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Edible Packaging for Fish and Fishery Products

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Abstract

Rising plastic waste and environmental concerns have intensified the demand for sustainable food packaging. In seafood preservation, edible packaging offers an effective, eco-friendly solution. Made from natural biopolymers like proteins, polysaccharides, and lipids, these films and coatings protect fish products from oxidation, moisture loss, and microbial spoilage. This article outlines recent used in edible packaging, including materials like chitosan, gelatin, starch, alginate, whey protein, zein, fatty acids, and waxes, along with their functions. Techniques for film formation (wet and dry methods) and coating application (dipping, spraying, and brushing) are also discussed. Edible packaging provides a sustainable substitute for plastics, despite issues including moisture sensitivity and fragility. Its wider use could transform seafood packaging and advance international goals for sustainability.

Keywords: Edible film and coatings, Polymers, Preservation, Shelf life, Environmental sustainability.

Introduction

The modern food industry is increasingly challenged by the dual imperatives of ensuring food safety and minimizing environmental impact. Traditional plastic packaging although effective in preserving food quality has contributed significantly to global environmental contamination. The prevalence of plastic waste and micro plastics in ecosystems has spurred both consumer demand and regulatory pressures to seek sustainable alternatives. In this context edible packaging emerges as a promising solution that not only reduces reliance on conventional plastics but also aligns with broader environmental and health-conscious objectives (Klemes *et al*., 2021). In the seafood industry, the need for innovative packaging solutions is particularly acute. Fish and other fishery products are highly perishable making them susceptible to rapid spoilage due to moisture loss, oxidation and microbial contamination. Maintaining freshness and extending shelf life are critical challenges, especially in a market where consumer safety and quality are paramount. Edible films and coatings have shown great potential in addressing these challenges by forming effective barriers that limit moisture migration and oxidative reactions thereby preserving the intrinsic qualities of seafood. Edible packaging is crafted from natural biopolymers including polysaccharides, proteins and lipids, which are inherently biodegradable and safe for consumption. These materials offer a unique advantage over traditional packaging by serving a dual purpose as a protective barrier for food products while simultaneously being consumed along with the food. A wide range of natural materials such as chitosan, alginate, collagen, waxes and vegetable oils have been explored for their suitability in creating edible packaging. Each of these biopolymers offers distinct functional benefits. Additionally various application methods such as spraying, dipping and brushing enable the integration of these edible coatings into existing seafood processing lines ensuring that the packaging process is both efficient and adaptable. Beyond its functional advantages, edible packaging holds considerable promise as an eco-friendly alternative that directly addresses the growing problem of plastic waste.

Edible packaging contributes to a more sustainable lifecycle for food products. This article explores the use of edible packaging for fish and fishery products examining its potential to improve moisture control, oxidation resistance and microbial protection. Ultimately the adoption of edible packaging represents a forward-thinking strategy that could revolutionize the seafood industry while playing a vital role in the broader movement toward sustainable food systems.

Edible packaging

Primary packaging composed of edible substances is known as edible coatings or films. The thin coating of an edible material is applied directly on food or food wrapping film without modifying the original ingredients. Coatings and films that are edible have been applied to enhance a variety of foods mechanical qualities, sensory perception, convenience, microbiological safety, gas, moisture barrier and shelf life. They can enhance the nutritional value of both frozen and fresh foods by preventing the growth of microorganisms, decreasing water loss, lipid oxidation and serving as carriers for dietary additives including antioxidants and antimicrobials

Composition of Edible packaging: Polymer is the main ingredient for a variety of edible surfaces. The choice of edible packaging is influenced by the main food type, storage conditions and time. There are two types for edible packages edible coating and edible film. Edible films and coatings may be categorized into three primary classes based on the kind of material they are composed of polysaccharides, lipid and proteins. Edible films used as wall materials are mostly composed of proteins and polysaccharides. Lipids are utilized as coatings or combined with biopolymers to create composite films which provide superior protection against water vapor because they are not biopolymers like proteins, polysaccharides and cannot form cohesive films.

