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A review on advanced packaging technology for fish and fishery products

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Abstract

Packaging is acknowledged as a significant factor in enhancing the shelf life and marketability of fish, representing one of the most dynamic, competitive, and evolving markets. Fish packaging is essential for maintaining the quality and safety of seafood from harvest to consumption. This overview delves into the evolving landscape of seafood packaging innovation, focusing on its role in extending shelf life, preserving freshness, and ensuring safety. Various preservation methods, including Modified Atmosphere Packaging (MAP), Vacuum Packaging (VP), and Active Packaging (AP), are explored in detail.

Keywords: Consumer safety, packaging, preservation, seafood

Introduction

Fish packaging plays a vital role in maintaining the freshness, quality, and safety of seafood from the moment it is caught until it reaches consumers' tables. Effective packaging not only keeps the fish's taste and texture intact but also prolongs its shelf life, ensuring it remains in prime condition. Due to its high perishability, fish requires careful handling to prevent spoilage [16]. Various preservation methods have been employed to combat fish spoilage. Proper packaging, coupled with suitable preservation methods, helps to extend the shelf life of fish. As the global demand for seafood continues to rise, there is an urgent need for packaging solutions that not only prolong shelf life but also maintain product quality. Advanced packaging technology offers various approaches, including modified atmosphere packaging and active and intelligent packaging systems, tailored to address specific industry challenges [5]. This overview takes us on a journey through the complex landscape of seafood packaging innovation. We will explore how these advancements not only mitigate the risks of spoilage and contamination but also improve convenience and traceability for consumers. Seafood is highly perishable and tends to spoil faster than other types of meat. Freshly caught fish undergoes quality changes due to autolysis and bacterial activity, with the extent of these changes over time determining the product's shelf life. Proper storage conditions are essential to prevent fish and fishery products from spoiling. Several emerging technologies show promise in extending shelf life, including High Pressure Processing, Irradiation, Pulsed Light Technology, Pulsed Electric Field, Microwave Processing, Radio Frequency, Ultrasound, among others. Packaging technologies such as Modified Atmosphere, Active, and Intelligent Packaging also play a crucial role in fish preservation. Moreover, compostable packaging, biodegradable packaging, and sustainable packaging have been developed and utilized recently, contributing to the management of environmental pollution issues threatening many ecosystems.

Basic function of packaging for fish and fishery product

The primary function of packaging for fish and fishery products is to preserve the freshness, quality, and safety of the seafood throughout the supply chain, from harvest to consumption. Here are the basic functions of packaging for fish and fish`ery products:

Preservation: Packaging creates a protective barrier that helps prevent contamination, spoilage, and deterioration of the fish due to exposure to air, moisture, light, and microorganisms. Proper packaging techniques such as vacuum sealing, modified atmosphere packaging (MAP), or ice packing help extend the shelf life of the fish and fishery products by controlling temperature and minimizing oxygen exposure.

Physical damage: Packaging provides a physical barrier to protect fish from crushing, puncturing, or other forms of damage during handling, transportation, and storage.

Microbial spoilage: Packaging can help to prevent the growth of bacteria, mould, and other microorganisms that can cause spoilage. This is often achieved by using materials that create a barrier to oxygen or moisture.

Chemical spoilage: Packaging can help to prevent fish from reacting with oxygen, light, or other chemicals that can cause discoloration, rancidity, and other forms of quality deterioration.

Protection: Packaging provides physical protection to the fish during handling, transportation, and storage. It shields the seafood from mechanical damage, crushing, bruising, and impacts that could affect its quality and appearance.

Temperature control: Packaging helps regulate the temperature of the fish to maintain optimal conditions for freshness and safety. Insulated packaging materials and techniques help prevent temperature fluctuations that could lead to spoilage or bacterial growth.

Moisture management: Packaging materials with moisture barriers help control moisture levels to prevent dehydration or excessive moisture absorption, which can affect the texture and flavour of the fish.

