TRENDS IN AGRICULTURE SCIENCE
ISSN:2583-7850

Popular Article
Domain: Dairy Science
Vol 5 Issue 2, Feb 2026, 150-153

Electrostatic Coating of Dairy Products: A Modern Tool for Food Quality and Shelf-Life Enhancement

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DOI:10.5281/TrendsinAgriculture.18498934

Introduction

Dairy products such as cheese, paneer, milk powders, and dairy-based snacks are highly sensitive to environmental conditions during processing and storage. The loss of coating materials, uneven distribution of flavours or protective agents, dust generation, and limited shelf life are common challenges faced by the dairy industry. To address these issues, modern food processing is increasingly adopting innovative technologies that improve efficiency while reducing waste. One of the promising emerging technologies for the coating of food products is electrostatic coating. The electrostatic coating is originally developed for industrial applications like painting and material finishing, but nowadays it has recently gained attention in food processing, including dairy applications. This technology uses electrical charges to improve the adhesion and uniformity of coatings applied to food surfaces. Research over the past decade, particularly in cheese and dairy powders, shows that electrostatic coating can significantly enhance coating efficiency, product quality, and shelf life while supporting sustainable processing practices. (Barringer & Sumonsiri, 2015; Murid-Khan *et al*., 2022).

Principle of Electrostatic Coating in Dairy Processing

Electrostatic coating operates on the basic principle that oppositely charged particles attract each other. In this process, coating materials such as spices, flavours, antimicrobials, or functional powder which are electrically charged as they are sprayed. The dairy product surface is grounded or given an opposite charge, creating an electrostatic field that attracts the coating particles (Khan *et al*., 2012). This attraction enables the coating particles to deposit uniformly over the product surface, including edges and irregular areas, which are often difficult to coat using conventional methods. As a result, electrostatic coating provides better

coverage and stronger adhesion compared to that of gravity-based or mechanical coating techniques (Bailey, 2007).

Improved Coating Efficiency and Reduced Material Loss

The major advantages of electrostatic coating is its high transfer efficiency, defined as the percentage of coating material that successfully adheres to the product. Various studies on electrostatic powder coating of cheese slices have reported to have higher transfer efficiencies exceeding 80%, than conventional dry coating methods (Murid-Khan *et al.,* 2022). Higher transfer efficiency reduces ingredient wastage, airborne dust, and cleaning frequency, which is particularly important when using high-value additives such as natural colors, antimicrobial agents, or bioactive compounds (Barringer & Sumonsiri, 2015).

Application in Cheese and Cheese-Based Products

Cheese is one of the most extensively studied dairy products for electrostatic coating applications. Electrostatic powder coating has been successfully used to apply spices and functional powders to cheese slices. The study indicates that electrostatically coated cheese exhibits better coating uniformity, lower moisture loss, and reduced microbial growth during storage compared to conventionally coated samples (Murid-Khan *et al.*, 2022). These improvements contribute to extended shelf life and enhanced sensory appeal, making electrostatic coating particularly attractive for ready-to-eat and sliced cheese products.

Role in Dairy Powder Processing

Electrostatic principles are also applied in electrostatic spray drying, an emerging drying technology for dairy powders. In this process, liquid dairy feeds such as milk protein solutions are electrically charged prior to atomization, improving control over droplet formation and drying behavior (Chutani *et al.,* 2024). It has alos shown that electrostatic spray drying can reduce excessive heat exposure and limit undesirable chemical reactions such as the Maillard reaction, which negatively affects color, flavor, and nutritional quality of milk powders (Chutani *et al.,* 2024). This results in powders with improved functional and sensory properties.

Enhancement of Food Safety and Shelf Life

Electrostatic coating enables precise and uniform application of edible coatings and antimicrobial agents on dairy product surfaces. The uniform distribution ensures consistent antimicrobial effectiveness across the entire surface, reducing the risk of localized microbial growth (Kumar *et al.*, 2023). This is particularly beneficial for ready-to-eat dairy products, where surface contamination is a major food safety concern. The improvement in adhesion leads effective microbial control without increasing additive concentrations by electrostatic coating (Aloui & Khwaldia, 2023).

Environmental and Economic Benefits

From an environmental standpoint, electrostatic coating reduces dust emissions, ingredient losses, and overall waste generation. The improved process efficiency lowers raw material consumption and energy use, contributing to sustainable dairy processing by electrostatic coating technology (Barringer & Sumonsiri, 2015; Kumar *et al.*, 2023). Economically, better utilization of coating materials and reduced product rework translate into cost savings for dairy processors, making electrostatic coating an attractive option for large-scale industrial adoption.

Challenges and Future Prospects

Despite its advantages, the widespread adoption of electrostatic coating in dairy processing faces certain challenges. These include high initial equipment costs, the need for precise control of electrical parameters, and variability in dairy product surface characteristics such as fat content and moisture (Khan *et al.*, 2012). However, continuous advancements in equipment design and a growing emphasis on sustainable food processing are expected to drive wider adoption. As research expands and industrial-scale applications increase, electrostatic coating is likely to become a key technology for value-added dairy products (Galus & Kadzińska, 2022).

Conclusion

Electrostatic coating is a promising and innovative technology with significant potential in dairy processing. By enhancing coating efficiency, improving product quality, extending shelf life, and reducing waste, it offers a superior alternative to conventional coating methods. Applications in cheese processing and dairy powder production clearly demonstrate its versatility and effectiveness. With increasing focus on sustainability, food safety, and product innovation, electrostatic coating is expected to play an important role in the future of dairy processing and value-added dairy product development.

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