Polysaccharides based edible packaging: Complex carbohydrates called polysaccharides are utilized extensively in the manufacturing of edible packaging. The majority of research employ non-toxic polysaccharides derived from natural food materials both people and animals can safely eat these polysaccharide-based edible packaging. For the production of edible films and coating materials, polysaccharides such as cellulose, starch, pectin, and chitosan, are heavily utilized. Polysaccharides can provide non-oily, colorless, tasteless coatings and films that are effective at blocking carbon dioxide and oxygen but ineffective at blocking water vapor. The following major polysaccharides-based polymers are:

Cellulose: The most prevalent naturally occurring organic polymer that can be used to create edible films is cellulose. It is the primary structural component of the plant cell wall. Anhydrous β1-4 glycosidic linked glucose rings make up the linear-chain homopolysaccharide known as cellulose. High mechanical strength, low cost, low density, durability, non-toxicity, biocompatibility, biodegradability, renewability, good film-forming performance, chemical stability, and ease of creating chemical derivatives are some of its unique qualities. For edible coatings or films, four main forms of cellulose derivatives are utilized: methylcellulose (MC; E461), carboxymethylcellulose (CMC; E466), hydroxypropyl methylcellulose (HPMC; E464), and hydroxypropyl cellulose (HPC; E463). The shelf life of salmon fillets is increased by packaging films formed of CMC-tea waste and furcellaran, which prevent the growth of bacteria and accumulate of biogenic amine (Jamróz *et al.,* 2022). MC-based coatings are utilized in confectionery foods because they form a barrier that prevents the flow of lipids or oil in and out. Likewise, coatings or films based on HPMC prevent the absorption of oil, which is why they are utilized in fried foods.

Chitosan: Chitosan, a natural biopolymer derived from the deacetylation of chitin found in crustacean shells, Chitosan based packaging have demonstrated efficacy in the packaging of fresh agricultural products, dairy items, meat, and seafood, facilitating enhanced preservation and diminished spoilage rates. The antimicrobial and antioxidant characteristics inherent in chitosan contribute to the inhibition of bacterial proliferation, the retardation of oxidative processes, and the sustenance of food freshness, ultimately leading to a reduction in food waste. Silver carp and grass carp fillets' shelf life were extended by 6 and 13 days by coatings with 2% chitosan (Ramezani *et al.,* 2015). Additionally, the primary reason chitosan is utilized in food packaging is because of its potent natural antibacterial properties against food-grade filamentous fungi, yeasts, and Gram-positive and Gram-negative bacteria (Cazón *et al*., 2012). It is recommended to store catfish fillets in a refrigerator using chitosan and chitosan-alginate coatings. Fish burgers' shelf life is also increased by five days with the Lactoperoxidase system and chitosan (Ehsani *et al*., 2020).

Starch: Starch is a cost-effective, plant-derived polymer composed of amylose and amylopectin. It forms transparent, odorless films with good oxygen barrier properties. Usually, the type of starch used determines the characteristics of starch-based edible films and coatings. However, its films are sensitive to moisture, which limits water resistance. In fish packaging, starch films are often blended with other biopolymers or plasticizers to enhance flexibility and water resistance. Curcumin was added to a zein, potato starch, and chitosan composite film to create a possible bioactive packaging medium for Schizothorax prenati filets (Xin, 2020). A bioactive-intelligent package consisting of starch-based film and anthocyanin extracts was created to improve the shelf life of shrimp while they are being stored and to allow for visual monitoring of the spoiling process (Zhang *et al.,* 2021).

Alginate: Alginate extracted from brown seaweeds, it forms gel-like films when cross-linked with calcium ions. Because of its capacity to retain moisture and enhance texture, it is frequently utilized in fish edible coatings. Alginate films are tasteless, biodegradable, and provide a mild oxygen barrier, making them suitable for refrigerated seafood storage. Alginate coatings or films that include various bioactive substances, including lactoperoxidase, phenolic extracts, 6-gingerol, plant essential oils, and other natural substances, have been effectively employed to preserve the quality of various fish and fisheries products (Martinez *et al.,* 2018).

