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Non-Thermal plasma system for decontamination of fruits, vegetables and spices: A review

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Abstract

Cold plasma is used as a novel technology for food decontamination. The cold plasma process is claimed to offer a number of advantages over thermal technology for several fruits, vegetable. Non-thermal plasma technologies are relatively simple, inexpensive in design, short processing times, absence of toxicity and lack of residue formation. Cold plasma systems used for the food applications are atmospheric pressure plasma jet (APPJ), microwave-powered cold plasma treatments (CPTs), dielectric barrier discharge (DBD), low pressure cold plasma (LPCP). Atmosphere plasma system is more efficient for decontamination of food which offers new opportunities to decontaminate biological materials, including fresh foods. In this paper, types of plasma systems, mechanism and effect of plasma sources on fruits, vegetables and spices are reviewed.

Keywords: Plasma; atmospheric plasma; Dielectric barrier discharge; decontamination; microorganisms

1. Introduction

In India, about 76% of the total production of fruits and vegetables is consumed in fresh form. The demand for fresh and minimally processed food is steadily increasing due to consumer consciousness for health. Food safety is a major concern for food industry, regulatory agencies as well as consumers. Now a days farmers resort to applying an inordinate amount of pesticides to improve yield and to combat the insects and pests. This leads to contamination of commodities with pesticide residues which are harmful for humans (Kumari *et al*., 2002)[29]. A constant research for new pesticides is on-going to protect agricultural commodities from the resistance developed by pests against traditional pesticides. However, agricultural products cannot be sold if they contain pesticides exceeding the residual limit. The total number of 1299 spice samples comprising coriander, cardamom, fennel, black pepper, cumin, curry leaves and red chilli powder were collected and analysed, out of which 107 samples contained residues above Monitoring of Pesticide Residues at National Level in 2014. This implicates the need for development of methods to effectively eliminate residual pesticides in harvested crops.

In food industry, food-borne pathogens and spoilage microorganisms are problematic microbes because they lead to public health risks and economic impact (Ragni *et al*., 2010). [47] Microbial contamination of fruits and vegetables is another major problem. Unfortunately, all food undergoes varying degrees of biological, chemical and physical deterioration after harvest and during food storage, coming along with losses in nutritional value, safety and aesthetic appeal like colour, texture and flavour. The need for fast distribution of perishable fresh produce from farm to fork requires effective sanitation techniques to reduce microbial loads without any negative effects on product quality.

Effective and easy-to-apply inactivation approaches for fruits and vegetables have taken on a high priority. Various treatments were used to decontaminate undesirable microorganism which include UV treatment, steam, heat sterilization and irradiation. However, UV radiation is ineffective due to lack of penetration. Although steaming is effective for decontamination, the treatment has limitations and irradiated foods are unpopular in some countries. Conventional thermal methods of food sterilization are unsuitable for fruits and vegetables, since heating causes inevitable changes of color, smell, flavor, and a loss of nutritional value. For the past two decades, research in food science has largely focused on non-thermal technologies such as high pressure, non-thermal plasma, pulsed electric field, ultrasound, pulsed light, and ozone processing technologies to preserve food while limiting the impact of processing on nutritional and sensory quality, and without compromising safety (Grzegorzewski *et al*., 2010) [19].

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Non thermal plasma is a new discipline in food processing applied for decontamination and removal of pesticide residuals. It is considered to be the fourth state of matter in the world (Laroussi, 2006). Plasma is an ionized gas that consists of a huge number of various species such as electrons, photons, positive and negative ions, free radicals, gas atoms and molecules in the ground or excited state. The generation of plasma in wide range of temperature and pressure is carried out by means of coupling energy to gaseous medium. Fig. 1 depicts the generation of plasma from different states of material. The two major types of plasma systems are: thermal and non-thermal. Thermal plasma has electrons and heavy particles (neutral and ions) at the same temperature. The electrons of Cold Atmospheric Plasma (CAP) are at an elevated temperature than the heavy particles that are at room temperature. Hence CAP is said to be a non-thermal process.

