ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Cold Plasma Processing: A review

Anirban Dey[1], Prasad Rasane[1, 2]*, Asish Choudhury[1], Jyoti Singh[1], Daniel Maisnam[1], Pallavi Rasane[3]
[1] Department of Food Technology and Nutrition, Lovely Professional University, Jalandhar, Punjab 144411
[2]Centre of Food Science and Technology, Banaras Hindu University, Varanasi, Uttar Pradesh 221005
[3] Department of Internal Medicine, Peoples Friendship University, Moscow 117198, Russia
*** Corresponding Author: Email: rasaneprasad@gmail.com, Ph. No.: +91 8968976119**

ABSTRACT

The increase in the outbreaks reported due to consumption of infected produce has increased to a larger extent. Conventional technologies hamper the quality of food. To fulfill the need of an efficient cold processing method, researchers came up with a novel technology known as plasma technology. Two type's thermal and non-thermal plasma exists. The non-thermal or cold plasma technology is now the prime consideration in food processing industries viz. post-harvest, meat, packaging etc. Cold plasma plays an important role in decontamination of food and packaging materials from microorganisms, manufacturing of packaging materials, active packaging and retards browning reactions. Cold plasma withholds the ability to manufacture high quality fresh and processed food products.

Keywords: Plasma, Novel technology, Microorganisms, Packaging, Food processing

1. INTRODUCTION

Consumers now a day has increasingly became aware of healthy habits and diet. Food has long been associated with numerous food borne diseases. They contain numeral pathogens. To control and eliminate pathogenic microorganisms effectively, sanitation techniques are used for post-harvest (CDC, 2012). One of the major concerns prevailing for the food industries, regulatory bodies and customers is the safety of food. Microorganisms and pathogens that cause spoilage are a major problem concerning the food processing industries as they have an unfavorable impact on the health and economy of the public (Afshan and Hosseini, 2012). To eliminate various microorganisms, pathogens and spores, thermal inactivation techniques are practiced such as pasteurization, autoclaving, ohmic heating, canning and steam sterilization. All these methods are effective and efficient; however, they possess numerous side effects viz. nutritional loss, effect sensory properties and degrade functional properties of the food. For overcoming the side effects, some novel cold processing technologies are introduced viz. pulse electric field (PEF), high hydrostatic pressure (HPP), irradiation, ultrasound etc. however, these processes requires specialized equipment, trained personnel and relatively very expensive (Yun, 2010).

Cold plasma is one of the most modern technologies tested for microbial inactivation or destruction (Sharma, 2009). Plasma is generated when an inert gas gets in contact with electricity; reactive substance composed of charged particles, free radicals, photons and various radiations are formed. This whole formulation is known as plasma. Plasma produced at an ambient temperature is referred to as cold plasma having a temperature of 30-60°C, which is mostly preferably used in the food processing industries (Misra, 2011). Cold plasma technology is successfully studied for effective microbial inactivation of *Escherichia coli* from fresh produce (Bermudez-Aguirre, 2013), *Aspergillus parasiticus* and *Penicillium* sp from seeds of various vegetable, legumes and cereals (Selcuk, 2008), *Erwiniacarotovora* in potatoes (Moreau, 2007), *Listeria monocytogenes* from plastic trays, paper cups and aluminum foil (Yun, 2010) etc. Other than decontamination, plasma technology works in various other phenomena such as effect on seed germination (Sera, 2012) and retarding browning reaction (Tappi, 2014).

This paper reviews the various aspects of cold plasma technology viz. plasma generation, mechanism of microbial inactivation, its significance in the food industry and future scope helping in better understanding about non thermal plasma technology.

Plasma generation: Plasma is a term which refers to the fully ionized gas composed of various substances such as photons and free electrons, along with atoms in excited state having a neutral charge. Plasma has a net charge of zero due to its equal number of positive and negative ions (Kudra and Majumdar, 2009). Plasma consists of two types of species, light (photons) and heavy (all the other constituents). For retaining such particular property, it is regarded as plasma is regarded as the fourth state of matter which starts from solid to liquid state, liquid to gas and finally to plasma (Misra, 2011).

Types of plasma: In general plasma is classified into two types: thermal and non-thermal plasma is differentiated based on generation mechanism. Thermal plasma generation requires high pressure and temperature with heavy electrons. Non-thermal or near ambient temperature plasma (NTP) is generated under atmospheric or vacuum at temperatures of 30-60°C requiring low energy. NTP can be formed by electrifying or using electromagnetic waves on gas at reduce pressure, having a thermodynamically non-equilibrium nature. There are some typical approaches in creation of plasma at atmospheric pressure, consists of dielectric barrier discharge, corona discharge and gliding arc discharge, which are of kin interest in food industries requires mild conditions (Misra, 2011).

