Turning Fish Waste into Gold: The Rise of Blue Bioplastics

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ABSTRACT

Bioplastics produced from residual marine biomass (like fish scales and prawn shells) are a sustainable alternative to traditional plastics and contribute to the circular economy. Key biopolymers are chitosan, valued for its nontoxicity and film-forming ability, and gelatin, which in turn can be efficiently extracted from fish waste at up to 58.25%. The mechanical properties of these materials can be engineered for strength and flexibility: for example, chitosan films can be chemically tuned, while reinforcement with cellulose nanocrystals (CNCs) can achieve enhanced tensile strength to values as high as 27.64 MPa. Derived from the sea, these bioplastics also show fast biodegradability; studies report up to 85% degradation in 14 days and between 71-84% of biodegradation in soil within 21 days. Furthermore, their functionality goes beyond passive packaging, incorporating natural extracts with active protection of foods. Gelatin films with fig leaf extract exhibited excellent antioxidant and antibacterial activity. On the other hand, chitosan films enriched with Borago officinalis extract can extend the shelf life of rainbow trout by six days. These findings underlined the large potential of marine waste as a source of eco-friendly, high-performance bioplastic packaging for the food industry.

INTRODUCTION

The modern world is built on plastic. What started, rather humbly, at 2 million metric tons in 1950 has grown to a staggering 368 million metric tons annually by 2019. This explosive growth represents how deeply plastics have been interwoven into everyday life, especially in the food industry, where packaging alone accounts for nearly 40% of total plastic consumption in the European Union. Yet, it is precisely these qualities that make plastics convenient-properties of strength, durability, and resistance to breakdown-which have created a global environmental crisis. These petroleum-based polymers do not degrade naturally. Instead, they accumulate in landfills, contaminate soil, damage aquatic habitats, and fragment into toxic microplastics that infiltrate ecosystems, wildlife, and even the human food chain.

This growing pollution issue requires an immediate change in material science. The world needs to move away from conventional plastics towards sustainable alternatives that originate from renewable and green sources. Ironically, one of the most promising solutions is emerging from what once was considered industrial refuse: the waste products of the seafood industry. Scientists are now working with blue bioplastics-innovative materials engineered from residual marine biomass, such as fish skins, scales, bones, and crustacean shells. These biopolymers, derived from organic wastes, are naturally biodegradable, renewable, and compostable, thus representing a pragmatic and environmentally benign alternative to the traditional plastics.

This unlocks the latent value in seafood processing waste, enabling the shift from a linear “take–make–dispose” model to a circular economy by turning what was once ocean-bound waste into sustainable, high-performing materials.

Bio-Polymers from Seafood Waste

Raw materials for this transformation are not scarce; they can be found in the plentiful, currently wasted discards from the gigantic global seafood industry. These materials contain powerful biopolymers ready for extraction and use.

One of the most abundant biopolymers from the ocean, chitosan is derived from chitin in the exoskeletons of shellfish. Therein, marine organisms produce an estimated 100 billion tons of chitin annually. It has also seen its star rise in sustainable packaging due to its remarkable properties. Chitosan films are biodegradable, nontoxic, and naturally antimicrobial. Unsurprisingly, more than 20,000 scientific papers have focused on its film applications in just the past few years. Besides chitosan's non-toxicity and biodegradability, it also intrinsically possesses antimicrobial and antifungal properties, immediately becoming highly useful in food packaging and medical applications (Schnabl *et al*., 2023).

The second foundational material is gelatin, a protein extracted from collagen, which is the major component of fish skin, scales, and bones (Mottalib *et al*., 2024; Liu *et al*., 2025; Fauzan *et al*., 2023). Sourcing gelatin from fish waste is a matter of strategic necessity, as there are no safety risks, such as BSE, nor religious restrictions impeding the use of land mammals' gelatin (Biscarat *et al*., 2015). Fish waste is a rich protein source. It was found that fish waste cartilage contains approximately 75% collagen compounds (Vijayakumar *et al*., 2024). Further studies show that even in fish scale waste, there is a composition of collagen and hydroxyapatite, thus having properties similar to human hard tissues (Núñez-Tapia *et al*., 2025; Vijayakumar *et al*., 2024).

Valuable seafood waste

The production of blue bioplastics represents a victory of the circular bioeconomy, transforming huge environmental liabilities into sustainable wealth. The global catch fishing industry is considered one of the most notorious for producing colossal amounts of by-products like heads, skin, scales, and viscera, accounting for as much as 25% to 75% of the total raw material harvested. Traditionally, this waste was burned, dumped, or sent to landfills, causing widespread pollution.

By developing commercial procedures to extract high-value biopolymers from these discards, scientists are offering a robust solution that minimizes environmental contamination while generating supplementary economic worth for the industry. Such an innovative approach can be viewed in various works aimed at combining marine waste, like fish scales, with agricultural waste, such as orange peels, in the production of sustainable composites-an effective way of loop closure on several streams of waste.

Conversion of Fish waste to Bioplastics

The manufacturing process for these next-generation films is closely controlled:

- Purification: In this step, the raw waste product, such as fish scales, has to undergo chemical pretreatment in order to eliminate all those non-collagenous proteins and minerals so that only purified biopolymer sources are obtained.
- Preparation of Film Solution: The gelatin or chitosan polymer is dissolved in order to prepare the film-forming solution. This is the stage where necessary additives are added for usability.
- Plasticization for Flexibility: One key additive is a plasticizer, typically glycerol (GLY), which is added to enhance the elasticity and workability of the film since the biopolymer films are brittle in their pure form (Surya *et al.*, 2023). Glycerol works by lowering the friction between the chains, thereby providing substantial softening of the material (Schnabl *et al.*, 2023).
- Shaping the Film: The final, homogeneous mixture is poured onto plates (solution casting) and dried to form a transparent film. In other large-scale processes, the blend may be fed into an extruder's hopper- a long-heated chamber-to be shaped into continuous film rolls.

