**A NON-THERMAL TREATMENT: COLD PLASMA TECHNOLOGY IN FOOD PROCESSING**

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**INTRODUCTION**

In the ultimate two decades, non-thermal processing applied sciences have gained enormous attention from the food industry fascinated by moderate and fantastic processes. These alternative technologies may extend functionality and shelf-life, lowering the negative influence on food nutrients and natural taste (Huang *et al.,* 2017). Some of the most successful non-thermal techniques are high-pressure processing (Kalagatur *et al.,* 2018), ultrasound (Pinon*et al.,* 2020), pulsed electric-powered area (Clemente *et al.,* 2020; Schottroff *et al.,* 2020), ultraviolet mild (Correa *et al.,* 2020), high-intensity pulsed light (Moraes and Moraru, 2018), gamma irradiation (Deshmukh *et al.,* 2020), and, most recently, bloodless plasma (CP) (Govaert *et al.,* 2020; Kim *et al.,* 2020). Plasma can be described as an ionized gasoline containing reactive oxygen species (ROS: O, O2, ozone (O3), and OH), reactive nitrogen species (RNS: NO, NO2, and NOx), ultraviolet radiation (UV), free radicals, and charged particles (Bourke *et al.,* 2018; L. Han *et al.,* 2016a, 2016b). Typically, plasma is generated when electrical power is applied to a gas present or flowing between two electrodes with a high electrical potential difference that reasons gasoline ionization (Mandal *et al.,* 2018) due to free electrons colliding with those gas molecules. When the ionized gasoline is formed by means of extraordinarily low power (1–10 eV) and digital density (up-to 1010 cm− 3), it is referred to as CP (Roualdes and Rouessac, 2017). In the CP, there is a thermodynamic non-equilibrium between electrons and heavy species. Hence, the temperature between them is distinct because electrons are a whole lot lighter than ions and impartial molecules, and solely a small fraction of the complete strength is exchanged (Misra *et al.,* 2018, 2019b). Thus, the cooling of the ions and uncharged molecules is more effective than electricity transfer from electrons, and the gas stays at a low temperature (Misra *et al.,* 2016b). The common electron energy of CP, up to 10 eV, is perfect for the excitation of atomic and molecular species and breaking chemical bonds (Eliasson and Kogelschatz, 1991). All natural molecules having similar ionization and dissociation energies from three to 6 eV can without problems be destroyed by plasma (Suhr, 1983). CP science has been used in many manufacturing industries, such as scientific devices, textiles, automotive, aerospace, electronics, and packaging substances (Bermudez-Aguirre, 2020; Olatunde *et al.,* 2019a). Recently, CP has been integrated into the meals enterprise to limit microbial count (Govaert *et al.,* 2020; Kim *et al.,* 2020; Mahnot *et al.,* 2019; Moutiq *et al.,* 2020; Olatunde *et al.,* 2019a; Zhao *et al.,* 2020; Zhou *et al.,* 2019), degrade mycotoxin (Puligundla *et al.,* 2020; Sen *et al.,* 2019), inactivate enzymes (Chutia *et al.,* 2019; Kang *et al.,* 2019), increase the concentration of bioactive compounds (Silveira *et al.,* 2019), enhance antioxidant pastime (X. Li *et al.,* 2019a, 2019b), and decrease pesticides (Phan *et al.,* 2018; Toyokawa *et al.,* 2018) and allergens (Ekezie *et al.,* 2019b; Venkataratnam *et al.,* 2019) in meals products. However, CP therapy is nevertheless a rising process concerning unfavorable effects in meals (e.g., lipid oxidation), safety evaluation, and regulatory approval.

Matter on Earth exists basically in three distinct phases (gas, liquid and solid) however when the universe is viewed as the fourth state of matter which abundantly exists. So, Plasma is hence referred to as the fourth kingdom of matter, next to solids, liquids and gases. The time period ‘Plasma’ was once first employed by means of Irving Langmuir in 1928 to define this fourth kingdom of remember which is a partially or wholly ionized state of fuel and observed plasma oscillations in ionized gas. The trade of phase from solid to liquid and further to fuel happens as we increase the energy input likewise increasing the electricity input past a certain level in gasoline state motives ionization of molecules which yields their plasma state. Agostino et al. pronounced that plasma can be got both in low temperature, non-equilibrium glow discharge or high temperature, equilibrium thermal plasma. Based on the residences of plasma, it is used in various fields like textile, electronics, life sciences, packaging etc. The application of plasma technology as a floor cleaning tool has been commercially adopted for the removal of disinfection chemicals utilized in scientific units manufactured from heat-touchy plastics. In the biomedical sector plasma technological know-how is used for bloodless sterilization of instruments and prostheses as well as many thermo labile materials used in the biomedical science region for its unique advantages, including its average or negligible impact on substrate materials and use on nontoxic compounds. Conventionally, sterilization strategies such as heat, chemical solutions are used for the surface disinfection of fruits, seeds, and spices etc., which are often time-consuming and negative or have toxic residues. Van de Veen et al. suggested that the impact of cold plasma on bacterial spores is extra than the conventional techniques like heat, chemical compounds and UV treatment. The objective of this assessment are first, to current expertise on effect of bloodless plasma on microbial inactivation and structural modifications of packaging materials as many critiques has been published on these topics. Secondly, the impact of cold plasma on endogenous enzymes, seed germination, starch modifications and limitations for its practicable software in the meals sector as novel technology. One of the essential challenges associated with bloodless plasma technology is ensuring high microbial inactivation while preserving sensory qualities that make a certain their sparkling appearance.