Instrumentation of plasma treatment: Generally, plasma treatment is done in a vacuum chamber but due to advancement in technologies, researchers have come up with more developed technique such as atmospheric pressure plasma system which helped in reducing the cost, applicability and increased treatment speed in industries. For the generation of cold plasma (gliding arc), the equipment consists of two components, power supply and plasma emitter. The system requires AC power (60 Hz) and operating output rate (max. 60 mA at 15kV). Gas-injected gliding arc system is modified slightly to be used as plasma emitter. The system operates at open air having electrodes of 3 mm thick which is attached at the top and bottom with stainless steel lugs. Rods were fixed at certain distance of 3mm from the plasma generation point and curved at 45° angle and the gap between the gas inlet and plasma generation point is kept 8 mm (Niemira and sites, 2008).

Mechanism involved in microorganism inactivation: The effect of sterilization using plasma was first document in the year 1960 and the technology was patented in 1968 by Menashi (Menashi, 1968). The lysis of microorganisms during plasma treatment occurs as the microorganisms are exposed to radical bombardment on the surface of the cell with great intensity. The bombardment of the radicals provokes lesions on the surface of the cell which the microorganisms are unable to repair quickly, leads to destruction of the living cell rapidly. This is termed as "etching" (Pelletier, 1992). The phenomenon of lesion formation is because of accumulation of electrostatic forces on the exterior surface of the living cell. The efficiency of non-thermal plasma depends upon two factors substrate type and characteristics of microorganisms like load, type and physiological state (Stratakos and Koidis, 2015). Diagrammatic expression on efficiency of cold plasma is presented in Fig. 1.

Action of charged particles along with reactive species in non-thermal plasma damages cell membrane and causes denaturation of DNA and chemical bonds which results in an antimicrobial effect on the cell. The mechanism behind interaction between the microorganisms and species present in plasma is still unclear but certain reactions such as oxidation and peroxidation occurs inside and outside the cell which is mainly catalyzed by the plasma ions (Dobryinin et al., 2009).

Potential of cold plasma technology in food processing: The cold plasma technology has shown great potential towards the novel processing fresh foods, processed food products and packaging. This technology helps in processing of heat liable foods while retaining the physico-chemical, textural and functional properties of the food.

Inactivation of microorganisms: The cold plasma technology has been evaluated on bacteria (positive and negative), molds, yeasts, spores and viruses (Montie, 2000). Cold plasma is used in minimal processing or acts as a chlorine replacer during washing for decontaminate fruits, vegetables and leafy vegetables from pathogens. Pasquali et al. (2016) showed the effect of cold plasma on red chicory (*Cichoriumintybus*) was treated with atmospheric cold plasma kept at a difference of 70 mm from discharge. The conditions were kept stable with a temperature of 22°C and 60% RH, only treatment time varied for 15 and 30 min. The load of *E. coli* and *L. monocytogenes* at the initial stage was 10^8cfu/ml and 1.2 x 10^8 to 1.6 x 10^8cfu/ml respectively, treated for 15 min and 30 min, respectively. In 15 min of atmospheric cold plasma treatment *E. coli* reduced to 1.35 log MPN/cm^2 whereas, *L. monocytogenes* took 30 min to have a final load of 2 log cfu/ml. The duration of treatment time did not show any prominent loss in antioxidant activity and appearance of radicchio leaves.

Dielectric barrier discharge atmospheric gas plasma was used on deionized water, celery and radicchio leaves to decontaminate *Listeria monocytogenes* and *Escherichia coli* O157 and O26. The conditions maintained during application of plasma was 26 ± 1°C having a RH of 53%. The cell density present in the deionized water was 10^6cfu/ml, reduced more than 6 log cfu/ml after 40 min of treatment. However, as the vegetables were dipped in deionized water the rate of efficacy reduced upto 2.5 and 3.7 log cfu/ml for *L. monocytogenes* and *E. coli*, respectively. The atmospheric gas plasma showed decrease in appearance in the radicchio during the storage period but there was no changes observed in visual, textural and total solid content of cut celery (Berardinelli, 2016).

