



Cold Plasma Applications in Non-Thermal Food Preservation

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DESCRIPTION

Cold Plasma (CP) processing is an innovative non-thermal technology that uses ionized gases to reduce microorganisms on food products and food-contact surfaces. Plasma contains energetic electrons, ions, reactive oxygen species, reactive nitrogen species and other chemically active components. These species can interact with microbial cells and produce cellular damage without requiring the high temperatures commonly associated with conventional thermal sterilization.

Cold plasma can be generated under atmospheric or reduced-pressure conditions. Atmospheric-pressure systems are particularly attractive for food applications because they can operate without the need for complex vacuum chambers. Depending on the design, plasma can be generated using gases such as air, oxygen, nitrogen, helium, or combinations of different gases. Electrical parameters, gas composition, humidity, treatment distance and exposure time influence the resulting plasma chemistry.

The antimicrobial activity of cold plasma involves several mechanisms. Reactive species can interact with microbial membranes, causing structural damage and increased permeability. Proteins may undergo oxidation or modification, while nucleic acids can also be affected. The simultaneous action of multiple reactive components may produce broad antimicrobial effects. However, microorganisms differ in resistance and treatment conditions must therefore be optimized according to the target organism and food surface.

Fresh produce, grains, spices, nuts and other foods may acquire microorganisms during harvesting, transportation, processing and handling. Plasma can provide a low-moisture treatment that reduces surface contamination without requiring large quantities of washing water. This feature may be particularly useful in processing environments where water conservation is important.

Packaging materials and food-contact surfaces can also be treated using plasma. Contamination of packaging surfaces may contribute to post-processing microbial transfer. Plasma-based sanitation could provide an additional hygienic barrier before

filling or sealing operations. The technology can potentially be integrated into automated production lines where treatment occurs continuously.

However, microbial inactivation is not the only consideration. Reactive plasma species can also interact with food components. Lipids may undergo oxidation, pigments can change and aroma compounds may be modified if treatment intensity is excessive. Protein functionality and surface appearance may also be affected. Therefore, successful cold plasma processing requires a balance between microbial reduction and preservation of food quality.

Food geometry can influence treatment uniformity. Plasma exposure may be greater on directly accessible surfaces than in irregular structures, cracks, or protected regions. Surface roughness and moisture can further affect microbial response. Consequently, treatment systems should be evaluated using realistic food surfaces rather than relying exclusively on smooth laboratory materials.

Cold plasma is also being studied for the treatment of agricultural commodities. Seeds and grains can carry microorganisms on their outer surfaces and dry plasma processing may provide an alternative to chemical sanitation. Nevertheless, conditions must be optimized carefully because excessive exposure could influence seed viability, germination, appearance, or functional properties.

The combination of cold plasma with other preservation technologies is an important area of research. Plasma may be integrated with modified atmosphere packaging, refrigeration, antimicrobial coatings, or other non-thermal treatments. Combination systems could potentially achieve microbial targets at lower individual treatment intensities.

Industrial adoption requires reliable process monitoring and safety assessment. The reactive species generated by plasma should be characterized and potential chemical changes in treated foods must be evaluated. Equipment must also be designed to protect workers from electrical hazards and unintended exposure to reactive gases.

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Received: 21-Nov-25, Manuscript No. JFPT-25-32876; **Editor assigned:** 24-Nov-2025, Pre QC No. JFPT-25-32876 (PQ); **Reviewed:** 08-Dec-2025, QC No. JFPT-25-32876; **Revised:** 15-Dec-2025, Manuscript No. JFPT-25-32876 (R); **Published:** 22-Dec-2025, DOI: 10.35248/2157-7110.25.16.1190

Citation: Chen W (2025). Cold Plasma Applications in Non-Thermal Food Preservation. J Food Process Technol.16:1190.

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Energy efficiency and scalability are additional considerations. Laboratory plasma systems can produce promising microbial reductions, but industrial equipment must provide consistent treatment across large quantities of food. Continuous systems, moving belts, rotating chambers and optimized gas flow may help address these challenges.

Future research will likely emphasize standardized treatment protocols, improved plasma generation, real-time process control and detailed assessment of chemical changes. Better understanding of food-surface interactions could allow

treatment conditions to be customized for different commodities.

In conclusion, cold plasma processing offers an important opportunity for non-thermal microbial control. Its ability to treat surfaces at relatively low temperatures and with limited water use makes it particularly attractive for selected foods and packaging applications. With appropriate validation and technological refinement, CP could become an important component of sustainable food-safety strategies.