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Postharvest Technology

Bioactive MAP Films from Fruit Waste: Self-Regulating Atmosphere for Berry Cold Storage

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Abstract: -

Berries are highly perishable fruits with elevated respiration rates and susceptibility to fungal decay, leading to postharvest losses of up to 40% during cold storage. Bioactive Modified Atmosphere Packaging (MAP) films derived from fruit waste, such as pectin- and phenolic-rich extracts from apple pomace and citrus peels, represent a sustainable strategy to address these challenges. These films create a self-regulating microenvironment by modulating oxygen and carbon dioxide levels in response to berry respiration while gradually releasing natural antimicrobial and antioxidant compounds. The controlled atmosphere suppresses metabolic activity and inhibits major postharvest pathogens, thereby preserving firmness, color, and sensory quality and significantly extending shelf life. In addition to improving storage performance, the use of fruit waste–based bioactive films supports circular bioeconomy principles by valorizing agro-industrial by-products and reducing reliance on synthetic plastics. Integration with cold-chain systems and emerging smart monitoring technologies further enhances their potential for commercial application. Overall, bioactive MAP films offer an effective, eco-friendly postharvest solution for improving berry storage and reducing food losses.

Introduction:

Maintaining berry freshness during cold storage presents a major challenge due to their high respiration rates and vulnerability to fungal decay. Worldwide, postharvest losses of berries can reach up to forty percent, resulting in significant economic and food security concerns, according to Youssef *et al.*, 2023. Modified Atmosphere Packaging films imbued with bioactive compounds derived from fruit waste, such as pectin and phenolics, offer a promising solution. These films create a self-

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regulating microenvironment by selectively absorbing carbon dioxide generated by berry respiration and releasing antimicrobial agents. This technology not only extends shelf life but also promotes sustainability by valorizing agro-industrial by-products, as highlighted by Singh *et al.*, 2024.

Mechanisms and Composition of Bioactive Films

Bioactive MAP films are typically formulated using pectin polymers blended with natural antimicrobials, including apple pomace extract. These extracts slowly release phenolic compounds with antioxidant and antifungal activity throughout storage, helping maintain fruit quality and suppress spoilage organisms, according to Rueda *et al.*, 2025. The films modulate gas exchange by selectively absorbing CO_2 produced by berry respiration, which reduces internal oxygen levels and slows down metabolic activity. In raspberries stored at four degrees Celsius, the application of such films extended shelf life from seven to eighteen days while reducing fungal incidence by thirty-five percent compared to conventional packaging, as reported by Martínez-Hernández *et al.*, 2024.

The selective gas permeability of the films arises from their microstructure, which is influenced by polymer crosslinking density and the use of plasticizers. This allows the maintenance of oxygen levels around three to five percent and carbon dioxide levels between five and eight percent inside the packaging. The controlled microenvironment suppresses fungal growth while preserving firmness, color, and flavor. Additionally, the phenolic compounds released by the films directly inhibit common postharvest pathogens, such as Botrytis cinerea, by disrupting cell membranes and inhibiting spore germination, according to Lopez-Mata *et al.*, 2025.

Sustainability and Production Advantages

The production of bioactive MAP films supports circular bioeconomy models by utilizing fruit waste streams, including apple pomace and citrus peels, reducing environmental disposal burdens. These films can be applied as standalone packaging or as edible coatings, fully compatible with existing cold chain infrastructure. They are biodegradable under composting conditions within sixty days, making them environmentally sustainable alternatives to conventional synthetic packaging, according to Rueda *et al.*, 2025 and Martínez-Hernández *et al.*, 2024.

Future Prospects

Advances in nanotechnology offer potential enhancements to bioactive films, such as embedding nanosensors capable of monitoring internal gas composition and berry freshness in real time. When integrated with AI-driven cold chain management, these sensors could automate ventilation and other environmental controls based on dynamic feedback, optimizing storage conditions for different berry types and batch sizes. Research also suggests expanding these bioactive films to other perishable fruits and vegetables, which could reduce global postharvest waste by up to thirty percent by 2030, according to Youssef *et al.*, 2023 and Singh *et al.*, 2024.

Conclusion

Bioactive Modified Atmosphere Packaging films utilizing fruit waste extracts provide a sustainable and effective postharvest solution for berries. By creating self-regulating microenvironments, they extend shelf life, maintain fruit quality, and reduce spoilage. Adoption of these films not only enhances food security but also contributes to circular economy initiatives within the fruit industry, supporting both environmental and economic sustainability.

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