# Bioenzymes from Fish Waste: Sustainable Utilization of Fishery Resources in a Circular Bioeconomy

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India ranks as the world's second-largest fish producer, with a record output of 197.75 lakh tonnes (2024-25), representing about 8% of global fish production. It has 646 registered seafood processing units. In FY 2025–26, India achieved a historic seafood export total of 1.97 MMT valued at ₹73,890.46 crore (USD 8.46 billion). During processing, industries generate significant waste, including heads, viscera, skin, scales, bones, and frames. Viscera, comprising roughly 5-10% of the waste, are a rich source of industrial bioenzymes. These enzymes are highly efficient, substrate-specific, and active at low temperatures, making them valuable in the food, pharmaceutical, biotechnology, and environmental sectors. Extracting bioenzymes from fish waste reduces environmental impact and supports sustainable use of fishery resources within a circular bioeconomy.

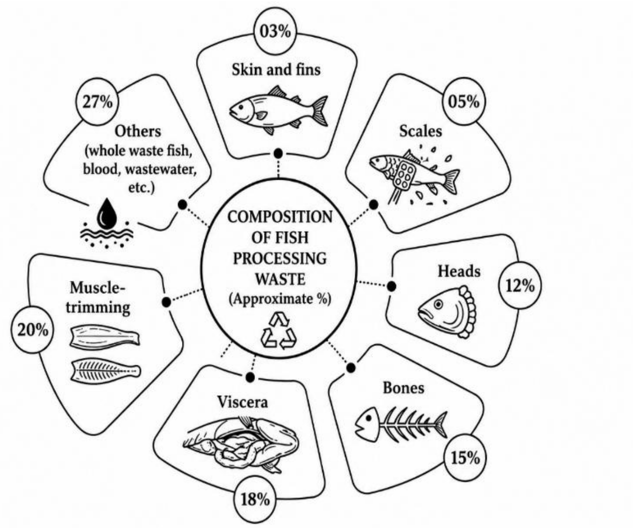


**Fig. 1. Composition of fish processing waste**

**Table 1. Major Bioenzymes obtained from fish waste**

| Enzymes | Sources | Applications |
|---|---|---|
| Proteases (Trypsin, Chymotrypsin, Pepsin, Alkaline proteases) | Pyloric caeca, pancreas, stomach, intestine | Protein hydrolysis, fish protein hydrolysates, food processing, leather industries, detergents, pharmaceuticals |
| Collagenase | Skin, scales, connective tissues | Wound debridement, tissue engineering, collagen extraction, regenerative medicine |
| Lipases | Live, pancreas, viscera | Biodiesel production, flavour development, dairy processing, detergents, organic synthesis |
| Transglutaminase | Muscle and viscera | Restructured seafood products, meat processing. Edible films, food texture improvement |
| Hyaluronidase | Fish skin and connective tissue | Drug delivery, cosmetics, ophthalmic formulations |
| Phosphatases | Intestine and liver | Clinical diagnostics, molecular biology, biosensors |
| Alkaline phosphatase | Intestine | Diagnostic kits, immunoassays, and molecular biology |
| DNase/RNase | Pancreatic tissues | Molecular biology, biotechnology, nucleic acid processing |
| Elastase | Pancreas | Peptide production, biomedical research, cosmetics |

### Advantages of fish waste-derived bioenzymes

- Converts processing waste into high-value products
- Reduces environmental pollution and disposal costs
- Supports sustainable fisheries and the circular bioeconomy
- Marine enzymes often exhibit high activity at low temperatures, reducing industrial energy consumption
- Biodegradable and environmentally friendly alternatives to chemical catalysts
- Creates additional revenue streams for the seafood processing industries

### Industrial applications

- **Food industry**: Fish waste-derived enzymes, especially proteases, lipases, and transglutaminases, are widely employed in food processing to boost product quality and functionality. These enzymes assist in protein hydrolysis to create fish protein hydrolysates, enhance flavour development, tenderise meat, support cheese ripening, reshape seafood products, and improve digestibility- leading to nutritious, high-value foods.

