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Cold Plasma a Non-Thermal Technology for Food Applications

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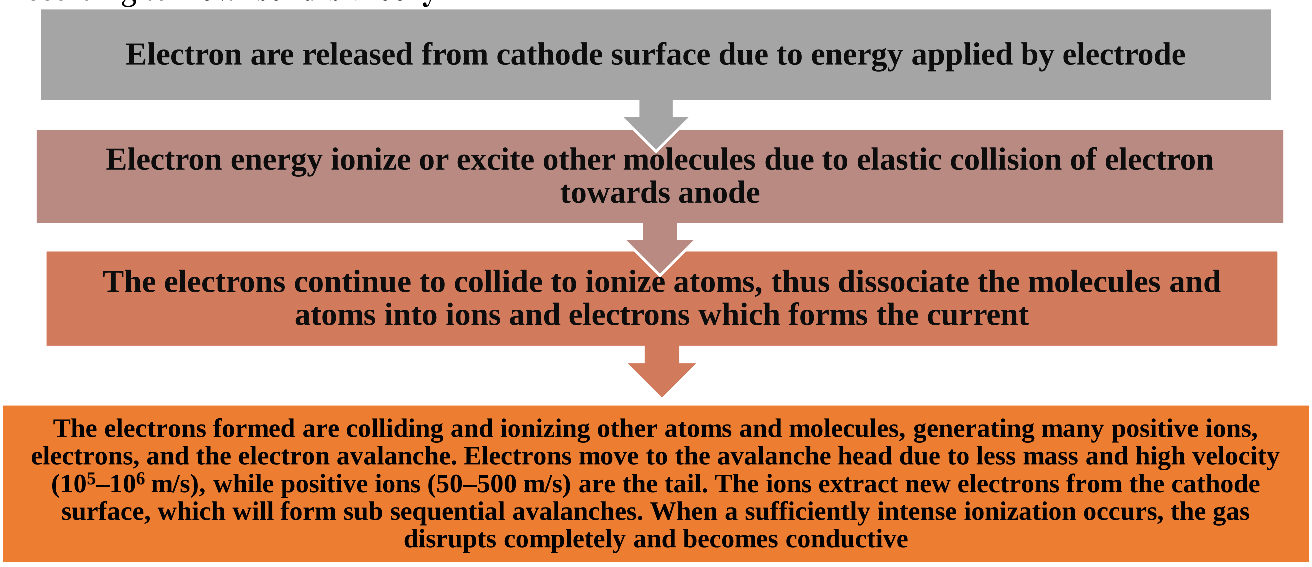
SUMMARY

Application Non thermal technologies consisting, high-pressure processing, ultrasound, pulsed electric field, ultraviolet light, high-intensity pulsed light, gamma irradiation in food are nowadays increasing due to their reduce microbial count, inactivate enzyme, increase the concentration of bioactive compounds, enhance antioxidant activity, and reduce pesticides and allergens in food products. Cold plasma is generated by three methods like, dielectric barrier discharge, corona discharge and plasma jet. Technology is having promising non-thermal effect in terms of improving food safety with minimal impact on food quality under optimal conditions.

INTRODUCTION

Non-thermal processing technologies have gained attention by increasing functionality, shelf-life, reducing the negative impact on food nutrients and natural pigments. The examples of such non-thermal methods are high-pressure processing, ultrasound, pulsed electric field, ultraviolet light, high-intensity pulsed light, gamma irradiation, and, most recently, cold plasma. The three conventional states of matter are solids, liquids, and gases; plasma has been described as the fourth state of matter. Cold plasma is a novel non thermal food processing technology that uses energetic, reactive gases to inactivate contaminating microbes on meats, poultry, fruits, and vegetables. Plasma can be defined as an ionized gas containing reactive oxygen species, reactive nitrogen species, ultraviolet radiation, free radicals, and charged particles. Plasma is generated when electrical energy is applied to gas present or flowing between two electrodes with a high electrical potential difference that causes gas ionization due to free electrons colliding with those gas molecules. When the ionized gas is formed by relatively low energy (1 to 10 eV) and electronic density (up to 10^{10} cm^{-3}), it is called Cold Plasma. The average electron energy of Cold Plasma, up to 10 eV, is ideal for the excitation of atomic and molecular species and breaking the chemical bonds. Reductions of greater than 5 logs can be obtained for pathogens such as Salmonella, Escherichia coli, Listeria monocytogenes, and Staphylococcus aureus. Effective treatment times can range from 120 s to as little as 3 s, depending on the food treated and the processing conditions.