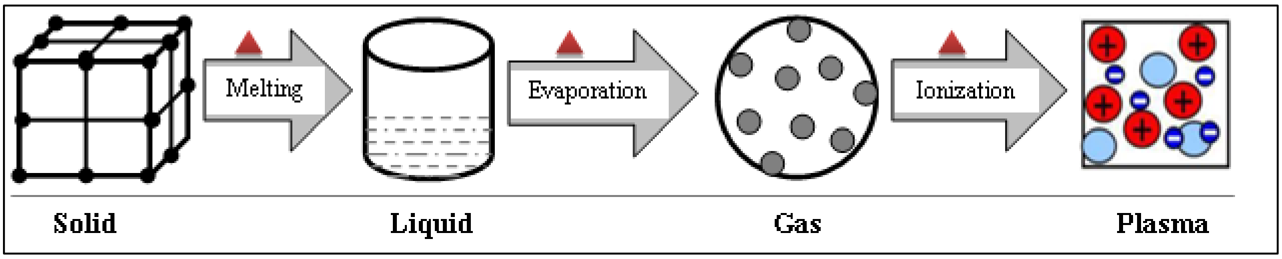

Fig. 1: Generation of plasma from different states of material

The key advantages of non-thermal plasma technologies are their relatively simple and inexpensive design, short processing times, absence of toxicity, and lack of residue formation. Recently, the use of cold plasmas that are operating at ambient pressure in air (or other operating gases and gas mixtures), gained prominence for use in inactivation of microorganisms including bacteria, bacterial spores, fungi, biofilm and decomposition of pesticide (Perni,2008, Zhu, 2010) on heat sensitive foods.

The basic mechanism of producing cold plasma is to apply high voltage pulse in a flowing gas. To produce cold atmospheric pressure plasma, different research groups have used different input parameters and based on the mode of plasma ignition, it is categorized as Resistive Barrier Discharges (RBD), Dielectric barrier discharges (DBD), Corona Plasma Discharges (CPD), Cascaded Dielectric Barrier Discharge (CDBD), and the Atmospheric Pressure Plasma Jet (APPJ). Conrads and Schmidt (2000) provided a useful review about the methods of generating discharges of low-temperature plasmas by using electric fields of DC, AC, pulsed DC, radiofrequency, microwave, dielectric barrier, or electron and laser beams. Electric fields are the most commonly used method of generating plasmas for technological applications.

1.1 Plasma: a tool for microbial inactivation

Plasma generation leads to production of reactive spices which exert oxidative effects on the outer surface of microbial cells. Nitrogen and oxygen gas plasma are good sources of reactive oxygen-based and nitrogen-based spices such as O., O_2, O_3, OH, NO., NO_2. These act on the doubled bond of unsaturated fatty acids of membrane cell, thereby disturbing the transport of bimolecular across it. The oxidation of the lipids, amino acids and nucleic acids makes cells and spores unable to active and lead to microbial death or injury. In addition to reactive spices, UV photons can modify the DNA of the microorganisms and interrupt cell replication (Boudam *et al.*, 2006) [10].

The potential advantage of non-thermal plasma is that UV radiation, radicals and other reactive species can arise everywhere from within the plasma to inactivate microorganisms. In biological systems reactive oxygen species are capable of oxidizing cellular proteins, nucleic acids, membranes and lipids thus giving rise to cellular aging, mutagenesis or carcinogenesis. ROS contribution possibly proceeds through destabilization of membranes, DNA damage and oxidation of low-density lipoprotein. They can react with almost all cell components, leading to single-stranded DNA breaks, base and sugar modifications, and DNA-protein cross-links. They arise from incomplete reduction of O_2 in the electron transporting chain of from the catalytic cycle of redox enzymes involved in purine and lipid metabolism or antibacterial defence.

Reactions
$H2 + O \rightarrow H + \cdot OH$
$CH4 + O \rightarrow \cdot CH3 + \cdot OH$
$H2O + O \rightarrow 2\ \cdot OH$
$O2 + O \rightarrow O3$
$CO + O \rightarrow CO2$

Plasma may inactivate both vegetative cells and bacterial endospores. The practical technical challenge lies in presenting the food product in an appropriate way to the plasma field to take advantage of the generation of microcidal species. Dry particulate food products can be prone to contamination with microbial spores and commercially suitable inactivation treatments are limited following the banning of ethylene oxide gases and the adverse perceptions associated with treatments of gamma irradiation and high energy (10 MeV) electron beams. Those products of low lipid and fat content, (i.e. dried herbs and spices and other horticultural products) in which UV and radical exposure would have minimum impact on oxidation or other chemical changes, may offer the best opportunities for application of low-temperature plasma to food product (Wan *et al.*, 2009).

2. Pesticide degradation mechanism of plasma

Plasma discharge contains ozone, hydroxyl ions, as well as a large number of high-energy electrons, which contribute to the degradation of organic compounds, most of pesticides are organic pesticides and pesticide degradation by plasma is effective way where ozone concentrations were detected immediately after plasma treatment. It can be considered ozone as one of the active species responsible for the degradation of the pesticides. Ozone can also undergo reaction with water to yield peroxide and hydroxyl radicals (Misra *et al*, 2014a). Very limited numbers of studies have demonstrated the successful degradation of pesticides and decontamination of microorganisms by non-thermal plasma. In our country, no such work has been reported so far. There is a need to optimize the suitable non thermal system which generates effective plasma production for potential cold plasma treatment for the degradation of pesticide residues, decontamination of microorganism on fruits, vegetables and spices.

