The term "silent discharges" has previously been used to describe dielectric barrier discharges (DBDs). Additionally, they work at pressures that are similar to atmospheric pressure (usually 0.1 to 1 atm). A dielectric layer (made of glass, quartz, ceramic material, or polymers) is once more positioned between the electrodes, and an alternating current (A.C.) voltage with an amplitude of 1-100 kV and a frequency of a few Hz to MHz is delivered to the discharge. A continuous current will flow through the discharge when a potential difference between the cathode and the anode is provided, creating a direct current (D.C.) glow discharge. In order to have each electrode act alternately as the cathode and anode, alternating voltage is placed between the two electrodes, resulting in capacitively connected (CC) radio-frequency (RF) discharges. These alternating voltages are commonly transmitted at frequencies in the radiofrequency (RF) range (1 kHz–103 MHz, with 13.56 MHz being the most prevalent). As they do not put the food system under excessive stress, non-thermal gas discharges at atmospheric pressure are of interest to the food sectors. Table 2 listed the properties of different cold plasma generators.

****

**Fig. 1: Generation of Plasma (Mishra *et al.,* 2016)**

**Table 2: The characteristics of various cold plasma generators** (Zainal *et al.,* 2015)

|  |  |
| --- | --- |
| **Generator** | **Characteristics** |
| Pulsed (DC) | Plasma produced inside of fluorescent lighting fixtures. It is utilized to alter ion energies during the production of materials, in magnetrons used as sputter sources, and for the physical mechanism of surface modification. It features a complicated structure, simple shape, and voltage-current properties in addition to being simple to create. |
| Capacitively Coupled Plasma (CCP) | Similar to glow discharge plasmas, but produced by high frequency RF electric fields, usually at 13.56 MHz, as opposed to DC or low frequency electric fields. In the manufacturing of integrated circuits (ICs) and micro fabrication, it is commonly employed. |
| Inductively Coupled Plasma (ICP) | The electrodes are made of a coil that is wrapped around the discharge volume, which inductively excites the plasma. This method is comparable to CCP and has similar uses. Since CCP is less intense (low ion density and low ion energy), ICP has a tiny edge over it. |
| Arc Discharge | Thermal discharges with a high power and a gas temperature of about 10,000 K. Thermionic emissions, which can be produced by a variety of power sources, keep the discharge going. utilized frequently in metallurgical applications. |
| Corona Discharge | A non-thermal discharge produced when strong voltage is applied to pointed electrode tips. Only a small area around the tip of the sharp tip experiences an electric field strong enough to cause breakdown; the rest of the discharge gap remains black. Coronas are typically utilized in ozone generators and particle precipitators. They are relatively weak discharges with very low electron and ion concentrations. |
| Dielectric Barrier Discharge (DBD) | When high voltages are applied across narrow gaps, a non-conducting layer stops the plasma discharge from evolving into a self-sustaining glow or arc, creating the non-thermal dielectric barrier discharge. During the discharge, breakdown appears as streamers, and charges accumulate on the electrodes. The discharge is cycled and maintained using a low frequency AC field of about 100 kHz. They are frequently utilized for treating fabrics in a roll-to-roll arrangement. |
| Atmospheric Pressure Plasma Jet (APPJ) | An example of an RF CCP plasma discharge that operates at atmospheric pressure is the atmospheric pressure plasma jet (APPJ). The APPJ's systems are stabilized by running on argon or helium gas. The operation of the atomic noble gas makes it much simpler to keep the system out of equilibrium. In pure helium, these systems can run steadily in both normal and pathological states. However, adding precursor gases is only permitted in very small amounts. |

**Principle and Mechanisms of Plasma Technology**

According to **Pignata et al. (2014)**, plasma is essentially created by providing energy to a gas mixture utilizing mechanical, thermal, chemical, and radiation energy, which ionizes the gas (low or atmospheric) and produces active species like electrons, free radicals, ions, etc. Inductively coupled plasmas, dielectric barrier discharges, corona glow discharges, gliding arc discharges, radio frequencies, atmospheric glow discharges, and microwave-induced plasmas are just a few examples of the various types of apparatus used to create cold plasma **(Conrads and Schmidt 2000; Guo et al., 2015).**

**Types of Cold Plasma**

Numerous technologies that can function at atmospheric pressure or in partial vacuum are being used to produce cold plasma. While the ionizing gas might be any synthetic noble gas mixture or regular air/nitrogen, the energy source could be electricity, lasers, or microwave radiations. This level of freedom in the selection of the ionizing gas media and power sources enables steady design of unique types of cold plasma systems. The distance between the plasma generation field and the product exposure area, or whether the product is placed far from the plasma generation field, close to the plasma generation field, or within the cold plasma generation field, was used to categorize the cold plasma. These classifications are actually based on the plasma chemistry of the charged active species, their reactivity, and their plasma half-life. However, one of the three types of cold plasma applies to the cold plasma systems used for food processing and food processing.