**COLD PLASMA TECHNOLOGY**

In 1928, Langmuir invented the time period “plasma” to outline an ionized fuel with a macro-scopically neutral electrical charge. Since the 17th and 18th centuries, plasma, a semi-ionized fuel composed of excited electrons, ions, and neutrals, has been studied. Plasma is the fourth country of depend and is composed of particles such as high quality and bad ions and free radicals. Plasma can be created with the usage of many kinds of strength that can ionize gases, including electrical, thermal, optical (UV light), radioactive (gamma radiation), and X-ray electromagnetic radiation. Despite this, CP is often generated using electric or electromagnetic fields. To generate CP, a plethora of methods are being developed at a speedy pace. These can operate at regular air pressure or in a partial vacuum. Several gases can technically be applied in CP; the fuel about to be ionized should be as simple as both nitrogen and air. Alternatively, it should be a more composed mixture containing components of noble gases such as helium, argon, or neon. Electricity, microwaves, or lasers may additionally be used as the driving energy. This diverse set of diagram elements demonstrates CP methods’ adaptability and the diploma to which special types of CP mechanisms are invented and tested. All CP techniques for meal processing are labeled into one of three groups. The position of the food to be handled with the CP being generated specifies these groups: a significant distance from the origin of plasma generation, a sensible nearness to the generation source, or even within the region of the era itself that produces plasma. These companies are based specifically on the half-life and homes of charged, active species inner the plasma and originate nearly solely from the essence of CP chemistry.

**PLASMA SOURCES**

Even though low-pressure plasmas are now not necessary for a direct cure of meals merchandise due to the vapor strain of water, which is around 23 hPa, they are of incredible activity in the subject of packaging material processing. Their advantage is that large-volume filling plasmas can easily be generated at low pressure. The drawback of high-priced technology such as vacuum vessels and vacuum pumps is often compensated with the aid of the reality that smaller quantities of pricey working gases are consumed. At the turn of the millennium, the opportunity of making use of very thin barrier layers to Polyethylene terephthalate (PET) bottles in particular, using the plasma-enhanced chemical vapor deposition (PECVD) process, met with outstanding activity in industry. Many widespread manufacturers of filling machines often in Europe and Japan but also in the USA developed approaches partly on glass layers but additionally based on amorphous hydrocarbon layers to improve the barrier properties. This science used to be transferred to production and machines with throughput quotes of up to 46,000 bottles per hour had been realized. A precise overview can be observed in Nakaya et al. (2015, 2018).

**Dielectric Barrier Discharge**

The dielectric barrier discharge is the workhorse of plasma technology. This precept of discharge technology is also the foundation for the ozone tube mentioned earlier. The principle is based totally on limiting the energy consumption of the plasma device. If a sufficiently high voltage is utilized between two electrodes at atmospheric pressure, an electrical breakdown occurs. Due to the excessive conductivity of this breakdown, an excessive cutting-edge flow is induced. This motivates a contraction of the discharge due to its magnetic field so that an arc discharge with excessive power density and temperatures of up to 50,000 K can result (pinch-effect). If one or each electrode are insulated by way of a dielectric, the cutting-edge waft is interrupted locally right now after the breakdown by using a local charge of the dielectric. By further growing the voltage, an in additional discharge can then be ignited at another location in the electrode arrangement. Due to this principle, the person discharges are evenly disbursed over the entire electrode area, even in large electrode arrangements. Due to the shortness of the individual discharges of a few 10–8 s, solely little power can be deposited in the machine (Fig. 2A). Typically, dielectric discharges are operated with alternating voltages in the frequency range from 50 Hz to numerous 104 Hz. Typical voltages range from a few kV to over one hundred kV. Therefore, such discharge systems are frequently used in ozone generators, for floor modification of plastic motion pictures or for exhaust air purification (Kogelschatz *et al.,* 1999). A direct use of food has been shown e.g. on eggs for consumption (Wan *et al.,* 2017). Other promising applications can be located in the treatment of packaged food. Examples are the remedy of sausages (Jung *et al.,* 2015a), fruits and packed fresh-cut salads (Misra *et al.,* 2014b; Ziizika*et al.* 2016).