In this review, our goal is to discuss and critically analyse the effect of non–thermal plasma on food material. The structure of the present paper is as follows: The plasma system for food products, followed by other effect of non-thermal plasma on microbial decontamination and pesticide degradation. Besides discussing the effect of processes we also discuss the effect of different plasma systems on different types of fruits, vegetables and spices. Finally, we lay directions for future research and end with conclusions.

3. Plasma Systems

As discussed above the types of plasma systems for food treatment. The plasma jet system includes the cathode, a needle electrode made of tungsten with a 1 mm diameter connected to a RF source (13.56 MHz). The needle electrode lies within a quartz tube whereas the anode electrode is grounded. Depending on the application, helium or argon were mixed with various gases Koinuma *et al.* (1992). Different gases such as He, mixture of He and O_2 or air to deactivate *Bacillus* spores. They observed that the use of pure He resulted in a D value of over 20 minutes, the use of the mixture of He and O_2 resulted in a D value of 10 minutes, and the use of air resulted in a D value of 20 seconds. The oxygen species were found to play a major role in the sterilization process due to their strong oxidative effects on the outer structures of cells Laroussi and Leipold (2004). Laroussi has also developed a miniature jet in (2006) which called plasma pencil. It consisted a dielectric cylindrical tube of 2.5 cm in diameter where two disk electrodes of the same diameter of the tube were inserted. The two electrodes were separated by a gap (the distance can vary from 0.3 to 1 cm) and consist of a thin copper ring attached to a dielectric disk. To create the plasma, sub microsecond high voltage pulses were applied between the two electrodes while a gas was injected through the holes of the electrodes. The electrical power was supplied to the electrodes by a high voltage pulse generator. The high voltage was supplied to the pulse generator by a DC voltage supply with variable output.

Later in 2008, Niemira and Sites developed DC and AC systems and evaluated the efficacy of cold plasma generated in an AC gliding arc, 15 kV at 60 Hz. The surface of apples was inoculated by applying cold plasma discharge to strains of *E. coli* O15:H7 and *Salmonella* on agar plates. The feed gas was air. The higher flow rates (up to 40 $l\ min^{-1}$) and longer treatment times (up to 3 minutes) were most effective. Reductions obtained for both pathogens ranged from 2.9 to 3.7 log. It reaches a maximum temperature 50.8˚C (28˚C above ambient). Further, Lu *et al.* (2009) studied atmospheric pressure plasma jet at peak current of 300 mA to investigate the role of the charged particles in microbial inactivation. The cold plasma plume produced charged particles. These played a minor role when 97%:3% He: N_2 was used as working gas, but are more significant when 97%:3% He: O_2 was used. The negative ions O^{-2} are key species in the antimicrobial mode of action, along with O and reaction products such as O_3 and metastable state O_2. Reaction products from other gases, such as excited He, N_2, and $N^{+\ 2}$ were thought to have no significant direct effect on the inactivation of bacteria. The authors also concluded that heat and UV play little or no role in the inactivation process. Also, Kostov (2009) reported cold atmospheric pressure plasma jet at the downstream end of a flexible plastic tube. The device consisted of a small chamber where dielectric barrier discharge (DBD) was ignited in argon. The discharge was driven by a conventional low frequency AC power supply. A commercial flexible plastic tube (up to 4 m long) with a thin floating Cu wire inside is connected to the exit of DBD. Ar plasma jet can be taken from the tube fixed downside which is based on certain conditions and there was no discharge inside the plastic tube.

Three types of cold atmospheric plasma jet generators was studied by Georgescu (2010). The three generators are supplied with high voltage pulses of 20 kV amplitude and up to 100 pulses per second. The lengths of cold atmospheric plasma jets obtained have lengths of up to 50 mm. Wei-Dong *et al.,* (2012) developed the plasma device consisting of two copper tubes as electrodes separated by a ceramic tube with a separation between the surfaces of the electrodes approximately 0.5 mm. The inner electrode was powered by a DC negative-polarity high-voltage power supply through a 5 kW ballast resistor and the outer electrode was grounded for safety considerations. The nozzle opening of the plasma device was 0.8 mm in diameter and approximately 1 mm deep. Premixed He/O_2 (2% in volume) was used as the working gas at a flow rate of 2.5 lpm (liters per minute). In air, the visible jet was ~25 mm at a sustaining voltage about 400 V and a discharge current of 35 mA.