Proteins based edible packaging: The covalent peptide bonds bind the amino acids in proteins, which are complex polymers with a variety of mechanical and physical properties that make them suitable for coating a variety of food items. Proteins come in two varieties: fibrous (water-insoluble) and globular (water-soluble). Common proteins from plant and animal sources used in food packaging include gelatin, whey protein, soy protein, collagen, bean protein, wheat gluten, peanut and casein protein. The following major protein based polymers are:

Gelatin: Collagen, which is usually derived from fish skin, bones, or cow hide, can be partially hydrolyzed to produce gelatin. It forms transparent, flexible, and odorless films with good oxygen and aroma barrier properties. Gelatin-based coatings are effective in preserving fish freshness, minimizing oxidative spoilage, and enhancing product appearance during storage. Fried salmon skin was successfully stored in an edible bag formed of fish gelatin bilayer films laminated with polylactic acid, as evidenced by an important reduction in the rate of lipid oxidation (Nilsuwan *et al*., 2020). Common carp fillets coated with gelatin have better quality and sensory qualities than fillets made of polyethylene plastic when they are frozen (Hussein *et al*., 2020). Certain foodborne bacterial infections can be controlled by the synergistic actions of gelatin and other biopolymers.

Whey Protein: A by-product of cheese production, whey protein creates transparent and odorless films with strong oxygen barrier properties. When applied as coatings on fish fillets, they help in delaying lipid oxidation and maintaining texture and color, especially during refrigeration. High oxygen barrier qualities and postponed peroxide production in frozen shrimp fried rice throughout a six-month period of frozen storage are demonstrated by coating packing materials with whey protein isolates (Song *et al*., 2020). The potential of whey protein-based films and coatings in preserving seafood have been evaluated because of its superior gas barrier qualities. Asian sea bass antioxidant films (Chaijan *et al.,* 2020), frozen Atlantic salmon (Rodriguez-Turienzo *et al*., 2012), were discovered to be effective in extending the shelf life of these items when made from whey protein.

Zein: Zein is a corn protein known for forming water-insoluble films with good mechanical and glossy surface properties. It provides moderate moisture and gas barriers, and is suitable for coating dried or smoked fish products. To maintain the quality of fish balls while they are being stored, bioactive zein coatings were created (Lin *et al*., 2009). Zein films can be loaded with essential oils to provide antimicrobial and antioxidant effects.

Lipid based edible packaging: Lipid molecules have been used as protective packing for a long time. However, they lack the many repeating units that are connected by covalent bonds to form cohesive individual films since they are not polymers. As a result, they are brittle and typically don't create a cohesive, self-supporting film. Lipid based packaging works well against humidity although it has higher oxygen permeability and less mechanical resilience (Bharti *et al.,* 2020). Lipids however can lower the quality of food by altering the taste of the food and the appearance by changing its transparency (Tavassoli-Kafrani *et al.,* 2016).

Vegetable oils, waxes and fatty acid are the most often utilized lipid components for edible coatings. The following major lipid-based polymers are

Waxes: Waxes have a higher molecular weight and are composed of esters of long-chain fatty acids and alcohols. Originating from both plants and animals, Natural waxes such as beeswax, carnauba wax, and synthetic waxes include paraffin wax are commonly used in edible coatings (Khalid *et al*., 2021). These materials are highly effective at reducing water vapor transmission, making them suitable for protecting fresh and frozen fish products from dehydration. Waxes are often layered over protein or polysaccharide films to improve moisture resistance.

Fatty Acids: Fatty acids and their derivatives, like stearic acid and glycerol monostearate, are used to enhance water resistance in edible coatings. They are often used in combination with starch or protein matrices to improve the overall packaging performance of fish products during storage and transport.