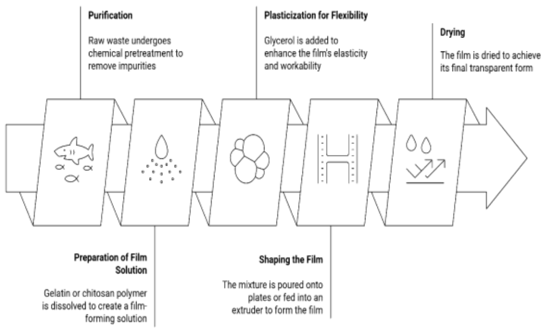

Fig. 1 Bio- Film manufacturing process

Mechanical Strength Through Reinforcement

In principle, blue bioplastics could only displace commercial plastics if they attained similar strength, durability, and barrier performance. The film is strengthened by added fillers:

- Cellulose nanocrystals from jute waste can greatly enhance tensile strength and flexibility. The addition of just 1% CNCs increased the tensile strength from 12.24 to 13.93 N/mm^2 and significantly enhanced the elongation at break from 48 to 64%. (Mottalib *et al.*, 2024)
- A composite made from fish scale powder mixed with corn starch resulted in a tensile

strength of 10.1 ± 0.05 MPa (Surya *et al*., 2023).

- The chitosan films show tunable stiffness, from extremely flexible to stiff as industrial polymers, depending on the fabrication conditions.

Barrier and Thermal Properties

Gelatin-based films have excellent oxygen and carbon dioxide barrier properties, which is comparable to synthetic nylon as stated by Biscarat *et al*. ,2014. Water resistance is highly developed with hydrophobic agents such as FASE. The composite films also have high temperature tolerance since major thermal degradation happened only between 250°C to 330°C, according to Surya *et al*. 2023, and Schnabl *et al*. 2023.

Rapid Biodegradability

The main characteristic of the blue bioplastics is that they degrade quickly and naturally. Films made from sericin and fish gelatin degrade up to 89% within 14 days when buried in soil. Visible decomposition of films containing chitosan is mediated by naturally occurring fungi like *Aspergillus spp*. in as short a period as 7 days (Surya *et al*., 2023; Mottalib *et al*., 2024). This is quite contrary to the fossil-based plastics that take centuries to show any degradation.

Protective Food Packaging Applications

Nowadays, for instance, blue bioplastics work not only as physical packaging but also as active systems that help to preserve food quality (Novak *et al*., 2020).

- **Seafood protection:** Chitosan films enriched with borage extract delayed the oxidation process, prevented discoloration, and extended the shelf life of trout fillets by six days during refrigerated storage (Güngören *et al*., 2025).
- **Protection of fatty foods**: Fish gelatin–soy polysaccharide films fortified with tea polyphenols prevented oxidation in beef tallow and also provided strong UV-shielding effects.
- **Fresh produce preservation:** Gelatin films that contained fig leaf extract exhibited high antibacterial activity; the addition of mango peel extract and FASE in films maintained cherry tomatoes firm and reduced water loss during storage (Fauzan *et al*., 2023).

Application	Seafood	Fatty Foods	Fresh Produce
Bioplastic Type	Chitosan film with borage extract	Fish gelatin-soy polysaccharide film with tea polyphenols	Gelatin film with fig leaf extract, mango peel extract, and FASE
Preservation Method	Delayed oxidation, prevented discoloration	Prevented oxidation, provided UV shielding	Antibacterial activity, maintained firmness, reduced water loss

Fig 2. Bioplastic Applications in Food Preservation

These advances show that blue bioplastics are able to perform as well or even better than traditional petroleum-based packaging, while remaining biodegradable, clean, and environmentally safe.

CONCLUSION

The triumph of blue bioplastics sends a strong message about sustainable ingenuity-that from discarded industrial waste in the sea, highly valued material solutions can be developed that address the mandate of the circular economy. Highly tunable films derived from abundant resources such as chitosan-from crustaceans-and gelatin-from fish waste-can be carefully engineered with green additives to precisely tailor their mechanical properties, up to a stiffness value of 8.5 GPa that enables them to compete directly with synthetic commercial polymers.

The greatest success, however, lies in their rapid, natural decomposition that avoids long-term environmental accumulation and reduces disposal costs. While normal plastics take a great deal of time to decompose, bioplastics containing fish waste components degrade at an astonishing speed: the degradation of some composite films was noticed after just 7 days in organic waste, and the rate was recorded to be nearly 89% after just 14 days in soil burial tests (Surya *et al*., 2023; Vijayakumar *et al*., 2024).

Finally, their value is confirmed by their application as active packaging: films enriched with natural extracts, such as fig leaf or borage, were able to successfully enhance antioxidant activity and strong antibacterial action (Fauzan *et al*., 2023). Most impressively, chitosan films enriched with Borago officinalis extract prolonged the shelf life of fresh rainbow trout fillets by six days in cold storage (Güngören *et al*., 2025). Providing safe, functional, and easily compostable alternatives, blue bioplastics are cementing their role as the foundation for packaging materials of tomorrow.

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