

Smart and active packaging in the food industry: a review

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Abstract: The food industry faces increasing challenges related to maintaining product quality, safety, and sustainability across complex supply chains. In this context, active and intelligent packaging systems have emerged as complementary approaches designed to both control degradation processes and monitor product conditions in real time. This paper presents a critical review of recent advances in these technologies, with particular emphasis on their mechanisms of action, materials, and application-specific performance. Key systems, including oxygen scavengers, antimicrobial packaging, time-temperature indicators, freshness indicators, and biosensors, are analyzed in relation to different categories of food products. The analysis highlights that active packaging directly modifies the internal environment of the package, whereas intelligent systems enable the assessment of product status without altering its stability. However, the effectiveness of these systems depends on the accurate correlation between detected signals and actual degradation processes, as well as on technological and economic constraints. Current trends emphasize the development of integrated packaging solutions that combine protective and monitoring functions, supporting improved quality control, reduced food waste, and more efficient supply chain management.

Introduction

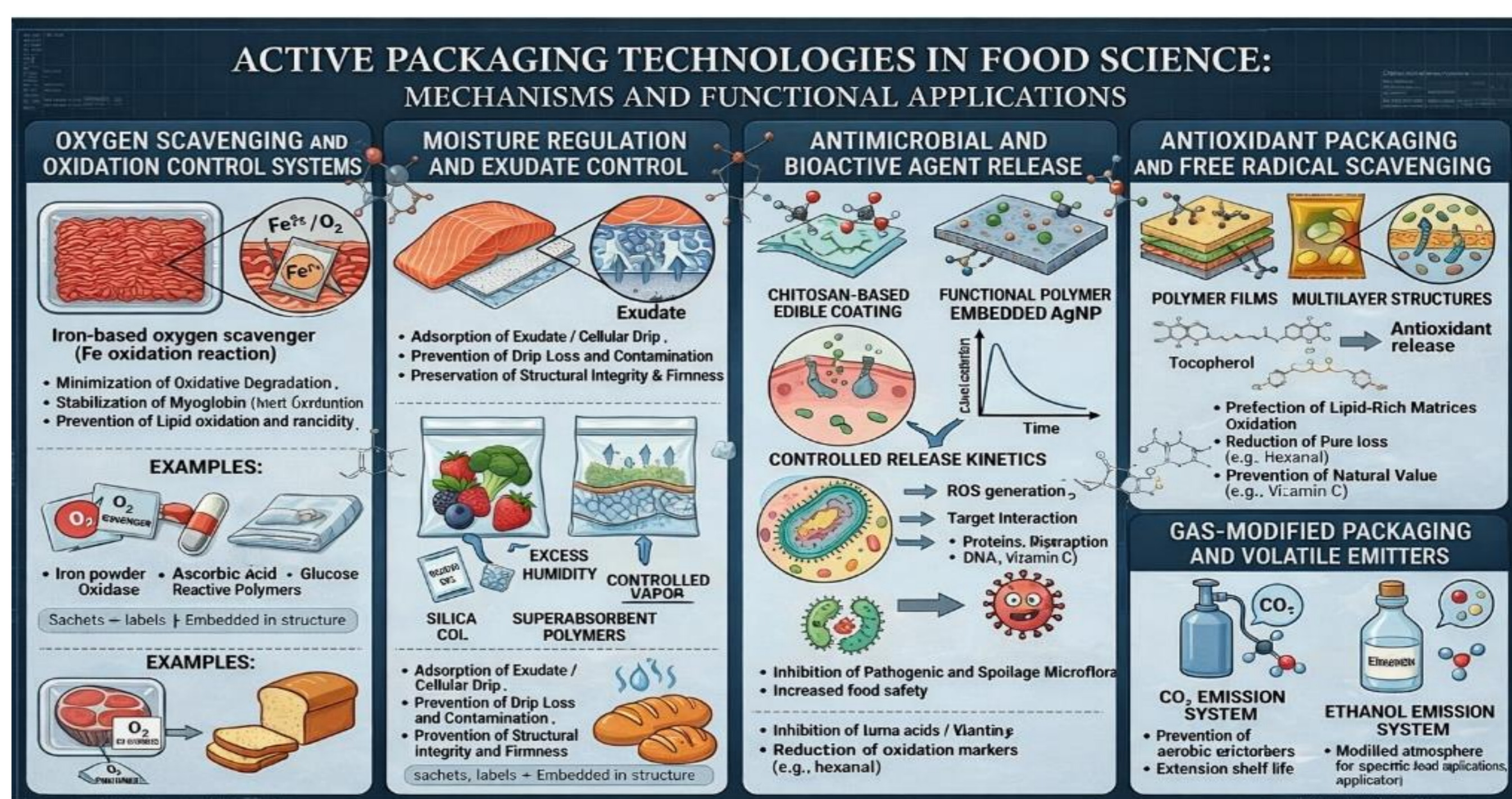
Food packaging plays an essential role in protecting food products, maintaining quality, and ensuring safety throughout the supply chain. Due to globalization and extended distribution times, packaging has evolved from a passive barrier into an active system that contributes to shelf-life extension and quality control. Recent advances in materials science have led to the development of active and intelligent packaging systems. Active packaging can inhibit microbial growth and preserve food quality, while intelligent packaging uses sensors and indicators to monitor parameters such as freshness and temperature in real time. In addition, sustainability has become a key aspect of packaging development, encouraging the use of biodegradable and bio-based materials within circular economy strategies. These innovations transform packaging into multifunctional systems that improve food safety, traceability, and supply chain efficiency. This study analyzes the main active and intelligent packaging systems used in the food industry.