Another plasma system is DBD plasma was used by Pankaj *et al.,* (2013) which consists of two circular aluminium plate electrodes (outer diameter = 158 mm) over perspex dielectric layers (10 mm thickness). When the potential across the gap reaches the breakdown voltage, the dielectric barrier acts as a stabilizing material forming of a large number of micro-discharges. The applied voltage to the electrode was obtained from a step-up transformer. The input of 230V, 50 Hz was given to the primary winding of high voltage step-up transformer from the mains supply. The atmospheric air condition at the time of treatment was 45 % RH and 22°C. The samples were treated at 70 and 80 kV for 0.5, 1.5, 2.5 and 3.5 min and stored at normal room conditions before analysis. Hoffmann (2013) also conducted experiments on Dielectric Barrier Discharge (DBD) which consists of two flat metal electrodes that are covered with dielectric material. A carrier gas moves between the two electrodes and is ionized to create plasma. One electrode is a high voltage electrode and the other is a grounded electrode. To create plasma, high voltages are required. Alternative Current (AC) of high voltages and power consumption between 10 and 100 W generally used to drive DBD's with frequencies in the kHz range. The atmosphere plasma jet contains two coaxial electrodes between which a feed gas (mixtures of helium, oxygen, and other gases) flows at a high rate. Radio Frequency (RF) power (50-100W) at 13.56 MHz is applied to the central electrode that creates a discharge, while the outer electrode is grounded. The reactive species produced exits the nozzle at high velocity and arrives to the area that is to be treated. APPJ has been used for the inactivation of several microorganisms. Baier *et al.,* (2013) used APPJ at the tip of a pin-type electrode mounted concentrically in a quartz capillary. Argon with 0.1% oxygen added can deliver by a gas supply unit and passed through the capillary (inner diameter 1.6 mm) at a flow rate of 5 L min^{-1}. A DC power supply (system power: 8 W at 220 V, 50/60 Hz) delivering a high frequency (HF) voltage (1.1 MHz, 2–6 kV) was coupled to the pin-type electrode. The process gas was transformed into plasma at the top of the centered electrode and driven out of the capillary into the surrounding air. Abd El-Aziz *et al.*, (2014) used the gas which was fed through an annular region between the two metal electrodes of 15 cm in length and 5mm in diameter and is powered with a pulsed high voltage power supply. The grounded outer electrode was separated from the inner electrode by a gap of a few millimeters. The APPJ device operates using 10-20 kV power supply with a gap between two electrodes of 2-3 mm under atmospheric pressure and a frequency of 25 Hz (pulses/s).

Misra *et al.*, (2014a) used the prototype dielectric barrier discharge (DBD) operating at a voltage of 40 kV and frequency of 50 Hz. The UV-Vis emission spectra of the plasma revealed emission bands for nitrogen and oxygen species, including strong emission lines for excited states of the atomic species O, O^+, N, and N^+. The electrodes consisted of circular aluminum plates of 150 mm diameter. The system was powered from a 230 VAC, 50 Hz supply. The input voltage to the electrodes was monitored with an oscilloscope. All treatments were carried out at 40 kV peak-to-peak potential differences across the electrodes at ambient temperature (16°C to 18°C). The results from the evaluation of methylene blue suggest that direct exposure to the plasma ionization field produced a greater oxidative effect compared to indirect exposure to minimize the bacterial growth.

4. Effect of non-thermal plasma on microorganisms and quality of fruits and vegetable

Vleugels *et al.*, (2005) used the biofilm-forming bacterium *Pantoea agglomerans* on bell peppers to show that atmospheric He-O_2 plasma was effective inactivation agent without causing unacceptable levels of discoloration to the peppers, and that they are superior to low pressure ultraviolet sources. Then in 2006, Deng *et al.* studied the inactivation of *Bacillus subtilis* by cold atmospheric plasma. The leakage of cytoplasm content and a complete rapture of the spore membrane were observed after plasma treatment. For improving production of reactive oxygen species and hence more inactivation, it was observed that it is more effective to use an atmospheric helium plasma plume rather than a comparable atmospheric helium-oxygen plasma plume, because the former supported a greater level of gas ionization oxygen dissociation.

Critzer *et al.* (2007) investigated the effect of atmosphere uniform glow discharge plasma on inactivation of *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes* on apples, cantaloupe and lettuce respectively. Samples were exposed inside a chamber attached to the plasma blower unit operated at a power of 9 kV and frequency of 6 Hz. An approximate 3 log cfu/g reduction was observed with *E. coli* O157:H7 on apples after exposure to plasma for 2 min, and similar levels of reduction were achieved with *Salmonella* and *L. monocytogenes* on cantaloupe and lettuce, respectively, after 3 min of exposure to plasma. Perni *et al*. (2008) evaluated the decontamination effect of plasma on pericarp of melon and mangoes inoculated by *Saccharomyces cerevisiae*, *Pantoea agglomerans*, *Gluconobacter liquefaciens*, and *E. coli.* It was observed that *S. cerevisiae* was the most resistant. *P. agglomerans* and *G. liquefaciens* disappeared below the limit of detection (3 log cfu/g) after only 2.5 s of exposition on both fruits, whereas to reach the same level of inactivation of *E. coli* required 5 s. Again in 2008, Selcuk observed the plasma treatment reduced the fungal attachment to seeds below 1% of initial load depending on the initial contamination level, while preserving germination quality of the seed. Within a short period of 15 min, a significant reduction of 3-log for both species was achieved with SF6 plasma treatment time.

