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Recent advances in edible coatings and films for extending the shelf life of fish and seafood products: A review

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ABSTRACT

Fish and seafood are highly perishable foods because of their high moisture content, nearly neutral pH, enzyme activity, microbial growth, and lipid oxidation. These factors can quickly reduce freshness, quality, and shelf life during storage. Edible coatings and films are biodegradable preservation methods that can help protect fish and seafood by forming a protective layer on the food surface. They can also carry antimicrobial and antioxidant compounds that help slow down spoilage. Recent research has focused on biopolymers such as chitosan, gelatin, alginate, and other natural materials, often combined with plant extracts, essential oils, phenolic compounds, and bioactive substances obtained from seafood by-products. Recent studies show that edible coatings, especially chitosan- and gelatin-based coatings with natural extracts and essential oils, can extend the shelf life of fish and seafood by reducing microbial growth and oxidation. Techniques such as nanoemulsions and ultrasound can improve coating effectiveness. However, sensory quality, coating uniformity, scalability, regulations, and consumer acceptance remain challenges. Future research should focus on sustainable and multifunctional coatings for safe and high-quality seafood preservation.

Keywords: Edible Coatings, Edible Films, Fish Preservation, Seafood, Chitosan, Gelatin, Essential Oils, Shelf Life, Antimicrobial Activity, Antioxidants

1. Introduction

Fish and seafood are nutritious foods that provide high-quality protein and polyunsaturated fatty acids. However they spoil easily because of their high moisture content, suitable pH for microbial growth, and susceptibility to oxidation. These factors can lead to changes in odour, flavour, colour, texture, and overall quality during storage (Kurek *et al.*, 2024) [1].

Traditional methods such as refrigeration, freezing, modified-atmosphere packaging, and chemical preservatives help slow down food spoilage. However, the growing demand for minimally processed foods and eco-friendly packaging has increased interest in alternative preservation methods. Edible coatings and films are gaining attention because they provide a protective layer and can contain natural antimicrobial and antioxidant compounds (Kurek *et al.*, 2024; Zhang *et al.*, 2025) [1, 2].

Edible coatings are thin protective layers applied directly to the surface of food, while edible films are usually prepared separately and then placed on the food. Both can help protect food from oxygen and moisture and can also carry active compounds such as antimicrobial and antioxidant substances. These coatings and films can be made from materials such as polysaccharides, proteins, lipids, or a combination of these (Kurek *et al.*, 2024; Sharma *et al.*, 2026) [1, 3].

Recent studies have focused on developing active, biodegradable, and multifunctional coatings that contain natural extracts, essential oils, antioxidants, phenolic compounds, and antimicrobial agents. Chitosan is widely used because it can form a protective film, reduce oxygen transfer, and inhibit microbial growth. Other materials, such as gelatin and alginate, are also used as protein- and polysaccharide-based coating materials (Zhang *et al.*, 2025) [2].

2. Edible coatings and films: Basic concept

Edible coatings and films are safe, food-grade layers used to protect food and maintain its quality during storage. Coatings are applied directly to the food surface, whereas films are prepared separately and then placed on the food. Both can help control the movement of moisture and gases and can carry active compounds that support food preservation (Kurek *et al.*, 2024) [1].

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The effectiveness of an edible coating depends on factors such as the type of polymer used, coating thickness, permeability, strength, active ingredients, their concentration, application method, and storage conditions. Depending on the food product and coating formulation, methods such as dipping and spraying can be used to apply the coating.

Adding antimicrobial and antioxidant compounds can improve the protective properties of edible coatings. Therefore, natural plant compounds such as polyphenols, essential oils, extracts, and other bioactive substances are increasingly used in active edible coating systems (Zhang *et al.*, 2025) [2].

Recent systematic evidence indicates that chitosan-based coatings containing essential oils can extend the refrigerated shelf life of fish products by approximately 2–9 days under conditions around 4 °C, although the effect varies with fish species, coating composition, active compound and storage conditions (Nik Ubaidillah *et al.*, 2026) [4].