Safety assurance: Packaging plays a crucial role in ensuring the safety of fish and marine products by reducing the risk of contamination and cross-contamination with pathogens or harmful bacteria. Sealed packaging methods such as vacuum packaging or MAP minimize exposure to air and bacteria, while proper labelling provides information on handling and storage instructions to maintain safety.

Convenience: Packaging enhances the convenience of handling, storing, and transporting fish and marine products for both suppliers and consumers. Convenient packaging formats such as portioned fillets, individually wrapped servings, or ready-to-cook packages offer ease of use and reduce preparation time.

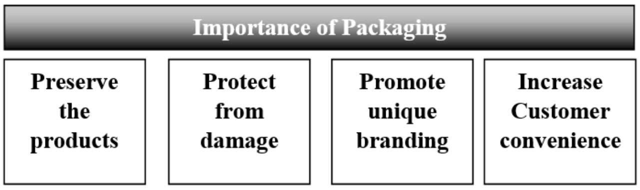

Fig 1: Importance of packaging

Modified Atmosphere Packaging (MAP)

The warm climate in our region promotes the rapid multiplication of microbes. Currently, ice and mechanical refrigeration are the predominant methods utilized to inhibit microbial and biochemical spoilage in freshly caught seafood during distribution and marketing. Nevertheless, as ice melts, it tends to contaminate fish, accelerating spoilage and decreasing shelf life. Modified atmosphere packaging, a technologically feasible method, has been developed as an adjunct to ice or mechanical refrigeration to mitigate losses and prolong the storage duration of fresh seafood products. In modified atmosphere packaging, air is substituted with various gas mixtures to regulate microbial activity and/or impede the discoloration of the products. The ratio of each component gas is predetermined during the introduction of the mixture into the package; however, no further adjustments are made during storage.

The potential extension of shelf life depends on various factors including species, fat content, initial microbial presence, gas composition, the ratio of gas to product volume, and importantly, storage temperature. The atmosphere consists predominantly of nitrogen (N_2) at around 78%, oxygen (O_2) at approximately 21%, argon (Ar) at roughly 1%, and trace amounts of other gases, with carbon dioxide (CO_2) making up about 0.03%. Oxygen in the atmosphere, crucial for aerobic respiration, readily triggers the oxidation of molecules and can interact with enzymatic systems. This oxidative process persists after death, leading to the deterioration of freshness and eventual spoilage [1]. The absence of oxygen effectively extends the shelf-life of meat, but anaerobic conditions have a lesser impact on the freshness of fish. Moreover, comparing the microbial composition of meat to that of whole, gutted, or filleted fish is challenging due to several fish-specific factors. Firstly, fish typically have a higher initial bacterial load, including microorganisms capable of thriving in low temperatures, some of which may be pathogenic and able to proliferate before spoilage sets in. Additionally, factors such as the higher pH of fish flesh, the redox potential (Eh) of fish muscle, and the structural damage caused by CO_2 on muscle tissue make Modified Atmosphere Packaging (MAP) more complex when applied to fish products [3]. CO_2 is the most important gas used in MAP of fish because of its bacteriostatic and fungistatic properties. It is highly soluble in water and fat and the solubility increases greatly with decreased temperature [20]. Even upon opening the packaging, the product gradually releases CO_2, maintaining its preservative effect, referred to as the "CO_2 residual effect [21]. The main impact of elevated carbon dioxide modified-atmosphere packaging is the prolongation of the 'lag' phase in bacteria growth on fish, the suppression of typical spoilage bacteria, and the support for a predominantly slower-growing Gram-positive flora [1, 17]. The gas mixture undergoes changes in its initial composition due to chemical, enzymatic, and microbial activity during storage. The enrichment of Carbon dioxide in the storage atmosphere plays a crucial role in controlling microbial growth, thereby extending the shelf life of products. Carbon dioxide has the ability to decrease the pH levels within tissues, both intra and extracellular, and potentially impact the pH levels of microorganisms as well. Additionally, it can influence the membrane potential of microorganisms and disrupt the equilibrium of decarboxylating enzymes. Various gas combinations, such as carbon dioxide alone, carbon dioxide mixed with nitrogen, carbon dioxide combined with oxygen, and carbon dioxide along with oxygen and nitrogen, are commonly used to prolong the shelf life of products beyond what can be achieved in traditional refrigerated storage. The inhibitory effects of carbon dioxide on microorganisms are evident through an extended lag phase and a slower growth rate during the logarithmic phase. Notably, the inhibitory effects of carbon dioxide are more pronounced when the product is stored at the lower end of the refrigerated temperature range [2]. Various packaging materials commonly used include flexible nylon/surylyn laminates, PVC trays with polythene lamination, and polyester/low density polythene film. The combination of high barrier film and modified atmosphere packaging (MAP) with CO2 helps prevent bacterial growth when storing fresh fishery products in refrigerated conditions [6]. The gas mixtures utilized for Modified Atmosphere Packaging (MAP) of fresh fish differ based on whether the fish in the package is lean or oily. In the case of lean fish, it is recommended to have a composition of 30% Oxygen, 40% Carbon dioxide, and 30% Nitrogen. Nitrogen, being inert and tasteless, is primarily employed as a filler gas due to its limited solubility in water and fat [20] and to prevent pack collapse [15]. Increased levels of carbon dioxide are employed for fatty and oily fish, resulting in a proportional decrease in oxygen levels within the mixture, ultimately leading to 40-60% nitrogen content. By eliminating oxygen, the onset of oxidative rancidity in fatty fish is delayed.

