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Use of Ozone and Cold plasma in Reducing Post-Harvest Losses in Fruits

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Post-harvest fruit losses continue to be a serious global challenge, with nearly one-third of production wasted because of spoilage, microbial contamination, and poor handling practices. Traditional preservation methods face limitations due to chemical residues, high energy consumption, and the development of resistant pathogens. Ozone and cold plasma have therefore gained attention as environmentally friendly, residue-free preservation options. Ozone inhibits microorganisms and breaks down ethylene, helping to slow fruit ripening, while cold plasma disinfects fruit surfaces without thermal damage. Both technologies effectively reduce microbial load, extend storage life, and preserve fruit quality, making them sustainable solutions for minimizing post-harvest losses.

Keywords: Post-harvest loss; Ozone treatment; Cold plasma; Fruit storage; Non-thermal technology; Shelf-life extension

Introduction

Each year, considerable quantities of fresh fruits are wasted due to spoilage and poor storage, leading to economic losses and threats to food security, particularly in regions with limited cold-chain facilities. The Food and Agriculture Organization stresses that reducing food loss is essential for improving sustainability and global food availability (FAO, 2019). Although refrigeration and chemical treatments are commonly practiced, concerns over chemical residues, pathogen resistance, and environmental effects have prompted the search for safer alternatives. Consequently, ozone and cold plasma have emerged as promising non-chemical methods for extending fruit shelf life while preserving quality and safety.

The Challenge of Postharvest Losses in Fruits

Fruits deteriorate rapidly after harvest due to on going respiration, moisture loss, and physiological changes that increase their susceptibility to microbial spoilage. Poor handling, physical injuries, inadequate hygiene, and high storage temperatures further accelerate quality deterioration. In tropical climates, postharvest losses in fruits may reach 20% to more than 50% in some crops, underscoring the urgent need for effective postharvest management strategies (Kader, 2004).

Ozone: A Powerful Antimicrobial Gas

Ozone (O_3) is a highly reactive oxygen molecule with strong oxidizing properties, widely used in water and sanitation treatments for its ability to kill bacteria, fungi, and viruses without leaving toxic residues (U.S. Food and Drug Administration, 2001). Unlike chlorine and other chemical sanitizers, ozone decomposes rapidly into oxygen, making it ideal for food-related uses (Güzel-Seydim, Greene, & Seydim, 2004).

Mechanism of Ozone action

When fruits or storage areas are exposed to ozone, it damages the cell walls and membranes of microbes, inactivating them. This oxidative process limits fungal and bacterial spoilage, helping reduce postharvest losses during storage and transport.

Ozone can be applied as gaseous ozone in storage spaces, ozonated water for washing, or generated on-site with ozone machines. Its short lifespan requires production at the point of use for safe and effective treatment.

Research findings confirm the role of ozone in postharvest fruit preservation. Studies on 'Keitt' mangoes revealed that gaseous ozone treatment reduced the occurrence of stem-end rot and slowed quality deterioration, resulting in longer storage life without compromising fruit quality (Bambalele et al., 2023). Other research has also shown that ozone is effective in lowering microbial contamination and improving the shelf life of various fruits and vegetables (Güzel-Seydim et al., 2004).

Advantages of Ozone Application

- Residue-free treatment: Ozone decomposes into oxygen after application.
- Broad-spectrum antimicrobial activity: Effective against bacteria, yeasts, and molds.
- Reduced dependence on conventional fungicides: Supports safer produce.
- Adaptable application: Suitable for small storage facilities and large industrial operations.

Limitations and Safety Considerations

Despite its many advantages, ozone application requires careful control:

- Excessive ozone levels may damage fruit tissues, causing surface injury or off-flavors.
- Ozone is a respiratory irritant: Proper ventilation and safety protocols are essential.
- Equipment-related costs: Ozone generators and monitoring devices increase infrastructure expenses.

Even with these limitations, ozone remains one of the most promising non-chemical approaches for reducing postharvest losses.

Cold Plasma: A New Frontier in Food Preservation

Cold plasma, a non-thermal ionized gas with reactive particles, preserves heat-sensitive fruits by killing microbes while keeping quality intact (Ohta, Misra, Schlüter, & Cullen, 2016).

Mode of Action of Cold Plasma

When cold plasma is applied to fruit surfaces or packaged products, its reactive species interact with microbial membranes and DNA, resulting in microbial inactivation. These reactive species can also degrade ethylene, a plant hormone that accelerates ripening, thereby potentially slowing fruit senescence. Cold plasma is applied either by treating fruits directly in open chambers or by generating it inside sealed packages, effectively controlling microbes without affecting quality. According to Misra et al. (2014), in-package cold plasma reduced microbial growth on strawberries without altering their taste or texture, demonstrating its potential to extend shelf life.

Advantages of Cold Plasma Technology

- Strong antimicrobial action without the use of heat or chemicals.
- Minimal deterioration of quality attributes, including texture and sensory properties.
- Potential to degrade ethylene and delay ripening.
- Compatibility with packaged products, reducing contamination risks.

These characteristics make cold plasma an attractive option for postharvest treatment of fresh fruits.

Challenges and Considerations

Despite its potential, cold plasma technology is still in an early stage of development:

- High initial investment: Equipment and power requirements may be costly for small-scale users.
- Need for process optimization: Treatment conditions must be standardized for different fruits.
- Limited large-scale adoption: Most research remains at laboratory or pilot scale.

Nevertheless, continued research efforts are refining these technologies and moving them closer to commercial application.

Comparing Ozone and Cold Plasma

Ozone and cold plasma are modern, non-chemical approaches used to limit microbial growth and prolong the shelf life of fresh fruits. Ozone controls spoilage mainly through its strong oxidizing action and is already widely used in post-harvest sanitation systems. Cold plasma, on the other hand, produces reactive particles that damage microbial cells and their DNA and may also lower ethylene activity, helping to slow fruit ripening. While ozone is an established technology, cold plasma is still developing and holds considerable potential for future commercial application.

Implementation and Future Outlook

Adoption of ozone or cold plasma technologies should be guided by the nature of the fruit, handling capacity, existing facilities, and adherence to safety norms. Their effectiveness depends on maintaining cleanliness, minimizing physical damage, managing storage temperatures, and applying treatments at appropriate levels. Worker safety must be given priority. Proper ventilation and monitoring are essential for ozone use, while cold plasma systems require electrical safety measures and regular upkeep. Looking ahead, both technologies are expected to gain wider importance in sustainable postharvest systems. Innovations such as automated ozone control, combined non-thermal approaches, and expansion into commercial packing and distribution units are likely to enhance their practical application. Continued research is helping refine these methods to better preserve fruit quality and extend storage life.

Conclusion

Reducing fruit losses after harvest is key to strengthening food systems and environmental sustainability. Both ozone and cold plasma provide chemical-free solutions for controlling microbial spoilage and prolonging storage life. Ozone is already well established in postharvest sanitation, whereas cold plasma is gaining attention for its effectiveness in treating delicate fruits, especially through in-package applications, supporting safer and more sustainable handling practices.

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