



From Fish Processing Waste to Value-Added Products: Innovation for a Sustainable and Circular Blue Economy

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ABSTRACT

Fish processing generates enormous quantities of by-products—heads, skins, bones, viscera, scales, and shells—that are frequently discarded despite holding substantial biological and economic value. As global seafood consumption rises, so does the volume of this waste, creating both an environmental burden and a missed opportunity for resource recovery. Emerging technologies now allow these residues to be transformed into valuable products such as fish protein hydrolysates, collagen and gelatin, chitosan, fish oil rich in omega-3 fatty acids, bioactive peptides, fertilizers, and biofuels. Such valorization not only reduces pollution and disposal costs but also opens new revenue streams for fishery-based industries, aligning with the principles of a circular economy. This article explores the diverse pathways for converting fish processing waste into commercially viable and nutritionally beneficial products, highlighting recent innovations in extraction and processing techniques.

KEYWORDS

Fish waste valorization; Circular economy; Blue economy; By-product utilization; Bioactive compounds

Introduction

Fish processing generates a considerable quantity of residual biomass that does not reach consumers as edible fillets. Depending on the species and processing method, approximately 50–70% of the original fish biomass may remain as by-products, including heads, skin, bones, scales, viscera, fins, and trimming residues (Kaushik et al., 2025; Jimenez-Champi et al., 2024). Traditionally, these materials have been discarded, landfilled, or converted into relatively low-value products such as fishmeal and animal feed. Globally, fish-processing by-products are estimated to account for approximately 50–130 million tonnes annually, indicating the enormous quantity of potentially valuable biomass that remains underutilised (Haque et al., 2026).

Rather than being regarded solely as waste, these materials are increasingly recognised as valuable secondary raw materials. Fish-processing residues contain proteins, collagen, gelatin, lipids, omega-3 fatty acids, minerals, enzymes, peptides, and other bioactive compounds that can be recovered and utilised in food, nutraceutical, pharmaceutical, cosmetic, feed, and biotechnology applications (Rigueto et al., 2023; Jimenez-Champi et al., 2024).

This concept is closely associated with the blue economy and circular economy, which emphasise efficient utilisation of aquatic resources while minimising environmental impacts. Fish by-product valorisation involves converting processing residues into useful and commercially valuable products rather than treating them as waste. Such approaches can reduce disposal problems, improve resource efficiency, generate additional revenue, and contribute to a more sustainable seafood sector (Rigueto et al., 2023; Haque et al., 2026).

A Problem Hiding a Resource

Fish-processing by-products retain considerable nutritional and functional value. Heads, frames, bones, and trimmings contain proteins, minerals, and lipids, whereas skin and scales are important sources of collagen and

other structural proteins. Fish viscera also contain proteins, lipids, enzymes, and other compounds with potential applications in food, nutraceutical, pharmaceutical, and industrial sectors (Blanco et al., 2017; Wang et al., 2024). However, these residues are highly perishable due to their high moisture content and the activity of endogenous enzymes and microorganisms. Improper handling and disposal can result in environmental pollution and the loss of potentially valuable biological resources. Consequently, increasing attention is being given to valorisation technologies, including enzymatic hydrolysis, fermentation, extraction, and other green-processing approaches for recovering high-value compounds from seafood residues (Waqar et al., 2025; Rigueto et al., 2023).

Turning Fish Trimmings into Nutrition: Protein Hydrolysates

One of the important approaches for recovering value from fish-processing residues is enzymatic hydrolysis. In this process, proteolytic enzymes break down proteins present in fish heads, frames, skin, bones, viscera, and other tissues into smaller peptides and soluble protein fractions. The resulting fish protein hydrolysates (FPHs) have demonstrated several biological activities, including antioxidant, antihypertensive, and antimicrobial properties. These characteristics make them promising ingredients for functional foods, nutraceuticals, and aquaculture feeds (Nemati et al., 2024; Cassol et al., 2025; Fan et al., 2026).

Enzymatic hydrolysis is also attractive from an environmental perspective because it can be carried out under relatively mild conditions compared with some conventional chemical treatments. Consequently, it provides a promising route for converting low-value fish-processing residues into higher-value protein ingredients while supporting resource recovery and circular-economy principles (Baraiya et al., 2025; Nemati et al., 2024).

Skin and Scales: Collagen and Gelatin

Fish skin, scales, bones, and related processing residues are important sources of collagen and gelatin. Marine-derived collagen has gained attention as an alternative to mammalian collagen because it can reduce concerns related to zoonotic disease transmission and religious or cultural restrictions. In addition, fish-processing residues provide relatively inexpensive raw materials for collagen recovery. Recovered fish collagen has potential applications in food products, nutraceuticals, cosmetics, pharmaceuticals, tissue engineering, and biodegradable materials. These diverse applications have increased interest in fish-derived collagen as a commercially valuable biomaterial rather than simply a processing residue (Rajabimashhadi et al., 2023; Rigueto et al., 2023).