Packaging: The plasma technology is offering high potential in food packaging as it enhances the adhesion properties, polymerization and helps in good printability (Pankaj et al., 2013). The polyethylene terephthalate (PET) has many good properties such as strength, transparency, gas barrier property, formability and resistant to chemicals however PET polymers have low surface energy which should be activated to enhance good adhesion, printing and dyeing properties. Cold plasma treatment helps in determining the change in crystal structure of PET films towards the surface energy (Jacobs, 2011). The active packaging system was developed to preserve the quality and increase the storage life of the food products. The technology includes physical, chemical and biological actions, changes the interaction between a product, packaging material and even the headspace inside the package to get a desired outcome (Yam, 2005). The active packaging of red delicious apples were done using plasma reactor known as atmospheric pressure cold plasma reactor (APCPR), atmospheric pressure cold plasma was achieved by increasing the voltage between needle-to-needle configuration. Argon was chosen as carrier gas and vanillin was taken as a monomer as it has the ability to form plasma polymerized films. The chamber which was kept below the zone of activation was used to treat the apple for proper deposition of film on the apple surface (Fig. 2). The study concluded that smooth thin layered film can be deposited in the apple surface however nodules were observed which can occurred during the condensation of vanillin powder after sublimation (Fernandez-Gutierrez, 2010). Oh et al. (2016) prepared edible film treated with cold plasma based which is based on defatted soybean meal had better tensile strength, elongation and moisture barrier than control.

Effect on physico-chemical and antioxidant properties: The qualitative parameters of fresh cut melons such as soluble solid content, titratable acidity, dry matter and colour change during storage. The samples were treated with cold gas plasma (15+15 min and 30+30 min on each side), then packaged in propylene trays and sealed using micro perforated polypropylene film and stored at 10°C and 95% RH for 4 days. During the period of storage, there was increase in dry matter and decrease in soluble solid content of plasma treated samples, significant decrease in titratable acidity was observed. Colour change was observed only in 15+15 min treated samples after 2 and 4 days of storage. The firmness of the plasma treated melon was unaffected (Tappi, 2016).

Seed germination: Application of plasma has been reported to have both negative and positive effect on the germination of buck wheat seed. The seeds were subjected to four kind of plasmas viz. glidarc, atmospheric cold plasma in apparatus having planar rotating electrode, surface dielectric barrier discharge and downstream microwave plasma for varied time of 180, 300 and 600 s. The glidarc method showed the best results in seed germination and length of sprout compared to control. The percentage of seed germination decreased from 109 to 81% as the time of exposure increased whereas, 90 to 107% increase in sprout length was observed with the increase in treatment time The glidarc and planar rotating electrode (non-thermal plasma at atmospheric pressure) showed almost similar values on weight of sprouts which decreased with the increase in exposure time. In other plasma treatments, all the parameters decreased with the increase in treatment time (Sera, 2012). There was positive effect on wheat seed treated with cold plasma. Treatment of 15 min increased the dry matter, wettability and root:sprout ratio (Dobrin et al., 2015).

Effect on browning: The major problem with the fresh cut fruits and vegetables is enzymatic browning which affects the quality attributes. Tappi et al. (2014) used dielectric barrier discharge atmosphere gas plasma to check the metabolic activity of fresh cut apples. The samples were treated for 10, 20 and 30 min and the best results obtained were approximately 65% reduction of browning area for 30 min as compared to control samples. The increase in the treatment time eventually decreased the polyphenol oxidase residue up to 42%. This shows that plasma treated fresh cut apples has low metabolic activity than control samples.

Bubler et al. (2016) showed the impact of plasma processed air on polyphenol oxidase and peroxidase enzymes present in apples and potatoes. The cut apple and potato tissue was treated for 10 min with plasma processed air which showed reduction of polyphenol oxidase up to 62% and 77% respectively, peroxidase reduced about 65% in cut apple and 89% in potato tissue.

