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Modified Atmosphere Packaging and Its Impact on the Shelf Life of Processed Fish

*Tanuja S[1], P.R. Sahoo[2], Bibek Bhaskar Jena[3] and Elizabeth Martin[4]
[1]Senior Scientist, ICAR-CIWA, Bhubaneswar, India
[2]SMS – Fisheries, KVK, ICAR-CIFA, Bhubaneswar, India
[3]YP-II, ICAR-CIWA, Bhubaneswar, India
[4]Ph.D. Scholar, Department of Food and Nutrition, University of Agricultural Sciences, Dharwad-580005, Karnataka, India
*Corresponding Author's email: tanujasomarajan@gmail.com

Modified Atmosphere Packaging (MAP) is a modern packaging technology designed to extend the shelf life and preserve the sensory and nutritional quality of fish and fish-based products. The technology operates by altering the gaseous composition surrounding the product—primarily using carbon dioxide (CO_2), nitrogen (N_2), and oxygen (O_2)—to retard microbial growth, oxidative spoilage, and enzymatic degradation. This article reviews the principles of MAP, gas composition strategies, microbial and physicochemical impacts, and its role in enhancing the storage stability of processed fish.

Introduction

Fish and fishery products are highly perishable due to their rich protein content, unsaturated lipids, and neutral pH, which provide an ideal environment for microbial proliferation and oxidative degradation (Sivertsvik et al., 2002). Traditional preservation techniques, such as freezing, salting, and smoking, often alter sensory properties or require high energy input. Modified Atmosphere Packaging (MAP) has emerged as an effective non-thermal preservation strategy that extends shelf life while maintaining product freshness and quality (Parlapani et al., 2015).

Principle of Modified Atmosphere Packaging

Modified Atmosphere Packaging involves replacing the normal air inside a package with a specific mixture of gases to slow down spoilage mechanisms. The primary gases used are carbon dioxide (CO_2), nitrogen (N_2), and oxygen (O_2).

- CO_2 acts as a bacteriostatic agent, inhibiting the growth of spoilage microorganisms such as *Pseudomonas* and *Shewanella* spp.
- N_2 is an inert filler gas that prevents package collapse and oxidative rancidity.
- O_2 may be included in small proportions to prevent the growth of anaerobic pathogens (e.g., *Clostridium botulinum*) and to maintain pigment stability in certain fish species (e.g., tuna and salmon).

The efficiency of MAP depends on the gas composition, headspace volume, storage temperature, and barrier properties of the packaging film (Sivertsvik et al., 2003).

Gas Compositions and Their Applications

The gas ratios in MAP are tailored according to species type and product form (raw, smoked, or cooked). Typical gas mixtures used in fish packaging are as follows:

Fish Type / Product	Typical Gas Composition (CO_2:N_2:O_2)	Shelf Life Extension
Raw white fish fillet	60:40:0	2–3× longer

Fish Type / Product	Typical Gas Composition (CO_2:N_2:O_2)	Shelf Life Extension
Oily fish (e.g., mackerel, salmon)	40:60:0	1.5–2× longer
Smoked fish	50:50:0	1.5–2× longer
Tuna / Red fish (color retention)	30:50:20	Maintains color and freshness

High CO_2 concentrations (≥50%) are most effective in retarding microbial growth but may cause exudate formation ("drip loss") due to protein denaturation. Therefore, optimal CO_2 balance is essential to preserve both microbial safety and textural integrity.

Impact on Microbial and Chemical Quality

Microbial Growth

CO_2 dissolves readily in the aqueous phase of fish muscle, forming carbonic acid that lowers the pH and inhibits psychrotrophic aerobic bacteria, notably *Pseudomonas spp.*, *Shewanella putrefaciens*, and *Aeromonas hydrophila*. Studies have shown that MAP can extend the microbial shelf life of chilled fish from 3–5 days to 10–14 days, depending on species and gas ratio (Farber, 1991).

Lipid Oxidation and Rancidity

Fish lipids are rich in polyunsaturated fatty acids (PUFAs), which are prone to oxidation, leading to rancidity and off-flavors. The exclusion of oxygen under MAP reduces oxidative reactions, thereby maintaining the peroxide value, thiobarbituric acid reactive substances (TBARS), and sensory quality during storage.

Protein and Textural Stability

MAP minimizes proteolytic degradation and retains textural firmness by slowing down enzymatic reactions. However, prolonged storage under high CO_2 may cause mild acidification and changes in muscle water-holding capacity.

Influence of Packaging Materials

MAP performance is closely linked to the gas barrier properties of the packaging material. Multilayer films composed of polyamide (PA), polyethylene (PE), ethylene vinyl alcohol (EVOH), or polyethylene terephthalate (PET) are commonly used. These materials prevent gas permeation, ensuring a stable atmosphere throughout storage. The integration of active packaging (with oxygen scavengers or antimicrobial coatings) further enhances shelf life and product safety.

Cold Chain Integration

Temperature is a critical factor influencing MAP efficiency. MAP is not a substitute for refrigeration—it is most effective when combined with proper cold chain management (0–4°C). Any temperature abuse can accelerate microbial growth, especially of psychrotrophic pathogens like *Listeria monocytogenes*. The synergy of low temperature and modified atmosphere ensures maximal preservation of sensory and nutritional quality.

Advantages and Limitations

Advantages:

- Shelf life extended by 2–3 times compared to air packaging.
- Reduction in microbial spoilage and oxidative degradation.
- Maintenance of sensory attributes and nutritional quality.
- Lower dependence on chemical preservatives.

Limitations:

- Equipment cost and gas mixtures increase initial investment.
- Inappropriate gas composition or temperature abuse may lead to spoilage or safety risks.
- Drip loss and texture changes can occur under high CO_2 conditions.

Recent Developments and Future Prospects

Recent innovations in MAP include intelligent packaging systems integrated with freshness indicators (e.g., CO_2 sensors, time–temperature indicators) and biodegradable films compatible with modified atmospheres. Additionally, research on active MAP systems incorporating natural antimicrobial agents (chitosan, essential oils, or bacteriocins) is gaining attention for improving both shelf life and sustainability.

The future direction focuses on developing species-specific MAP protocols, predictive microbial modeling, and smart packaging analytics to optimize preservation while reducing environmental impact.

Conclusion

Modified Atmosphere Packaging represents a scientifically sound and commercially viable solution for extending the shelf life of processed fish. By precisely controlling gaseous environments, MAP effectively suppresses microbial growth, minimizes lipid oxidation, and preserves sensory quality without the need for chemical additives. When integrated with cold chain management and sustainable packaging innovations, MAP offers a promising pathway toward safe, high-quality, and eco-friendly seafood preservation.

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