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Non-Thermal Decontamination: A Closer Look at Emerging Technologies

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Introduction:

Fresh fruits and vegetables are the main components of a healthy diet, providing essential nutrients vitamins, minerals, and antioxidants. They have a short shelf life primarily because of their high-water content, ongoing biochemical processes, and vulnerability to spoilage by microorganisms. Many food products can also carry harmful microorganisms that can cause foodborne illnesses. Foodborne illnesses are a serious global health concern, impacting millions of people each year. To mitigate this risk, non-thermal decontamination technologies offer a promising solution. By non-thermal decontamination techniques, microorganisms can be effectively inactivated and controlled. These innovative techniques have numerous advantages over traditional heat-based methods, including the preservation of food quality, nutritional value, and sensory attributes (taste, texture, color) of fresh produce.

Thermal vs. Non-Thermal Decontamination: Which is Best?

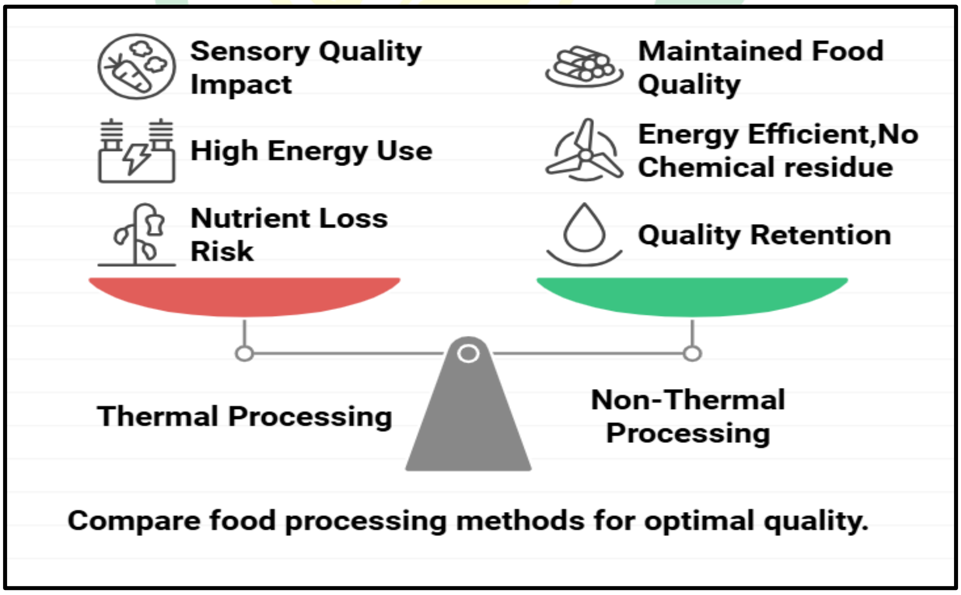
Traditional heat-based processing methods, including blanching, pasteurization, and canning, have long been used to ensure food safety. While effective in reducing microbial load, these methods often involve preparatory steps like peeling and cutting, which can lead to nutrient loss and oxidation. Moreover, high temperatures can negatively impact the sensory attributes of food, changing its color, flavor, and texture.

In contrast, non-thermal technologies offer a promising alternative. Non-thermal technologies, such as High-Pressure Processing (HPP), Pulsed Electric Fields (PEF), Cold Plasma treatment, Ultraviolet (UV) irradiation, Ozone treatment, and Ultrasound, offer promising alternatives for inactivating microorganisms without subjecting the food to harsh thermal conditions.

These methods offer several advantages:

- **Preservation of Nutritional Value**: Non-thermal technologies minimize the loss of vitamins, minerals, and antioxidants, preserving the food's nutritional profile.
- **Retention of Sensory Quality**: These techniques help maintain food products' original color, flavor, and texture.
- **Energy Efficiency:** Non-thermal processes often require less energy input than thermal methods, making them more environmentally friendly.
- **Reduced Chemical Usage:** Non-thermal technologies can reduce reliance on chemical preservatives and can lead to the decontamination of foods with a cleaner label and a more natural character.
- **Increase Shelf Life**: - Effective decontamination extends the shelf life of food product, reducing waste and improving food security.
- **Improved Food Safety**: Many of these decontamination technologies are effective at inactivating a wide range of foodborne pathogens, enhancing food safety.

While thermal processing remains a reliable method, non-thermal decontamination methods are gaining increasing attention because they can deliver safer, healthier, and more appealing food products.