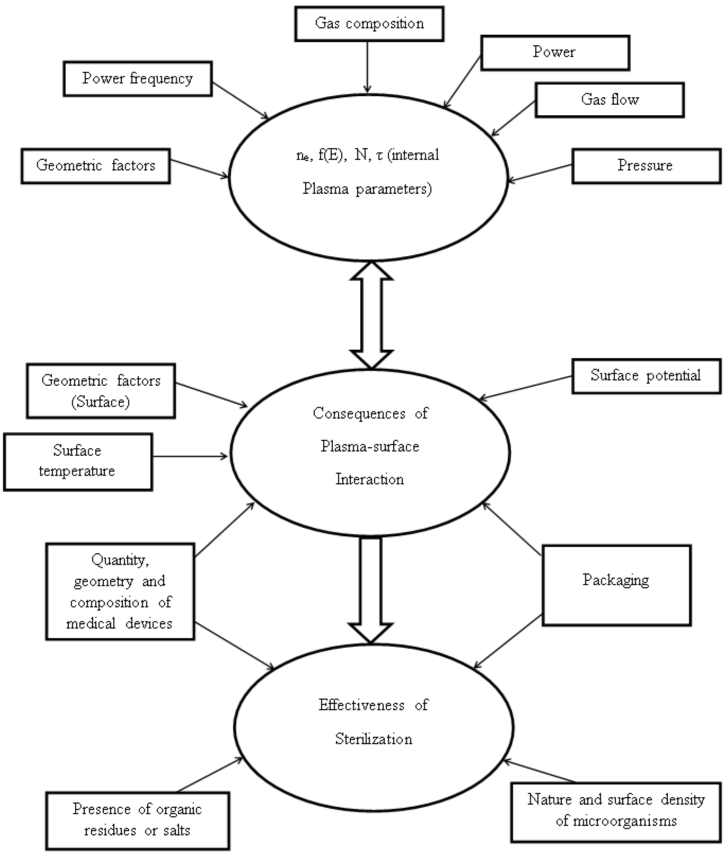

Fig.1.Efficiency of plasma in destruction of microorganisms (Lerouge, 2001)

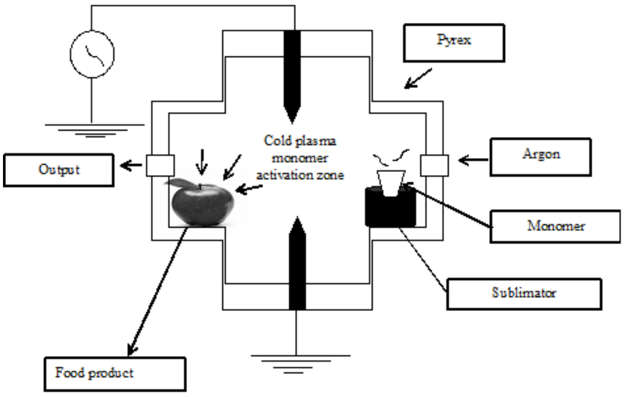

Fig.2.Schematic diagram of plasma reactor (Fernandez-Gutierrez, 2010)

2. CONCLUSION

Cold plasma is an emerging novel technology in the recent era. Cold plasma technology is gaining fame for its unique characteristics like treatment in low or ambient temperature for a short period of time which helps in retaining the integrity and quality of food products. Cold plasma has proved to be efficient in sanitizing equipment for inactivating the foodborne pathogens from fresh produce and packaging materials. It also helps in catalyzing certain manufacturing processes, acts as an active packaging and retards browning reaction in fruits and vegetables. Being a cold treatment it is effective in retaining the texture, sensory and functional properties of foods. Thus, cold plasma is a promoting technique for food processing in near future.

REFERENCES

Afshan R, Hosseini H, Atmospheric pressure plasma technology: A new tool for food preservation, International conference on Environment. Energy and Biotechnology 33, 2012, 275-278

Berardinelli A, Pasquali F, Cevoli C, Trevisani M, Ragni L, Mancusi R, Manfreda G, Sanitisation of fresh-cut celery and radicchio by gas plasma treatment in water medium. Postharvest Biology and Technology, 111, 2016, 297-304

Bermudez-Aguirre D, Wemlinger E, Pedrow P, Barbosa-Canovas, Garcia-Perez M, Effect of atmospheric pressure cold plasma (APCP) on the activation of *Escherichia coli* in fresh produce. Food Control, 34, 2013, 149-157

Bubler S, Ehlbeck J, Schluter OK, Pre-drying of plant related tissue using plasma processed air: impact on enzyme activity and quality attributes of cut apple and potato. Innovative Food Science and Emerging Technologies, 2016, http://dx.doi.org/10.1016/j.ifset.2016.05.007

Centers for Disease Control and Prevention (CDC), Multistate Outbreak of Listeriosis Linked to Whole Cantaloupes from Jensen Farms, Colorado, 2012. Available at: http://www.cdc.gov/listeria/outbreaks/cantaloupes-jensen-farms/082712/index.html (accessed 15.06.16)

Dobrin D, Magureanu M, Mandache NB, Ionita MD, The effect of non-thermal plasma treatment on wheat germination and early growth. Food Science and Emerging Technologies, 29, 2015, 255-260

Dobryinin D, Fridman G, Fridman A, Physical and biological mechanisms of direct plasma interaction with living tissue. New Journal of Physiscs, 11, 2009, 115020