Application of gliding arc cold plasma to inactivate *Escherichia coli* and *Salmonella stanley* on the surfaces of apples is applied by Niemira and Sites (2008). They showed that both pathogens were inactivated, and the rate of inactivation increased with increasing gas flow, where as Klockow and Keener observed decontamination of fresh spinach inoculated with *E. coli* inside a sealed package. After 5 min of exposure, the reductions of 3 to 5 log 10 cfu/leaf was after 24 h of storage. Also, Niemira and Sites (2008) reported the reduced in viable populations of *Salmonella* and *E. coli* 0157:H7 inoculated on apple surfaces using cold plasma generated in a gliding arc. The direct current corona discharges for reduction of *E. coli* O157:H7 in apple juice was employed and the number of cell reduction was more than 5 log cfu/g after 40 s treatment at a frequency of less than 100 Hz with 4000 pulses of 9000 V peak voltage. In 2012 Tipa *et al.* studied in vitro effects of cold plasma treatment on inactivation of Gram positive and Gram negative bacteria. Under high doses, bacteria suffered a damage and showed decrease in the number of colonies. Wang (2012) applied direct-current, atmospheric-pressure air cold plasma microjet (PMJ) to disinfect *Salmonella* on fresh fruit and vegetable slices. Effective inactivation was achieved on sliced fruit and vegetables after 2 min plasma treatment. The physiochemical properties of the slices, such as water content, color parameters, and nutritional content were monitored before and after plasma treatment and found within an acceptable range.

Bermudez-Aguirre *et al*. (2013) used atmospheric pressure cold plasma for the inactivation of a surrogate microorganism of the pathogenic strain *E. coli* inoculated on lettuce, carrots, and tomatoes. The highest voltage and longest treatment time were more effective in microbial inactivation. Color parameters did not show significant changes after processing. Later in 2013, Fernandez *et al*. observed that the rate of inactivation of *S. typhimurium* was independent of the growth phase, growth temperature and chemical treatment on lettuce, strawberry and potato respectively. The surface area of contaminated samples of lettuce, potato and strawberry was observed through scanning electron microscopy. The results showed that *S. typhimurium* cells can be protected from the active species generated by plasma. Under optimal conditions, 2 min treatment resulted in a 2.71 log-reduction of *S. typhimurium* viability on membrane filters whereas a 15 min treatment was necessary to achieve 2.72, 1.76 and 0.94 log-reductions of viability on lettuce, strawberry and potato, respectively. Due to difference in the surface features of food, there is a variability in efficiency of CAP treatment for inactivating *S. typhimurium.*