**Plasma-Jet**

The plasma jet is a discharge that takes the area in a dielectric tube and is expelled from the tube via an excessive fuel flow. The electrical power coupling generally takes vicinity in the range of a few kHz up to 27 MHz with powers of a few W up to the kW range and pronounced with the aid of Ehlbeck *et al*., (2011). The two electrodes required for the power coupling are regularly positioned in a ring on the outside of the tube with a distance between them depending on the experimental conditions. Often, this association can only be used to operate plasmas in without difficulty ignited by noble gases such as argon or helium. For operation in air, therefore, an association with only one ring and a needle-shaped counter electrode concentrically placed in the tube is often used. The drawback of this arrangement is that countless jets have to be linked collectively for a high vicinity output, whereby the system prices and the operating expenses due to the greater gasoline consumption have to be taken into account.

**Microwave Discharge**

Microwave discharges at atmospheric stress are usually plasma torches, which are operated with excessive fuel flows similar to the plasma jets (Fig. 2C). The torches are generally operated at 2.45 GHz in the power range from some 10 W up to about 6 kW. For higher powers, multi-stage systems can additionally be used (Schnabel *et al.,* 2019b). For very high strength levels, it makes extra sense to set up systems working at a frequency of 915 MHz At this frequency, plasma torches up to 70 kW are available. The torches can be operated at atmospheric pressure with noble gases as properly as with air. However, plasma ignition poses a problem due to the low electrical field strength on hand in ordinary waveguide arrangements. To overcome this subject a number of options are found using resonance and top results to gain the electric-powered discipline power for plasma ignition. The excessive temperatures reached in the plasma torches are at first a quandary for the use of this technological know-how for food treatment. For decreased power, a solution can be completed with the aid of increasing the distance. The then still sturdy impact of the plasma effluent could be demonstrated with biofilms (Handorf *et al.,* 2019). A technologically very fascinating opportunity is the use of the gas modified with the aid of the plasma torch. In the case of air as a working gas, a strong antimicrobial impact is effects from the reactive nitrogen species (RNS) shaped in the gasoline (Drost, 1978). Due to its high temperatures, this technique of gasoline can be used for simultaneous drying and inactivation of existing microorganisms in bulk materials. If the method gas is cooled, it can also be used for temperature-sensitive products, for example, for the remedy of fruit to improve storage properties (Schnabel *et al.,* 2014). Furthermore, the technique gasoline can also be added into contact with water and this water can be used for washing of sparkling produce.

**APPLICATION OF COLD PLASMA IN THE FOOD INDUSTRY**

A CP device has been investigated for an extensive range of functions at several phases of meal manufacturing, which include the remedy of substances or closing products, as well as the therapy of processing equipment, facilities, and the environment, due to the fact of its several advantages. Among the CP benefits are low-temperature operation, short time frames, power efficiency, and great antibacterial efficacy with negligible effects on food great and the environment. Many researchers have mentioned the achievable uses of CP for distinct purposes. Some of the CP makes use of related to meal production.

**Germination**

The system by way of which the embryo in the grain evolves to be a plumule and radicle is recognized as seed germination. Grains take up water, which causes non-active tissues to swell and mobile division to begin. The radicle develops from micropylar and starts to move into the growing medium. These in the end improve the root system, which provides nourishment and water to the flowers at some point in their lifetimes. Seed dormancy is a naturally taking place grain function that lets in a species to reproduce in order to continue to exist. Plasma remedy generates a range of agents capable of breaking dormancy (e.g., UV radiation, radicals-and chemical reactions). According to reports, CP has previously been evaluated with distinctive plants: CP treatments treatment drought stress injury to oilseed rape. The CP method and techniques have remarkably increased seedling growth and germination due to improved seed wettability, antioxidant enzyme activities, soluble sugar and protein contents, and reduced lipid peroxidation-linked membrane deterioration. Therefore, CP treatment can be used to guard seeds from the harm triggered by drought stress. The CP treatment can be fine in reducing seedling mortality and improving seed germination rate. Seed germination rates were observed to be faster after plasma treatment. Plasma-reactive species have been shown to be successful in penetrating into the seed coat and having-a significant influence on the cells within. Furthermore, plasma publicity reasons surface ablation on the seed coat, which actively encourages moisture and oxygen entry into the embryo and stimulates seed germination. Plasma has additionally been proven to destabilize the cell wall and impact the enzyme pastime that brings the seed out of dormancy and encourages germination. Germination and early growth are aided by way of bloodless plasma. These results are linked to decreases in the proportion of fungi-infected seeds, adjustments in the physiochemical parameters and biochemical properties of seed coats (higher hydrophilicity), as properly as modifications in antioxidant and phytohormone profiles. Cold helium plasma seed therapy can doubtlessly expand wheat yield by improving germination, merchandising wheat development, and raising its physiological quality, resulting in extended grain manufacturing and better resistance to pests and mycotoxins. CP redress has been proven to make bigger soybean germination and seedling productivity. The enhancement in soybean seed germination and seedling growth in response to CP therapy seems to be due to extent-in water absorption, seed supply consumption, and soluble carbohydrate and protein contents. Peanut seed germination and plant growth also expanded with CP treatment. CP treatment extensively accelerated seedling growth parameters, expanded plant growth potential, germination percentage, dry mass, greater vegetative growth, and dry weight at the fruiting stage. Additionally, it improved plant length, stem dimension, root dry mass at maturity level, and yield in field conditions. Brief plasma methods (30–60 s) have been proven in research to substantially improve wheat seeds’ germination homes and seedling boom parameters; the mechanism of plasma exposure and spending time in an enclosed reactor after the technique determined these effects. The most high-quality remedy used to be an oblique plasma therapy for 60 s, accompanied using 24 h of contact time between plasma-produced compounds and grains after treatment. When compared to control samples, this used to be found to decorate wheat germination by using 14.7%. Numerous exceptional increase factors have also been enhanced. CP can be a suitable substitute for pre-sowing grain strategies used in farming to enhance germination. In optimized conditions, plasma remedy causes the functionalization of the wheat seed surface with oxygen functional groups, notably oxidizing the lipid molecules found naturally on the target surface. Water gets into the seed pericarp smoothly, lowering the water contact angle and higher water uptake. The plasma response technique has the advantages of now not being harmful to the seed, applicability to an extensive variety of crop species, and being environmentally safe.

