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Blue Bioeconomy: Turning Fish Waste into Sustainable Packaging

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Abstract

The rapid expansion of the Blue Bioeconomy offers a unique opportunity to tackle one of the seafood sector's most pressing issues: the vast quantities of fish processing waste generated worldwide. Globally, up to 70% of fish biomass is discarded during processing, leading to environmental degradation, greenhouse gas emissions, and wasted economic value. However, recent advances in biotechnology and material science now make it possible to convert fishery by-products such as skins, bones, scales, and crustacean shells into high-value, biodegradable packaging materials. By extracting functional biomolecules like collagen, gelatin, chitin, and chitosan, industries can produce compostable films, edible coatings, and bio-plastics that help replace conventional fossil-based plastics. Case studies such as Marina Tex and the Iceland Ocean Cluster highlight how innovation, circular economy principles, and cross-sector partnerships can drive this sustainable transition, creating green jobs and new revenue streams for coastal communities. While technical, economic, and regulatory challenges remain, the future outlook for fish-waste-based packaging is highly promising. As governments phase out single-use plastics and consumers demand sustainable alternatives, converting fish waste into eco-friendly packaging can play a pivotal role in addressing marine pollution, promoting resource efficiency, and advancing global sustainability goals.

Keywords: Blue Bioeconomy, Fish Waste Valorisation, Sustainable Packaging, Biopolymers.

Introduction

The **Blue Bioeconomy** is an emerging concept that focuses on the sustainable and innovative use of living aquatic resources to support economic growth, enhance social well-being, and maintain the health of marine ecosystems (European Commission, 2018). Unlike the traditional bioeconomy, which often centres on agriculture and forestry, the blue bioeconomy specifically harnesses marine and aquatic biomass including fish, algae, and other marine organisms to create new, high-value products such as pharmaceuticals, nutraceuticals, bioenergy, and sustainable packaging solutions (Naylor et al., 2021).

One pressing challenge within the seafood sector is the immense volume of waste generated during fish processing operations. Globally, it is estimated that between 30% and 50% of the total weight of fish caught is discarded as waste including heads, bones, skin, scales, and viscera (Rustad et al., 2011). This waste often ends up in landfills or is disposed of in the ocean, leading to significant environmental and economic concerns. Improper disposal contributes to greenhouse gas emissions through decomposition, adds pressure on waste management systems, and represents a lost opportunity for resource recovery (Arvanitoyannis & Kassaveti, 2008). However, this so-called *waste* holds untapped potential as a valuable raw material for the production of bio-based and biodegradable products. Advances in biotechnology and material science have enabled the extraction of functional biomolecules such as collagen, gelatine, chitin, and chitosan from fishery by-products (Ahmed et al., 2022).

Understanding Fish Waste: Scale, Impact, and Recent Developments

Globally, the fish processing industry generates significant by-products, with estimates indicating that 30–70% of the total fish biomass is discarded as waste depending on the species and processing methods used (Food and Agriculture Organization [FAO, 2021). Common waste components include heads, bones, viscera, skins, scales, and shells in crustaceans. For instance, tuna canning operations can discard up to 70% of the fish, while shrimp processing may leave behind 40–60% as by-products (FAO, 2023). Overall, the FAO (2021) estimates that approximately 8.5 million tons of seafood biomass is lost or discarded annually, accounting for nearly 10% of the global catch. Regionally, nearly half of the edible seafood catch in Europe and the United States remains unused due to processing inefficiencies and by-catch (Frontiers in Sustainable Food Systems, 2021). The waste composition typically includes heads (15–25%), bones (10–34%), scales (2–5%), and gut or viscera (12–20%) (FAO, 2023). In India alone, over 567,000 tonnes of fish waste were produced in 2015–2016, representing about 36% of fish weight processed (Rajeswari et al., 2018). Improper disposal of these by-products can lead to environmental pollution due to high biological oxygen demand (BOD) and nutrient loads, while also wasting valuable proteins, oils, and enzymes with high economic potential (Caruso et al., 2020). Recent developments have focused on valorizing fish waste through innovative uses such as producing fishmeal, fish oil, and fish silage for animal feed; extracting chitin and chitosan from crustacean shells for pharmaceutical and biomedical applications; and developing bioplastics and food packaging materials from fish skins, scales, and collagen (Mdpi, 2022). Integrated multi-trophic aquaculture (IMTA) systems are also being adopted to recycle nutrients and organic by-products sustainably (Wikipedia, 2024). Landfill disposal also occupies valuable land area and contributes to leachate production, which can contaminate soil and groundwater resources if not properly managed (Caruso et al., 2020).