3. Major materials used in fish and seafood coatings

3.1 Chitosan

Chitosan is widely used in fish preservation because of its film-forming and antimicrobial properties. It can also be combined with natural extracts and essential oils to improve its antioxidant and antimicrobial effects (Zhang *et al.*, 2025) [2]. Recent studies have used chitosan with green tea extract, astaxanthin, moringa oil, sea buckthorn oil, and oregano oil for different fish products (Lüdtke *et al.*, 2025 [5]; Schouten *et al.*, 2025 [6]; Alak *et al.*, 2026; Kara & Alak, 2026; Lüdtke *et al.*, 2026) [7].

3.2 Gelatin

Gelatin is a protein-based material that can be obtained from fish-processing by-products. It is useful for edible coatings and can also carry antimicrobial compounds such as lactic acid and potassium sorbate (Parraga *et al.*, 2026) [8].

3.3 Alginate

Sodium alginate is a commonly used polysaccharide in edible coatings. It can form stable gels and provide good coating strength, especially when combined with calcium. Alginate can also be used with essential oils and other active compounds (Zhang *et al.*, 2025) [2].

3.4 Composite coatings

Composite coatings combine different polymers or active compounds to improve properties such as barrier strength, mechanical stability, and antimicrobial and antioxidant activity. Protein-polysaccharide combinations are increasingly studied for seafood preservation (Sharma *et al.*, 2026) [3].

4. Role of active compounds in edible coatings

Adding active compounds can improve the preservation ability of edible coatings. Essential oils, plant extracts, phenolic compounds, and antioxidants can provide antimicrobial and antioxidant effects (Zhang *et al.*, 2025) [2].

Essential oils such as oregano oil can help control microbial growth and oxidation. However, their concentration should be optimized be-

cause high levels may affect the flavour, odour, or colour of fish products (Lüdtke *et al.*, 2026) [7].

Seafood-processing by-products are also being explored as sources of useful bioactive compounds. For example, astaxanthin obtained from shrimp waste was incorporated into a chitosan coating for sardine fillets, combining waste utilization with food preservation (Schouten *et al.*, 2025) [6].

5. Recent research on edible coatings for fish preservation

5.1 Chitosan–fish oil–green tea extract coating

Lüdtke *et al.* (2025) [5] developed a chitosan coating containing fish oil and green tea extract for Atlantic bonito (*Sarda sarda*). The coating reduced microbial growth and oxidation while helping to maintain colour and texture. It also extended the shelf life by at least six days.

5.2 Shrimp-waste astaxanthin–chitosan coating

Schouten *et al.* (2025) [6] studied a chitosan coating containing astaxanthin extract from shrimp waste for sardine (*Sardina pilchardus*) fillets stored at 4 °C. The coating reduced microbial growth and lipid oxidation and helped maintain colour and texture during storage.

5.3 Chitosan–moringa oil nanoemulsion

Alak *et al.* (2026) [9] developed a chitosan coating containing moringa oil nanoemulsion for rainbow trout (*Oncorhynchus mykiss*). The coating reduced microbial growth, oxidation, and discoloration during refrigerated storage and extended shelf life by approximately three days.

5.4 Chitosan–sea buckthorn oil coating

Kara *et al.* (2026) [10] investigated a chitosan coating containing sea buckthorn oil for fish fillets. The coating helped reduce microbial and chemical deterioration and maintained sensory quality during refrigerated storage.

5.5 Fish-skin gelatin coating

Parraga *et al.* (2026) [8] studied fish-skin gelatin coatings containing lactic acid and potassium sorbate for fresh catfish fillets. The coating improved microbial and oxidative stability, showing the potential of fish-processing by-products as coating materials.

5.6 Ultrasound-assisted gallic acid coating

Jiang *et al.* (2026) [11] developed a gelatin coating containing gallic acid for snakehead fish fillets and used ultrasound to improve its performance. The treatment reduced TVB-N values and enhanced the release of gallic acid, showing the potential of ultrasound-assisted edible coatings.

5.7 Oregano oil emulsion coating

Lüdtke *et al.* (2026) [7] investigated oregano oil emulsion coatings for Atlantic bonito fillets stored at 5 °C. The coating reduced microbial growth and oxidation and helped maintain colour quality. The study also showed that adding fish gelatin could improve the antimicrobial performance of the coating.

