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CHAPTER 6

Valorization of Fish Waste for Organic Fertilizer Production: Advances, Challenges, and Future Prospects

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Abstract

Fish processing generates substantial quantities of heads, viscera, skin, bones, scales, frames and other residues. When discarded without adequate treatment, these materials can create odour, leachate, microbial and water-quality problems. Yet fish waste contains organic matter, nitrogen (N), phosphorus (P), calcium and other minerals that can be recovered for agricultural use. This narrative review synthesizes literature on the conversion of fish waste into solid compost, fish

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hydrolysate or silage, liquid fish emulsion and digestate from anaerobic digestion. Published sources report that by-products may account for approximately 30–70% of whole-fish weight, depending on species and processing method. Experimental studies indicate that mature fish-waste compost can improve plant biomass and nutrient accumulation, although outcomes depend on feedstock composition, composting conditions, application rate and crop. The review also highlights important constraints: rapid putrefaction, salinity, ammonia or organic-acid phytotoxicity, pathogens, trace metals, variable nutrient availability and regulatory requirements. Effective use therefore requires source segregation, prompt processing, co-composting with carbon-rich bulking agents, quality testing and agronomic dose optimization. Fish-waste fertilizer should be viewed as a nutrient-recycling input and potential supplement to integrated soil fertility management rather than a universally interchangeable replacement for mineral fertilizer. More field-scale research under Indian agro-climatic conditions is needed to standardize production, verify crop response and establish safe application guidelines.

Keywords: Fish waste; organic fertilizer; composting; fish hydrolysate; nutrient recycling; circular bioeconomy; soil fertility; sustainable agriculture.

Introduction

Fish is highly perishable, and processing for filleting, gutting, scaling, heading and trimming produces a heterogeneous residue stream. Heads, viscera, bones, skin, fins and scales may be discarded, rendered into fishmeal, used in silage, or converted into other value-added products. The proportion classified as by-product varies with species and processing intensity; FAO reports that by-products can reach 70% of processed fish in some settings, while a review of fish-based fertilizers gives a broad estimate of 30–70% of the original fish [1–3]. These figures describe a range, not a universal yield for every fishery.

Poorly managed residues decompose rapidly because of high moisture, protein and lipid content and a substantial microbial and enzyme load. Uncontrolled disposal can cause odour, oxygen depletion in receiving waters, attraction of scavengers and loss of potentially recoverable nutrients. The same biochemical composition that makes fish waste unstable also makes it a potentially valuable fertilizer feedstock when it is treated and stabilized appropriately [1,2].

Organic fertilizers supply nutrients while contributing organic matter or biologically active compounds. Fish-derived materials can provide nitrogen from proteins, phosphorus and calcium from bones, and smaller amounts of other minerals. The exact composition depends on fish species,

tissue proportions, washing, storage, processing method and dilution. Therefore, fertilizer value should be established by analysis of the final product rather than inferred from the raw material alone [2,3].

The use of fish residues in agriculture aligns with circular-economy principles: nutrients extracted from aquatic food systems are recovered and returned to terrestrial production. This can reduce waste-disposal burdens and partially displace purchased nutrient inputs. However, resource recovery must not transfer contaminants or pathogens from waste streams to soil, crops or farm workers. This review evaluates the principal conversion routes, agronomic evidence, quality-control needs and research priorities, with attention to practical relevance for India.

Review objectives

- To summarize the types and resource potential of fish-processing waste relevant to fertilizer production.
- To compare major conversion methods: composting, fermentation/hydrolysis, fish emulsion and anaerobic digestion.
- To review reported effects on soil fertility, plant growth and nutrient uptake.
- To identify environmental, operational and food-safety risks and propose practical quality-control measures.
- To highlight research needs for reliable, locally adapted fish-waste fertilizers.