**Remote Cold Plasma System:** This technique involves creating cold plasma at a single location and moving it to the surface to be treated. The flow of feed gas is most frequently used to transport the created cold plasma to the location of action, however magnetic fields may also be used occasionally. This particular form of cold plasma has the distinct benefit of locating the goods to be treated at a distance from the source of generation, simplifying fabrication processes and enhancing the flexibility of the shapes and sizes of the treated objects.The main drawback of this type of cold plasma is that during the time of flight, the free electrons generated at the source point would react with other charged atomic species, leading to the formation of secondary chemical species that had poor reactivity and longer half-lives. As quench plasma travels to the target location, the concentration of reactive ions decreases. According to Fridman and Kennedy (2004), the ions in this afterglow plasma are known to generate UV light for the activation of chemical species upon contact with the target, although their concentration was much lower than that of the active plasma with the help of the electric field.

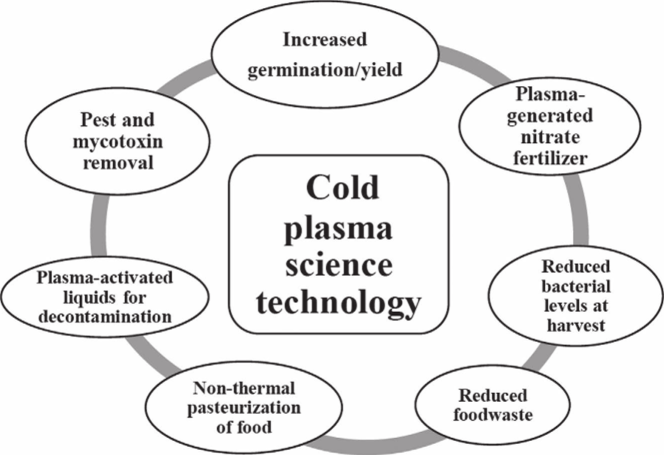
**Direct Cold Plasma System:** In the direct system, as opposed to the remote cold plasma system, the point of cold plasma formation and the object to be treated remain relatively near together. Because they are consumed relatively quickly before being recombined and/or destroyed, this method offers higher concentrations of active ions for target treatment. These plasma systems produce pulse frequencies that range from hundreds to thousands per second while operating in pulsed mode. The intensity of UV radiation produced by recombination is significantly higher on the target object due to the relative closeness of the source of plasma formation and the target items. The commodities with greater internal moisture/water activity could conduct high-voltage electricity resulting in localized heating and thus causing subtle changes in the sensory properties of the food products. As a result, these cold plasma systems need to be precisely built in order to prevent the flow of concentrated high voltages through the product, protecting it from heat damage. As a result, these direct systems are more difficult to manufacture and operate than remote cold plasma systems. However, depending on the type of emitter, these plasma systems are adaptable in terms of target size and shape, albeit there may be potential restrictions on the kinds of products that can be treated in this way.

**Electrode Contact System:** The target item that needs to be sterilized is put physically between the electrodes in this cold plasma system, which is where the cold plasma is generated. According to Fridman et al. (2006), the objects are exposed to the widest range of active plasma components, including charged ions, free radicals, electrons, and UV radiation at the highest conceivable intensities. In order to prevent point discharges and concerns with localized heating, sufficient care must be taken while fabricating these plasma systems to match the form and content of electrodes with the target commodity to be sterilized. While the physical constraint in this system is the space between the electrodes, the flexibility in changing the feeder gas composition and design of one or both electrodes allow for some target objects that could physically fit in this space. Smaller or flatter things, such as seeds, berries, nuts, etc., are most suited for these types of cold plasma systems.