**Pesticide’s Degradation**

Several research confirmed that CP had the attainability to degrade pesticide residues in fruits and vegetables. CP’s potential to eliminate pesticide residues has been associated with the production of reactive oxygen and nitrogen species. Pesticides are a large variety of chemical substances, extensively utilized in agricultural production to defend plants and prolong crop deterioration. Nevertheless, pesticide resistance necessitates increased utility rates. Pesticide residues are a supply challenge in the food business due to their fitness threats. After 5 min of plasma cure at 80 kV, pesticide residues on blueberries satisfactorily deteriorated with degradation efficiencies of 75% and 80% for boscalid and imidacloprid, respectively. Appropriate modifications in the evaluated nice characteristics have been seen for the therapy conditions. These findings imply that CP cure at 60 kV 5 min and 60 s at 80 kV can maintain the blueberries’ dietary qualities. Pesticides in water have been correctly degraded by the use of atmospheric strain dielectric barrier discharge plasma in air. The discharge was examined at excessive voltages in the filamentary regime. It was determined to be a quick and positive supply of oxygen radicals, excited nitrogen species, and different plasma species. Degradation merchandise is exceptional by using simpler chemical groups. According to studies, CP cure substantially reduced organophosphorus pesticides without any damaging, hazardous, or undesirable consequences on the appearance or texture of many agricultural samples.

**Pest and Mycotoxin Removal**

Controlled ecosystem storage is an environment-friendly way to hold pests and mycotoxin producing fungi at bay throughout storage. However, the use of modified atmosphere storage is hampered by means of the technology’s high price and the want for a greater appreciation of its mechanisms. In recent years, CP has been used to control various pests and mycotoxin-producing fungi. Australia’s existing postharvest cereal grain administration methods are efficient versus the widespread majority of postharvest pathogens and insect pests. Still, they have several drawbacks, such as high prices for maintenance and the development of chemical electricity and toughness within insect pests. Innovative postharvest tactics must be sought with the aid of Australia’s grain sector. Numerous research has shown CP to be fine against fungal species, mycotoxins, and insect infestation while having little effect on cereal crops. CP approaches may want to certainly serve to limit the presence of pests in stored foods. Sutar *et al.,* have proved that the cure of wheat flour with 60 W for 30 min averted the improvement or appearance of insects (larval stage, pupae, and eggs). Based on its special bodily and chemical properties, CP is a promising technology for decontaminating surfaces and air in the meals industry. CP is a promising science for pest and mycotoxin removal.

**Food Sterilization**

To ensure the most appropriate meal safety, it is fundamental to use dependable and steady meal sterilization techniques. Due to its functionality to inactivate a wide variety of foodborne pathogens without affecting meal quality, CP is a promising meal sterilization technology. The most researched of the numerous possible mechanisms is the chemical interplay of cell membranes with radicals (O, OH...), excited or reactive molecules (O2, O3, NO...), and charged particles. Reactive species, created by using the breakdown of air such as O3, atomic oxygen, superoxide, peroxides, and hydroxyl radicals, are imperative in the destruction of microbes and viruses like Coronavirus SARS-CoV-2. NO and NO2 play roles in microorganism inactivation via degrading chemical factors such as protein molecules, fats, and nucleic acids. Moreover, Hun They have shown that plasma can additionally harm the DNA/RNA, proscribing the SARS-CoV-2 for viral replication. The reactive species generated in plasma interact with the amino acids in proteins, making structural adjustments and damaging the microbial cell. CP has been confirmed fantastic in treating biofilms and decontaminating foods such as meats, poultry, fruits, and vegetables. CP systems are being researched and developed worldwide because investigation has established that they effectively reduce human pathogens.