Materials and Methods

This article was prepared as a narrative literature review. Literature was identified through targeted searches of scientific publisher platforms, PubMed-indexed records, FAO publications and agricultural research journals using combinations of the terms “fish waste fertilizer”, “fish waste compost”, “fish hydrolysate”, “fish silage”, “organic farming”, “plant growth”, “compost maturity” and “food safety”. Priority was given to peer-reviewed review articles, experimental studies reporting crop or compost outcomes, and authoritative FAO resources.

Sources were screened for relevance to (i) fish by-product generation and composition, (ii) fertilizer-processing methods, (iii) crop or soil responses, and (iv) safety or quality control. Findings were compared qualitatively because studies differed in raw materials, compost recipes, application rates, crop species, soil type, experimental duration and analytical methods.

Fish waste: types and fertilizer potential

Fish waste is not a uniform substrate. Viscera and soft tissues may contribute readily degradable nitrogen-rich organic matter and lipids; heads, frames and bones contribute mineral fractions, including calcium and phosphorus; skin and scales contain collagenous proteins and structural material. Mixed waste may therefore have a useful nutrient profile but also an imbalanced carbon-to-nitrogen ratio, high moisture and strong odour. Co-processing with sawdust, dry leaves, straw, wood chips or other carbon-rich bulking materials improves porosity and moisture balance during composting.

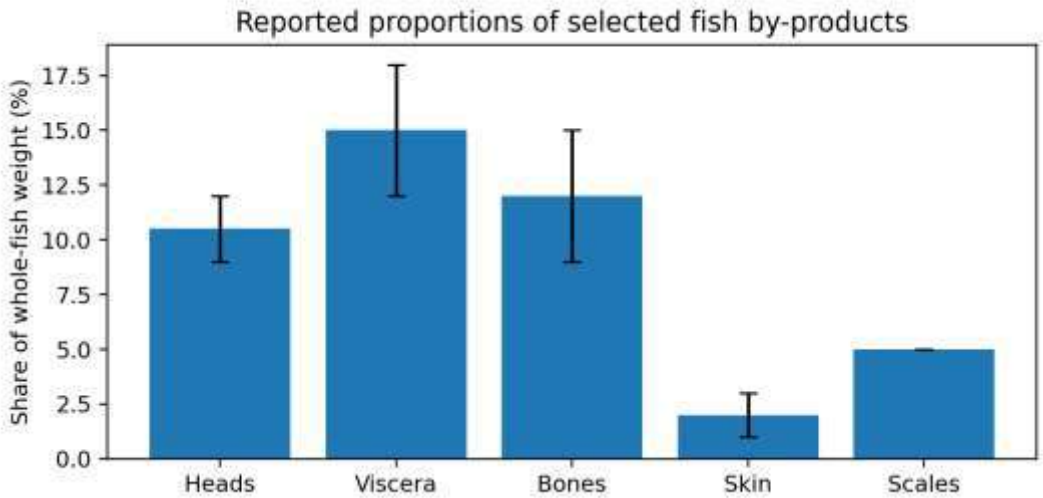

Figure 1. Reported proportions of selected fish by-products. Bars show the mid-point of the published range where a range was given; error bars show the reported range. Categories are not intended to sum to 100% because values vary by species and processing system. Source: FAO [1].

Waste fraction	Potential fertilizer contribution	Main handling consideration
Heads, frames and bones	Phosphorus, calcium, protein and organic matter	Bones decompose slowly; particle-size reduction may help
Viscera and soft tissues	Nitrogen-rich proteins, lipids and readily degradable organic matter	Very rapid spoilage; collect and stabilize promptly
Skin and scales	Collagenous proteins and mineral fractions	May require size reduction and longer processing
Trimmings and mixed residues	Combined organic matter and macro-/micronutrients	Composition varies substantially by species and process

Fish-processing wastewater/sludge	Dissolved or suspended nutrients, depending on treatment	Must be characterized; contaminants and high organic load may limit direct use

Processing technologies for organic fertilizer

Composting and co-composting

Composting combines biological decomposition with stabilization. Fish waste is mixed with a dry, porous carbon source such as sawdust, wood chips, straw or dry plant residues. A suitable mixture should retain moisture while allowing oxygen movement. Turning or forced aeration supports aerobic decomposition; temperature, moisture and odour should be monitored. Because raw fish waste is wet and nitrogen-rich, adding a bulking agent is usually essential. Co-composting with plant residues or seaweed has been investigated as a route to produce fertilizer for horticultural and organic farming [4,5].