Type of Non-thermal Decontamination Technologies:

- Cold Plasma
- Ultrasonication:

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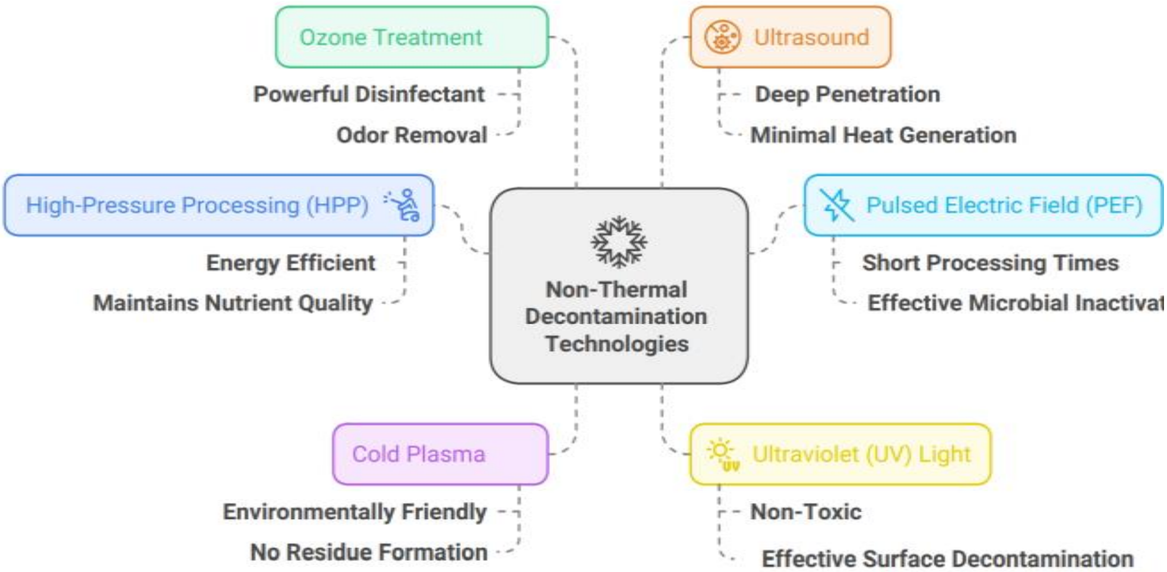
- Ozonation:
- Ultraviolet (UV) irradiation
- High Hydrostatic Pressure (HHP)
- Pulsed Electric Field disruption (PEF)
- Irradiation



How effective are non-thermal technologies in killing microorganisms?

1. **Atmospheric Cold Plasma (ACP):** Atmospheric Cold Plasma is an innovative technology that harnesses the power of ionized gas to inactivate microorganisms. Plasma is the fourth state of matter that generates a complex mixture of highly reactive species, including reactive oxygen species (ROS) and reactive nitrogen species (RNS), such as ozone, hydroxyl radicals, and nitric oxide. Plasma is generated by adding energy to a gas, which causes the atoms to lose electrons and become ionized. This ionization process can be achieved through various methods, including thermal ionization, where heating gas to extremely high temperatures provide the necessary energy. Electrical discharge, as seen in fluorescent lights and neon signs, utilizes high voltage to ionize the gas. Additionally, exposure to electromagnetic radiation, such as X-rays or ultraviolet light, and particle impact can also impart sufficient energy to strip electrons from atoms, resulting in plasma formation. ACP offers a significant solution for food safety, as it can preserve the fresh-like qualities of treated foods, ensuring they

remain appealing to consumers. This green and sustainable technique is gaining significant attention in the food industry due to its potential to revolutionize food safety practices without compromising quality. These species disrupt microbial cell walls, causing cell death and achieving effective decontamination.