The recommended ratio between the volume of gas and the volume of food product, known as the G/P ratio, is typically 2:1 or 3:1 (gas to food product). This higher G/P ratio is crucial in preventing package collapse caused by the solubility of CO_2 in wet foods. The solubility of CO_2 can also affect the food's ability to retain water, leading to increased drip. On the other hand, oxygen can hinder the growth of anaerobic bacteria such as *Clostridium botulinum*, although the sensitivity of anaerobes to oxygen varies widely. It is important to note that including only a small amount of oxygen with nitrogen or carbon dioxide does not guarantee the prevention of botulism. When it comes to MAP studies, cod is undoubtedly the preferred species. Typically, shelf-life doubles from 6-9 days in air and at chilled temperatures to 12-20 days in MAP, based on the gas mixture ratio mentioned above.

The main concern lies in the potential growth and toxin production of psychrotrophic *Clostridium botulinum* type E, along with non-proteolytic type B and F. These strains can develop at temperatures as low as 3.3°C, release toxins, and yet retain satisfactory odour and appearance for customers. The optimal MAP packaging method for inhibiting toxin production was identified as an equal mixture of O_2 and CO_2 [7]. However, despite these promising findings, the adoption of MAP does not eradicate the essentiality or the requirement for careful handling at every stage, commencing from the factory until it reaches the table [15].

Advantages of MAP

- The product retains its natural color.
- The product retains its form and texture
- Inhibits the proliferation of microorganisms.
- The product retains its essential vitamins and flavours, while also preventing the oxidation of fats
- The use of preservatives is minimized due to the product's natural preservation properties
- To help businesses reach out to far-off locations, thereby expanding their market opportunities. The product's transparent packaging enhances its presentation, providing customers with a clear view of its contents.
- A sanitary stackable package, sealed and devoid of any product leakage
- Enhanced shelf life of fresh food items / reduction in spoilage.
- Extends the shelf life of fish in chilled / refrigerated storage by 2 – 3 times

Disadvantages of MAP

- Capital-intensive because of the high expenses associated with machinery
- Costs related to gases and packaging materials
- Additional expenses for a gas analyzer to guarantee proper gas composition
- Lack of control over gas composition post-packaging
- Expansion of package size, which will negatively impact transportation expenses and retail display area
- The advantages of MAP are no longer effective once the packaging is opened or damaged.
- Anaerobiosis may be promoted by a high concentration of CO2.
- It is crucial to maintain temperature carefully in order to prevent the growth of *C. botulinum* and *L monocytogenes.*