6. Comparison of recent experimental studies

Fish/seafood product	Coating system	Important active component	Storage condition	Main quality effects	Reference
Atlantic bonito	Chitosan + fish oil + green tea extract	Green tea extract	Refrigerated storage	Reduced microbial growth and oxidation; preserved colour and texture; at least 6-day shelf-life extension	Lüdtke <i>et al.</i> (2025)
Sardine	Chitosan + shrimp-waste astaxanthin extract	Astaxanthin	4 °C, 13 days	Reduced microbial growth and lipid oxidation; maintained colour and texture	Schouten <i>et al.</i> (2025)

(continued on next page)

Fish/seafood product	Coating system	Important active component	Storage condition	Main quality effects	Reference
Rainbow trout	Chitosan + moringa oil nanoemulsion	<i>Moringa</i> oil	Refrigerated, 12 days	Reduced microbial growth, oxidation and discoloration; at least 3-day shelf-life extension	Alak <i>et al.</i> (2026)
Fish fillet	Chitosan + sea buckthorn oil	Sea buckthorn oil	4 °C, 12 days	Reduced microbial and chemical deterioration; improved quality retention	Kara & Alak (2026)
Catfish	Fish-skin gelatin + antimicrobial agents	Lactic acid / potassium sorbate	Refrigerated storage	Improved microbiological and oxidative stability	Parraga <i>et al.</i> (2026)
Snakehead fish	Gelatin + gallic acid	Gallic acid	Refrigerated storage	Reduced TVB-N; ultrasound enhanced active-compound migration	Jiang <i>et al.</i> (2026)
Atlantic bonito	Oregano oil emulsion ± fish gelatin	Oregano oil	5 °C, 10 days	Delayed microbial growth and oxidation; improved colour stability	Lüdtke <i>et al.</i> (2026)

Recent research is moving from simple coatings toward multifunctional systems. These coatings generally combine a film-forming material with antimicrobial or antioxidant compounds. Chitosan is widely studied, while gelatin is gaining attention as a sustainable protein-based material (Zhang *et al.*, 2025; Sharma *et al.*, 2026) [2, 3].

7. Effect of edible coatings on fish quality

7.1 Microbial quality

Microbial growth is a major cause of fish spoilage. Edible coatings can slow microbial growth by forming a protective barrier and releasing antimicrobial compounds. Chitosan, essential oils, plant extracts, and organic acids can improve this effect. Studies using chitosan with green tea extract, astaxanthin, oregano oil, and sea buckthorn oil have shown reduced microbial growth during storage (Lüdtke *et al.*, 2025; Schouten *et al.*, 2025; Lüdtke *et al.*, 2026; Kara *et al.*, 2026) [10, 5, 7, 6].

7.2 Lipid oxidation

Fish contains unsaturated fatty acids that are easily oxidized, causing rancid odour, undesirable flavour, and quality loss. Antioxidant coatings can reduce oxidation by limiting oxygen exposure and scavenging free radicals. Reduced lipid oxidation has been reported in bonito and sardine treated with chitosan-based coatings (Lüdtke *et al.*, 2025; Schouten *et al.*, 2025) [5, 6].

7.3 Protein oxidation

Protein oxidation can affect fish texture and functional properties. Chitosan-based coatings containing green tea extract and moringa oil have shown potential to reduce protein oxidation during storage (Lüdtke *et al.*, 2025; Alak *et al.*, 2026) [5, 9].

7.4 tvb-n

TVB-N is commonly used to assess fish freshness and spoilage. Coatings that reduce microbial and protein degradation can slow the increase in TVB-N. Lower TVB-N values have been reported with sea buckthorn–chitosan and ultrasound-assisted gallic acid coatings (Kara *et al.*, 2026; Jiang *et al.*, 2026) [10, 11].

7.5 Colour

Colour is an important indicator of fish quality and freshness. Edible coatings can help maintain colour by reducing oxidation and moisture loss. However, natural pigments in extracts and oils may also change the colour of coated fish products (Lüdtke *et al.*, 2025; Kara *et al.*, 2026) [5, 10].