Also, Ziuzina *et al.*, (2013) studied the antimicrobial efficacy of a dielectric barrier discharge ACP device against *Escherichia coli*, *Salmonella enterica* and *Listeria monocytogenes* which are inoculated on cherry tomatoes and strawberries. The raw materials are treated for 300 s which resulted in a reduction of *E. coli*, *Salmonella and L. monocytogenes* populations by 3.5, 3.8 and 4.2 log CFU/ sample, respectively. Further reduction of microflora in tomatoes was found to be very effective. Zhang *et al.*, (2013) investigated the feasibility of non-thermal low-pressure oxygen plasma on sanitizing the surfaces of vegetables. Low-pressure oxygen plasma promotes chemical reactions like oxidation which will affect the cuticle layer. Also, it decomposes the carbon chains, which could otherwise be removed by water. Misra *et al.*, (2014c) found new opportunities to decontaminate biological materials such as strawberries, by generating a low temperature plasma at normal atmospheric pressure. The raw material was treated with atmospheric cold plasma (ACP), which contains a dielectric barrier discharge pulsed at 50 Hz, across a 40 mm electrode gap, generated inside a sealed package containing ambient air (42% relative humidity). The results concluded that, within 24 h of post-ACP treatment, the microflora of strawberries treated for 5 min was reduced by 2 log10. Finally, microorganisms on fresh produce surfaces inside a sealed package can be eliminated by subjecting it to an atmospheric cold plasma treatment with 24 h post-treatment storage. Misra *et al.* (2014b) evaluated the effect of in-package atmospheric pressure cold plasma treatment on cherry tomatoes. The plasma treatment of cherry tomatoes does not adversely affect critical quality parameters of color, firmness, pH, and weight loss. Antibacterial tests were performed on corn salad, cucumber, apple, and tomato and achieved an inactivation of artificially inoculated *Escherichia coli* DSM 1116 of 4.1 ± 1.2, 4.7 ± 0.4, 4.7 ± 0, and 3.3 ± 0.9 log units, respectively, after 60 s treatment time, Baier (2014). Tappi *et al*. (2014) investigated the effect of gas plasma on fresh-cut apples using DBD generator. The promising results have been obtained regarding enzymatic browning inhibition and the reduction of polyphenol oxidase activity. The enzyme residual activity decreased linearly by increasing the treatment time (up to about 42 %). The results showed that treatments slow down the metabolic activity of the tissue. The effect of microwave processed plasma air on seven different microorganisms spiked on apple (peal and pulp), strawberry, lamb's lettuce, and carrot was studied by Schnabel *et al*. (2015). The investigation showed promising results, because after only 7 s of direct plasma activity followed by 15 min incubation in microwave processed plasma, the microbial load was reduced more than 6 log cfu/g. The sensory properties, texture, and appearance of tested fruits and vegetable remained unaffected. Misra *et al.* (2014a) studied the effect of DBD on strawberries. The background microflora of strawberries consisted of mesophilic aerobic bacteria and fungi (molds, yeasts) which were reduced within 5 min by 2 log cfu/g. The color and firmness of strawberries were not significantly affected by the plasma treatment. Ramazzina *et al.* (2015) evaluated the effect of cold plasma treatment on the quality of fresh-cut kiwifruit. The results showed that plasma treatments positively influenced the quality maintenance of the product, by improving color retention and reducing the darkened area formation during storage. The plasma treatments caused an immediate slight loss of pigments, but a better retention during storage. Non-significant changes in texture and antioxidants including ascorbic acid and polyphenols were observed among treated samples and control ones. Matan *et al*. (2015) studied the combined effect of cold plasma (20 and 40 W) and green tea extract on pathogens of fresh-cut dragon fruit. The higher values of total phenolic content, crude protein, crude fat, and crude fiber were observed in the fresh-cut dragon fruit with green tea after the plasma treatment. The results revealed that combination of green tea extract and atmospheric plasma can protect the fresh-cut dragon fruit against the growth of pathogens and also extends the shelf life of the fruit by retaining its nutritional and sensory quality. In 2015 Lacombe *et al*. found that atmospheric cold plasma treated on blueberries showed reduction in microbial growth and firmness.

The effect of DBD atmospheric gas plasma was tested against *L. monocytogenes* and shigatoxin producing *E. coli serogroups* O157 and O26 on samples of cut celery and radicchio leaves (Berardinelli *et al*. 2016). For deionized inoculated water alone, a treatment time-dependent strong effect was observed and a pathogens reduction higher than 6 log cfu/g. No significant changes were observed on celery visual attributes, soluble solids content and textural. Garofulić *et al*. (2015) evaluated the effect of cold atmospheric pressure gas phase plasma treatment on anthocyanins and phenolic acids in sour cherry Marasca juice. Short exposure of plasma treatment dissociates the agglomerates or particles and consequently leads to increases in anthocyanin content of sour cherry. Lee *et al.* (2015) studied the effect of cold plasma treatment on the microbiological safety of cabbage, lettuce, and dried figs. The plasma treatment at 900 W, for 10 min using nitrogen as a plasma-forming gas, inactivated *S. typhimuriuminoculated* on cabbage and lettuce by approximately 1.5 log cfu/g. The cold plasma treatment at 400 to 900 W and 667 Pa, for 1 to 10 min using a helium-oxygen gas mixture, inactivated *L. monocytogenes* on cabbage and lettuce by 0.3 to 2.1 log cfu/g and 1.8 log cfu/g respectively. The reductions in numbers of *E. coli* O157:H7 and *L. monocytogenes* on figs increased from 0.5 to 1.3 log cfu/g and from 1.0 to 1.6 log cfu/g, respectively. Atmospheric cold plasma appears to be a promising processing technology for the decontamination of leafy vegetables by Pasquali *et al*. (2016). The 30 min plasma treatment significantly reduced *L. monocytogenes* counts (2.2 log cfu/g) inoculated on radicchio leaves. Immediately after cold plasma treatment, no significant effects emerged in terms of antioxidant activity assessed by the ABTS and ORAC assay and external appearance of the radicchio leaves.