Cold Plasma generation theory: There are two theories namely Townsend's theory and Streamer theory which explain cold plasma generation.
According to **Townsend's theory**



According to **Streamer theory**,

Anode captures the electrons forms a volume of positive ions between the electrodes (space charge). The ions recombine with free electrons, and photons are emitted, causing the nearby gas photoionization, and generating more electrons. Thus, new avalanches are formed (secondary avalanches).

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The secondary avalanches join the main avalanche, as the electrons recombine with their positive ions

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A consecutive and rapid process occurs, with photons release and new avalanches formation creating a highly conductive channel, known as streamer discharge theory

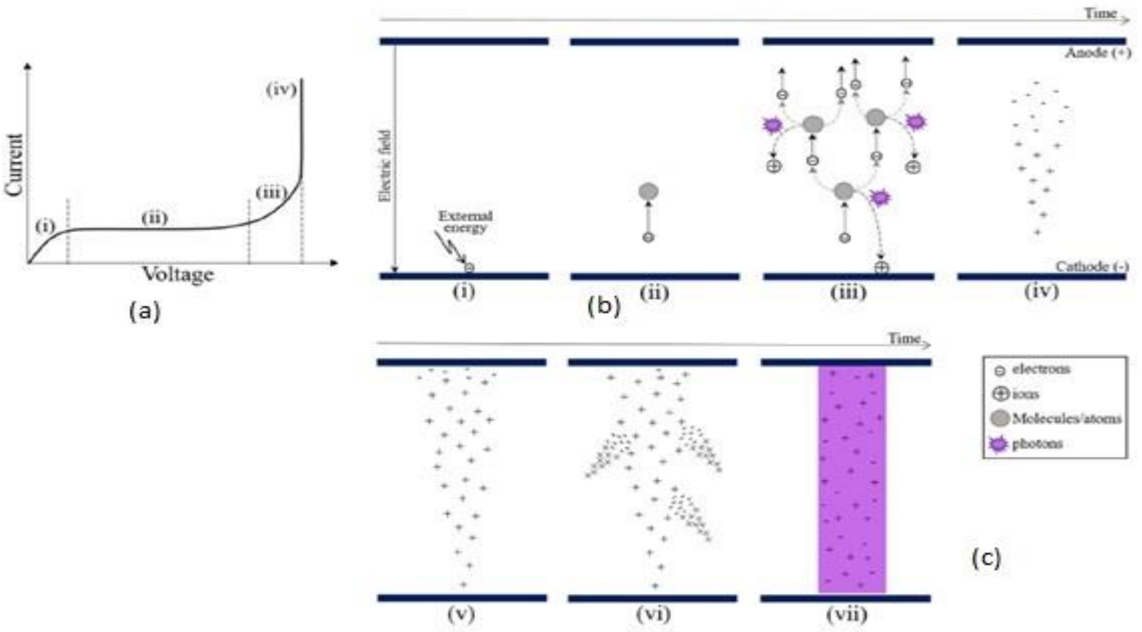

Fig. 1. (a) Voltage *versus* current gas discharge and (b) gas breakdown by Townsend theory, and (c) streamer theory. (i) Electrons released from the cathode, (ii) electrons accelerated opposition to the electric field, (iii) electrons collision and molecules/atoms dissociation, (iv) avalanche formation and gas breakdown, (v) electrons captures by anode and volume of positive ions, (vi) secondary avalanches join the main avalanche, (vii) highly conductive channel formation.

Mode of Application: The Cold Plasma for food processing are categorized into dielectric barrier discharge (DBD), plasma jet (PJ), corona discharge (CD), radiofrequency (RF), and microwave (MW) mode.

Mode of Application of Cold Plasma

Corona Discharge (CD): It is defined as a luminous glow localized in space near sharp points, edges, or thin wires in a highly non-uniform electric field. An asymmetric electrode pair characterize this discharge type, e.g., a point and a plane are formed when the electric field exceeds the breakdown threshold in a limited spatial region. The high electric field near the electrode exceeds the gas breakdown strength, creating a weakly ionized plasma

Plasma Jet (PJ): It consist of two rings, coaxial electrodes, in which the gas flows between the pair of electrodes. The outer electrode is grounded, and the central electrode is excited at 13.56 MHz, accelerating the free electrons that collide with gas molecules forming various reactive species. The gas flowing under a high flow rate, usually a noble gas or a mixture with a reactive gas, pushes the plasma formed outside the electrode region, projected as a jet, and discharges plasma species in the open environment