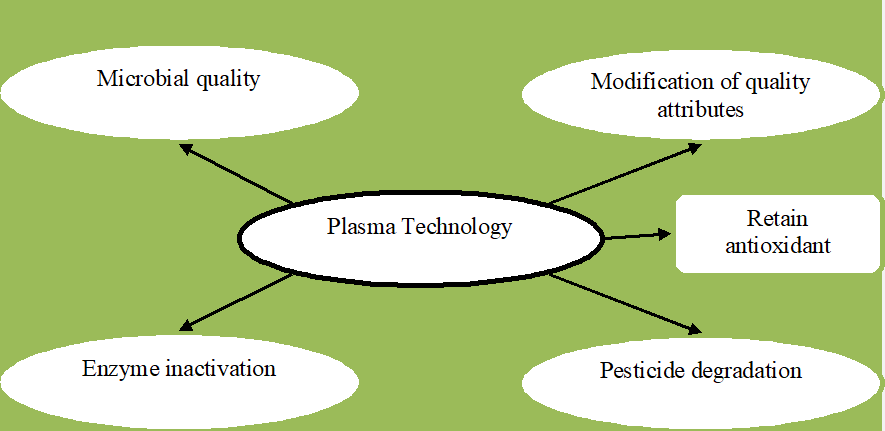
**Applications of cold plasma**

Cold plasma can effectively be used to kill microorganisms on fresh products to lengthen their shelf life. According to **Feichtinger et al. (2003),** cold plasma technology is a substitute source for surface sterilization and disinfection processes that can operate quickly on both vegetative cells and spores. Free radicals, highly reactive species, and radiations frequently produced in a range from UV to visible make up the chemical makeup of plasma. It is thought that the gas and operating pressure affect the function of various constituents. Reactive species like free radicals are responsible for the UV-induced degradation of microbial DNA, the volatilization of chemicals from spores, and the so-called "etching" of the spore surface by adsorption **(Philip et al., 2002).**

Possibility of using it in food NTP has been used in the food sector to decontaminate egg surfaces, genuine food systems (cooked meat, cheese), and raw agricultural items (Golden Delicious apple, lettuce, almond, mangoes, and melon). **Pasquali et al. (2016)** described the impact of atmospheric cold plasma maintained at a difference of 70 mm from discharge on red chicory (*Cichorium intybus*). With the exception of the treatment time, which varied between 15 and 30 minutes, the conditions were maintained at 22°C and 60% RH. The initial loads of L. monocytogenes and E. coli were 108cfu/ml and 1.2 x 108 to 1.6 x 108cfu/ml, respectively, after treatments of 15 and 30 minutes. In 15 min of atmospheric cold plasma treatment E. coli reduced to 1.35 log MPN/cm2 whereas, L. monocytogenes took 30 min to have a final load of 2 log cfu/ml.



**Fig. 1: Applications of cold plasma for increasing food safety and quality.**

****

**Fig. 2: Applications of plasma for increasing food preservation.**

**Table 1: Applications of Cold Plasma** (**Zainal *et al.,* 2015**)

|  |  |  |
| --- | --- | --- |
| **Sectors** | **Impact of plasma** | **Reference** |
| Enhance Mechanical properties | 1. Improve mechanical properties of ceramic fibres tensile system. 2. Improve tensile strength, stress of jute fibre/Poly (lactic acid) biodegradable composites. | (Xiem et al., 2009)  (Nam Gibeop *et al.,* 2013; Jung, 2013) |
| Improve adhesion | 1. Improve adhesion of Polymer-Polyethylene, Polypropylene, Polystyrene and Poly (ethylene terephthalate). 2. Packaging surface treatment on wetting and adhesion. 3. Improve adhesion of polymers for good packaging. | (Dixon and Meenan, 2012; Borcia *et al.,* 2011)  (Wolf and Sparavigna, 2010)  (Pankaj *et al.,* 2014) |
| Treatment | 1. Decontamination of strawberries. 2. Treatment on recycle paper-hydrophobic to hydrophilic. 3. Improve fertilization and irrigation of germination. 4. Increase viscoelasticity, Strength of the dough. 5. Softening cotton and reduce felting of wool. 6. Create water repellent on wood. 7. Water, air, food, and drink treatment. | (Misra *et al.,* 2014b)  (Gaiolas *et al.,* 2012)  (Jiang *et al.,* 2014)  (Misra *et al.,* 2014a)    (Niemira, 2011; Redzuan, 2010; (Yarahmadi *et al.,* 2011) |
| Biology and Medicine | 1. Can Ablate some cancer cells (Lung, Melanoma, head and neck, brain and bladder) 2. Clean and sterilize infected tissue in a dental cavity or on root channel. 3. Treatment of Infectious skin diseases and wound healing. 4. Deactivation of Biofilims –S- Mutans Bacteria- E. Coli. 5. Tooth Bleaching. 6. Instrument sterilization – Dental Instruments. 7. Activation of p23 protein. 8. Activation of p21 CDK inhibitor. 9. Treatment of chronic Venous Leg Ulcers. 10. Reducing bacterial and Fungal Species | (Keidar *et al.,* 2013)  (Geyter and Morent, 2012)  (Heinlin *et al.,* 2011)  (Hoffmann *et al.,* 2013)  (Emmert *et al*., 2012)  (Daeschlein *et al.,* 2012) |

**Cold Plasma Technology in Food Sectors**

Cold plasma technology shows promising dimensions for various sectors of food processing.

