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Cold Plasma Technology: Transforming the Future of Food Preservation

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Non-thermal technologies, such as cold plasma, are gaining popularity in the food industry due to their eco-friendly and sustainable nature (Harikrishna et al., 2023). Cold plasma technology has several advantages, including being non-thermal, operating at atmospheric pressure, and requiring little energy and water. It generates reactive species that inactivate microorganisms, preserving food quality. Compared to other non-thermal methods like high-pressure processing (HPP) and pulsed electric fields (PEF), cold plasma technology has distinct advantages. HPP can affect food texture and is energy-intensive, while PEF requires careful control to avoid adverse effects on food quality. Cold plasma technology shows promise in enhancing functional properties of proteins, reducing allergenicity, and improving extraction efficiency of bioactive compounds. It is a versatile and effective alternative in non-thermal food processing technologies (Cen et al., 2014). While its efficacy in sterilization is still being studied, cold plasma technology has the potential to benefit the food industry in various ways, making it a promising area of research and development.

Plasma sources and types

When matter is energized, its state undergoes a transformation related to the material phase diagram. For instance, when a solid is heated to its melting point, it transitions into a liquid. Similarly, when a liquid is subjected to heat, it transforms into a gas. These changes occur due to energy input, such as heat or electric power. Plasma, often referred to as the fourth state of matter, is formed when a gas is heated to the point where it contains reactive ion species, including electrons, positive and negative ions, free radicals, gas molecules, and photons, among others.