Furthermore, when fish waste is discarded directly into water bodies, it increases the **biological oxygen demand (BOD)** and chemical oxygen demand (COD) of the receiving waters. This excessive organic load can deplete dissolved oxygen levels, harm aquatic life and disrupting local ecosystems (Frontiers in Sustainable Food Systems, 2021). In developing countries and coastal communities with inadequate waste management infrastructure, fish processing waste is often discarded untreated, worsening local water pollution and posing risks to human health through contaminated water sources (Rajeswari et al., 2018).

Concept of Sustainable Packaging

Sustainable packaging refers to packaging solutions specifically designed to minimize negative environmental impacts throughout their life cycle by using renewable, biodegradable, compostable, or recyclable materials (Ritchie & Roser, 2018). Unlike traditional packaging, which often relies heavily on fossil fuel–derived plastics, sustainable packaging seeks to reduce resource depletion, lower greenhouse gas emissions, and avoid pollution at disposal or end-of-life stages (Marsh & Bugusu, 2007). Each year, an estimated 8 million metric tons of plastic waste enters the oceans, harming marine biodiversity and posing risks to food safety and human health (Geyer et al., 2017). As awareness of these impacts grows, there is a rising demand from consumers, industries, and policymakers for sustainable alternatives that reduce dependency on single-use plastics. At the same time, technological advances and circular economy initiatives are encouraging the development of innovative bio-based packaging made from renewable sources such as agricultural residues, seaweed, or fish by-products, which can biodegrade safely in natural environments (Siracusa et al., 2008).

How Fish Waste Becomes Sustainable Packaging

The transformation of fish processing by-products into eco-friendly packaging is a promising example of how waste valorisation can support circular economy principles and reduce dependence on fossil-based plastics (Arvanitoyannis & Kassaveti, 2008). Fish waste contains valuable biopolymers such as collagen, gelatin, chitin, and chitosan, which can be extracted and repurposed into biodegradable packaging materials (Shavandi et al., 2017). For instance, gelatin extracted through enzymatic hydrolysis or acid/alkaline treatments is mixed with plasticizers and sometimes combined with other natural polymers such as starch or cellulose to produce flexible films for food packaging (Gómez-Guillén et al., 2009). Such films can act as barriers to oxygen and moisture, extending shelf life and adding antimicrobial properties if infused with natural extracts (Zhang et al., 2022). Chitin and its derivative chitosan are extracted mainly from the shells of crustaceans such as shrimp and crabs. Through deproteinization, demineralization, and deacetylation, chitin is converted into chitosan, which is prized for its biodegradability, film-forming ability, and natural antimicrobial activity (Kumar, 2000). Chitosan-based films can be used alone or blended with other biopolymers to produce flexible or rigid packaging solutions such as food wraps, biodegradable trays, and compostable shopping bags (Arvanitoyannis & Kassaveti, 2008). The typical processing steps for transforming fish waste into packaging materials involve cleaning, grinding, chemical or enzymatic extraction, purification, and conversion into usable forms. The resulting biopolymers are then mixed with plasticizers or other natural additives, cast or extruded into films, or molded into rigid shapes depending on the intended use (Shavandi et al., 2017). Recent practical examples illustrate the potential of this technology. Researchers in Indonesia and Thailand have developed edible films from fish skin gelatin blended with seaweed extracts, yielding packaging that is both biodegradable and suitable for direct food contact (Nur Hanani et al., 2023). Another study by Zhang et al. (2022) produced antimicrobial food wraps from fish gelatin reinforced with essential oils, demonstrating extended shelf life for perishable products. Companies such as Marina Tex, a UK startup, have piloted biodegradable bags made from fish skin waste combined with red algae these bags break down within four to six weeks under home composting conditions (MarinaTex, 2022).