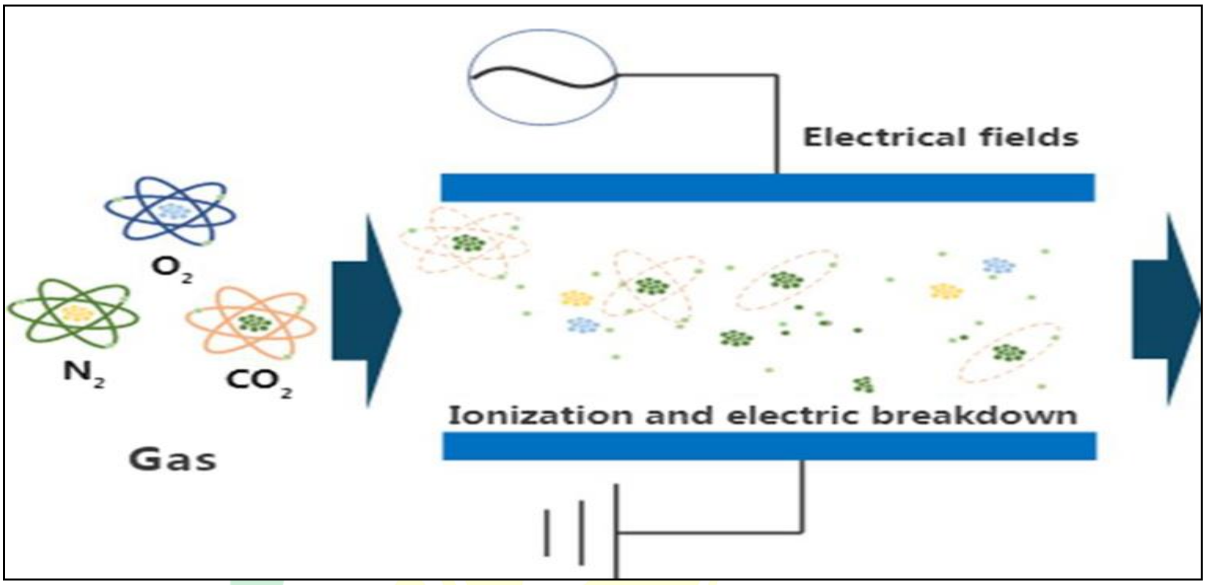


Fig.- 1 Schematic Representation of Cold Plasma Generation

2. **Ultrasonication:** Ultrasonic cleaning leverages the power of sound waves to effectively decontaminate fruits and vegetables. When the introduction of ultrasonic waves into a cleaning solution causes the formation of microscopic bubbles that rapidly expand and collapse, generating intense localized pressure and temperature fluctuations. This phenomenon, known as cavitation, disrupts the microbial cell membranes, resulting to their inactivation. Moreover, ultrasound treatment has been shown to effectively reduce the activity of crucial enzymes like polyphenol oxidase (PPO), peroxidase (POD), and pectin methylesterase (PME), thereby extending the shelf life and maintaining the freshness of produce. Ultrasonic equipment typically employs frequencies between 20 kHz and 10 MHz for food decontamination The application of ultrasound in cleaning demonstrates considerable potential, driven by factors such as low equipment costs, straightforward operation, high levels of automation, and exceptional cleaning effectiveness. The mechanical forces generated by cavitation, combined with the increased penetration of the cleaning solution into surface irregularities, contribute to the removal of dirt, debris, and microbial

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contaminants. This non-thermal technique offers a promising approach to enhance food safety without compromising the quality of the produce. The effectiveness of ultrasonic cleaning for decontamination depends on factors like frequency, power density, cleaning solution, sonication time, and temperature. Lower frequencies are suitable for larger items, while higher frequencies are better for delicate surfaces. Increased power density enhances cleaning but can damage delicate materials. The choice of cleaning solution and the duration of sonication also play crucial roles in achieving effective decontamination. Ultrasonication, employing frequencies from 20 kHz to 100 MHz, finds applications in various fields. Low-frequency (20-100 kHz) ultrasound is used for the extraction of bioactive compounds and emulsification process. Medium-frequency (100 kHz-1 MHz) ultrasound is suitable for debinding processes. High-frequency (1-100 MHz) ultrasound is employed for intensified synthesis reactions.

