

Advances in smart packaging for food preservation: A sustainable approach.

Brief Report*

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Received: 01-Feb-2025, *Manuscript No.* AAFTP-25-167058; *Editor assigned:* 03-Feb-2025, *PreQC No.* AAFTP-25-167058(PQ); *Reviewed:* 16-Feb-2025, *QC No.* AAFTP-25-167058; *Revised:* 22-Feb-2025, *Manuscript No.* AAFTP-25-167058(R); *Published:* 25-Feb-2024, *DOI:* 10.35841/2591-796X-9.1.271

Introduction

The global food industry is constantly challenged by the need to preserve food quality, extend shelf life, and minimize food waste. Traditional packaging, while serving as a basic protective barrier, often fails to provide real-time information about food freshness and safety. In response, smart packaging has emerged as a transformative solution, integrating advanced materials and sensing technologies to enhance preservation, promote sustainability, and reduce environmental impact [1].

Smart packaging refers to innovative systems that go beyond simple containment, offering functional benefits to improve food safety and quality. These systems generally fall into two categories: active packaging and intelligent packaging. Active packaging works by directly interacting with the food or its surrounding environment—using oxygen scavengers, moisture absorbers, or antimicrobial agents to prolong freshness. Intelligent packaging, on the other hand, incorporates sensors, indicators, and communication tools such as RFID (Radio Frequency Identification) tags to monitor and convey the real-time condition of the product [2].

Among the most notable innovations in smart packaging are Time-Temperature Indicators (TTIs). These small devices continuously track temperature changes along the supply chain, alerting retailers and consumers to possible spoilage caused by

improper storage conditions. TTIs are particularly valuable for perishable items such as dairy products, seafood, and meat, where temperature control is critical for maintaining safety and quality.

Oxygen scavenging systems have also proven essential in combating spoilage. Since oxygen exposure accelerates microbial growth and oxidation, integrating oxygen-absorbing compounds into packaging materials helps extend shelf life. These systems are widely applied in baked goods, processed meats, and snacks, where even minimal oxygen presence can significantly affect quality [3].

In addressing environmental concerns, edible and biodegradable packaging has gained attention. Researchers have developed films made from natural sources like chitosan, essential oils, and plant extracts. These materials not only reduce reliance on synthetic plastics but also possess antimicrobial properties, contributing to both sustainability and improved food safety. Such packaging represents a promising balance between ecological responsibility and functional performance.

Freshness indicators add another layer of consumer protection. These devices detect spoilage-related gases such as ammonia and sulfur compounds, changing color to signal food quality deterioration. By providing a clear visual cue, freshness indicators empower consumers to make informed

decisions, reducing unnecessary food waste and ensuring products are consumed at their optimal state [4].

Advanced tracking technologies like RFID and Near-Field Communication (NFC) tags have transformed food logistics and inventory management. These systems enable real-time product tracking, streamline supply chains, and minimize losses due to spoilage. When combined with temperature monitoring, they offer comprehensive solutions for maintaining product integrity from production to consumption.

Sustainability remains a driving force behind smart packaging development. The adoption of recyclable, compostable, and biodegradable materials, coupled with technologies that reduce spoilage, directly contributes to lowering greenhouse gas emissions. While challenges such as high production costs, regulatory hurdles, and consumer acceptance persist, ongoing research promises more affordable and accessible solutions. In the near future, the integration of nanotechnology and AI-driven sensors could further revolutionize smart packaging, making it an indispensable tool for ensuring global food security and environmental preservation [5].

Conclusion

Smart packaging represents a transformative approach to food preservation, combining

technology with sustainability to reduce food waste and enhance food safety. As research and industry efforts continue, the adoption of smart packaging will play a crucial role in shaping a more sustainable and efficient food supply chain.

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