Materials and methods

This study was conducted as a comprehensive narrative review on active and intelligent food packaging systems. Scientific literature published between 2000 and 2025 was identified through databases including ScienceDirect, PubMed, Scopus, Web of Science, and journals indexed by MDPI. The search strategy included keywords related to active packaging, intelligent packaging, oxygen scavengers, antimicrobial systems, freshness indicators, biosensors, and food quality monitoring. Studies were selected based on thematic relevance, scientific quality, and applicability to the food industry. A total of 48 scientific papers were comparatively analyzed to identify current trends, technological limitations, and future perspectives in food packaging technologies.

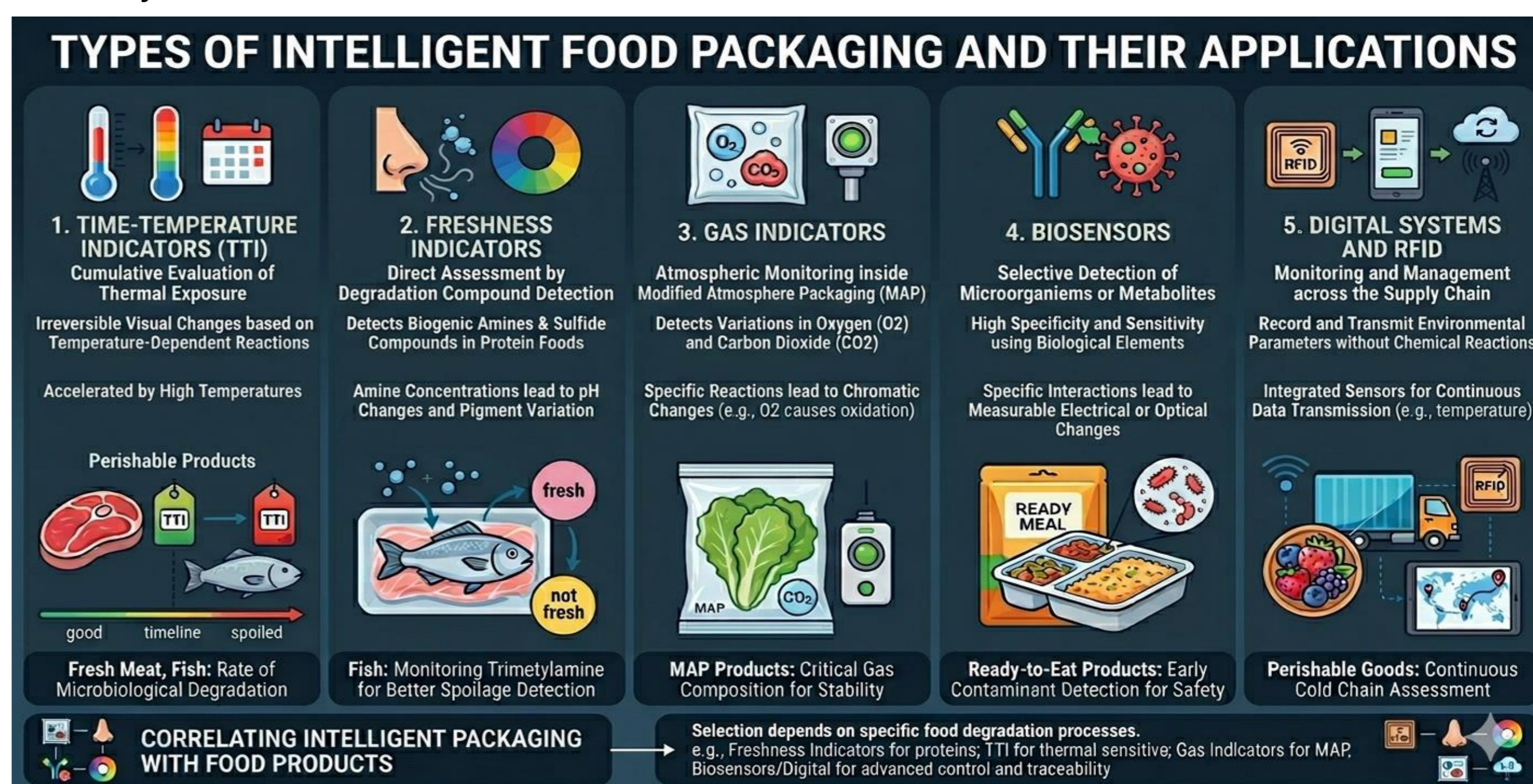
Results and discussions

Active packaging systems represent innovative solutions designed to interact with the food product and its surrounding environment in order to maintain quality and extend shelf life. Unlike conventional packaging, these systems actively regulate factors such as gas composition and moisture, contributing to improved food stability and safety during storage and distribution. The effectiveness of active packaging depends on the interactions between the packaging material, the food product, and storage conditions. Therefore, their development requires the integration of functionality, safety, and compatibility with food products.



Active packaging technologies are mainly focused on controlling major food degradation factors such as oxygen, moisture, and microbial activity. These systems use different active compounds to improve food quality, safety, and shelf life, while current trends emphasize the development of multifunctional packaging solutions adapted to modern food industry requirements.

Smart packaging systems are designed to monitor food quality in real time and provide information about product status throughout the supply chain. Unlike active packaging, which interacts with the food environment, smart packaging focuses on detecting and communicating changes related to freshness, temperature, or storage conditions. These systems improve food safety and quality control by enabling more accurate monitoring compared to traditional expiration dates. In addition, smart packaging supports traceability and logistics optimization, reflecting the increasing digitalization of the modern food industry.



The main types of intelligent food packaging systems, including time-temperature indicators, freshness indicators, gas indicators, biosensors, and RFID technologies, all designed to monitor food quality, safety, and storage conditions in real time.

Conclusions

Active and intelligent packaging systems improve food quality, safety, and shelf life by combining protection and real-time monitoring functions. Future packaging technologies will focus on smart, sustainable, and digitally integrated solutions adapted to modern food industry requirements.