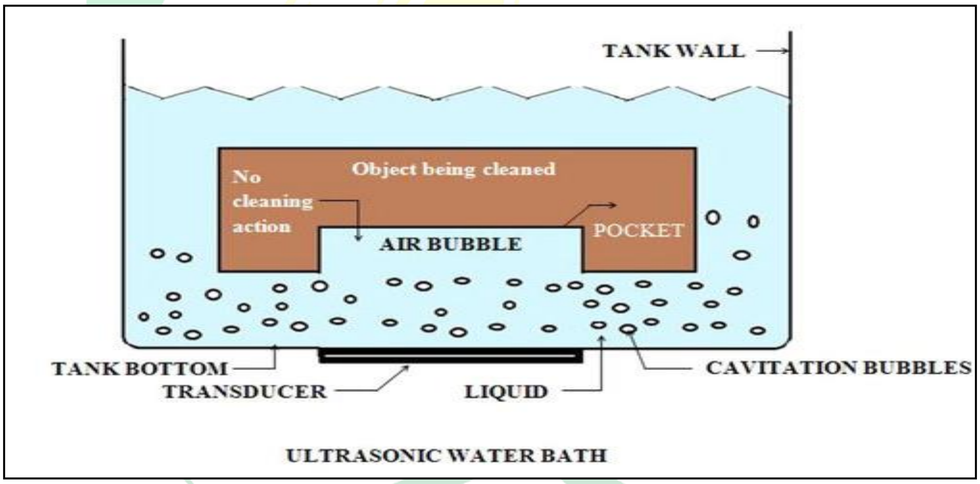

Fig.- 2 Ultrasonication Device

3. **Ozonation**: Ozone, a potent oxidizing agent, is increasingly applied for reducing microbial contamination on fruits and vegetables. Generated through specialized ozone generators, this unstable molecule readily reacts with organic and inorganic matter, inducing oxidative stress on microbial cells. Ozone molecules can penetrate cell membranes, damage proteins, and disrupt genetic material, leading to cell death. This broad-spectrum antimicrobial activity makes ozone active against a wide range of microorganisms, including bacteria, viruses, and fungi. Ozone treatment can be applied in two ways: as a gas or dissolved in water. A significant advantage of ozone treatment is its environmentally friendly nature. After decontamination, ozone decomposes into

oxygen, leaving no harmful residues on the produce. This minimizes the risk of chemical contamination, ensuring food safety. To optimize ozone treatment, concentration and exposure time should be carefully optimized by controlling these parameters, it is possible to achieve effective microbial reduction while maintaining the quality and nutritional composition of the produce.

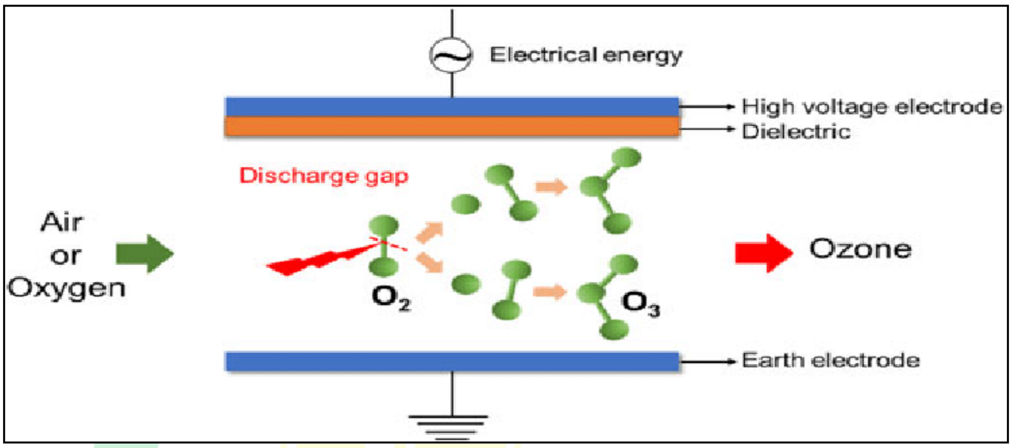

Fig.-3 Ozone formation

4. **Ultraviolet (UV) Radiation:** UV light exhibits strong antimicrobial activity, it causing damage to the DNA or RNA within microorganisms. Specifically, the nucleic acids within microbial cells absorb UV light in the UV-C range, typically around 254nm (nanometres). This absorption induces the formation of covalent bonds between adjacent nucleotides, creating thymine or uracil dimers. These DNA or RNA dimers affect the normal functioning of genetic material in microorganisms, impeding their ability to replicate and rendering them inactive. UV light finds widespread disinfection applications in water purification, air purification, and surface decontamination. While these treatments effectively reduce the number of pathogens on the surface of fresh fruits and vegetables, they are selective in their action. Consequently, employing nonselective treatments to eliminate surface pathogens on fresh produce might be a more effective approach. The effectiveness of UV light in microbial inactivation is affected by various factors like the intensity and duration of exposure, the types of microorganisms present, and the environmental conditions. While UV disinfection is a well-established method, its successful use relies on proper application and understanding of its limitations. Established method, its successful use relies on proper application and understanding of its limitations. UV light for surface decontamination

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uses UV-C light with a wavelength range of 200-280 nm, which is extremely effective at killing microorganisms. UV-A (320-400 nm) and UV-B (280-320 nm) wavelength radiation are less effective for disinfection.