The final product must be mature and stable before application. A strong putrid or ammonia odour, reheating after turning, high electrical conductivity or poor seed germination may indicate incomplete stabilization or excessive salts. Maturity is better assessed through several indicators' temperature stability, respiration or stability tests, pH, electrical conductivity, carbon-to-nitrogen ratio and a germination/phytotoxicity test than through appearance alone. A study using fish waste and pine bark reported a mature, stable and non-phytotoxic compost and improved lettuce biomass and tissue nutrient concentrations [4].

Fermented fish hydrolysate, silage and liquid fertilizer

Hydrolysis breaks proteins into smaller peptides and amino acids. Fish silage can be produced through acidification, enzymatic hydrolysis or lactic-acid fermentation, depending on the method. Sugar or another fermentable carbon source may be used in some fermentation approaches. Liquid products are easier to transport and apply through watering or fertigation systems, but their nutrient concentration can be variable. They may also have high biological oxygen demand, odour, acidity or salinity if processing is poorly controlled. A defined dilution rate should be based on laboratory analysis and small-scale crop testing, not a universal recipe.

Liquid fish products can deliver readily available nutrients and organic compounds, but they should not automatically be described as plant biostimulants unless the relevant effect has been tested. Fermentation is not a substitute for hygienic handling or quality assurance. The finished

product should be checked for pH, electrical conductivity, nutrient content, microbial safety and stability.

Fish emulsion and dried fish-based fertilizers

Fish emulsion generally refers to a processed liquid fertilizer derived from fish material, whereas dried fish meal or fish-bone meal is a solid product. Drying can improve storage and transport, but requires energy and process control. Bone-rich products may be useful as slower-release sources of phosphorus and calcium; protein-rich products may provide nitrogen. Commercial products vary in formulation and guaranteed analysis, so label claims and local fertilizer regulations should guide use.

Anaerobic digestion and digestate

Anaerobic digestion converts biodegradable organic matter into biogas and digestate under oxygen-free conditions. Fish waste may be co-digested with manure or plant residues to improve process balance. Digestate can retain plant nutrients, but it is not automatically a finished fertilizer: it may require separation, post-treatment, stabilization and testing. High protein can lead to ammonia inhibition during digestion, while salt and lipid levels can affect process performance. Where feasible, biogas recovery offers an additional energy benefit alongside nutrient recycling [2,3].

Method	Typical product	Advantages	Limitations / controls
Aerobic composting	Solid, stabilized compost	Adds organic matter; easier to store and transport	Needs bulking material, aeration, time and maturity testing
Fermentation / hydrolysis	Liquid hydrolysate or fish silage	Concentrated nutrients; potentially rapid availability	Odour, acidity, variable composition; requires dilution and safety checks
Rendering / drying	Fish meal or bone-rich fertilizer	Longer shelf life; nutrient-dense solid	Energy demand; nutrient release depends on processing and particle size
Anaerobic digestion	Biogas plus digestate	Energy recovery and nutrient recycling	Process sensitivity; digestate needs quality assessment
Co-composting with plant residues/seaweed	Mixed organic fertilizer	Balances feedstock and may improve handling	Recipe-specific; salinity and maturity must be checked

Results of the literature review

The reviewed literature supports the technical feasibility of converting fish residues into fertilizer products, but it does not support one universal nutrient profile or application rate. Product composition and crop response are strongly process-dependent. Table 3 summarizes representative published evidence.

