

Active Packaging with Antimicrobials for Prolonging Shelf Life of produce

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Abstract: -

Fruits and vegetables are perishable commodities, are prone to significant post-harvest losses. There is a need of innovative preservation techniques to extend shelf life and active packaging with antimicrobial agents offers an effective strategy to extending shelf life by incorporating natural extracts, essential oils or nanoparticles (e.g.- silver, zinc oxide) into packaging materials and it inhibit the microbial growth on the produce surface, reduces the enzymatic degradation. Active antimicrobial packaging minimizes food waste as well as it supports sustainable supply chains and consumer safety.

Keywords: Active packaging, antimicrobials, shelf life etc.

1. Introduction:

Perishable commodities, including fruits, vegetables, meat and dairy products, are susceptible to rapid degradation due to microbial infection and physiological processes, resulting in economic losses and food insecurity. The Food and Agriculture Organization (FAO) reports that around one-third of all food produced worldwide is lost each year, with post-harvest losses being a major factor. Active packaging involves the integration of additional agents into packaging

materials to preserve or prolong the quality and shelf life of food products (Lee *et al.*, 2015).

Active packaging including antimicrobials is a novel technology that can release antimicrobial agents to inhibit the activity of specific microbes, hence enhancing food quality and safety during prolonged storage. It can engage directly with food and its environment to postpone deterioration. Anwar *et al.*, (2018) state that active packaging is engineered to monitor alterations

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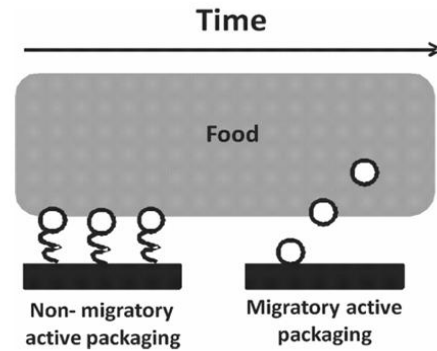
in the internal environment and adapt the packages properties to extend the shelf life of food products.

Antimicrobials are bioactive agents integrated into packaging films, coatings, or sachets. These compounds may either transfer to the foods surface or remain within the packaging material to suppress microbial proliferation. The mechanism differs according on the agent utilized. Bacteriocins compromise bacterial cell membranes, essential oils obstruct microbial metabolism, and organic acids lower pH, making the environment less favourable for microbial proliferation. Antimicrobial packaging can eradicate or suppress bacterial growth, so ensuring the safety of perishable food and extending its shelf life. This is accomplished by establishing adverse conditions in the microorganisms environment, removing critical developmental components, or via direct engagement with a specific antimicrobial chemical (Han, 2005).

2. Classification of Active packaging:

Active packaging can be classified into **two main** types

- 2.1. Non migratory active packaging- Acting without intentional migration.
- 2.2. Migratory active packaging-Allowing controlled migration of non-volatile agents or emission of volatile compounds in the atmosphere surrounding food.



3. Types of Antimicrobial Agents

Types	Antimicrobial agents
Natural antimicrobials	Essential oils (thyme, oregano, clove), chitosan and plant extracts
Microbial metabolites	Bacteriocins such as nisin and pediocin, enzymes like lysozyme
Organic acids	Sorbic acid, lactic acid, benzoic acid
Inorganic antimicrobials	Silver nanoparticles, zinc oxide, titanium dioxide, copper-based agents

3.1. Natural Antimicrobials:

Natural antimicrobial agents derived from flora, fauna and beneficial microorganisms are progressively acknowledged by consumers as healthier substitutes for traditional food preservatives. A variety of natural antimicrobial agents, including organic acids, plant essential oils, naturally occurring polymers like chitosan, and their mixtures, have been employed to prolong shelf-life.

Essential oils exhibit extensive antibacterial efficacy against various foodborne pathogens, including

Staphylococcus aureus, Bacillus cereus and Escherichia coli. Rosemary, clove, cinnamon, thyme, oregano, garlic, bay leaf, lavender, sage, basil, and others have been utilized as antibacterial agents (Cole, 2016).

Chitosan is a natural polymer composed of a linear binary heteropolysaccharide derived from the diacylation of chitin found in marine shells or fungal cell walls. Chitosan exhibits a wide range of efficacy against both Gram-positive and Gram-negative bacteria (Confederat, 2021).

3.2. Microbial metabolites:

Bacteriocins function by compromising bacterial cell membranes, resulting in cell mortality. Lysozyme, a naturally occurring enzyme, demonstrates significant antibacterial efficacy, particularly against Gram-positive bacteria. It operates by cleaving the β (1 \rightarrow 4) glycosidic bonds in peptidoglycan within the cell wall. This activity compromises the cellular structure, resulting in lysis and effectively inhibiting bacterial growth and survival.

3.3. Organic Acids:

The antibacterial mechanism of organic acids is attributed to the lipophilic nature of their undissociated acid form, facilitating their penetration through the peptidoglycan layer of Gram-positive bacteria or the phospholipid membrane of Gram-negative bacteria.

Food-grade organic acids, including lactic, malic, tartaric, citric, acetic, formic, propionic, butyric, sorbic, and fumaric acids, together with their salts, have been documented as helpful in prolonging shelf-life (Taylor and Doores, 2020).

3.4. Inorganic antimicrobials:

Some examples of inorganic materials, including AgNPs, nanoclay, zinc oxide NPs (ZnONPs), titanium oxide NPs (TiO₂ NPs) and titanium nitride NPs (TiNNPs), have been introduced to food packaging as functional additives.

AgNPs are the most used antimicrobial components in the food packaging industry because of their larger surface area than their bulk counterpart. The antimicrobial mechanism of AgNPs is related to the accumulation of AgNPs on the cell wall of bacteria, damaging the cell membrane by creating irregular shapes and protrusions. ZnONPs are relatively more efficient than AgNPs due to less toxicity and cost-effectiveness (Pavithra and Devadathan, 2026)

4. Conclusion:

Active packaging using antimicrobial chemicals effectively prolongs the shelf life of fresh items by controlling microbial growth and reducing spoilage. These approaches include natural or synthetic compounds such as organic acids, essential oils, plant extracts, microbial metabolites and inorganic

antimicrobials into packaging materials for controlled release onto food surfaces. This approach preserves quality, safety and freshness while minimizing postharvest losses. Despite hurdles such as cost, regulatory approval and sensory effects, it offers a sustainable and effective alternative for improving food preservation and minimizing supply chain waste.

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