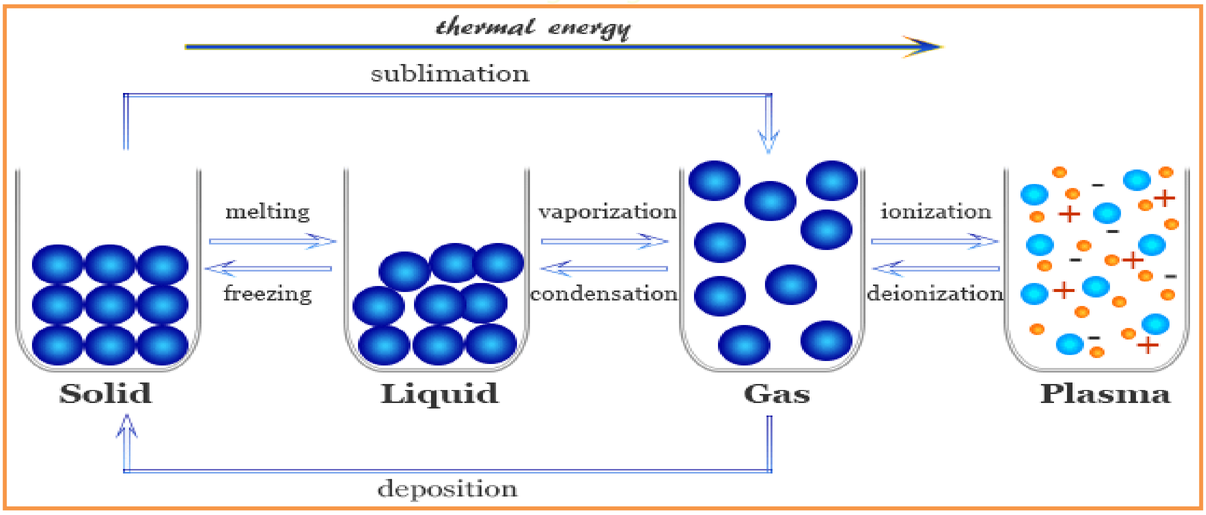
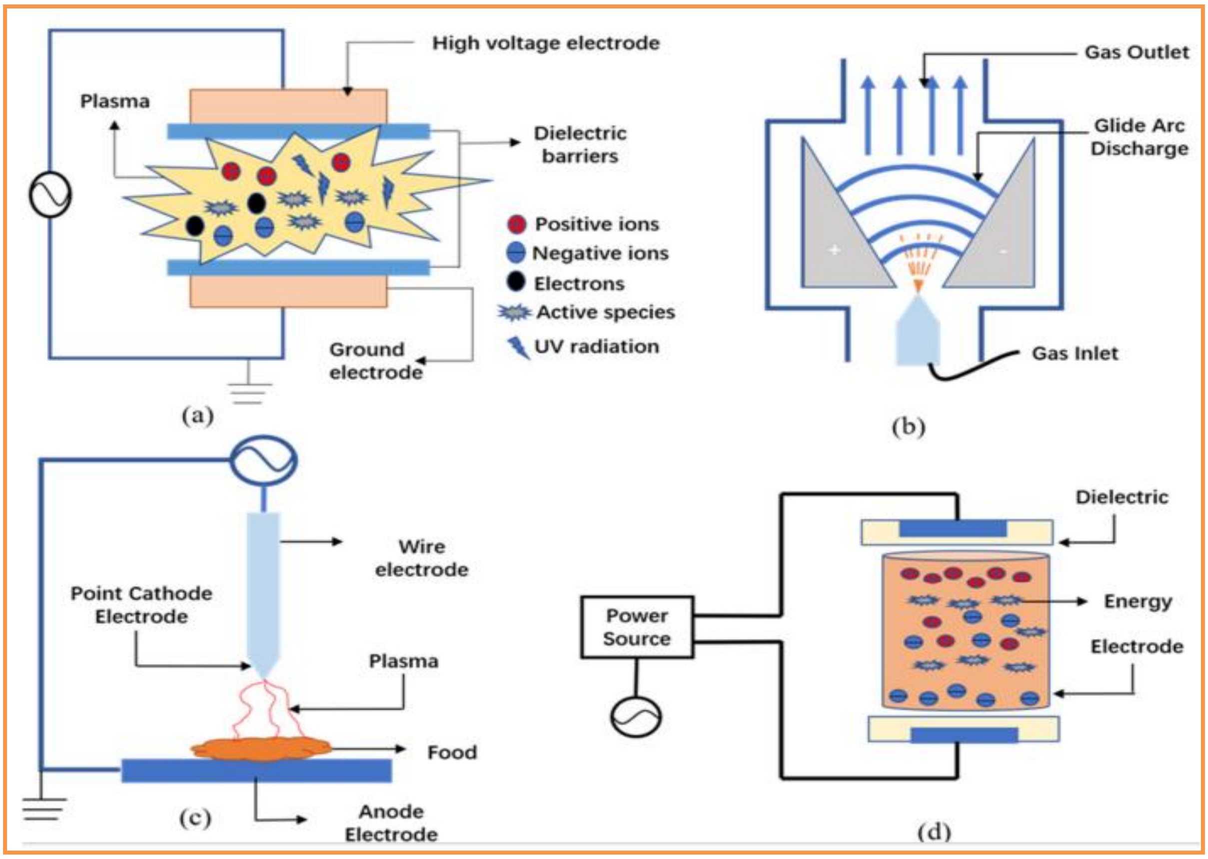


Illustration of plasma state

In the realm of cold plasma, this form of non-thermal plasma has emerged as a promising technology with versatile applications in the food and agriculture sectors. Created through electrical discharges within a room-temperature gas environment, cold plasma maintains low temperatures of ions and gas components, making it particularly valuable for food industry applications. Its utilization aids in preserving the quality and sensory attributes of food products while ensuring their safety (Amrinder and Gurbhej, 2023). A variety of techniques are employed to generate cold plasma, including radio frequency, corona discharges, dielectric barrier discharges, gliding arc discharges, one atmospheric uniform glow discharges, plasma spray, plasma needle, and atmospheric pressure plasma jet.



