

Active and intelligent packaging: The future of food storage.

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Introduction

In recent years, the packaging industry has undergone significant transformations, driven by the demand for more efficient, sustainable, and consumer-friendly solutions in food storage. Among the most exciting developments are active and intelligent packaging technologies, which represent a new frontier in how food is preserved, monitored, and protected during storage and transport. These advanced packaging systems go beyond traditional methods by not only serving as a barrier to external factors but also actively interacting with the product to maintain its freshness and quality. This article delves into the concepts of active and intelligent packaging, exploring how these innovations are revolutionizing food storage and shaping the future of the food industry [1].

Active packaging refers to packaging systems that interact with the food product to extend its shelf life and preserve its quality. Unlike passive packaging, which simply protects food from environmental factors such as moisture, oxygen, and light, active packaging goes a step further by incorporating substances that actively affect the food's environment. These substances can include antimicrobial agents, oxygen scavengers, moisture regulators, and flavor absorbers. For example, oxygen scavenger packets are placed inside packaging to absorb excess oxygen, preventing oxidation that can lead to rancidity in fats and oils. Similarly, moisture-absorbing packaging helps maintain the desired texture and prevents the growth of mold and bacteria, which thrive in humid environments [2].

Intelligent packaging, also known as smart packaging, takes the concept of active packaging a step further by incorporating sensors or indicators that monitor the condition of the food throughout its lifecycle. These sensors can measure a range of factors, such as temperature, humidity, pH levels, and the presence of gases, providing real-time information about the food's status. For instance, temperature indicators can help ensure that perishable products like dairy, meat, and frozen foods have been stored at the correct temperature throughout transport and storage. This allows consumers and food producers to track the quality and safety of food more accurately, ensuring that food is consumed at its peak quality [3].

One of the primary benefits of active and intelligent packaging is its ability to significantly increase the shelf life of food products. By maintaining optimal conditions for food storage—such as controlling temperature, humidity, or oxygen

levels—these packaging systems help preserve the quality and safety of food for longer periods. This not only improves the consumer experience but also helps reduce food waste, which is a growing global concern. According to the Food and Agriculture Organization (FAO), roughly one-third of all food produced globally is wasted. Active and intelligent packaging can play a key role in mitigating this issue by ensuring that food stays fresh longer, particularly in the supply chain, where food is often exposed to suboptimal conditions [4].

In addition to prolonging shelf life, active and intelligent packaging provides consumers with greater convenience and confidence in the food they purchase. With features like color-changing indicators or QR codes that link to detailed product information, consumers can easily assess the freshness and quality of the food without opening the packaging. For example, an intelligent packaging system might feature a color indicator that changes when the product has been exposed to unsafe temperatures, signaling to the consumer that the product may no longer be safe to consume. This real-time feedback helps prevent the consumption of spoiled or unsafe food, improving food safety and reducing the risk of foodborne illness [5].

As environmental concerns continue to grow, the food packaging industry is under increasing pressure to find more sustainable solutions. Both active and intelligent packaging technologies are designed with sustainability in mind. Many active packaging materials, such as oxygen scavengers and moisture regulators, can be made from biodegradable or recyclable materials, reducing the environmental impact of packaging waste. Furthermore, intelligent packaging systems can reduce food waste by ensuring that products are consumed at the right time, thereby decreasing the amount of food that is thrown away due to spoilage. These innovations align with global efforts to reduce packaging waste and promote more sustainable food production and consumption practices [6].

Active packaging is particularly beneficial for the preservation of meat and seafood, two food categories highly susceptible to spoilage. The presence of moisture and the growth of microorganisms are major factors that contribute to the deterioration of these products. Active packaging solutions such as moisture-absorbing films and antimicrobial agents can extend the shelf life of meat and seafood by reducing bacterial growth and maintaining optimal moisture levels. Oxygen scavengers are also crucial in preventing the oxidation of fats in meat, which can lead to rancidity and off-flavors. By improving the quality and safety of perishable products, active

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packaging helps reduce waste in the meat and seafood sectors, which are particularly vulnerable to spoilage [7].

Intelligent packaging also offers significant advantages in terms of traceability and transparency throughout the food supply chain. With the integration of RFID (radio-frequency identification) tags or NFC (near-field communication) technology, food products can be tracked from production to consumption. This allows both producers and consumers to access detailed information about the product's origin, manufacturing process, transportation conditions, and storage history. This traceability enhances food safety by providing transparency regarding the handling and storage of food, which is particularly important in the event of a recall or food safety concern. Additionally, consumers can make more informed purchasing decisions based on the information available through intelligent packaging [8].

Despite the numerous benefits, there are challenges associated with the widespread adoption of active and intelligent packaging. One of the main hurdles is the cost of these advanced packaging materials and technologies. For many small and medium-sized food producers, the expense of integrating smart packaging into their operations may be prohibitive. Additionally, regulatory issues surrounding the use of certain materials, especially those that come into direct contact with food, need to be carefully managed to ensure safety and compliance with food standards. Overcoming these challenges will require further innovation, collaboration across the food industry, and government support in the form of regulations and incentives [9].

Looking ahead, the future of active and intelligent packaging is promising. As the technology continues to evolve, it is expected that these packaging systems will become more affordable, efficient, and widely adopted. Advances in nanotechnology, sensor technology, and biodegradable materials will likely lead to even more sophisticated and sustainable packaging solutions. Moreover, the integration of artificial intelligence and machine learning could enable more personalized food packaging systems that adapt to individual consumer preferences, further enhancing the convenience and efficiency of food storage [10].

Conclusion

Active and intelligent packaging represents a significant leap forward in food storage technology. By improving food

preservation, extending shelf life, enhancing food safety, and promoting sustainability, these packaging innovations are revolutionizing the way food is stored, transported, and consumed. As the technology continues to develop, active and intelligent packaging will become an integral part of the food industry, helping to reduce food waste, improve quality, and meet the growing demands of consumers for smarter, more sustainable food products. The future of food storage is smart, and active and intelligent packaging is leading the way.

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