Fernandez-Gutierrez S, Pedrow PD, Pitts MJ, Powers J, Cold atmospheric-pressure plasma applied to active packaging of apples. IEEE Transactions on Plasma Science, 38(4), 2010, 957-965

Jacobs T, De Geyter N, Morent R, Van Vlierberghe S, Dubruel P, Leys C, Plasma modification of PET foils with different crystallinity. Surface and Coatings Technology, 205(2), 2011, S511-S515

Kudra T, Majumdar AS, Advanced drying technologies, Edn 2, CRC Press, Boca Rotan, 2009

Lerouge S, Wertheimer MR, Yahia LH, Plasma sterilization: a review of parameters, mechanisms and limitations. Plasma and Polymers, 6(3), 2001, 175-188

Menashi WP, Treatment of surfaces. US Patent 3,383,163, 1968

Misra NN, Tiwari BK, Raghavarao KSMS, Cullen PJ, Nonthermal plasma inactivation of food-borne pathogens. Food Engineering Reviews, 3, 2011, 159-170

Montie TC, Kelly-Wintenberg K, Reece JR, An overview of research using the one atmosphere uniform glow discharge plasma (OAUGDP) for sterilization of surfaces and materials. Plasma Science, IEEE Transactions, 28, 2000, 41-50

Moreau M, Feuilloley M, Veron W, Meylheuc T, Chevalier S, Brisset JL, Orange N, Gliding arc discharge in the potato pathogen *Erwiniacarotovora* subsp. *atroseptica*: mechanism of lethal action and effect on the membrane-associated molecules. Applied Environmental Microbiology, 73(18), 2007, 5904

Niemira BA, Sites J, Cold plasma inactivates *Salmonella* Stanley and *Escherichia coli* O157:H7 inoculated on golden delicious apples. Journal of Food Protection, 71(7), (2008), 1357-1365

Oh YA, Roh SH, Min SC, Cold plasma treatments for improvement of the applicability of defatted soybean meal-based edible film in food packaging. Food Hydrocolloids, 58, 2016, 150-159

Pankaj SK, Bueno-Ferre C, Misra NN, Milosavljevic , O'Donnell CP, Bourke P, Keener KM, Cullen PJ, Application of cold plasma technology in food packaging. Trends in Food Science & Technology, xx, 2013, 1-13

Pasquali F, Stratakos AC, Koidis A, Berardinelli A, Cevoli C, Ragni L, Mancusi R, Gerardo M, Trevisani M, Atmospheric cold plasma process for vegetable lead decontamination: a feasibility study on radicchio (red chicory, *Cichoriumintybus* L.). Food control, 60, 2016, 552-559

Pelletier J, Sterilization by plasma processing. Aggressologie, 33, 1992, 457-477

Selcuk M, Oksuz L, Basaran P, Decontamination of grains and legumes infected with *Aspergillus* spp. and *Penicillium* spp. by cold plasma treatment. Bioresource Technology, 99(11), 2008, 5104-5109

Sera B, Gajdova I, Cernak M, Gavril B, Hnatiuc E, Kovacik D, Kriha V, Slama J, Sery M, Spatenka P, How various plasma sources may affect seed germination and growth. Optimization of Electrical and Electronic Equipment, 13th International Conference on IEEE, 2012, 1365-1370

Sharma A, Collins G, Pruden A, Differential gene expression in *Escherichia coli* following exposure to non-thermal atmospheric pressure plasma. Journal of Applied Microbiology, 107, 2009, 1440-1449

Stratakos AC, Koidis A, Suitability, efficiency and microbiological safety of novel physical technologies for the processing of ready-to-eat meats and pumpable products. International Journal of Food Science and Technology, 50(6), 2015, 1283-1302

Tappi S, Berardinelli A, Ragni L, Dalla Rosa M, Guarnieri A, Rocculi P, Atmospheric gas plasma treatment of fresh cut apples. Innovative Food science and Emerging Technologies, 21, 2014, 114-122

Tappi S, Gozzi G, Vannini L, Berardinelli A, Romani S, Ragni L, Rocculi P, Cold plasma treatment of fresh cut melon stabilization. Innovative Food Science and Emerging Technologies, 33, 2016, 225-233

Yam KL, Takhistov PT, Miltz J, Intelligent packaging: concepts and applications. Journal of Food Science, 70, 2005, R1-R10

Yun H, Kim B, Jung S, Kruk ZA, Kim DB, Choe W, Jo C, Inactivation of *Listeria monocytogenes* inoculated on disposable plastic tray, aluminum foil and paper cup by atmospheric pressure plasma. Food Control, 21(8), 2010, 1182-1186.