Vacuum packaging

In recent times, vacuum packaging has gained popularity as a method for preserving fish and fishery products due to its effectiveness in extending shelf life and maintaining product quality. The process involves extracting air from the packaging container before sealing it, creating a vacuum environment that hinders microbial growth, prevents oxidation, and retains the sensory characteristics of the product. Its primary aim is to eliminate oxygen by ensuring close contact between the packaging material and the product. As the vacuum is applied, the oxygen concentration in the package is significantly reduced by 97–99%, thus inhibiting the proliferation of aerobic SSO (specific spoilage organisms) responsible for product spoilage. This decrease in oxygen concentration also diminishes the degree of oxidation. For instance, if the pressure is reduced from 1000 mbar (1 atm) to 100 mbar, approximately 2.1% oxygen will remain in the package. This chapter examines the underlying principles, advantages, and practical uses of vacuum packaging for fish and fishery products. Vacuum-packed foods maintain their freshness and flavour 3 to 5 times longer than with conventional storage methods, because they don't come in contact with oxygen. Foods maintain their texture and appearance, because microorganisms such as bacteria mould and yeast cannot grow in a vacuum. Freezer burn is eliminated, because foods no longer become dehydrated from contact with cold, dry air. Moist foods won't dry out, because there's no air to absorb the moisture from the food. Dry, solid foods, won't become hard, because they don't come in contact with air and, therefore, can't absorb moisture from the air. Foods that are high in fats and oils won't become rancid, because there's no oxygen coming in contact with the fats, which causes the rancid taste and smell.

Benefits of vacuum packaging include reducing fat oxidation and preventing the survival of aerobic organisms, as well as decreasing the evaporation rate to minimize dryness and freezer burn in frozen products, ultimately extending shelf life. However, the necessity for high barrier materials and the maintenance of aerobic conditions for products with sharp edges or delicate textures pose limitations, as they can encourage the growth of *Clostridium botulinum* and *Listeria monocytogenes*. Overcoming these microorganisms requires additional barriers, which can be costly. The incorporation of oxygen scavengers into vacuum packaging facilitates an active packaging system, effectively reducing oxygen levels to less than 0.01% within 24 hours, serving as a preservation method [12].

Materials for vacuum packaging

The packaging material chosen for vacuum packaging (VP) must possess both high gas and moisture barrier properties, along with the ability to be heat sealed [18]. Barrier materials such as PET/LDPE, PA/LDPE, LDPE/PA/LDPE, etc., as well as high barrier materials like PET/PVdC/LDPE, PA/PVdC/LDPE, PA/EVOH/LDPE, LDPE/EVOH/LDPE, PS/EVOH/LDPE, PP/EVOH/PP, etc., typically in the form of multi-layer films or sheets, are suitable for the prolonged storage of vacuum-packaged cooked muscle-based products. The oxygen permeability of the vacuum packaging film for cooked and processed meat/fish products is usually below 150 cm3/m2.24 h. atm when PET or PA are utilized as barrier materials, or lower than 10 cm3/m2.24 h. atm when PVdC or EVOH are employed as high barrier materials [9].

Principles of vacuum packaging

Vacuum packaging relies on the principle of removing oxygen from the packaging environment, which slows down the deterioration of fish and fishery products. Oxygen is a major contributor to food spoilage, as it promotes the growth of aerobic microorganisms and leads to oxidative reactions that degrade the quality of the product. By eliminating oxygen, vacuum packaging helps to extend the shelf life of fish and fishery products and preserve their freshness, colour, texture, and flavour.

