AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 02, Issue: 09 (September, 2025)
Available online at http://www.agrimagazine.in
©Agri Magazine, ISSN: 3048-8656

Smart Packaging Solutions for the Future of Food: Active Packaging Technologies

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Innovative packaging methods have been developed to meet consumers' needs for high-quality, safe, user-friendly, and ready-to-use products. Packaging is a complex concept with various functions and considerations. It aims to protect, preserve, and transport products, while also conveying information and enhancing user convenience (Bolanca et al., 2020). Active packaging is a novel method designed to preserve or extend the shelf-life of food items while preserving their quality, safety, and integrity (Yildirim et al., 2017). As defined in the European regulation (EC) No 450/2009, active packaging comprises packaging systems that interact with the food in such a way as to "deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food" (European Commission, 2009). Active packing systems can be categorized into active scavenging systems (absorbers) and active-releasing systems (emitters) (Yildirim et al., 2017). The active scavenging systems eliminate undesirable substances like moisture, carbon dioxide, oxygen, ethylene, or odor from the meal or its surroundings; the active releasing systems add substances to the mixture, such as antimicrobial substances, carbon dioxide, antioxidants, tastes, ethylene, or ethanol, or into the headspace of aged food (Yildirim et al., 2017). This article primarily addresses active packaging methods that have been successfully implemented in the food industry, emphasizing their advantages.

O_2 scavenging systems

The application of oxygen scavengers (OS) constitutes a primary active packaging technology designed to eliminate residual oxygen within food packaging or enhance barrier qualities by functioning as an active barrier (Sängerlaub et al., 2013). O_2 scavengers, also referred to as O_2 absorbers, can significantly shorten food shelf life by reducing high oxygen levels in packaging, which can also promote microbial growth, the formation of bad flavors and odors, color changes, and nutritional losses. Therefore, regulating the amount of oxygen in packaging is necessary. The oxygen scavenging component can be introduced to a package in the form of a sachet, sticker, coating, or direct inclusion into the packing film (Gokoglu, 2020).

Moisture scavenging systems

Another system of active packaging is moisture absorbers. The food in these containers is impacted by temperature variations during storage and transportation because of condensation and fogging caused by the high moisture content in the headspace of the packaging (Gokoglu, 2020). Moisture absorbers such as calcium oxide, activated clays, silica gel, and minerals in tear-resistant permeable plastic sachets are generally used for dried foods(Gokoglu, 2020). In high water activity foods such as vegetables, meats, poultry, and fish, besides moisture absorber sachets, moisture-drip absorbent pads, sheets and blankets are used to control the moisture in the package (Gokoglu, 2020).

Carbon dioxide Emitters

Generally, higher levels of CO_2 are advantageous for food preservation, since they inhibit microbial proliferation and oxidative processes, hence sustaining food freshness by minimizing physiologically reactive degradation, including respiration and ethylene generation (Hu et al., 2022). Carbon dioxide has a significant impact on growth of bacteria. It works effectively against aerobic degradation and gram-negative bacteria like *Pseudomonas* species (Gokoglu, 2020). Typically, sodium bicarbonate, ascorbic acid, ferrous carbonate, or a combination of sodium bicarbonate and citric acid constitute these systems. CO_2® Fresh Pads and UltraZap® XtendaPak pads, which include an antimicrobial pad and a CO_2 emitter, are examples of commercial carbon dioxide emitters (Hu et al.,2022).

Antimicrobial packaging systems

Antimicrobial packaging intends to release an antimicrobial agent that inhibits the growth of undesirable bacterial species that cause spoilage of food (Mohan et al.,2010; Ahvenainen et al., 2003). Since antimicrobial food packaging materials prolong the lag phase and decrease the growth phase of bacteria, they help to increase shelf life and preserve product quality and safety (Appendini et al., 2002). There are two types of antimicrobial films Type 1: Films that release (migrate) antimicrobial agents to the food surface and Type 2: Films that act directly on microbes without migration, effective only on the surface (Suppakul et al., 2003). The classes of antimicrobials include: organic acids (benzoic, propionic, sorbic acid), bacteriocins, i.e., nisin, polysaccharides such as chitosan, enzymes (lysozyme, peroxidase, glucose oxidase), EOs (thyme, oregano, rosemary), herbal extracts, chelators (EDTA), acid anhydrides (SO2, ClO_2). ZnO, TiO_2, MgO and silver zeolite have been extensively studied among inorganic nanoparticles for antimicrobial packaging applications.

Antioxidant releasing systems

Food shelf life is shortened by lipid oxidation because it alters the food's flavour and/or odor, degrades the texture and functionality of muscle foods, and lowers the nutritional value (Pereira et al., 2010). Food oxidation can be prevented by using antioxidants and oxygen scavengers in the packaging. Pereira et al. (2010) state that the purpose of this type of packaging is to stop or reduce oxidation reactions that degrade food quality. Antioxidants can be used for oil, nuts, butter, fresh meat, meat derivatives, bakery products, fruits and vegetables (Prasad and Kochhar 2014). Natural preservatives from various sources, such as chitosan from animals, essential oils and plant extracts from plants, lactic acid bacteria and bacteriocins from microbiological sources, and organic acids from various sources, have all illustrated the great potential for use in seafood systems (Baptista et al. 2020). Natural preservatives include both antibacterial and antioxidant capabilities, which contribute to increased food safety.

Conclusion

Active packaging interacts with the product and its surroundings to improve food preservation. In addition to managing moisture and preventing microbial growth, it also controls gases such as carbon dioxide, ethylene, and oxygen and retains or eliminates odours. Biopolymer-based composites for active food packaging are a creative substitute for traditional plastic packaging that lessens recycling problems and avoids the exclusive use of non-renewable resources. These techniques make packaging more efficient and effective while extending shelf life, maintaining quality, and enhancing food safety.

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