**Grain science and processing sector**

Prior to and following treatment with plasma products, the presence of Aspergillus spp. and Penicillum spp. in food grains and legumes was examined. Cold plasma species have the ability to change the properties of starch depending on the technique of formation, length of treatment, and kind of starch contained in the food grains. Food grains are subject to surface alteration, molecular degradation/granular etching, or corrosion when exposed to cold plasma reactive species. In order to enhance the functional qualities of different food grain starches, such as banana starch, rice starch, zein, pea protein isolates, brown rice, and basmati rice, application of cold plasma was successfully examined **(Ezeh et al., 2018)**.

Food grains' ability to swell, cook at a lower temperature, paste more smoothly, dissolve in water, and hold water are all improved by Cold Plasma. Cold plasma that contains oxygen can cause lipid oxidation in foods high in fat, which lowers its acceptability. The level of resistant starch and amylose content in plasma treated with banana starch at various voltages (30kV, 40kV, and 50kV) for 3 min time intervals did not change, but the relative crystallinity and gelatinization temperature do. As a result, it was determined that plasma might be a useful tool to alter the properties of starches such as banana starch and other starches. Bacterial counts of *Bacillus cereus*, *Bacillus subtilis* and *E. Coli* were tested on brown rice using plasma. High antioxidant activity was observed on brown rice when treated with plasma and that could probably increase the nutritional value of the consumer **(Chen *et al*., 2016)**.

**Food packaging**

Cold Plasma treatments are now used to improve the mechanical and antibacterial qualities of food packaging and biofilms. It has been demonstrated that when plasma products interact with food packaging, they produce surface energies that have a favorable influence on a variety of packaging characteristics, including as glazing, sealability, moisture/gas barrier capabilities, etc. It is regarded as a trustworthy and affordable form of technology. The capacity to process materials dependably and affordably is crucial in the packaging sector, whether it is for jam jar labeling, printing on glass jars, or sealing liquid packing. It is feasible to prepare a variety of materials and coatings, some of which are quite thin, using atmospheric-pressure plasma pretreatment, such as when creating composite packaging. In labeling glass bottles, atmospheric-pressure plasma is employed for pretreating glass. This allows the use of a universal and low-cost water-based adhesive **(Mishra *et al.,* 2016).**

Cold plasma technology was initially applied to packaging materials to enhance surface modification and printability. The low density polyethylene (LDPE), high density polyethylene (HDPE), polystyrene (PS), tygon, and other packaging materials have all been used in studies of the in-package plasma technology for foods. This technique relies on the use of the polymeric package itself as a dielectric layer. The packing material in this case is exposed to the plasma discharge and is a crucial component of the treatment stage. The internal package surface is decontaminated since the packaging material's surface was exposed to the reactive plasma species. In reality, PET foils, polystyrene, LDPE, and other polymeric materials have all had their microbial loads reduced through the use of cold plasma.

**Animal Meat sector**

Meat can easily support the growth of pathogens such L. monocytogenes, E. coli O157:H7, Campylobacter jejuni, and Salmonella spp., which can lead to serious foodborne illness in people. It is vital to develop and use cutting-edge technologies in the meat business to meet the rising demand for high-quality and secure meat products. In one of the most well-known research, **Jayasena et al. (2015)** showed that using the SDBD within package plasma configuration in air, L. monocytogenes, E. coli O157:H7, and S. Typhimurium inoculated on pork-butt were inactivated by 2.04 log10, 2.54 log10, and 2.68 log10 CFU/g, respectively. The amounts of L. monocytogenes, E. coli, and S. were found in beef loin, correspondingly. In the meat industry, the use of Cold Plasma was claimed to improve the quality, lengthen the shelf life, and remove microbes from beef, hog, and chicken meat. According to the findings (Lee et al., 2011), cold plasma species are efficient against E. coli, salmonella species, L. monocytogenes, yeast, and mold species on meat surface. According to Ragni et al. (2010), the application of CP technology has positive effects on the surface decontamination of egg shell membrane against S. enteritidis and S. typhimurium microorganisms. Jayasena, et al. (2015) discovered that the color and texture had little changed. However, they noticed that treatment intervals longer than 10 minutes caused the malonaldehyde levels to increase. You may remember that the level of malonaldehyde is a sign of oxidized lipids.