7.6 Texture

Fish texture can change because of protein degradation, moisture loss, and oxidation. Chitosan-based coatings have been reported to help maintain hardness, springiness, and other texture properties in bonito and sardine fillets (Lüdtke *et al.*, 2025; Schouten *et al.*, 2025) [5, 6].

8. Emerging technologies

8.1 Nanoemulsion-based coatings

Nanoemulsions can improve the dispersion and delivery of poorly water-soluble bioactive compounds. A chitosan–moringa oil nanoemulsion showed antimicrobial and antioxidant effects in rainbow trout fillets during refrigerated storage (Alak *et al.*, 2026) [9].

8.2 Ultrasound-assisted coatings

Ultrasound can improve the distribution and release of active compounds from coatings. It has been shown to enhance gallic acid release and preservation performance in snakehead fish fillets (Jiang *et al.*, 2026) [11].

8.3 Intelligent packaging

Edible films are increasingly being combined with smart packaging systems. Freshness indicators, particularly pH-sensitive films, may provide visual information about seafood quality while also acting as protective barriers (Sharma *et al.*, 2026) [3].

8.4 Seafood by-product valorisation

Seafood-processing wastes can be used as sources of useful coating materials and bioactive compounds. Shrimp waste-derived astaxanthin and fish skin gelatin have been investigated for fish preservation applications (Schouten *et al.*, 2025; Parraga *et al.*, 2026) [6, 8].

9. Sustainability of edible coatings

Edible coatings can provide biodegradable alternatives to conventional plastic packaging. They can be produced from renewable proteins and polysaccharides and may also use seafood-processing by-products as raw materials (Sharma *et al.*, 2026) [3].

The use of shrimp waste and fish skin demonstrates the potential for converting processing residues into useful preservation materials (Schouten *et al.*, 2025; Parraga *et al.*, 2026) [6, 8]. However, sustainability also depends on raw material availability, processing energy, safety, cost, scalability, and end-of-life behaviour.

10. Advantages of edible coatings

The main advantages of edible coatings for fish preservation include:

1. Reducing microbial growth.
2. Delaying lipid and protein oxidation.

3. Maintaining colour and texture.
4. Slowing chemical spoilage.
5. Extending refrigerated shelf life.
6. Allowing the use of natural antimicrobial and antioxidant compounds.
7. Reducing dependence on conventional plastic packaging.
8. Utilizing seafood-processing by-products.
9. Supporting active and smart packaging technologies (Kurek *et al.*, 2024; Zhang *et al.*, 2025; Sharma *et al.*, 2026) [1, 2, 3].

11. Limitations and challenges

Edible coatings have some important limitations. High levels of essential oils may change the flavour, odour, or colour of fish, so their concentration should be carefully optimized (Kara *et al.*, 2026) [10]. Coating performance can also vary with fish species, storage conditions, coating thickness, and formulation. In addition, large-scale production, cost, uniform application, and processing time need further study. Advanced systems such as nanoemulsions may require special equipment and further safety and regulatory evaluation (Alak *et al.*, 2026) [9].

12. Future perspectives

Future studies should focus on multifunctional coatings that control microbial growth, oxidation, moisture loss, and quality changes. Combining biopolymers with natural antioxidants and essential oils may improve preservation (Zhang *et al.*, 2025; Nik Ubaidillah *et al.*, 2026) [2, 4]. Nanoemulsions and encapsulation can support controlled release of active compounds, while seafood by-products can provide sustainable coating materials (Alak *et al.*, 2026; Schouten *et al.*, 2025; Parraga *et al.*, 2026) [9, 6, 8]. Further research should also consider smart packaging, cost, consumer acceptance, safety, and large-scale application (Sharma *et al.*, 2026) [3].

13. Conclusion

Edible coatings and films offer a sustainable approach for preserving fish and seafood. Chitosan, gelatin, and other biopolymers can deliver antimicrobial and antioxidant compounds and help maintain product quality. Emerging technologies such as nanoemulsions, ultrasound-assisted coatings, essential oils, and by-product-based materials are further improving these systems. However, optimization of safety, sensory quality, cost, and processing conditions is needed for wider commercial use.

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