Case Studies and Success Stories

Recent years have seen the emergence of pioneering companies, research institutions, and collaborative projects that demonstrate how fish waste can be successfully transformed into valuable biodegradable packaging materials. These examples highlight the potential of innovative partnerships between the seafood industry, biotech startups, and sustainable packaging companies. Marina Tex (United Kingdom) is one of the most well-known startups using fish waste for biodegradable plastic alternatives. Founded by Lucy Hughes, Marina Tex developed a home-compostable film made from fish skins and scales combined with red algae. The material is strong, flexible, and fully biodegradable within 4–6 weeks in a home composting environment. Marina Tex won the prestigious 2019 James Dyson Award for its breakthrough innovation and has been widely cited as a model for how seafood waste can be converted into value-added, ocean-safe products (Marina Tex, 2022; Dyson, 2019). Iceland Ocean Cluster (Iceland) has pioneered the concept of the “100% Fish” approach, which aims to use every part of the fish to create high-value products. Companies within the cluster

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collaborate to extract collagen and gelatin from fish skins and bones for biodegradable films and cosmetics, chitin from shrimp shells for medical and packaging applications, and other by-products for nutraceuticals and functional foods (Iceland Ocean Cluster, 2020). This model demonstrates how integrated fisheries and biotech companies can maximize resource efficiency and boost local economies while reducing waste. Chitosan Packaging Research (Asia &Europe) Several university research groups have developed promising prototypes for chitosan-based packaging. For example, researchers at Kasetsart University in Thailand have extracted chitosan from shrimp shells to develop biodegradable, antimicrobial films for food packaging (Chaiwarit et al., 2021). Similar projects in Spain and Norway have explored blending chitosan with plant fibers to enhance mechanical properties and biodegradability (de Oliveira et al., 2021). Many of these lab-scale innovations are progressing toward commercialization with the support of public–private partnerships. Real-World Product Examples Companies like Oceanium (Scotland) are integrating fish processing by-products and seaweed to produce compostable flexible packaging films and edible coatings. Their pilot projects supply food brands looking to replace single-use plastics with certified compostable alternatives (Oceanium, 2023).

Challenges and Limitations

Technical barriers one of the foremost technical challenges lies in ensuring that biopolymers derived from fish waste such as collagen, gelatin, chitin, and chitosan meet the functional performance requirements of modern packaging materials. Conventional petroleum-based plastics are valued for their strength, flexibility, moisture resistance, and durability (Shen et al., 2020). In contrast, biopolymer-based films can exhibit lower mechanical strength, higher water solubility, and variable barrier properties, which may limit their use for certain products, especially for foods with high moisture content (Ahmed et al., 2022). Many bio-based packaging solutions are still in the pilot or demonstration phase and lack the economies of scale enjoyed by fossil-fuel plastics. Additionally, fluctuating availability and quality of fishery by-products can affect consistent production and pricing (Rustad et al., 2011). This necessitates rigorous testing and certification, which can be time-consuming and costly. Furthermore, consumer perceptions and acceptance of packaging derived from fish waste may vary depending on cultural contexts and levels of awareness (Bazzani et al., 2021). Clear communication, labelling, and education are needed to build trust and demonstrate the safety and sustainability benefits of these materials.

Future Outlook for Fish Waste–Based Sustainable Packaging

The future of transforming fish processing by-products into sustainable packaging is promising, driven by advances in bio-based material science, the integration of circular economy models, and supportive policy frameworks (Arvanitoyannis & Kassaveti, 2008; FAO, 2021).On the innovation front, ongoing research is focused on developing stronger, multifunctional bioplastics that overcome some of the limitations of first-generation biodegradable films, such as low moisture resistance or mechanical weakness. Advances in polymer blending, nanocomposite reinforcement, and bioactive coatings are improving the performance of gelatin, collagen, chitin, and chitosan-based materials (Gómez-Guillén et al., 2009; Shavandi et al., 2017). For example, combining fish-derived biopolymers with natural fibres, plant starches, or bioactive agents can create packaging films with enhanced barrier properties, antimicrobial functions, or edible applications (Siracusa et al., 2008).

Conclusion

In summary, converting fish processing by-products into biodegradable packaging represents a practical and scalable pathway toward sustainable production and consumption. This innovation not only diverts waste from landfills and oceans but also unlocks new economic value for fisheries and coastal communities. As advances in material science, circular economy practices, and supportive policies converge, fish-waste-based packaging can help replace single-use plastics with eco-friendly alternatives, strengthening the resilience of both marine ecosystems and local economies.

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