Steps of vacuum packaging

The vacuum packaging process for fish involves several critical steps to ensure proper preservation and quality maintenance. Let's break down each step in detail;

1. Preparation of fish: Before vacuum packaging, the fish must undergo thorough preparation. This includes cleaning, gutting, scaling, and removing any undesirable parts such as fins or bones. Additionally, the fish may be portioned into fillets, steaks, or whole pieces, depending on the desired end product.

2. Selection of packaging material: The appropriate packaging material is crucial for effective vacuum packaging. Vacuum pouches or bags made from high-quality materials such as polyethylene (PE) or polyethylene terephthalate (PET) are commonly used. These materials should be food-grade, durable, and capable of withstanding the vacuum sealing process without tearing or puncturing.

3. Placing the fish in the packaging: Once prepared, the fish pieces are carefully placed into the vacuum pouches or bags. It's essential to arrange the fish in a single layer to ensure uniform sealing and efficient removal of air during the vacuum process. Overcrowding the packaging can lead to uneven vacuuming and compromise the quality of the final product.

4. Evacuating air from the packaging: The next step involves removing air from the packaging to create a vacuum environment. This can be done using a vacuum sealing machine or a vacuum chamber. In a vacuum sealing machine, the open end of the pouch is placed inside the machine, and a vacuum pump removes the air before sealing the pouch. In a vacuum chamber, the entire package is placed inside a chamber, and air is evacuated by reducing the pressure within the chamber.

5. Sealing the packaging: Once the desired level of vacuum is achieved, the open end of the pouch is sealed to maintain the vacuum and prevent air from re-entering. The sealing process may involve heat sealing, where the edges of the pouch are fused together using heat, or other methods such as impulse sealing or ultrasonic sealing. Proper sealing is critical to maintaining the integrity of the package and ensuring the freshness of the fish.

6. Labelling and date coding: After sealing, the vacuum-packaged fish should be labelled with relevant information such as product name, weight, date of packaging, and any other necessary labelling requirements. Date coding helps in monitoring the shelf life and ensures proper rotation of stock to maintain freshness.

7. Storage and distribution: Once packaged and labelled, the vacuum-sealed fish can be stored in refrigerated or frozen conditions, depending on the specific requirements of the product. Proper storage temperature is essential for preserving the quality and extending the shelf life of the vacuum-packaged fish. The packaged fish can then be distributed to retailers, wholesalers, or consumers for sale or further processing.

Advantage and disadvantage of vacuum packaging [11]

Advantages of vacuum packaging

- Reduces fat oxidation
- Reduces growth of aerobic microorganisms
- Reduces evaporation
- Reduces weight loss
- Reduces dryness of product
- Reduces freezer burn
- Reduces volume for bulk packs Eg. Tea powder, dry leaves etc
- Extends the shelf life

Disadvantages of vacuum packaging

- Cannot be used for crispy products and products with sharp edges
- Requires high barrier packaging material to maintain vacuum
- Creates anaerobic condition, which may trigger the growth and toxin production of *Clostridium botulinum* and the growth of *Listeria monocytogenes*. Additional barriers / hurdles are needed to control these microorganisms.

Active packaging

"A type of packaging that changes the condition of the packaging and maintains these conditions throughout the storage period to extend shelf-life or to improve safety or sensory properties while maintaining the quality of packaged food" is the definition of the novel idea known as "active packaging" [14]. This entails adding certain chemicals to packaging containers or film in order to preserve and increase the shelf life of the product [19]. Active packaging technique is either scavenging or emitting systems added to emit (e.g., N_2, CO_2, ethanol, antimicrobials, antioxidants) and/or to remove (e.g., O_2, CO_2, odour, ethylene) gases during packaging, storage and distribution. Some of the active packaging systems include; Oxygen scavengers; Carbondioxide emitters; Moisture regulators; Antimicrobial packaging; Antioxidant release; Release or absorption of flavours and odours; Carbondioxide scavenger and Active packaging systems with dual functionality (combination of oxygen scavengers with carbon dioxide and/or antimicrobial / antioxidant substances) [4]. Future developments are anticipated to bring more attention to further active packaging systems, such as color-containing films, light-absorbing or regulating systems, microwave heating susceptors, gas-permeable/breathable films, anti-fogging films, and insect-repellent [10].