**Wastewater treatment**

The food processing industry uses plenty of water in cleaning, washing and processing of food and their equipment. Therefore effluent of food processing flora is prosperous in natural loads and other chemicals. In addition effluent water of meal processing flora is bountiful in diet and their disposal without any treatments leads to hazard of the pathogenic outbreak. Hence masses of technologies are developed for the food industry discharge. Reactive species are reported in decontamination, and degradation of chemical compounds from waster of a range of industries therefore it can be suited in food processing industry for chemical compounds elimination barring decontamination of waste effluent. 120s or 150s publicity of 25KV plasma jet was efficient in the decontamination of waste from date and tomato processing industries. Whilst Benidris *et al.,*pronounced AG25 dye removal in 10 min after GAD plasma treatment. Jovic et al. investigated the DBD application in the degradation of mesotrione and compared it with three more process, specifically Fenton, ozonation and photocatalysis. Interestingly, similarity between DBD and ozoniation was discovered with the frequent position of O3 in degradation. However they suggested efficient and speedy removal of mesotrione-by using DBD compared to others. The superb have effect on of technological know-how has led the demand for wonderful scale-up of the science with customized gear design to be healthy for the food processing enterprise to deal gaint-scale waste disposal.

**Packaging material processing**

The bactericidal effect of plasma is well confirmed and protected herewith however its utility is not restrained to microbial exposure but it can be utilized for surface redress and surface sterilization of packaging materials too. The surface amendment includes the addition or elimination of specific useful crew or turn-able floor energies to the packaging fabric floor for improving antimicrobial efficiency and extending mechanical power like adhesion, absorbance, sealing, veneering, coating etc. Plasma can be beneficial for depositional barrier coating on the surface of polymers. Conditioning coating would assist to decrease gas permeation and undesirable contaminants besides any traces. Furthermore, plasma therapy helps to preserve sealing homes of polymers and laminates. Non-thermal plasma sterilization is unique, much less time eating and secure sterilization approach for packaging materials like polyfilms, plastic bottles, containers and lids, besides any aspect effects and zero waste residues. Moreover it is very advantageous for the sterilization of heat-touchy materials like polycarbonate and polythene at low temperatures. Recently Oh et al. demonstrated plasma software on edible film made from defatted soyabean meal (DSM) for smoked salmon covering. Exposer of DSM movie to argon plasma at 400 W for 15min has shown increase in 24.4 pp. moisture barrier property, 13.4% elongation and 6.8 % tensile electricity while reduction in lipid peroxidation in the course of 4°C storage. Similarly Kim et al. said 3-4 log CFU/cm2 discount in E coli O157:H7, S. Typhimurium and L. monocytogenes biofilm after 10 min of 50 W jet plasma treatments on food containers.

**INTERACTIONS WITH FOOD CONSTITUENTS**

Food matrices normally consist of varying quantities of macronutrients as proteins, lipids, carbohydrates and water, and micronutrients such as minerals and vitamins. The complexity of real ingredients may also result in a variety of specific plasma reactions, such as the oxidation of food components. The reported results of CP on the most vital food elements are summarized below.

**Proteins**

The plasma reactive species can have an effect on proteins and protein-based buildings such as enzymes. Plasma-induced consequences on proteins and enzymes in food mannequin systems have been reviewed by using Misra et al. (2016a). Recent work (Takai *et al.,* 2012; Surowsky *et al.,* 2013; Bubler *et al.,* 2015b,c; Segat *et al.,* 2015, 2016; Surowsky *et al.,* 2015; Zhang *et al.,* 2015b; Bahrami *et al.,* 2016; Misra *et al.,* 2016a) has targeted on the underlying interactions between atmospheric pressure plasma and proteins, particularly enzymes, in food model systems. The research investigated the effects of plasma on the structure and undertaking of endo and exogenous enzymes as well as on the techno-functional houses of proteins. The results of the research point out that the foremost mechanisms of protein denaturation and enzyme inactivation are attributed to the oxidation of amino acids present in each free and polypeptide chain, depolymerization of polypeptide chains and destruction of secondary structural elements of proteins by means of interaction of plasma reactive species with amino acids (Li *et al.,* 2014) and loss of a-helix and b-sheet structure (Segat *et al.,* 2016). To damage the active website online in the native structure of enzymes the accumulation of several events may also be required, such as oxidation of amino acid side chains or disruption of hydrogen bonding in the tertiary structure of the protein (Alkawareek *et al.,* 2014). It was once evidenced that plasma manner parameters as nicely as the plasma source, the working gas, the type of protein/enzyme, the pattern extent and the therapy medium play a necessary role on the plasma\_induced protein denaturation/modification and enzyme inactivation. Taking into consideration that enzyme inactivation with the aid of CP could supply a fascinating and vital new tool for the meals industry, some troubles such as optimization of processing parameters, appreciation of inactivation mechanisms and elucidating defensive effects of one-of-a-kind food components (Attri *et al.,* 2015) need to be especially investigated. The targeted functionalization of plant and animal-related proteins may want to in addition provide an innovative strategy for tailor-made amendment of techno-functional meals properties.