Vegetable Oils: Natural oils such as soybean oil, palm oil, or fish oil can be incorporated into films to improve water barrier properties and sometimes to deliver antioxidants or omega-3 fatty acids. However, films based solely on oils are not structurally strong, so they are typically used as additives rather than base materials In fish meatballs, chitosan coatings treated with peppermint essential oil emulsion inhibited microbial development when they were kept cold (4 ± 1 °C) (Uçak *et al*., 2022). It was found that rainbow trout with zein coatings enhanced with essential oil extended their shelf life (Esmaeli *et al*., 2019).

Method of Edible Film and Coating Preparation

The edible packaging process for fish and fish products involves several methods to ensure proper preservation and quality maintenance. It can be used in two different ways, direct application of an edible coating to the food or the food was wrapped in a premade film. Films and coatings for edibles are very diverse. While edible films serve as packaging materials, Fruits, seafood, vegetables and other foods can have their surfaces directly coated with edible substances. Edible coatings/films provide consistent quality to foods with commercial safety, nutritional value and economical production costs in the food processing sector. Both methods when properly formulated can improve the sensory properties of packaged seafood and if present can slow down oxidation and microbial spoilage. Their mechanical qualities and permeability however are often inferior to those of manmade films (Kester & Fennema, 1986).

Edible film: Edible films can be prepared using two main techniques wet and dry methods, based on the form of the film-forming material during processing.

Wet Method (Solvent Casting): In the wet method, biopolymers are dissolved in a solvent to form a uniform solution. This solution is cast onto a flat surface and dried under controlled conditions to form a thin film.

Dry Method (Extrusion, Compression Molding): The dry method involves mixing and heating the dry ingredients, forming a molten mass, which is then shaped into a film using extrusion or molding.

Edible coatings: Edible coatings are thin, protective layers applied directly to the surface of fish and fishery products to improve shelf life, safety, and quality. Applying thin coatings of edible substances directly to food products surfaces through brushing, spraying or dipping (Dhall, 2013). The main techniques include:

Dipping: Food is dipped by submerging it in a coating solution for a while to ensure full coverage of the product. Therefore, products with irregular shapes are more suited for this procedure, Coatings are typically applied in liquid form and solidify upon drying and commonly Coating fish fillets, shrimp, or whole fish.

***Spraying**:* In this method, a fine mist of the coating solution is applied using manual or automated spray nozzles. Spraying is common in industrial seafood processing for continuous or large-batch production lines

Brushing: A manual method where the coating solution is applied with a brush or roller. It is generally used in research laboratories or pilot-scale experiments for testing new formulations or small batches.