**Dairy Industry**

Sliced cheese and a variety of milk products, including whole milk, skim milk, UHT (ultra high temperature) milk, have already been tested with cold plasma. The study's findings suggested that cold plasma might replace other milk processing methods because it has a lower likelihood of affecting the color, pH, flavor, and nutritional content of milk products. In addition, it quickly inactivated the alkaline phosphatase enzyme and contaminating bacteria (Song et al., 2009; Coutinho et al., 2018). In-package cold plasma has been investigated as a decontamination intervention in the hopes that a non-thermal technique to reducing the microbial load may allow to maintain the particular nutrition and flavor of milk. Whole milk treated with in-package SDBD cold plasma at 15 kHz for 10 min after being inoculated with E. coli, L. monocytogenes, and S. Typhimurium. It was demonstrated that the procedure may reduce CFU/g by 2 log10–3 log10 without significantly altering the color or lipid oxidation. The pH variations that come from treating milk with cold plasma are a particular problem; it was discovered that a 10-minute treatment reduced the pH from 6.9 to 6.6 (Kim et al., 2015). Since milk contains many nutrients, it is especially vulnerable to microbial deterioration. Conventionally, harmful microbes are controlled in raw milk using heating procedures. Thermal processing to reduce the microbial load, though effective, changes the organoleptic and nutritional properties in dairy foods **(Myer *et al.,* 2016)**.

**Fruits and vegetable processing sector**

Foodborne illness outbreaks involving organisms including Shiga Toxin-producing Escherichia coli, Salmonella, and L. monocytogenes continue to be mostly caused by fresh produce. Applying post-harvest decontamination measures, which can either replace or enhance the washing process, is an efficient way to manage contamination in fresh food (Murray et al., 2017). It is a clever way to use cold plasma therapy instead of water and chlorine to clean various fruits and vegetables. Cold plasma therapies on berries, cherries, apples, melons, kiwis, and other fruits and vegetables were investigated. Results showed that applying CP to the surface of fruits and vegetables (F&V) changed their pH and acidity. This happens when moisture on the surface reacts with active plasma species. It is also found that the treated produce shows slight changes in texture (firmness) and colour during their storage period. The results were quite promising with 1.5 log10 -2 log10 reduction after 0.5 hour of treatment and up to 3-5 log10 reduction within 24 h of treatment at 12 kV for 5 min. Later, cold plasma treatment of fresh produce was shown to reduce the total aerobic microbes by up to 5 log10 in products such as tomatoes and strawberries, when using a volumetric DBD powered at 60 kV and 50 Hz frequency **(Misra, et al., 2014)**. According to Xu et al. (2017), the in-package decontamination procedure is especially crucial for fruits, vegetables, and ready-to-eat foods because these food categories necessitate the employment of ambient temperature methods to ensure safety while having the least possible influence on product quality. The treatment of spinach that had been inoculated with E. coli O157:H7 inside a flexible packaging was the subject of the first study of volume DBD-based in-package plasma (Klockow and Keener, 2009).

**Waste water (Effluent) treatment**

According to Jiang et al. (2013), the physico-chemical effects of plasma lead to the formation of oxidizing species, including radicals (H, O, OH) that can diffuse into liquids and molecules (H2O2, O3, etc.), shockwaves, ultraviolet light, and electrohydraulic cavitation that can break down pollutants in waste water or transform them into other compounds. Plasma can be produced in both liquid and gas, either directly in the liquid, in the gas directly above the liquid, or, in the case of hybrid rectors, simultaneously in both the liquid and the gas. By diffusing gaseous phase species into liquid, waste water can be treated more effectively and with less energy (Jiang et al., 2014). Due to the high concentration of organic loads in the water that leaves the food sector, waste water disposal has become a significant problem. Different thermal, chemical, and filtration processes have been employed in the past to treat waste water. Cold plasma's ROS (Reactive Oxygen Species) have been shown to quickly alter how liquid waste degrades or decomposes. According to Ekezie et al. (2017), the pyrolytic impact is indirectly caused by UV photons produced during CP treatment via electrohydraulic cavitation. It is difficult to create an advanced oxidation method that is new and unique for treating waste water. As complete oxidation is required for the treatment of waste water and transfer of contaminants is not complete in methods like photocatalysis, ultrasonication, UV/ozone (**Reddy and Subrahmanyam, 2012)**.

**Limitations**

1. Several ROS species has limited penetration into food products.
2. It may affect the sensory and nutritional attributes of the food to some extent during processing.
3. Treatment of bulky and irregularly shaped food is difficult.
4. Restricted volume and size of the food for treatment.
5. It may accelerate lipid oxidation and causes negative impact **(Coutinho *et al*., 2018; Mandal *et al*., 2018; Niemira, 2012; Pankaj and Keener, 2017)**.

