

Active Packaging of Meat and Meat ProductsV. Monish^{*1}, G. Sujana¹**Introduction:**

Meat and meat products are important sources of high-quality protein, essential amino acids, vitamins and minerals. However, their high moisture content, nutrient availability and favourable pH make them highly susceptible to microbial and chemical deterioration. During storage, microbial growth, lipid oxidation, protein degradation, moisture loss and pigment oxidation can progressively reduce meat quality, safety and consumer acceptability.

Refrigeration is the most commonly used method for slowing these changes, but it cannot completely prevent deterioration. Conventional packaging mainly provides a physical barrier against contamination, moisture loss and environmental conditions. Modern meat preservation therefore requires packaging systems that can perform additional functions.

Active packaging is one such emerging technology. It is designed to interact with the food or the atmosphere surrounding it to maintain quality and extend shelf life. Oxygen scavengers, antimicrobial packaging, antioxidant systems, moisture absorbers and carbon dioxide regulators are among the

important active packaging technologies investigated for meat and meat products.

Active Packaging: What Makes It Different?

Conventional packaging mainly contains and protects food, whereas active packaging performs an additional preservation function. An active system may remove an undesirable substance, such as oxygen, or release a beneficial substance, such as an antimicrobial or antioxidant compound.

In meat preservation, the major objectives of active packaging are to:

- reduce microbial growth;
- control oxygen availability;
- delay lipid oxidation;
- maintain desirable colour;
- reduce development of off-odours and flavours; and
- extend refrigerated shelf life.

The effectiveness of active packaging depends on the type of meat, packaging material, active ingredient, storage temperature, package atmosphere and intended shelf life.

Importance of Active Packaging in Meat PreservationV. Monish^{*1}, G. Sujana¹¹Sri Venkateswara Veterinary University, Tirupati, Andhra Pradesh, India -517502

Fresh meat is particularly vulnerable to microbial spoilage and oxidative deterioration. Microorganisms growing on the meat surface can produce unpleasant odours, slime, discoloration and other quality defects. At the same time, oxygen can accelerate lipid oxidation and influence the oxidation state of myoglobin, the principal pigment responsible for meat colour.

Lipid oxidation is especially important because it can result in rancid flavours and undesirable odours. Oxidative reactions may also reduce nutritional quality by affecting sensitive nutrients and fatty acids.

Active packaging attempts to control these processes by modifying the environment immediately surrounding the meat. Instead of depending solely on refrigeration, it provides an additional preservation barrier.

Oxygen Scavenging Systems

Oxygen scavengers are among the most widely investigated active packaging systems for meat. They remove residual oxygen from the package atmosphere and can also react with oxygen entering through the packaging material during storage.

Iron-based scavengers are commonly used, while other systems may contain reducing agents such as ascorbic acid. The reduction of oxygen can slow oxidative reactions and may contribute to better colour stability and reduced lipid oxidation.

The performance of an oxygen scavenger depends on several factors, including its formulation, moisture availability, temperature, package volume, oxygen permeability of the packaging material and amount of residual oxygen after sealing.

An effective oxygen-scavenging system therefore requires proper matching between the scavenger and packaging material. A high-barrier package combined with an appropriate oxygen scavenger can provide better protection than either approach used independently.

Antimicrobial Active Packaging

Microbial growth remains one of the major limitations to the shelf life of fresh meat.

Antimicrobial packaging aims to inhibit or delay microbial growth at the food-package interface.

Antimicrobial compounds may be incorporated into polymer films, coatings, pads or sachets. Natural substances such as essential oils, plant extracts, organic acids and bacteriocins have received considerable attention.

Essential oils from plants such as clove, oregano, rosemary and lemongrass contain bioactive compounds with antimicrobial properties. Their incorporation into packaging can provide localized antimicrobial activity and potentially reduce the growth of spoilage microorganisms.

However, the concentration of antimicrobial compounds must be carefully optimized. High concentrations may produce strong flavours or aromas that negatively affect consumer acceptance. Therefore, microbial effectiveness must always be considered alongside sensory quality.

Natural Antioxidants in Active Packaging

Growing consumer interest in natural and minimally processed foods has encouraged research into plant-derived antioxidants for active packaging. Herbs and spices contain phenolic compounds and other bioactive substances that can inhibit oxidative reactions. **Clove, rosemary, oregano and lemongrass** are examples of plant sources investigated for their antioxidant potential.

Lemongrass contains citral and related compounds, while clove is particularly rich in eugenol. These compounds may help reduce oxidative deterioration and, in some cases, contribute to antimicrobial activity.

Natural active ingredients are attractive alternatives to conventional preservatives, but their stability, concentration, migration, sensory effects and regulatory status must be carefully evaluated before commercial application.

Active Films, Coatings and Sachets

Active compounds can be incorporated into packaging in several ways. One common approach is the use of **active sachets**, which

are placed inside the package and release or absorb specific substances without being directly mixed with the food.

Another approach involves incorporating active compounds directly into polymer films. Such films may provide controlled release of antimicrobial or antioxidant compounds at the food surface. Active coatings provide another alternative and can be applied to packaging materials or, where permitted and appropriate, directly to food products.

Each system has advantages and limitations. Sachets can provide relatively high activity without substantially modifying the packaging film, whereas active films provide a more integrated packaging solution. The choice depends on the product requirements and intended application.