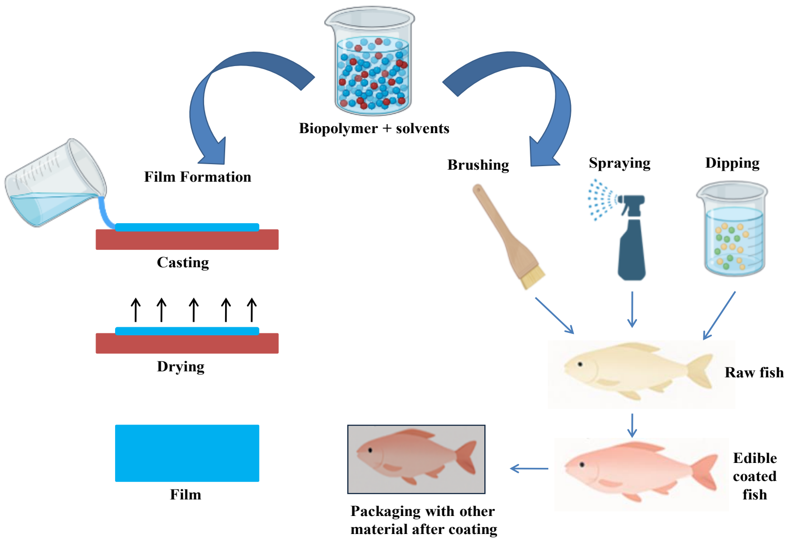

Fig.1. Method of edible film and coating

Advantage of edible packaging: Edible packaging for fish and fishery products is an innovative and sustainable alternative to traditional packaging methods. This type of packaging is typically made from natural, food safe materials like proteins, lipids, polysaccharides or combinations of these designed to be taken with the product or to break down without harming the environment. All things considered, edible coatings improve consumer safety while also preserving the quality of seafood products (Yu *et al*., 2019)

Moisture Barrier: Edible films help control the moisture content of seafood preventing dehydration and excess water retention, which is a major factor in seafood spoilage, leading to changes in texture and taste. A good moisture barrier keeps seafood juicy and prevents it from drying out.

Oxidation resistance: edible films protect seafood from oxidative damage due to a decrease in oxygen. Lipids and food ingredients oxidizing the enzymatic browning of fresh products or the staining of myoglobin pigment in pieces of freshly cut meat are the main causes of food damage or deterioration. Hypoxic permeability edible packaging can be utilized for items that are sensitive to oxygen. This prolongs the shelf life of oxygen goods and preserves their quality.

Antimicrobial Properties: Many proteins based and polysaccharide based Natural antimicrobial substances like chitosan, essential oils or antimicrobial peptides are incorporated into edible films. These characteristics decrease the development of fungus and bacteria that might cause spoiling.

Mechanical resistance and flexibility: Edible films must have sufficient mechanical strength to avoid tearing or breaking during loading, unloading and transportation. At the same time, they must be flexible enough to conform to the shape of the fish or seafood.

Biodegradable and Sustainable: With growing environmental concerns over plastic waste the use of biodegradable edible films offers an even more ecofriendly solution for seafood packaging. Biodegradable edible films reduce the environmental impact of plastic waste by breaking down naturally.

Disadvantages of Edible packaging

Water solubility: Many edible packaging materials break down in water particularly those derived from substances like starch or agar, can dissolve when exposed to moisture. This makes them less reliable in environments with high humidity or for products that need protection from water.

Allergies: Some edible packaging ingredients such as wheat, soy or dairy are known allergens. This poses a risk for people with food sensitivities or allergies, limiting the widespread use of such packaging.

Off flavors: The flavor of the food may be adversely affected or disputed with by the taste of some edible packaging materials. This could occur due to the inherent taste of the packaging material itself or how it interacts with the food.

Permeability: Edible packaging is generally more permeable than traditional packaging. This means it may not effectively block air, moisture or contaminants compromising the food's shelf life or quality.

Moisture loss: Some edible films or coatings can cause food to lose moisture especially if the packaging is poorly designed. This could lead to products like baked goods or fresh produce drying out or becoming stale more quickly.

Contamination: Edible packaging can be prone to contamination by bacteria, mold or other harmful agents during manufacturing, handling or transport. This risk compromises both the packaging's integrity and the safety of the food inside.

Physical damage: Compared to traditional materials like plastic or glass, edible packaging can be more fragile and susceptible to breaking or tearing. This reduces its ability to protect food from physical harm while being stored or transported.

Conclusion

Edible packaging, especially for seafood products offers an innovative and sustainable alternative to traditional plastic packaging. With increasing concerns over micro plastics, environmental pollution and the negative health impacts associated with plastic waste, edible films made from natural biopolymers present a promising solution. These materials not only improve the preservation of seafood by enhancing its shelf life, moisture retention and resistance to oxidation but also reduce microbial spoilage making them more effective than conventional packaging methods. Edible packaging provides an environmentally sustainable, health-conscious and practical solution for seafood preservation. As research in this field continues to progress the broader adoption of edible films and coatings in the food industry will likely contribute to reducing plastic waste, improving food safety and supporting a more circular economy.

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