**Conclusion**

Equipment sanitization using cold plasma has shown to be effective in inactivating pathogenic germs from fresh produce and packing materials. Additionally, it functions as active packaging, aids in the catalysis of several manufacturing processes, and slows the browning reaction in fruits and vegetables. Since it is a cold treatment, food's texture, sensory, and functional qualities are well preserved. Cold plasma is a cutting-edge technology that has the power to destroy microorganisms, alter the substrate's surface, and have negative impacts on the nutritional value of food. High efficacy, preservation, and lack of toxicity are all benefits of plasma sterilization. The most crucial step is choosing specific gases that already possess germicidal capabilities in order to boost plasma sterilization effectiveness. The cold plasma techniques are food preservation methods with little thermal effects on food's nutritional and sensory quality characteristics and no chemical residues. They are effective at room temperature. Molds, yeasts, spores, and viruses have all been tested along with bacteria (both good and bad). When pathogens are present, fruits, vegetables, and leafy vegetables are decontaminated using cold plasma, which is utilized in minimal processing or as a chlorine replacement during washing. For its distinctive qualities, such as treating food at low or ambient temperature for a brief period of time to preserve its integrity and quality, cold plasma technology is becoming more and more well-known.

**REFERENCE:**

1. **Borcia, C., Borcia, G. and Dumitrascu, N. (2011).** Surface Treatment of Polymers by Plasma and UV Radiation, *Romanian Journal of Physics*. 56(1-2): 224-232.
2. **Chen, H.H., Chang, H.C., Chen, Y.K., Hung, C.L., Lin, S.Y. and Chen, Y.S. (2016).** An improved process for high nutrition of germinated brown rice production: Low-pressure plasma. Food chemistry, 191:120-127.
3. **Conrads, H. and Schmidt, M. (2000).** Plasma generation and plasma sources. Plasma Sources Sci Technol 9, 441–454.
4. **Coutinho, N.M., Silveira, M.R., Rocha, R.S., Moraes, J., Ferreira, M.V.S., Pimentel, T.C., *et al*. (2018).** Cold plasma processing of milk and dairy products. Trends in Food Science & Technology, 74:56-68.
5. **Daeschlein, G., Scholz, S., Emmert, S., Podewils, S. V., Haase, H., *et al.* (2012).** Plasma Medicine in Dermatology: Basic Antimicrobial Efficacy Testing as Prerequisite to Clinical Plasma Therapy. *Plasma Medicine*. 2(1-3): 33-69.
6. **Dixon, D. and Meenan, B.J. (2012).** Atmospheric Dielectric Barrier Discharge Treatments of Polyethylene, Polypropylene, Polystyrene and Poly (ethylene terephthalate) for Enhanced Adhesion. *Journal of Adhesion Science and Technology*. 26: 20-21, 2325-2337.
7. **Ekezie, F.G.C., Sun, D.W. and 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.
8. **Emmert, S., Brehmer, F., Hanble, H., Helmke, A., Mertens, N., *et al.* (2012).** Treatment of Chronic Venous Leg Ulcers with a Hand-Held DBD Plamsa Generator. *Plasma Medicine*. 2(1-3): 19-32.
9. **Ezeh, O., Yusoff, M.M. and Niranjan, K. (2018).** Nonthermal processing technologies for fabrication of microstructures to enhance food quality and stability. In Food Microstructure and Its Relationship with Quality and Stability Woodhead Publishing, 239-274.
10. **Feichtinger, J., Schulz, A., Walker, M. and Schumacher,** **U. (2003).** Sterilization with low-pressure microwave plasmas, *Surface and Coatings Technology, 174,* 564.
11. **Fridman, A. and Kennedy, L.A. (2004).** Plasma Physics and Engineering. CRC Press, Florida.
12. **Fridman, G., Peddinghaus, M., Balasubramanian, M., Ayan, H., Fridman, A., Gutsol, A. and Brooks, A. (2006).** Blood coagulation and living tissue sterilization by floating-electrode dielectric barrier discharge in air. Plasma Chem. Plasma Process. 26 (4), 425–442.