O_2-scavengers: Fish products are extremely sensitive to oxygen because it promotes the growth of aerobic microorganisms and oxidation, which results in unfavorable color changes (such as the discoloration of pigments like myoglobin and carotenoids), flavors and off-odors (like rancidity due to lipid oxidation), and nutrient loss (such as the oxidation of vitamin E, beta-carotene, and ascorbic acid). Each of these detracts from the quality. Thus, it's critical to regulate the oxygen content of food packaging to slow down the rate at which food deteriorates and spoils. Foods that are O_2-sensitive and have low residual oxygen levels can have their quality alterations minimized by using an O_2-scavenger, which absorbs the leftover O_2 after packaging.

CO_2-emitters: For moist food goods like fish, shellfish, and meat products, high CO_2 levels (10–80%) are ideal as they prevent surface microbial development and increase shelf life. Overall, CO_2 causes a rise in the development time and lag phase of rotting microorganisms. One way to get around the limitations of Modified Atmosphere Packaging (MAP) is to combine it with a carbon-dioxide generating device. Many commodities have been studied in relation to the good retention of CO_2 in MAP and, more recently, the creation of CO_2 inside the packaging system. These systems rely on ferrous carbonate, citric acid, ascorbate, sodium bicarbonate, and so forth.

Antimicrobial packaging

Particularly for fish and meat products, antimicrobial packaging is an active packaging technology that is rapidly developing. Because post-processing handling causes microbial contamination of these items mostly at the surface, using antimicrobials in packaging can help to increase safety and postpone spoiling. In order to increase shelf life and preserve product quality and safety, antimicrobial films work primarily by releasing antimicrobial substances into the food, which lengthens the lag phase and shortens the development phase of microorganisms. Antimicrobial agents can be applied to package materials by coating, incorporating, immobilizing, or surface-modifying them to start the antimicrobial activity. Acid anhydride, alcohol, bacteriocins, chelators, enzymes, organic acids, and polysaccharides are among the classes of antimicrobials. In addition, several plant compounds and derivatives from shellfish waste, such as chitosan, can be added as antimicrobials to the packaging system. Because antimicrobial compounds are subject to tight rules regarding their use for human consumption, this technology is not as extensively recognized or exploited as it could be.

Intelligent packaging

Intelligent packaging, also known as smart packaging, senses certain characteristics of the food it contains or the environment it is stored in and communicates this information to the producer, merchant, and customer. "Packaging systems which monitor the condition of packaged foods to provide information about the quality of the packaged food during transport and storage" is the definition of intelligent packaging. These consist of indicators for the time and temperature, leaks, freshness, etc [13]. Food safety is enhanced and the shelf life of packaged foods is prolonged by active and intelligent packaging solutions. But in the seafood industry, technology are changing, and many of these systems are still in the research and development phase [8].

Conclusion

Smart packaging systems proved to be an effective mechanism to improve the food safety and shelf-life extension of the packaged foods. However, these technologies are in development stage in the seafood sector and needs ongoing researches and continued innovations to anticipate future advancement in food quality, safety and stability. Aquatic foods play a vital role in addressing issue of Food & Nutritional security. Product diversification, value addition, increasing exports and reducing post-harvest losses can contribute to economic growth and to reduce hunger in the world. Consumers demand high quality processed products with minimal changes in nutritional and sensory properties. Emerging thermal and non-thermal processing technologies will help in extending shelf life, maintain or improve sensory and nutritive properties, ensures safety, increases convenience, reduce waste, facilitate exports/cross boundary trade and most importantly increases economic value. Continued research and innovation in thermal and non-thermal processing technologies are vital for addressing food security challenges, reducing post-harvest losses, and meeting consumer demands for high-quality seafood products with extended shelf life and minimal changes in sensory properties.

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