Schematic diagram of various equipment for generating plasma (a) dielectric barrier discharge, (b) corona discharge, (d) glide arc discharge

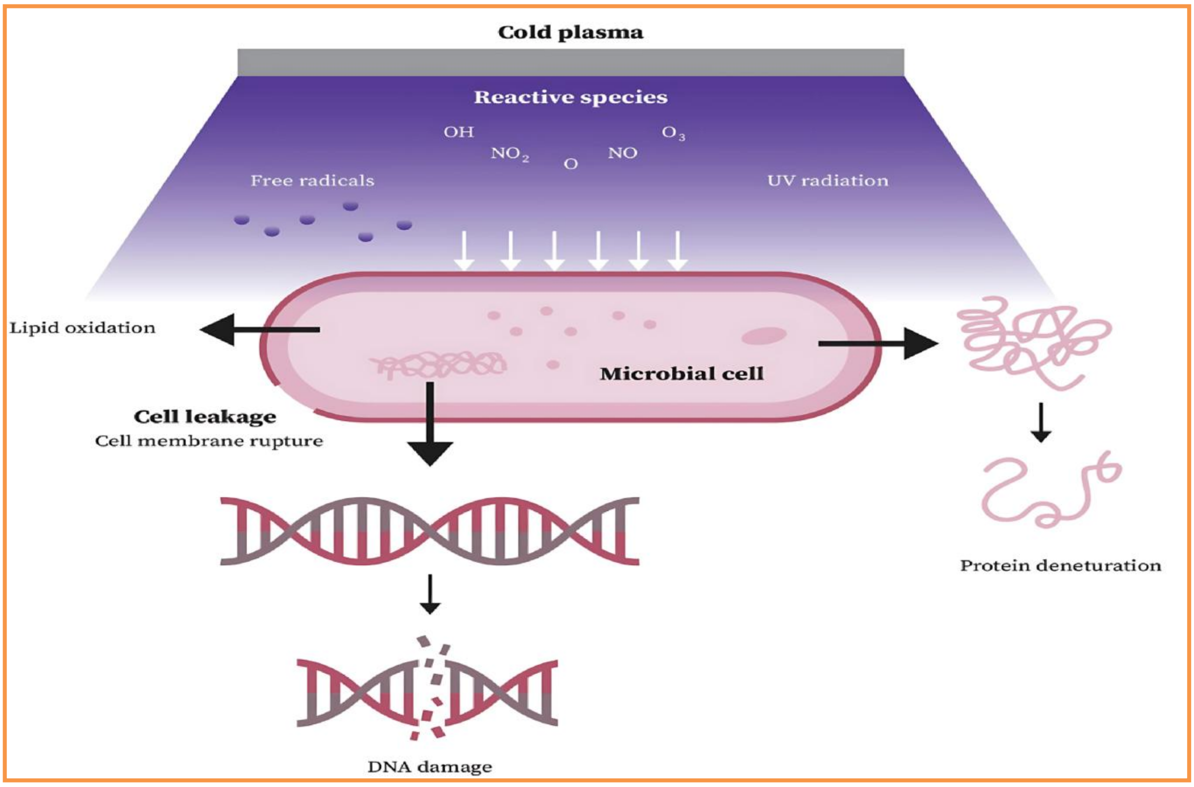
Plasma reaction

Cold plasma systems generate plasma through gas ionization, producing ions, electrons, and reactive species. These species participate in chemical reactions, degrading or modifying organic compounds and altering surface properties. Cold plasma is used in various applications, including biomedical, environmental, and industrial settings, for surface modification, sterilization, and other purposes (Dharini et al., 2023).

