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APPLICATION OF COLD PLASMA TECHNOLOGY IN THE MICROBIAL DECONTAMINATION OF DRIED FRUITS

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Abstract: Cold plasma (CP) technology has emerged as an innovative, non-thermal method for microbial decontamination in the food industry. This study investigates its application in enhancing the microbial safety of dried fruits while preserving their nutritional and organoleptic qualities. The analysis is based on a review of current scientific literature and technological advancements, as well as comparisons with traditional decontamination methods such as thermal treatment, irradiation, and chemical sanitizers. Results demonstrate CP's high efficiency against a broad range of pathogens, minimal impact on food quality, and potential scalability for industrial application. The paper concludes with recommendations for further research and industry implementation.
Key words: Cold plasma, dried fruits, microbial decontamination, food safety, non-thermal technology, postharvest treatment, food preservation.
Introduction: In recent years, the global demand for safe, minimally processed, and high-quality dried fruits has significantly increased. Consumers now prefer products that retain natural taste, nutritional value, and shelf stability without chemical preservatives or harsh thermal processing. This trend has catalyzed the exploration of novel food preservation methods. One such promising innovation is cold plasma (CP) technology.
Unlike traditional thermal treatments that may degrade food quality, CP offers a non-thermal alternative capable of inactivating a wide spectrum of microorganisms. Originating from the field of physics, CP is an ionized gas composed of ions, electrons, neutral particles, and reactive species such as ozone, atomic oxygen, and hydroxyl radicals. Its ability to decontaminate food surfaces without raising product temperature has gained interest in the fruit drying sector, particularly for microbial control after drying and during storage.
Literature Review: To understand the efficacy of CP in dried fruit treatment, various studies across multiple fruit types and plasma systems have been reviewed. Scholarly research from 2015 to 2024 provides ample evidence of CP's effectiveness.
For instance, Misra et al. (2016) demonstrated the use of atmospheric cold plasma (ACP) for decontaminating Escherichia coli and Salmonella on apple slices without significant sensory deterioration. Similar results were obtained by Niemira (2018), who applied CP to dried apricots and figs, achieving over 4-log reductions in microbial load with minimal texture and flavor alterations.
Comparative analyses also suggest that CP is superior to ozone treatment in preserving antioxidants (Gavahian et al., 2019) and more sustainable than irradiation or chemical sanitizers, which may leave residues or require complex regulatory approval.
Theoretical Framework: The effectiveness of CP stems from the complex interactions between reactive species and microbial cell structures. Reactive oxygen and nitrogen species (RONS) generated during plasma discharge disrupt cell membranes, denature proteins, and fragment

DNA. The synergy of these effects leads to microbial inactivation within seconds to minutes of exposure.

This mechanism aligns with the fundamental principles of oxidative stress and free radical chemistry. Importantly, CP's action is primarily surface-limited, making it suitable for whole fruits or dried pieces with irregular geometries — a major advantage over liquid-based disinfection.

Methodology: Though this article does not report on original experimental results, a structured methodology was employed to synthesize the literature and assess CP's applicability to dried fruits:

Data Collection: Peer-reviewed journals, patents, and scientific conference proceedings from databases such as Scopus, Web of Science, and PubMed.

Technology Evaluation Criteria: Efficacy of microbial inactivation, impact on fruit quality, energy consumption, environmental safety, and industrial feasibility.

Comparative Analysis: Benchmarking CP against traditional decontamination methods including thermal treatment, UV-C, ozone, and chemical washes.

Results and Discussion: Microbial Inactivation

Studies consistently report 2–6 log reductions in common foodborne pathogens including Listeria monocytogenes, Salmonella spp., and E. coli O157:H7. These results depend on exposure time, plasma type (dielectric barrier discharge or gliding arc), gas composition (air, nitrogen, argon), and humidity levels.

Nutritional and Sensory Quality

CP treatment preserves key quality parameters such as vitamin C, phenolics, color, and texture better than thermal or chemical treatments. For instance, CP-treated dried apples retained up to 90% of their polyphenols compared to 65% in steam-treated samples.

Equipment and Scalability

Current CP systems are available in both batch and continuous formats. While lab-scale setups dominate academic studies, industrial-scale systems are emerging. Companies like Relyon Plasma and AcXys Technologies have developed prototypes for fruits and vegetables, yet adaptation to dried products remains under development.

Energy and Environmental Considerations

Unlike conventional heat-based or chemical methods, CP uses only electricity and gas (often ambient air), minimizing energy input and eliminating chemical residues. However, ozone and NOx emissions must be managed via exhaust filtration systems.

Challenges and Limitations

Despite its promise, several limitations of CP technology must be addressed:

Surface Limitation: CP acts mainly on the surface, so internalized microbes are not effectively inactivated.

Non-uniformity: Irregular fruit shapes may result in uneven exposure.

Cost: High initial equipment cost and need for skilled personnel may deter small-scale producers.

Standardization: There is a lack of standardized protocols and regulations for CP-treated dried fruits.

Ongoing research is required to optimize operating conditions and ensure consumer safety while maintaining product quality.

Future Perspectives

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Cold plasma is expected to become a key technology in the food preservation toolkit, especially as demand for clean-label and additive-free products grows. Future developments should focus on:
Integrating CP with packaging technologies (e.g., in-package plasma)
Automating control systems to ensure repeatability
Developing portable, modular plasma units for small processors
Regulatory alignment with international food safety standards
Collaborative efforts among academic institutions, equipment manufacturers, and food processors will be vital to accelerate adoption.

Conclusion: Cold plasma technology offers a compelling alternative for the microbial decontamination of dried fruits. It ensures high microbial reduction while preserving quality attributes and meeting sustainability goals. Though still in the early stages of commercial adoption, CP's potential in the fruit drying sector is undeniable. Further research, pilot trials, and policy support will pave the way for its widespread use in Uzbekistan and beyond.

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