**Lipids**

Although the action of radicals on lipids to result in oxidation and formation of essential and secondary oxidation merchandise as properly as the resulting formation of off-odors used to be pointed out in the context of CP treatment of food very early (Misra *et al.,* 2011), for quite a length of time now not a whole lot experimental work has been carried out. Then numerous publications reported the oxidative effect of CP on food components and a number of publications centered on the negative plasma-induced results on the fatty acids of rice, wheat flour, pork, beef, chicken, seafood, sushi, cheese, milk, and olive oil has these days been reviewed (Gavahian *et al.,* 2018). Involving free radical chain mechanisms forming fatty acyl peroxides or other oxidation products, lipid oxidation represents a very complicated method (Ladikos and Lougovois, 1990). Studies on CP results on lipids in various foods are as an alternative limited. Nevertheless, in view of the research reported, remedy time and plasma gas can be considered as critical factors in finding out lipid oxidation. As fruits and veggies normally comprise very low quantities of fat and oils, unique plasma-induced oxidation does now not appear to be a sizeable impediment when treating plant foods. This is different when treating grains and flours, the place lipid oxidation should be problematic. Further, lipid oxidation and resulting undesirable modifications in the color, taste, odor, and shelf lifestyles is a major problem for muscle meals and specific investigations on these issues are vital to analyze the plasma effect on lipids current in the muscle foods. Besides muscle foods, lipid oxidation is undesirable in many other food systems. But the capability of CP in intensifying the oxidation fee in the presence of oxygen has been leveraged as a device for accelerated lipid oxidation to simulate ordinary slow oxidation reactions and balance trying out methods (Vandamme *et al.,* 2015; Van Durme and Vandamme, 2016). Further, CP has been recognized for its fast esterification of waste frying oils to produce biodiesel (Cubas *et al.,* 2016). The potential of hydrogen plasma to be used for the manufacturing of partly hydrogenated soybean oil barring any trans-fatty acid and without any catalyst was once tested displaying unique blessings of CP technological know-how over the cutting-edge hydrogenation processes (Yepez and Keener, 2016). CP technological know-how has proven that this hydrogenation can be carried out at room temperature, under atmospheric pressure. Although this method demonstrates an alternative to the typical catalytic hydrogenation, further research is wished to optimize the treatment process and evaluate the performance of partly hydrogenated oil made from CP.

**Carbohydrates**

Regarding the plasma-induced effects on carbohydrates, the degradation of lowering sugars, such as fructose and glucose, and non-reducing sucrose as properly as the degradation of the oligosaccharides with an excessive diploma of polymerization have been reported (Almeida *et al.,* 2015; Rodríguez *et al.,* 2017). Ozonolysis was once recommended to be the major route of degradation main to the cleavage of glycoside bonds, inducing the de-polymerization of the macromolecule and the oxidation of functional agencies to form carbonyl and carboxyl compounds, lactones, hydroperoxides, and CO2 (Benko *et al.,* 2013; Almeida *et al.,* 2015). Research on the effect of CP on polysaccharides has especially centered on starch in pulses and cereal products. Surface etching and the make bigger water binding sites due to the fragmentation of starch and protein by way of plasma reactive species caused an amplify in the water uptake charge in black grams (Sarangapani *et al.,* 2017c). To learn about additionally evidence that the cooking time of brown rice was reduced, suggesting the uptake of polar companies between starch molecules (Thirumdas *et al.,* 2016), as well as an in the diploma of gelatinization. The decrease in amylose content, gelatinization temperature, paste temperature, retrogradation tendency and diploma of hydrolysis was pronounced following the plasma remedy of rice starch (Thirumdas *et al.,* 2017). In conclusion, in most cases polymerization and crosslinking reactions precipitated by CP cure had been found to affect the structural, purposeful and rheological houses of starch. According to a model based totally on good-sized experimental sets with plasma-handled potato starch (Zhang *et al.,* 2015a), the functionality adjustments end result from polymerization/crosslinking reactions, making starch molecules extra branched and networked; from crosslinking hindering the stretch-ability of the molecules throughout granule swelling, which outcomes in a minimize in the maximum viscosity of the starch paste; from a constrained stretch of the chain, ensuing in overall viscosity lowering, and a superior high-temperature paste steadiness even after rupturing of the starch granule; and ultimately from a net effect causing weaker retrogradation and enhancing paste-cooling steadiness due to the constrained possible rearrangement throughout cooling.