13. **Gaiolas, C., Costa, A.P., Silva, M.S., Thielemans, W., and Amaral, M.E. 2012.** Cold Plasma Assisted Paper Recycling, *Industrial Crops and Products*. 43: 114-118.
14. **Geyter, N.D. and Morent, R. (2012).** Nonthermal Plasma Sterilization of Living and Non-living Surfaces. *Annual Review of Biomedical Engineering*. 14: 255-274.
15. **Guo, J., Huang, K. and Wang, J. (2015).** Bactericidal effect of various non-thermal plasma agents and the influence of experimental conditions in microbial inactivation: a review. Food Control 50, 482–490.
16. **Heinlin, J., Isbary, G., Stolz, W., Morfill, G., Landthaler, M., Shimizu, T., Steffes, B., Nosenko, T., Zimmermann, J. and Karrer, S. (2011).** Plasma Applications in Medicine With a Special Focus on Dermatology. *J. Eur. Acad. Dermatol. Venereol.* 25(1): 1-11.
17. **Hoffmann, C., Berganza, C. and Zhang, J. (2013).** Cold Atmospheric Plasma: Methods of Production and Application in Dentistry and Oncology. *Medical Gas Research.* 3(1).21.
18. **Jayasena, D.D., Kim, H.J., Yong, H.I., Park, S., Kim, K., Choe, W. and Jo, C. (2015).** Flexible thin-layer dielectric barrier discharge plasma treatment of pork butt and beef loin: Effects on pathogen inactivation and meatquality attributes. Food Microbiology, 46, 51-57.
19. **Jiang, B., Zheng, J., Lu, X., et al., (2013).** Chem. Eng. J. 215, 969.
20. **Jiang, B., Zheng, J., Qiu, S., Wu, M., Zhang, Q., Yan, Z. and Xue, Q. (2014).** Review on electrical discharge plasma technology for wastewater remediation, *Chem. Eng. J.*, 236: 348-368.
21. **Jiang, J., He, X., Li, L., Li, J., Shao, H., Xu, Q., *et al.* 2014**. Effect of Cold Plasma Treatment on Seed Germination and Growth of Wheat. *Plasma Science and Technology*. 16(1):54-58.
22. **Jung II Song. (2013).** Effect of Plasma Treatment on Mechanical Properties of Jute Fiber/Poly (Lactic Acid) Biodegradable Composites. *Advanced Composite Materials*. 22(6): 389-399.
23. **Keidar, M., Shashurin, A., Volotskova, O., Ann Stepp, M., Srinivasan, P., Sandler, A. and Trink, B. (2013).** Cold Atmospheric Plasma in Cancer Therapy. *Physics of Plasmas*. 20: 057101, DOI:http://dx.doi.org/10.1063/1.4801516.
24. **Kim, H.-J., Yong, H.I., Park, S., Kim, K., Choe, W. and Jo, C. (2015).** Microbial safety and quality attributes of milk following treatment with atmospheric pressure encapsulated dielectric barrier discharge plasma. Food Control, 47: 451-456
25. **Klockow, P.A. and Keener, K.M. (2009).** Safety and quality assessment of packaged spinach treated with a novel ozone-generation system. LWT - Food Science and Technology, 42, 1047-1053.
26. **Lee, H.J., Jung, H., Choe, W., Ham, J.S., Lee, J.H. and Jo, C. (2011).** Inactivation of Listeria monocytogenes on agar and processed meat surfaces by atmospheric pressure plasma jets. Food microbiology, 28(8):1468-1471.
27. **Mandal, R., Singh, A. and Singh, A.P. (2018).** Recent developments in cold plasma decontamination technology in the food industry. Trends in food science & technology, 80: 93-103.
28. **Mishra, R., Bhatia, S., Pal, R., Visen A. and Trivedi H. (2016).** Cold Plasma: Emerging As the New Standard in Food Safety. *International Journal of Engineering and Science,* 6(2):15-20.
29. **Misra, N.N., Kaur, S., Tiwari, K.B., Kaur, A., Singh, N., and Cullen, P.J. (2014a).** Atmospheric Pressure Cold Plasma Treatment of Wheat Flour. *Food Hydrocolloids*. 44: 115-121.
30. **Misra, N.N., Keener, K.M., Bourke, P., Mosnier, J.P. and Cullen, P.J. (2014b).** In-package atmospheric pressure cold plasma treatment of cherry tomatoes. Journal of Bioscience and Bioengineering, 118, 177-182.
31. **Misra, N.N., Martynenko, A., Chemat, F., Paniwnyk, L., Barba, F.J., and Jambrak, A.R. (2018).** Thermodynamics, transport phenomena, and electrochemistry of external field-assisted nonthermal food technologies. *Critical Reviews in Food Science and Nutrition,* 58: 1832-1863.