4.1 Effect of plasma on spices

Plasma processing is also used for decontamination of spices and showing the promising results. Hertwig *et al*. (2015a) studied the effect of plasma treatment on natural microbial load and quality parameters of selected herbs and spices (pepper seeds, crushed oregano, and paprika powder). After 60 min of plasma treatment, the microbial flora of the pepper seeds and the paprika powder was reduced by more than 3 log cfu/g. But the colour of red paprika powder was lost when treatment time exceeds 5 min due to destruction of carotenoids. Hertwig *et al.* (2015b) studied the antimicrobial effect of two different atmospheric pressure plasma on the decontamination of whole black pepper. Results of the direct cold atmospheric pressure plasma treatment showed a much lower inactivation, probably due to different involved inactivation mechanisms and the complex surface structure of peppercorns. The *S. enteric*, *B. subtilis* spores and *B. atrophaeus* spores were reduced to 4.1, 2.4, and 2.8 log cfu/g, respectively after 30 min remote plasma treatment, whereas, direct plasma jet did not result in equivalent inactivation levels. However, the quality parameters like color, piperince and volatile oil content were not significantly affected. In 2013, Kim *et al.*, studied the effects of the microwave-powered cold plasma treatments (CPT) on inhibition of microorganisms in red pepper powder, including *Aspergillus flavus* and *Bacillus cereus* spores. The inhibition of microorganisms took place at 900 W microwave power on exposure upto 20 min and the microorganisms was reduced by 2.5-0.3 log spores/g.

4.2 Effect of cold plasma on pesticides

Chen *et al.*, (2011) studied on adopting the inductively coupled plasma (ICP) source for successful degradation of dichlorvos pesticides coated on glass slides. It was found that with increase in applied power to plasma leads to an insignificant effect on the degradation of dichlorovos. This was also supported by Misra *et al.*, (2014c) [39] who found that plasma technology has a potential use for degradation of pesticide residues, namely Azoxystrobin, Cyprodinil, Fludioxonil and Pyriproxyfen on strawberries.

4.3 Effect of non-thermal plasma on enzymes

The emerging trend for microbiological decontamination of food and bio-materials is to adopt non thermal food technology i.e. atmospheric pressure cold plasma technology. Pankaj *et al* (2013) [43] demonstrated the usage of in-package cold plasma technology as a novel means for inactivation of peroxidase enzyme in tomato. Later in 2014, Tappi studied the use of gas plasma on fresh-cut apples using a Dielectric Barrier Discharge considering three different times: 10, 20 and 30min. In terms of browned areas, a significant decrease was observed in treated samples compared to the control ones (up to about 65% for 30min and after 4h of storage). On increasing the treatment time, the residual activity of PPO decreased linearly about 42%. In general the treatment appeared to slow down the metabolic activity of the tissue. Other qualitative parameters were slightly affected by the treatment. He concluded that on in-packed cold plasma makes this technique very encouraging for fresh-cut fruit stabilization. Abd El-Aziz *et al* (2014) [1] Non thermal plasma is a novel promising method for insect control. In order to study the effect of the atmospheric-pressure plasma jet (APPJ) on Plodia interpunctella, two treatment variables were used: 1) distance from nozzle of APPJ (11, 13 or 15 cm) and number of APPJ pulses (1, 5, 10, 15 or 20 pulses). Significant increases in larval and pupal mortality and a decrease in adult emergence were observed with increase of APPJ pulses and decrease of distance from the nozzle. Changes in antioxidant enzymes activities, catalase (CAT) e glutathione S-transferase (GST) and peroxidase (GSH-Px), in the body tissues of the last larval instar were examined after 24 h post treatment with 15 pulses at a distance of 11 cm. No significant change in GSH-Px activity was observed. A significant increase in the level of lipid peroxide (LPO) and reductions in the level of glutathione (GSH) and protein content occurred in treated larvae in comparison with the control.

In 2014, the effect of cold helium plasma on seed germination, growth and yield of wheat was studied by JIANG Jiafeng *et al*. The results showed that as compared to control, cold helium plasma treatment of 80 W could significantly increase the seed germination potential of 6.0% and germination rate of around 6.7%. When studied the effects of cold plasma treatment of 80 W for wheat seeds, they found that compared with control, plant height, root length and fresh weight increased up to 20.3%, 9% and 21.8% respectively at seedling stage. Also chlorophyll content, nitrogen and moisture content were higher than control around 9.8%, 10.0% and 10.0% respectively, suggesting that cold plasma treatment could promote the growth of wheat. Finally, the yield of plasma treated wheat increased up to 5.89% more than control.

Ramazzina *et al* (2015) [48] evaluate the effect of atmospheric double barrier discharge (DBD) plasma treatment on the quality maintenance of fresh-cut kiwifruit. The results revealed that plasma treatments have positive effect on the quality maintenance of the product, by maintaining colour retention and reducing the browning during storage. Also, no textural changes when compared with the control is being observed. Though there is a slight loss of pigments due to plasma treatments, but during storage better retention of pigment can be obtained. Antioxidants content and antioxidant activity were not affected among treated samples and control ones. Ozone treatments and enzymatic approaches such as use of lipoxygenase, pentosanases, proteolytic enzymes, redox enzymes, and reducing agents in combination (Lamsal and Faubion, 2009).[31] Among these, ozone is of relevance for the present study as it is a strong oxidising agent and yet it leaves no residues. Due to its oxidising properties, ozone has been reported to act as an alternative to potassium bromate, chlorine, and benzoyl peroxide for treatment of wheat flour (Sandhu *et al.*, 2012). The use of ozone in grain processing has been recently reviewed (Tiwari et al., 2010)[55] In order to achieve industrial adoption of ozone treatments for flour modification, it is important to develop efficient ozone generation processes. Ozone production often involves use of corona discharges in oxygen rich gas. Dielectric barrier discharges (DBD) are one of the most efficient methods to produce ozone (Alonso *et al*., 2005; Amjad *et al*., 2012).[3]