5. **High Hydrostatic Pressure:** High Hydrostatic Pressure (HHP) leverages water to apply pressure on food, effectively reducing populations of pathogenic bacteria (both Gram-negative and Gram-positive), yeast, and mold. This non-thermal method enhances food preservation by inactivating microorganisms. The effectiveness of HHP treatment is influenced by pressure, temperature, and the specific food type. HHP typically involves subjecting food to high pressure (200-700 MPa) for a brief duration
6. **Pulsed Electric Field (PEF):** Pulsed Electric Field (PEF) is a non-thermal technology that uses short, high-voltage electrical pulses to inactivate microorganisms in food. This innovative technique offers several advantages over traditional thermal methods, including minimal impact on the visual and nutritional quality of the food. PEF creates temporary pores in microorganisms' cell membranes, leading to cell death. This process effectively inactivates a wide range of microorganisms, extending the shelf life of food products and reducing the risk of foodborne illnesses. PEF is a versatile technology with use in various food processing areas, including juices, dairy products, and meat. It provides a sustainable and efficient approach to food preservation, safeguarding food safety and quality.

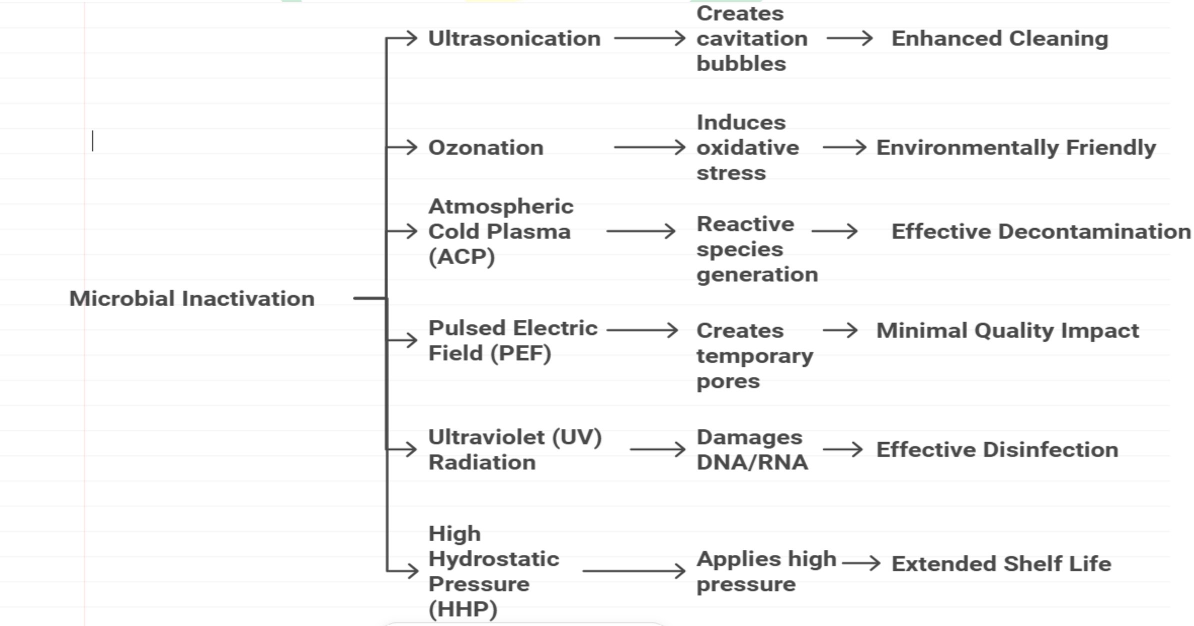

Fig.:4 Overview of Non-Thermal Decontamination Technology

Conclusion:

These techniques can effectively inactivate microorganisms and preserve food's sensory, nutritional, and functional properties. However, careful optimization of treatment parameters is crucial to avoid potential drawbacks such as oxidative changes and loss of quality. To fully realize the potential of non-thermal technologies, further research, and development are needed to address technical challenges and consumer perceptions. By developing efficient and scalable equipment, establishing standardized processing protocols, and educating consumers about the benefits of these technologies, we can promote their widespread adoption in the food industry. Ultimately, the integration of non-thermal technologies into food processing will produce safer, healthier, and more sustainable food products.

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