32. **Murray, K., Wu, F., Shi, J., Jun Xue, S., and Warriner, K. (2017).** Challenges in the microbiological food safety of fresh produce: Limitations of post-harvest washing and the need for alternative interventions. Food Quality and Safety, 1, 289-301.
33. **Myer, P.R., Parker, K.R., Kanach, A.T., Zhu, T., Morgan, M.T. and Applegate, B. M. (2016).** The effect of a novel low temperature-short time (LTST) process to extend the shelf-life of fluid milk. Springerplus, 5, 660.
34. **Nam Gibeop, D.W. Lee, C.Venkata Prasad, F. Toru, Byung Sun Kim & Jung II Song. (2013).** Effect of Plasma Treatment on Mechanical Properties of Jute Fiber/Poly (Lactic Acid) Biodegradable Composites. *Advanced Composite Materials*. 22(6): 389-399. DOI: 10.1080/09243046.2013.843814.
35. **Niemira, B. (2011).** Cold Plasma Decontamination of Foods. *Annual Review of Food Science and Technology*. 3: 125-142.
36. **Niemira, B.A. (2012).** Cold plasma decontamination of foods. Annual review of food science and technology, 3:125-142.
37. **Pankaj, S.K. and Keener, K.M. (2017).** Cold plasma: Background, applications and current trends. Current Opinion in Food Science, 16:49-52.
38. **Pankaj, S.K., Bueno-Ferrer, C., Misra, N.N., Milosavjevic, O`Donnell, C,P., *et al.* (2014).** Applications of Cold Plasma Technology in Food Packaging. *Trends in Food Science & Technology*. 35: 5-17.
39. **Pasquali, F., Stratakos, A.C., Koidis, A., Berardinelli, A., Cevoli, C., Ragni, L., Mancusi, R., Gerardo, M. and Trevisani,** **M. (2016).** Atmospheric cold plasma process for vegetable lead decontamination: a feasibility study on radicchio (red chicory, *Cichoriumintybus* L.), *Food control, 60,* 552-559.
40. **Philip, N., Saoudi, B., Crevier, M.C., Moisan, M., Barbeau, J. and Pelletier,** **P. (2002).** The respective roles of UV photons and oxygen atoms in plasma sterilization at reduced gas pressure: The case of N2-O2 mixtures, *IEEE Transactions on Plasma Science, 30,* 1429.
41. **Pignata, C., D’angelo, D., Basso, D., Cavallero, M.C., Beneventi, S., Tartaro, D., Meineri, V. and Gilli, G. (2014).** Low-temperature, low-pressure gas plasma application on Aspergillus brasiliensis, Escherichia coli and pistachios. J Appl Microbiol 116, 1137–1148.
42. **Ragni, L., Berardinelli, A., Vannini, L., Montanari, C., Sirri, F., Guerzoni, et al. (2010).** Non-thermal atmospheric gas plasma device for surface decontamination of shell eggs. Journal of Food Engineering, 100(1):125-132.
43. **Reddy, P.M.K. and Subrahmanyam, C. (2012).** Ind. Eng. Chem. Res. 51, 11097.
44. **Redzuan, N. (2010).** *Cold Plasma Air Decontamination* (Doctoral dissertation, University of Glasgow).
45. **Salim, R., Amin, F. and Nazir, F. (2018).** Applications of cold plasma technology in food sector. *International journal of advance research in science and engineering,*7(**4**):2706-2710.
46. **Song, H.P., Kim, B., Choe, J.H., Jung, S., Moon, S.Y., Choe, W., *et al*.** **(2009).** Evaluation of atmospheric pressure plasma to improve the safety of sliced cheese and ham inoculated by 3-strain cocktail Listeria monocytogenes. Food Microbiology, 26(4):432-436.
47. **Wolf, R., and Sparavigna, A.C. (2010).** Role of Plasma Surface Treatments on Wetting and Adhesion. *Engineering*. 2(6): 397-402.
48. **Xiem, N.T., Kroisova, D., Louda, P., Hung T.D., and Rozek, Z. (2009).** Effects of Temperature and Plasma Treatment on Mechanical Properties of Ceramic Fibres. *Journal of Achivement in Materials and Manufacturing Engineering*. 32(2): 526-531
49. **Yarahmadi, R., Mortazavi, S.B. and Moridi, P. (2011).** Development of Air Treatment Technology Using Plasma Method. *International Journal of Occupational Hygiene*. 4(1): 27-35
50. **Zainal, M.N.F., Redzuan, N. and Misnal, M.F.I. (2015).** Brief Review: Cold Plasma. *Jurnal Teknologi (Sciences & Engineering)* 74:10, 57–61.