**Vitamins**

In order to retain the dietary houses of the meal products, the sensitivity of vitamins to exceptional processing techniques is a key factor. So far, most research on CP remedy of food products has solely targeted on investigating the balance of vitamin C (ascorbic acid), and in most instances remedy of whole fruits and vegetables have now not extensively decreased the ascorbic acid content. In contrast, a reduction was stated following CP remedy of cut fruits and veggies as properly as orange (Xu *et al.,* 2017) and cashew apple juice (Rodríguez *et al.,* 2017) which may want to be attributed to the response of nutrition C with ozone and other oxidizing plasma species all through exposure to CP. It looks pretty evident that sample kind (whole/cut/pureed), treatment time and working conditions represent crucial factors and processing parameters for vitamin C degradation. However, there is a want for further studies to analyze the effects of CP on other vitamins in meal products along with the mechanism of degradation.

**Antioxidative Activity**

Further, antioxidant recreation of mannequin food and meals systems represents an indicator referring to the redox properties, including possible mechanisms such as free-radical scavenging activity, transition metal-chelating activity, and singlet-oxygen quenching capacity of a number of polyphenols, flavonoids and flavanols present in a multitude of food merchandise (Shan *et al.,* 2005). Reported results on the effects of CP remedy on the antioxidative endeavor of different meals merchandise have a large degree of variation and appear to be based on the accessibility of plasma-reactive species on antioxidant compounds, on the kind of food product, on the plasma supply as properly as mode of action, exposure time, and other treatment parameters. This is mirrored in effects like the decrease in the total phenols in orange juice (Almeida *et al.,* 2015), white grape juice (Pankaj *et al.,* 2017), and lamb’s lettuce (Grzegorzewski *et al.,* 2011) and a discount in antioxidant exercise after CP remedies in apples, white grape juice, and cashew apple juice on an extended publicity (Ramazzina *et al.,* 2016; Pankaj *et al.,* 2017; Rodríguez *et al.,* 2017). By contrast, in radish sprouts, kiwifruits, pink chicory and onion powder, no significant adjustments (Ramazzina *et al.,* 2015; Pasquali *et al.,* 2016; Kim *et al.,* 2017b; Oh *et al.,* 2017) and even an expansion in cashew apple juice (Rodríguez *et al.,* 2017) and blueberries (Chaitanya Sarangapani *et al.,* 2017b) in the antioxidant ability have been mentioned Dependent on the plasma application mode, a reduction in the antioxidant ability of prebiotic orange juice following direct treatment occurred, whereas insignificant consequences were suggested following oblique remedy (Almeida et al. 2015). These studies show that the kind of meals products, plasma generation source, mode of exposure and treatment parameters are essential in controlling the outcomes of CP on the antioxidant activity of meals merchandise and also spotlight the necessity of additional lookup to better understand the results of CP on antioxidants at a molecular level.

