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Commentary

Plasma-Driven Mycotoxin Mitigation in Food Systems: Mechanisms, Processing Strategies and Safety Perspectives

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DESCRIPTION

Mycotoxin contamination is one of the major challenges affecting food and feed safety worldwide. Fungal inactivation is one of the first mechanisms through which plasma can contribute to mycotoxin management. Plasma-generated reactive species can cause oxidative stress in fungal cells. Damage to the cell wall and membrane may increase permeability and disrupt cellular integrity. Oxidation of proteins and enzymes can interfere with essential metabolic functions, while damage to nucleic acids can affect cellular replication. These combined effects can reduce fungal viability and suppress further production of mycotoxins. However, eliminating viable fungi does not necessarily remove mycotoxins that have already accumulated in a food product. Direct degradation of the toxin is therefore an important additional objective of plasma processing.

An important consideration is the food matrix. The effectiveness of plasma treatment cannot be evaluated independently of the physical and chemical characteristics of the food. Grain kernels, flour, nuts, spices and dried fruits have different surface structures, moisture contents, particle sizes and chemical compositions. Mycotoxins located on exposed surfaces may be more accessible to reactive species than those located within cracks, pores, or internal structures. Surface roughness can therefore create protected areas where microorganisms and toxins are less exposed to plasma.

Moisture content also influences plasma chemistry and treatment effectiveness. Water can participate in the formation of reactive species, including hydrogen peroxide and hydroxyl radicals. However, changes in moisture can simultaneously influence the physical properties of food and the penetration of reactive species. Consequently, optimum plasma conditions for a dry cereal may not be appropriate for a higher-moisture food. Research must therefore establish commodity-specific processing conditions.

Nevertheless, plasma treatment itself can influence food quality. Reactive oxygen species do not exclusively react with mycotoxins and microorganisms, they can also interact with food constituents. Lipids may undergo oxidation, proteins can experience structural modification and pigments and other sensitive compounds may be affected. Excessive treatment can consequently alter color, flavor, texture, nutritional characteristics, or functional properties. The objective of plasma processing should therefore be selective and controlled decontamination, rather than simply maximizing treatment intensity.

Another important issue is the formation of mycotoxin transformation products. A reduction in the concentration of the original mycotoxin does not automatically demonstrate detoxification. Plasma may convert a parent toxin into one or more products with different chemical structures. Some products may have lower toxicity, whereas others may retain biological activity or have toxicological properties that are not yet known. Comprehensive safety evaluation therefore requires identification and characterization of transformation products using advanced analytical techniques such as High-Performance Liquid Chromatography (HPLC) and Liquid Chromatography–Mass Spectrometry (LC-MS).

Biological evaluation is equally important. Chemical disappearance of a toxin should ideally be supported by toxicological studies demonstrating reduced biological activity. Cell-based assays, microbial assays, enzyme-based systems and appropriate animal models can contribute to this assessment. Such investigations are particularly important for mycotoxins because their biological effects can involve oxidative stress, cellular signaling, Deoxyribonucleic Acid (DNA) damage, immune response and other molecular pathways.

Combining with other technologies may also improve its practical effectiveness. Hurdle technology involves applying several moderate preservation methods rather than relying on

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one severe treatment. Plasma could potentially be combined with modified-atmosphere packaging, drying, ultraviolet treatment, refrigeration, edible coatings, or biological preservation. Such combinations may improve microbial and mycotoxin control while reducing the intensity required from any individual treatment.

CONCLUSION

Plasma-driven mycotoxin mitigation represents a promising research area at the intersection of food technology, microbiology, chemistry, toxicology and genetics. CP can generate reactive oxygen and nitrogen species capable of suppressing fungal contamination and chemically modifying selected mycotoxins under relatively mild thermal conditions. However, treatment effectiveness depends strongly on mycotoxin structure, food-matrix characteristics, plasma parameters and exposure conditions. The identification and toxicological evaluation of transformation products remain essential for establishing true detoxification. Future integration of plasma technology with AI, advanced analytical methods, molecular toxicology and complementary preservation technologies could support the development of safer, efficient and more sustainable strategies for controlling mycotoxins throughout the food chain.