Study	Material / system	Reported result relevant to fertilizer use	Interpretation
Ahuja et al. (2020) [2]	Review of fish- and fish-waste fertilizers	Describes dry and liquid products, compost, silage/hydrolysate and digestate; reports positive plant-growth findings across cited studies	Broad evidence base, but many formulations and study conditions differ
Radziemska et al. (2019) [4]	Compost prepared from 80% fish waste and 20% pine bark (w/w)	Reported stable, mature, non-phytotoxic compost; lettuce yield and several tissue nutrient concentrations increased	Supports co-composting, with maturity and crop response assessed
Devi et al. (2024) [6]	Fish waste compost using sawdust, banana and jaggery supplementary materials	Reported pH 6.80, EC 1.45 dS/m and C:N ratio 28.6:1; germination tests indicated low phytotoxicity	Illustrates an Indian composting approach; recipe and values are study-specific
Devi et al. (2025) [7]	Fish-waste compost evaluated in broccoli pot culture in Mizoram	Reported positive crop responses in a treatment combining fish-waste compost with vermiwash and plant extract	Suggests potential, but combined treatment makes the individual fish-compost effect difficult to isolate
Radziemska et al. (2015) [5]	Compost from fish waste and seaweed in horticultural rotation	Reported yield improvement in tomato and residual effects on a succeeding lettuce crop at higher tested rates	Shows possible residual benefit; rates should not be transferred without local trials
Balkhande (2020, 2021); Balkhande & Issak (2024) [11–14]	Fish/crab-waste compost; groundnut response; Nanded fish-market survey	Reported compost N-P-K values; evaluated groundnut germination/morphology; documented local fish-market waste as a potential resource	Relevant Indian evidence; compare cautiously because methods and outcomes differ

Example nutrient values reported in published studies

Published compost values illustrate why source-specific testing is essential. Devi et al. (2024) reported carbon 10.56%, nitrogen 2.12%, phosphorus 0.82% and potassium 0.10% for their fish-waste compost. Radziemska et al. (2019) reported, on a dry-matter basis, organic carbon 566.2 g/kg, total nitrogen 1.92 g/kg, phosphorus 0.40 g/kg and potassium 0.94 g/kg for a fish-waste/pine-bark compost. These values come from different feedstocks, recipes and analytical contexts and must not be read as a controlled comparison.