Shellfish Processing Waste: Chitin and Chitosan

In addition to fish-processing residues, crustacean processing waste represents an important source of valuable biomaterials. Shrimp, crab, lobster, and other crustacean shells contain substantial quantities of chitin, which can be converted into chitosan. Chitosan is a biodegradable and biocompatible polymer with applications in biomedical materials, pharmaceuticals, cosmetics, food systems, water treatment, and biodegradable packaging. Conventional extraction generally involves acidic and alkaline treatments. However, enzymatic and fermentation-based approaches are increasingly being explored to reduce the dependence on harsh chemicals and minimise the environmental impact of chitin and chitosan production (Zou et al., 2021; Younes & Rinaudo, 2021).

Fish Oils Rich in Omega-3 Fatty Acids

Fish-processing residues such as viscera, heads, frames, and trimmings can also provide valuable marine oils containing long-chain omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These fatty acids

are nutritionally important and are widely incorporated into functional foods and dietary supplements. Several separation and purification technologies, including urea complexation, molecular or short-path distillation, and enzymatic fractionation, can be used to enrich or purify EPA and DHA from fish oils. These approaches increase the value of oils recovered from processing residues and provide alternatives to their use solely in low-value applications (Gámez-Meza et al., 2003; Aursand et al., 2014).

Fish By-products for Biodegradable Packaging

Another emerging application of seafood-processing residues is the production of biodegradable packaging materials. Fish proteins, collagen, gelatin, chitin, and chitosan can be processed into films and coatings with potential applications in food packaging. The development of these materials provides an opportunity to replace or reduce dependence on petroleum-derived plastics while simultaneously creating value from seafood-processing residues. However, many of these technologies are still at laboratory or pilot scale, and further improvements are required in mechanical strength, barrier properties, stability, processing performance, and economic feasibility before large-scale commercialisation (Lionetto & Esposito Corcione, 2021).

Beyond Fish: Toward an Integrated Marine Bioeconomy

Seafood by-product valorisation can extend beyond the recovery of individual products. Crustacean shells, for example, contain chitin, proteins, minerals, and carotenoid compounds such as astaxanthin. Similarly, fish tissues and organs can provide proteins, peptides, lipids, enzymes, and other bioactive compounds. Following the extraction of high-value components, the remaining biomass can be used for fertilisers, biofuels, anaerobic digestion, or other energy-recovery processes. This integrated approach is consistent with the

concept of a marine biorefinery, in which multiple valuable products are recovered from a single processing stream rather than relying on a single end product (Caruso et al., 2020; Maschmeyer et al., 2020).

Linking the Circular Economy with the Blue Economy

Fish by-product valorisation provides a practical connection between the circular economy and blue economy. Instead of treating harvesting, processing, consumption, and disposal as independent stages, a circular approach connects these stages so that materials generated at one stage become useful inputs for another. For example, a fish-processing facility could potentially recover protein hydrolysates from protein-rich residues, collagen from skin and scales, oils from fatty tissues, minerals from bones, and enzymes or other bioactive compounds from viscera. Such integrated utilisation can improve resource efficiency, reduce disposal requirements, and create additional economic opportunities within the seafood sector (Rigueto et al., 2023; Maschmeyer et al., 2020).

Challenges in Commercialisation

Despite its considerable potential, large-scale valorisation of seafood by-products continues to face several challenges. The composition and quality of processing residues can vary according to species, season, geographical origin, processing method, and storage conditions. Furthermore, extraction and purification technologies may involve significant capital and operating costs.

Maintaining the quality and stability of recovered compounds is another important consideration. Regulatory requirements can also influence the commercialisation of products intended for human consumption, nutraceutical applications, pharmaceuticals, and other high-value markets (Kaushik et al., 2024).

Future Prospects

A major priority for the seafood industry is to translate promising laboratory-scale extraction and valorisation technologies into economically competitive industrial processes. Future research should therefore focus on improving process efficiency, reducing energy and chemical requirements, developing integrated biorefinery systems, and establishing economically viable methods for the recovery of multiple products from the same processing stream. With continued technological development, seafood-processing residues can serve as raw materials for collagen, gelatin, protein hydrolysates, omega-3 oils, chitin, chitosan, bioactive compounds, biodegradable packaging, fertilisers, and energy products. Their systematic utilisation can reduce environmental pressure while creating additional economic value for seafood processors and coastal communities.

Conclusion

Fish-processing by-products should increasingly be regarded as valuable resources rather than unavoidable waste. Their conversion into high-value products such as protein hydrolysates, collagen, gelatin, omega-3 oils, chitin, chitosan, bioactive compounds, and biodegradable packaging demonstrates the potential of seafood valorisation to support both environmental sustainability and economic development. By integrating multiple recovery technologies within a circular production system, the seafood sector can reduce waste, improve resource efficiency, create additional revenue streams, and contribute to a more sustainable blue bioeconomy. Thus, fish by-product valorisation represents an important pathway for transforming an environmental challenge into an opportunity for innovation, resource conservation, and sustainable growth (Caruso et al., 2020; Rigueto et al., 2023).

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