**EFFECTS ON FUNCTIONAL FOOD PROPERTIES**

Up to now, the consequences of plasma remedy on the surface of meals have solely been studied in a few papers applying unique plasma sources. For example, the plasma remedy of plant ingredients appears to have the plausible to exchange the structure of the surface of the meal, thereby increasing the bioavailability of the phytochemicals contained in the plant material. Treatment of lamb’s lettuce with argon plasma resulted in an increase in floor wettability (Grzegorzewski *et al.,* 2010) and in damage to the microstructure of the lettuce (Grzegorzewski *et al.,* 2011). The thick platelets and small-sized granular wax characteristics on untreated samples disappeared with increasing exposure time. The erosion of the top epidermal tissue layers most probably induced with the aid of vigorous AR ions and/or ROS leads to the plasma-induced removal of wax crystals on the floor of remoted apple cuticle discs and a lowering thickness of the cuticle discs with growing exposure to plasma (Khanal *et al.,* 2014). With regard to chicory, floor erosion on leaves by using plasma was attributed to the oxidation of telephone aspects (Pasquali *et al.,* 2016). Plasma utility on plant seeds and sprouts for decontamination, coating, acceleration of germination and growth, as well as the change of ingredient profiles has attracted broad interest in agricultural and food sciences. Plasma-induced effects on the surface homes of seeds had been said to result in a trade in wettability and to motivate a limit in the apparent contact attitude of for instance lentils, bean, and wheat surfaces (Bormashenko *et al.,* 2012). Different seeds had been discovered to be influenced at some point of the early boom (Sera *et al.,* 2010; Mihai *et al.,* 2014). Plant increase response of seeds to plasma remedy was once discovered to be depending on plant species with a correlation between the boom enhancement and O3 and NOx awareness (Shiratani *et al.,* 2016). Different contents of treasured secondary plant metabolites between control sprouts and sprouts from handled seedlings illustrated adjustments in metabolism strategies in tested species (Bubler *et al.,* 2015a; Shiratani *et al.,* 2016). Applied to different grains, CP was similarly determined to reduce cooking time, enhance cooking houses and positively have an impact on the surface characteristics (Sarangapani *et al.,* 2017c), to expand a-amylase activity and water absorption (Lee *et al.,* 2016). CP ought to provide a modern future approach to modify seed germination characteristics and may also similarly be applied for decontamination, coating, acceleration of germination and boom of seeds and seedlings for different agricultural and food-related issues. Application of CP to intermediate products from grains e.g. flour, pellets etc. brought about a growing flour water maintaining capacity with extent in plasma energy and publicity time (Thirumdas *et al.,* 2016, 2017) as nicely as vast effects on solubility and swelling electricity alongside a discount in pasting viscosity. Mild oxidation in the proteins accompanied by an make bigger in carbonyl corporations and floor hydrophobicity as well as the reduction of free SH organizations had been attributed to reactions of reactive oxygen and nitrogen plasma species with whey protein isolate (Segat *et al.,* 2015). A certain diploma of unfolding may also be responsible for the enhancement in foaming and emulsifying potential determined. Water and fats binding capacities in protein-rich pea flour increased following CP redress in air (Bubler *et al.,* 2015c). Comparing the plasma-induced outcomes to those triggered by way of warmth treatment, the applicability of semi-direct CP cure during postharvest processing of Tenebrio molitor flour (Bubler *et al.,* 2016) validated the specificity of plasma modification. The secondary structure of gluten grew to be steadier following the publicity of wheat flour to air plasma and substantial modifications in the rheological residences of the corresponding dough’-s have been bought (Misra *et al.,* 2015). Plasma-induced outcomes on viscosity and elasticity have been located to rely on the treatment conditions, applied voltage and exposure time. The findings point out that CP may additionally serve as a modern approach to modulate the performance of wheat flour at some point of processing of wheat-based merchandise such as bread, pasta, noodles, cookies, and others. The floor change of bakery merchandise might also provide every other plasma application, considering that caused an increase in the hydrophobicity of freshly baked biscuit surfaces resulting in multiplied spreading of any oil sprayed and as a result decreased seepage (Misra *et al.,* 2014e). As the interplay of plasma with water consequences in the era of reactive oxygen and nitrogen species, along with nitrates and nitrites (Oehmigen *et al.,* 2010), frankfurters had been manufactured by replacing the nitrites of the curing salts with the aid of plasma-treated water (Jung et al. 2015ab) leading to residual nitrite content which was 30% lower in sausages processed with plasma-treated water. Comparable findings were acquired by immediateplasma-treating meat butter at extraordinary levels for the duration of sausage manufacturing. As a result, a patent to eliminate nitrites in meat products through CP science was once lately utilized for (Lim *et al.,* 2015). Results of recent studies are current a whole branch of plasma purposes in the discipline of inactivation of deteriorating enzymes, improvement of bodily and mechanical traits of films, as nicely as of techno-functional residences of meals components, and a discount in food allergenicity. Based on the kingdom of the art, the doable for in addition investigation on the enhancement of understanding of these plasma-underlying mechanisms at the molecular scale and of the improvement of kinetics of reactions is great. Considering that plasma in humid air, relying on the gasoline mixture and the voltage applied, consists of more than seventy-five species (Misra *et al.,* 2016b), the chemistry of CP is complex and the several plasma-immanent species will lead to almost 450 reactions(Kossyi *et al.,* 1992).

**ADVANTAGES AND DISADVANTAGES OF COLD PLASMA**

Despite numerous studies, countless components of the CP technique in the food industry remain unknown. For example, there are nevertheless some research gaps related to the effects of CP on allergens and antioxidants. Furthermore, research on the safety, toxicity, and/or health effects of CP-treated meal products on human beings is required. Because different plasma components have unique results on exceptional meal products, optimization studies for the type, intensity, and period of plasma treatments, as properly as the food type, are required. The growing use of inexperienced maintenance strategies has led to the improvement of di-verse technologies, each pursuing software in the food enterprise worldwide. Regrettably, most counseled inexperienced applied sciences are both restricted due to the high price of equipment, have an impact on product quality, are not appropriate for all meal types, or are inadequate for maximum meal product protection. On the one hand, most literature only described CP utility at pilot-scale stages with restrained surface coverage. As a result, increasing the plasma-generating electrode dimension may increase the plasma’s quantity and coverage. Regrettably, this complete progress is time-consuming and high-priced. On the other hand, CP enhances the dietary first-rate of some meal merchandise with the aid of increasing complete phenolic compounds, amino acids, and sugars. Such improvements, however, are structured on the gas mixture used to generate plasma and the mode of exposure/penetration over the food material.

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