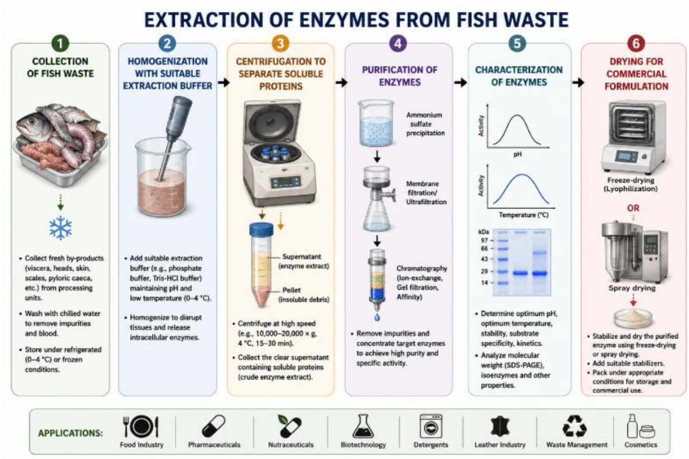


**Fig. 2. Extraction procedure of enzymes from fish waste**

- **Nutraceuticals:** Fish by-products are a valuable source of bioenzymes that help produce bioactive peptides with benefits such as antioxidant, antihypertensive, antimicrobial, and immunomodulatory effects. Enzymatic hydrolysis breaks down fish proteins into peptides that are easy to digest, making them suitable for use in functional foods and dietary supplements. These peptides support cardiovascular health, boost immune function, aid muscle recovery, and enhance overall well-being.
- **Pharmaceuticals:** Marine-derived enzymes such as collagenase, hyaluronidase, and proteases play important roles in pharmaceuticals. They are employed in wound cleaning, tissue repair, digestive enzyme products, controlled drug release, and peptide manufacturing. Their high selectivity and compatibility with the body enhance their usefulness in creating new treatments and regenerative medicine solutions.
- **Biotechnology:** Fish-derived bioenzymes are extensively utilised in biotechnology fields such as molecular biology, enzyme immobilisation, biosensor development, protein purification, and biocatalysis. Cold-active enzymes operate effectively at mild conditions, lowering energy usage without sacrificing catalytic performance. These enzymes facilitate sustainable industrial practices and propel progress in biomedical research.
- **Detergent industry:** Cold-active proteases and lipases derived from fish waste are important components in current detergent formulas. They efficiently eliminate protein and fat stains at low temperatures, helping to save energy and protect fabrics. Additionally, their biodegradability and high catalytic activity make them eco-friendly substitutes for traditional chemical cleaners.
- **Leather industry:** Proteolytic enzymes derived from fish-processing by-products are becoming more popular in eco-friendly leather manufacturing. They assist in dehairing, bating, and softening fibres without the need for harsh chemicals like lime and sulphides. This enzymatic approach enhances leather quality, lowers wastewater pollution, and promotes environmentally sustainable industrial methods.
- **Waste management:** Bioenzymes are crucial in transforming protein-rich fish-processing waste into useful products like biofertilisers, bioactive peptides, animal feed ingredients, and biogas. Their enzymatic action speeds up organic waste breakdown, reduces environmental pollution, cuts disposal costs, and supports circular bioeconomy principles by promoting sustainable resource use.
- **Cosmetics:** Marine-derived enzymes like collagenase and hyaluronidase are now frequently added to cosmetic products aimed at skin rejuvenation, anti-ageing, hydration, and collagen remodelling. They help improve skin elasticity, accelerate wound healing, support cellular regeneration, and contribute to the creation of natural, biodegradable, and sustainable cosmetics with better therapeutic effects.

**Future prospects**

Future research is likely to focus on creating cost-efficient extraction and purification methods, enhancing enzyme stability through immobilisation, producing marine enzymes via recombinant techniques, and achieving large-scale industrial commercialisation. Combining enzyme recovery with the extraction of collagen, gelatin, omega-3 oils, chitin, and bioactive peptides within a biorefinery framework will optimise the economic potential of fish-processing by-products while reducing waste. Progress in green extraction methods, enzyme engineering, and nanobiotechnology is expected to broaden the use of fish waste-derived bioenzymes across sectors such as food processing, healthcare, environmental cleanup, and sustainable manufacturing.

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