Properties of major reactive oxygen and nitrogen species of plasma

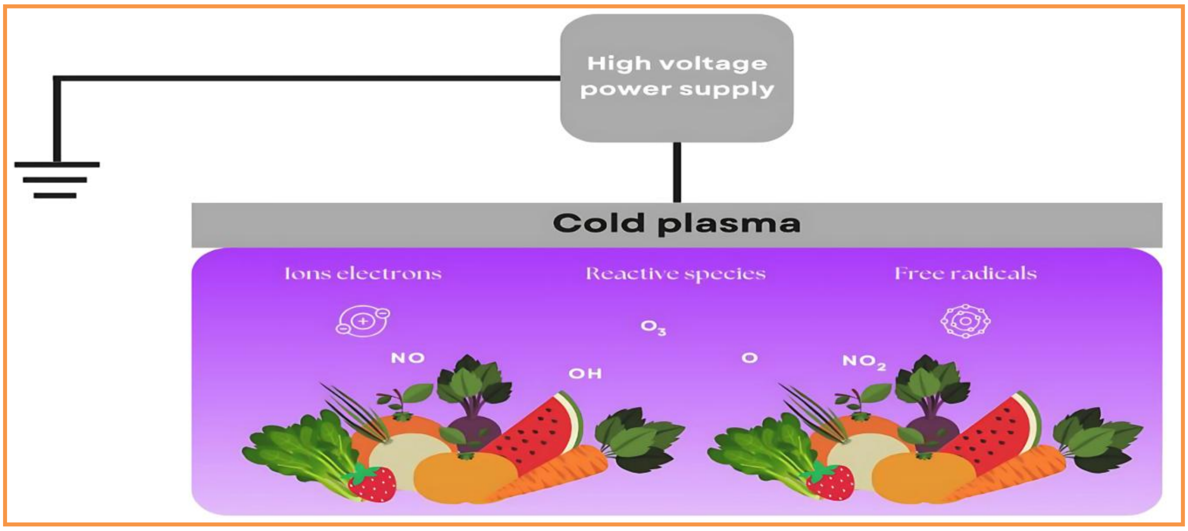
Impact of plasma on nutrient bioavailability: Plasma treatment enhances nutrient bioavailability by inducing structural changes in food components, such as proteins and lipids, making them more accessible to digestive enzymes. This process can partially denature proteins, increasing their digestibility and absorption. Additionally, plasma treatment can break down antinutritional factors like phytates, oxalates, and tannins, which hinder mineral absorption, making minerals more available for absorption (Dabade et al., 2023).

Plasma sterilization: Plasma sterilization is an advanced method for eliminating microbial pathogens, including bacteria, fungi, and viruses, in various industries such as healthcare and agriculture. It is used to sterilize medical and dental devices, ensuring equipment is free from harmful microorganisms. Unlike chemical disinfection methods, plasma sterilization does not leave residues or generate toxic compounds, and has broad-spectrum antimicrobial activity with minimal environmental impact. It can be applied to various packaging materials without causing damage, and has the potential to extend shelf life by inactivating spoilage enzymes, making it a promising advancement in food processing technology (Ucar et al., 2021).



Mechanisms of microbial inactivation by cold plasma

Plasma-activated water (PAW): PAW is a novel technology that harnesses plasma discharge to create a highly reactive and oxidizing aqueous solution. It is used in various stages of the food supply chain to ensure the safety and quality of consumable goods. It extends the shelf life of fresh produce by minimizing microbial contamination, enhancing food preservation, and reducing food waste. The vegetable and fruit processing industry utilizes cold plasma technology to reduce the total microbial load in products, such as juices and fresh-cut fruits and vegetables. This technology also preserves antioxidants, controls undesirable browning reactions, and decreases the activity of unwanted enzymes (Wang et al., 2021). Overall, PAW is a promising alternative to traditional chemical disinfectants for ensuring food safety and quality.



Cold plasma to extend the shelf life of fresh fruits and vegetables

Conclusion

Cold plasma technology holds great promise in the food industry, addressing key challenges, enhancing safety, and improving quality. It offers a non-thermal method for microbial inhibition, extending shelf life while preserving nutritional and functional qualities. Effective in reducing microorganisms in various foods. It enhances the digestibility of plant-based proteins and reduces allergenicity, creating safer, more digestible products. The technology also improves the extraction of bioactive compounds from plant materials, boosting nutritional profiles. Overall, cold plasma represents a transformative approach to food processing, driving innovation and meeting consumer needs.

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