Role of Packaging Materials

The packaging material plays a critical role in determining the performance of an active system. Different polymers vary in oxygen and moisture permeability.

Materials such as polyethylene terephthalate, polypropylene, polyethylene and ethylene-vinyl alcohol may be used individually or in multilayer structures. High-barrier materials reduce oxygen entry, while multilayer systems can combine mechanical strength with gas and moisture barrier properties.

The combination of an active component with an appropriate barrier material can therefore provide better control of the package environment.

Consequently, active packaging should be viewed as an integrated system involving **food, active component and packaging material** rather than as a single preservation component.

Evaluation of Active Packaging

The effectiveness of an active packaging system should be evaluated using several quality and safety parameters.

Important parameters include:

- ⇒ **pH:** Indicates changes associated with microbial and biochemical activity.
- ⇒ **Microbial counts:** Provide information about microbial growth and spoilage.
- ⇒ **Lipid oxidation:** TBARS and related measurements can indicate oxidative deterioration.
- ⇒ **Colour:** L*, a* and b* values help assess changes in meat colour.
- ⇒ **Gas composition:** Oxygen and carbon dioxide measurements help evaluate package performance.
- ⇒ **Drip or extract release:** Provides information on moisture and quality changes.
- ⇒ **Sensory characteristics:** Appearance, colour, odour, texture and overall

acceptability determine consumer suitability.

- ⇒ **Protein degradation:** Can provide additional evidence of deterioration.

No single parameter can adequately describe meat quality. A successful active packaging system should maintain microbiological quality while also preserving chemical stability and sensory acceptability.

Shelf-Life Extension and Food Waste Reduction

The principal advantage of active packaging is its potential to delay deterioration and extend the period during which meat remains acceptable.

This can have considerable importance throughout the meat supply chain. Meat products may spend several days in transportation, storage and retail display before reaching consumers. Even a moderate extension in shelf life can provide additional flexibility for distribution and marketing.

By slowing microbial and chemical deterioration, active packaging may also contribute to reducing food losses. This is particularly relevant because deterioration of fresh meat can result in substantial economic losses for producers, processors, retailers and consumers.

However, active packaging should not be considered a substitute for refrigeration. Maintaining an appropriate cold chain and

following good hygienic and manufacturing practices remain essential.

Sustainable Active Packaging

Environmental concerns associated with conventional plastic packaging have encouraged researchers to investigate biodegradable and renewable materials for active packaging.

Biopolymers such as **chitosan, starch, cellulose derivatives and polylactic acid** have been investigated as potential packaging materials. Natural extracts and essential oils can also be incorporated into these materials to provide antimicrobial or antioxidant functionality. Such systems have the potential to combine food preservation with reduced environmental impact. Nevertheless, biodegradable materials must still provide sufficient mechanical strength, barrier properties, stability and shelf-life performance to be commercially useful.

Future packaging systems will therefore need to balance **food safety, preservation efficiency, cost and environmental sustainability**.

Challenges in Commercial Application

Despite promising research findings, several challenges remain before active packaging can become widely used across the meat industry.

The first concern is **food safety**. Active substances must be evaluated for their toxicity,

migration and interaction with food components.

The second is **sensory acceptability**. Essential oils and plant extracts can impart strong aromas or flavours when used at higher concentrations.

Cost is another important factor. Active packaging should provide sufficient preservation benefits to justify its additional cost compared with conventional packaging.

Regulatory requirements must also be considered, particularly when active substances migrate into food.

Finally, laboratory studies may not always accurately represent commercial conditions. Large-scale studies under realistic transportation, retail and storage conditions are therefore required before widespread industrial adoption.

Future Perspectives

The future of meat packaging is likely to involve multifunctional systems that combine several preservation technologies.

One promising approach is the integration of **active and intelligent packaging**. Active packaging can help preserve food, while intelligent packaging can provide information regarding freshness, temperature abuse or package integrity.

Nanotechnology is also being explored to improve the performance of antimicrobial and antioxidant packaging. At the same time,

increasing attention is being given to natural compounds, biodegradable polymers and agricultural by-products as sources of sustainable packaging materials.

The development of controlled-release systems may further improve the efficiency of active ingredients by providing activity over an extended period rather than releasing the entire compound at once.

These developments could lead to packaging systems capable of simultaneously controlling oxygen, inhibiting microorganisms, reducing oxidation and providing information about product quality.

Conclusion

Active packaging is an emerging technology with considerable potential for improving the preservation of meat and meat products. Unlike conventional packaging, it can actively modify the environment surrounding food and thereby delay microbial and chemical deterioration.

Oxygen scavengers can reduce oxygen-related oxidation, while antimicrobial and antioxidant systems can help control microbial growth and oxidative changes. Natural compounds such as lemongrass, clove and other plant extracts offer additional possibilities for developing more consumer-oriented preservation systems.

At the same time, active packaging must be carefully designed with regard to food

safety, sensory quality, migration, cost, regulatory requirements and environmental sustainability. It should complement rather than replace refrigeration, hygienic handling and good manufacturing practices.

With continued research into natural active ingredients, biodegradable materials, controlled-release technologies and intelligent packaging, active packaging could become an important tool for producing safer, higher-quality and longer-lasting meat products while helping to reduce food waste across the supply chain.

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