Dielectric Barrier Discharge (DBD): DBD plasma is generated by a high voltage applied between two metal electrodes (a powered electrode and a ground electrode). One or both electrodes are covered with a dielectric material, such as a polymer, glass, quartz, or ceramic, separated by a variable gap ranging from 0.1 mm to several cm. Parameters for DBD operation is (i) gas pressures between 1×10^4 and 1×10^6 Pa, (ii) frequency band varying between 10 and 50 MHz, (iii) alternating current (AC) or pulsed direct current (DC) with voltage amplitude oscillating between 1 and 100 kV_{rms}

Food Application: Recently, Cold Plasma has been incorporated into the food industry to reduce microbial count, inactivate enzyme, increase the concentration of bioactive compounds, enhance antioxidant activity, and reduce pesticides and allergens in food products. However, Cold Plasma treatment is still an emerging process regarding adverse effects in foods (e.g., lipid oxidation), safety evaluation, consequences of Cold Plasma application to different food types and regulatory approval.

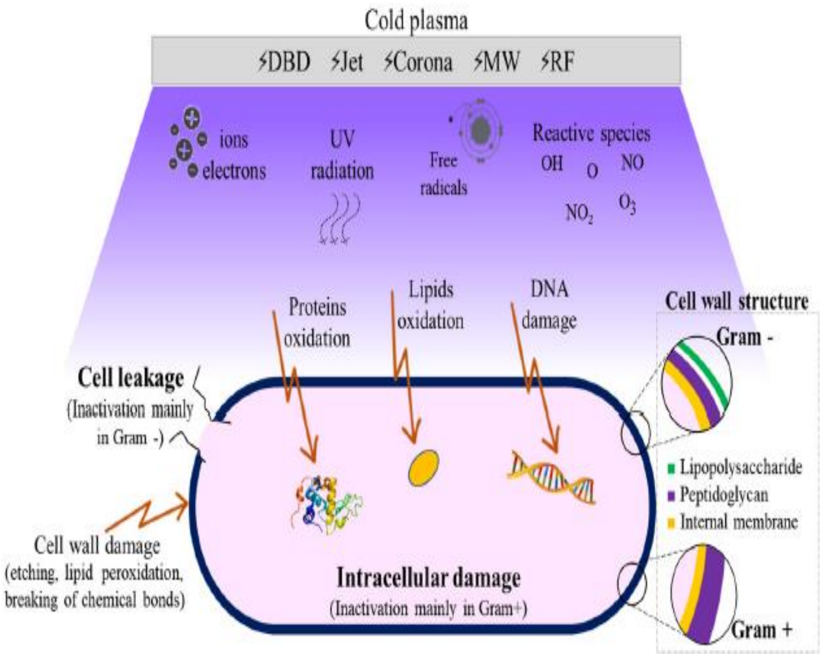

Fig. 2. Mechanism of Gram-negative and Gram-positive bacteria inactivation using CP

Microbial inactivation: The antimicrobial efficacy of CP depends on several parameters such as environmental factors (temperature and RH), food properties (moisture content, pH product composition, surface properties, and surface area/volume ratio), processing parameters (voltage, frequency, gas composition, flow rate, treatment time, electrode type, interelectrode gap, headspace, and exposure pattern time), and characteristics of the microorganisms (type, strain, growth phase, and initial count. Damage of the *E. coli* cell membrane, provoking cytoplasm leakage after PJ treatment in chokeberry juice is reported by Han et al. 2016. CP is more effective against Gram Negative than against Gram Positive bacteria due to peptidoglycan cell-wall thickness differences (Gan et al. 2019).

Effects on food components: Cold Plasma treatment can influence positively or negatively the food components and their nutritional properties. Plasma Jet in blueberry juice using Ar added 1 % of O_2 for 6 min, increasing the total phenolic content (TPC) from 113.32 µg/mL up to 121.64 µg/mL. (Hou et al. 2019).

Enzyme inactivation: The spread of the secondary structure, which generally represents the most stable part of proteins, due to plasma reactive species attack, causing the breakdown of specific bonds or chemical modifications of the side chains. Kinetics of peroxidase (POD) and polyphenol oxidase (PPO) inactivation in tender coconut water after DBD plasma treatments at atmospheric air showed that that the POD was more resistant than PPO (Chutia et al. 2019).

CONCLUSIONS

Cold plasma (CP) has been increasingly recognized as a promising non-thermal technology that can improve food safety with minimal impact on food quality under optimal conditions. It also requires considerable research to understand better reaction mechanisms, antibacterial pathways, and negative impacts and limitations on visual, chemical, nutritional, and functional properties of food products.

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