



THE FUTURE OF SMART MEAT PACKAGING: SHAPING THE FUTURE OF FOOD SAFETY AND SUSTAINABILITY

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INTRODUCTION

The future of smart meat packaging holds transformative potential for food safety and sustainability, revolutionizing how meat products are preserved, tracked, and consumed. Integrating advanced technologies such as sensors, blockchain, and interactive features, smart packaging offers unprecedented levels of transparency, quality control, and consumer engagement. By monitoring critical parameters like temperature, humidity, and microbial growth in real-time, these innovative solutions can significantly extend the shelf-life of meat products, reducing food waste and ensuring optimal freshness. Moreover, blockchain technology enhances traceability, providing consumers with verifiable information about the product's origin and journey through the supply chain. This transparency fosters trust and accountability, essential for food safety and compliance with regulatory standards. Interactive packaging further enriches the consumer experience by offering easy access to detailed product information and usage tips, promoting informed purchasing decisions (Han et al., 2018). Additionally, smart packaging's commitment to sustainability is

evident through the use of recyclable and biodegradable materials, addressing environmental concerns associated with traditional packaging. As the meat industry embraces these cutting-edge advancements, smart packaging is poised to play a pivotal role in shaping a safer, more sustainable food future, benefiting consumers, producers, and the planet alike.

1. Smart Labels and Sensors

Smart Labels: Smart labels equipped with sensors are becoming a significant part of the future of meat packaging. These labels can track various parameters such as temperature, humidity, and freshness in real-time. For example, labels embedded with time-temperature indicators (TTIs) can alert consumers and retailers if meat has been exposed to temperatures that could compromise its safety.

Sensors: Advanced sensors integrated into packaging can monitor the condition of the meat throughout its journey from production to consumer. These sensors can detect gases emitted by decomposing meat or changes in color and texture, providing valuable data on the product's freshness.

2. Blockchain for Transparency and Traceability

Blockchain technology offers a robust solution for enhancing transparency and traceability in the meat industry. By providing a decentralized and immutable ledger, blockchain ensures that every step in the supply chain from farm to fork is recorded accurately and transparently.

This technology allows for real-time tracking of meat products, ensuring that consumers can access detailed information about the origin, handling, and quality of the meat they purchase. Additionally, blockchain helps prevent fraud and ensures compliance with regulatory standards, thereby increasing trust among consumers and stakeholders. By fostering accountability and transparency, blockchain can significantly improve the safety and integrity of the meat supply chain.

3. Interactive Packaging

Interactive packaging for meat products integrates technology to engage consumers and provide valuable information, enhancing the shopping experience. This innovative approach can include QR codes, NFC tags, or augmented reality features that consumers can scan with their smart phones to access detailed product information, such as origin, nutritional content, and preparation tips. Interactive packaging can also offer real-time updates on freshness and quality, ensuring consumers are informed about the product's condition (Reshmy et al., 2021).

By offering a more engaging and informative experience, interactive packaging not only boosts consumer confidence and satisfaction but also promotes brand loyalty and differentiates products in a competitive market.

4. Sustainability through Smart Packaging

Smart packaging plays a crucial role in promoting sustainability in the meat industry by extending shelf-life, reducing food waste, and enhancing resource efficiency. Through technologies like freshness sensors and temperature monitors, smart packaging ensures optimal storage conditions, preventing spoilage and minimizing waste. Additionally, real-time tracking and transparency features help optimize supply chain logistics, reducing the environmental footprint associated with transportation and storage.

Smart packaging also supports sustainability by incorporating eco-friendly materials that are recyclable or biodegradable, addressing concerns about packaging waste (Chelliah et al., 2021). By combining advanced technology with sustainable practices, smart packaging not only improves food safety and quality but also contributes to a more sustainable and efficient meat supply chain, benefiting both consumers and the environment.

5. Temperature Control Innovations

Advanced packaging systems now include temperature-regulating technologies that maintain optimal conditions for meat preservation. For instance, phase-change materials (PCMs) can absorb and release heat, helping to stabilize the temperature during transportation and storage.

Integrated temperature sensors can provide continuous monitoring and alerts if the meat is exposed to conditions that might compromise its safety. This helps in preventing spoilage and ensuring that consumers receive products that are safe to eat.

6. Consumer Empowerment

Smart packaging empowers consumers with more information about their food. Educational components integrated into the packaging can inform consumers about the importance of proper storage, handling practices, and the environmental impact of their choices. Features like resealable packaging and portion control contribute to greater convenience, reducing the likelihood of meat going to waste and making it easier for consumers to manage their food supply.

7. Challenges and Considerations

Smart meat packaging represents a significant advancement in the food industry, offering enhanced safety, quality, and shelf-life for meat products. However, it faces several challenges. High production costs and the need for economies of scale can make smart packaging expensive, limiting its widespread adoption. Technological integration also poses difficulties, as ensuring reliable sensor performance and compatibility of various technologies within a single package is complex.

Consumer acceptance is another hurdle; educating the public about the benefits and safety of smart packaging while addressing privacy concerns is crucial. Regulatory compliance adds another layer of complexity, with varying standards and lengthy approval processes across regions. Moreover, environmental impact is a significant consideration. While smart packaging aims to improve food safety and quality, it must also address sustainability (Ghaani *et al.*, 2016). The use of electronic components can increase waste, necessitating a focus on recyclable or biodegradable materials.

Despite these challenges, smart packaging offers substantial benefits such as real-time monitoring, improved traceability, and better inventory management. By balancing functionality with sustainability and fostering collaboration between industry, academia, and regulatory bodies, the potential of smart meat packaging can be fully realized, leading to safer, higher-quality, and more sustainable meat products.

Conclusion

The future of smart meat packaging is promising to enhance food safety, improve sustainability, and offer consumers a more informed and convenient shopping experience. With innovations in sensors, block chain, interactive elements, and eco-friendly materials, the meat industry is on the brink of a transformation that will shape how we handle and consume meat products. As these technologies continue to evolve, they will play a pivotal role in meeting the demands of modern consumers and addressing the challenges of food safety and environmental impact.

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