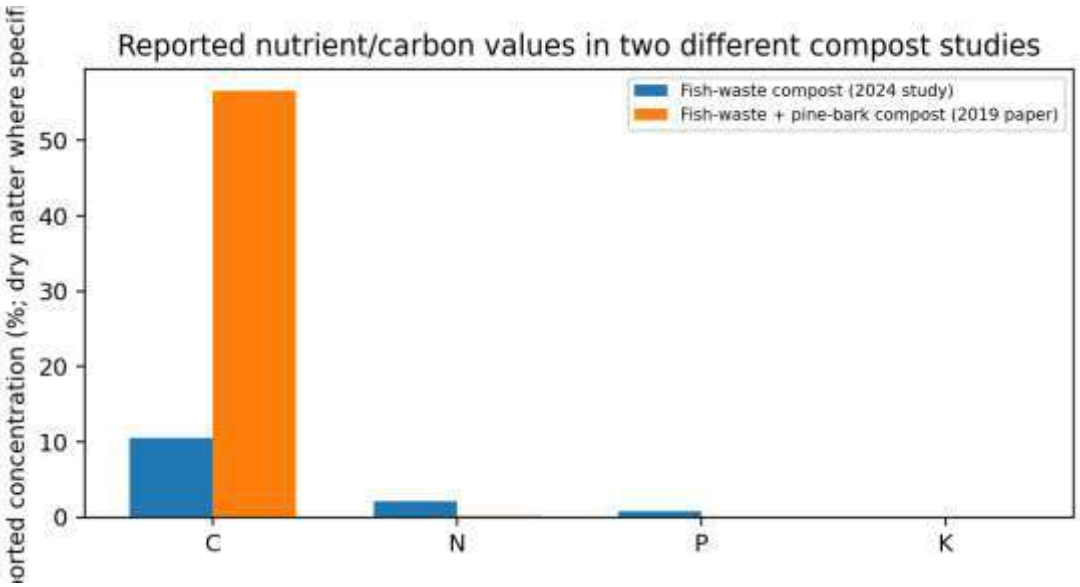

Figure 2. Carbon and macronutrient values reported by two separate compost studies. Values are plotted as percentages; 1 g/kg was converted to 0.1%. Carbon and nutrient values differ markedly between formulations, and the figure is descriptive rather than a quality ranking. Sources: Devi et al. [6] and Radziemska et al. [4].

Discussion

Nutrient recovery and soil fertility

The principal agronomic rationale for fish-waste fertilizer is nutrient recovery. Organic nitrogen is mineralized by soil microorganisms into forms that plants can absorb; the rate depends on temperature, moisture, soil biology and the stability of the product. Bone-derived phosphorus and calcium may be released more slowly than soluble nutrients in liquid formulations. Stable compost also adds organic matter, potentially supporting aggregation, water retention and microbial activity. These benefits are plausible and supported by experimental studies, but their magnitude varies with the soil and management system.

Fish-derived fertilizer is best positioned within integrated nutrient management. Soil testing, crop nutrient demand, fertilizer analysis and expected mineralization should determine application rates. Over-application can lead to excessive nitrogen or phosphorus, salt accumulation, nitrate leaching or nutrient runoff. Liquid products can injure seedlings if applied too concentrated or directly to foliage under unsuitable conditions. Field validation is needed before recommending a fixed rate for a crop or region.

Environmental and circular-economy benefits

Recovering fish waste can divert biodegradable material from uncontrolled dumping and return nutrients to agricultural soils. Composting can reduce volume and stabilize organic matter; anaerobic digestion may recover energy as biogas; hydrolysis and drying can create transportable products. The most sustainable pathway depends on local waste quantity, collection distance, energy needs, available bulking agents, market demand and regulations. Prevention of edible food loss and higher-value uses should be considered before fertilizer production where appropriate; fertilizer is one option in a broader by-product hierarchy [1,3].

Risks and quality assurance

The same nutrient richness that creates value also creates risk if the product is not properly processed. Raw fish residues spoil quickly and may carry microorganisms. Incomplete composting can leave phytotoxic organic acids or ammonia. Marine-derived feedstocks may have elevated salts, and fish from contaminated waters may contain trace metals or other pollutants. Contaminant levels depend on species, source and tissue; bones and viscera may differ from muscle. Therefore, a reliable quality programme should include traceability of the source, hygienic collection, validated processing, pathogen indicators where required, nutrient analysis, pH, electrical conductivity, maturity and phytotoxicity testing, and relevant contaminant testing.

Quality parameter	Why it matters	Practical assessment
Moisture, texture and odour	Affects aeration, storage and nuisance potential	Routine process monitoring; no persistent putrid odour in finished compost
Temperature and stability	Indicates progress of decomposition and stabilization	Temperature log plus stability/respiration assessment
pH and electrical conductivity (EC)	Extreme pH or high salts may inhibit germination	Laboratory measurement using a consistent method

C:N ratio and total N-P-K	Supports nutrient planning and product labelling	Representative sample analysed by an accredited laboratory
Germination / phytotoxicity	Screens for immature compost and inhibitory compounds	Seed germination and root elongation bioassay
Pathogens and trace elements	Protects workers, soil and food-chain safety	Test according to intended use and applicable regulations
Batch traceability	Allows recalls and process improvement	Record source, recipe, dates, temperature, tests and destination

Relevance and implementation in India

In India, fish markets, landing centres, processing units and aquaculture operations may provide feedstock, while horticulture, nurseries and farms can provide potential markets. A decentralized model may suit smaller markets if collection is frequent, the site is contained and trained operators can maintain process conditions. A practical pilot should begin with one or two well-characterized waste streams and a documented compost recipe rather than mixing all residues indiscriminately.