As shown in fig.1 schematic diagram of continuous plasma system in that required gas supply, power supply are available. Sample can pass through the conveyer belt and above it there is different plasma jets which treats the samples and directly go to packaging area for safe packaging. This technique may help in large scale treatment.

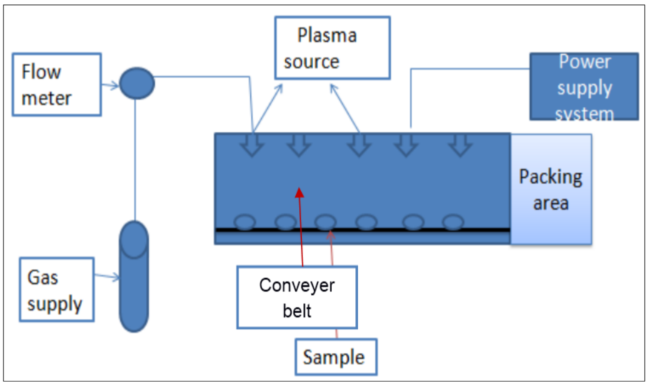

Fig 1: Schematic diagram of continuous plasma system for decontamination of food

5. Conclusion

The emerging technology, non-thermal plasma enhances the shelf life and safety of the food by inactivating the microorganisms and degradation of pesticides. Considering the reported results by direct plasma exposure and circulation, it was concluded that the confined environment enhances the efficient irradiation of plasma by eliminating air flow. This system can be applied to the storage to keep agricultural products freshly and exclusion of harmful materials on the products. Very limited numbers of studies have demonstrated the successful degradation of pesticides and decontamination of microorganisms by non-thermal plasma. In our country, no such work has been reported so far. There is a need to optimize the suitable non thermal system which generates effective plasma production for potential cold plasma treatment for the degradation of pesticide residues, decontamination of microorganism on fruits, vegetables and spices.

Table: 1: Different plasma systems on target microorganisms for different food

Target microorganism	Fruit/ vegetable	Plasma System	References
Inactivation of bacteria	Apples, melons, lettuce Mangos, melons, bell peppers Apple Juice Sliced cheese and ham Almonds	APP (Air)a APP (He/O2)b APP (Air)c APP (He)d	**a**=Critzer et al., 2007; Niemira and Sites, 2008, **b**= Perni et al., 2008; **c**= Montenegro et al., 2002, **d**= Song et al., 2009,
Inactivation of fungi	Hazelnut, peanut, pistachio nut	LPP (Air, SF6)	Basaran *et al*.,2008,
Inactivation of fungi Seed germination Cooking quality	Seeds (tomato, wheat, bean, lentils barley, oat, soybean, chick pea, rye,	LPP (Air, SF6)	Selcuk *et al.*, 2008
Seed germination	Seeds (Radish. Pea, soybean, bean, corn) Safflower	LPP (CF4, other)	Volin et al., 2000
Degradation of organic compounds/ macro molecules	Pesticides (in maize) Mycotoxins Starch (aq.) Proteins (BSA)	LPP (O2)a APP (Ar)b LPP (Ar)c APP(He,He/O2)d	a= Bai *et al*., 2009, b= Park *et al*., 2007, c= Zou *et al*, 2004, d= Deng *et al*., 2007.
Listeria monocytogenes	sliced cheese and ham	atmospheric pressure plasma The	Song *et al,2009*
Escherichia coli DSM 1116	corn salad, a perishable leafy green	atmospheric pressure plasma-jet	Baier *et al*, 2014
Stanley H0558	Apples surface	gas plasma air ionizer	Niemira and Sites (2008)
S. Typhimurium	lettuce and strawberry surfaces and potato tissue		Fernández *et al, 2013*
Salmonella enterica subsp.	spinach, lettuce, tomato and potato surfaces	nonthermal low-pressure oxygen plasma	Zhang et al, 2013
Salmonella directly	fresh fruit and vegetable slices	cold plasma microjet	Wang *et al*, 2012
Aspergillus flavus and *Bacillus cereus* spores	red pepper powder	microwave-powered cold plasma treatments (CPTs)	Kim *et al*,2014
Escherichia coli, *Listeria monocytogenes*, and *Salmonella Typhimurium*	Milk	DBD plasma treatment	Hyun-Joo Kim et al, (2009)

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