For an initial pilot, separate fish residues from plastics and other contaminants, chop or mince where practical, mix with dry carbon-rich bulking material, maintain aerobic conditions and monitor temperature and moisture. Do not distribute fresh or putrefying waste directly onto crops. Allow adequate curing, then test the finished product before a small, replicated crop trial. Local regulatory requirements for organic fertilizers, animal by-products, waste handling and use on food crops must be checked before commercial production or claims of organic certification.

Evidence from research by Balkhande and colleagues

Research by Balkhande and colleagues provides locally relevant evidence for the conversion of fish-market residues into organic fertilizer. Balkhande (2020) described a fish- and crab-waste composting approach and reported N, P and K values of 1.18%, 0.48% and 0.58%, respectively. Balkhande and Chavhan (2020) further discussed low-cost preparation and the potential for employment generation through improved waste management. In a subsequent crop-focused study, Balkhande (2021) examined germination and morphological characteristics of groundnut (Arachis hypogaea) following application of fertilizer prepared from fish waste. Balkhande and Issak (2024) surveyed fish waste from markets in Nanded city, adding a regional waste-resource perspective. Together, these papers connect practical waste conversion, fertilizer composition, crop testing and local waste assessment. Their results should be interpreted in the context of each study's design, and

further replicated field trials and standardized product-quality analyses would strengthen recommendations for wider adoption [11–14].

Recommended pilot workflow

- Feedstock assessment: identify species/source, daily quantity, tissue composition, seasonal variation and possible contamination.
- Collection and transport: use covered, leak-proof containers; minimize holding time and keep residues away from food-ready areas.
- Pre-processing: remove non-biodegradable contaminants; reduce particle size when needed.
- Recipe development: combine fish waste with a dry carbon-rich bulking agent; adjust moisture and porosity through pilot batches.
- Process monitoring: record temperature, moisture, turning/aeration, odour and time; use a validated pathogen-reduction process where required.
- Curing and testing: assess stability, pH, EC, nutrient composition, germination response and contaminants relevant to the source.
- Crop evaluation: test several safe application rates against an untreated control and a locally recommended fertilizer treatment; use replication and record growth, yield and soil properties.
- Scale-up: only scale after consistent batch quality, crop response, operating costs and compliance have been demonstrated.

Research gaps and future directions

Future work should compare composting, lactic fermentation, enzymatic hydrolysis and co-digestion using the same feedstock, with complete mass balances for carbon, nitrogen, phosphorus and salts. Field trials should include cereals, pulses, vegetables and fruit crops across soil types, not only pot experiments or horticultural crops. Trials need untreated controls, standard fertilizer controls, replication, statistical analysis, multi-season monitoring and explicit reporting of the nutrient dose applied. Research should also evaluate microbial communities, nitrogen mineralization, greenhouse-gas emissions, life-cycle costs and farmer acceptance. Standardized analytical methods and transparent product labels would make studies easier to compare and improve confidence among users.

Conclusion

Fish waste is a promising raw material for organic fertilizer because it contains recoverable organic matter, nitrogen, phosphorus, calcium and other nutrients. Composting, fermentation/hydrolysis, drying and anaerobic digestion provide different routes to convert unstable residues into useful products. The published evidence includes successful compost-maturity assessments and positive crop responses, including lettuce and broccoli studies, but results depend on the feedstock and treatment. Safe, effective use requires prompt collection, controlled processing, adequate stabilization, laboratory quality checks and application rates based on crop demand and soil conditions. Fish-waste fertilizer should be integrated with soil testing and other nutrient sources, not promoted as a universal one-for-one replacement for synthetic fertilizer. With locally validated methods and sound quality assurance, fish-waste valorization can contribute to waste reduction, nutrient circularity and more sustainable agriculture.

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