Indian J Anim Health (2022), 61(2)- Special Issue: 67-82
DOI: https://doi.org/10.36062/ijah.2022.spl.02222

Invited Review Article

Fish processing wastes: Environmental impacts and mitigation measures

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Abstract

In India, a lot of waste has been generated by the fish processing sector. These comprise low-value underutilized fish that are caught as by-catch in commercial fishing operations, as well as large amounts of wastewater expelled out from processing industry as effluent. Processing discards also include trash fish that have been generally stripped of their fins and shells. Proteins, amino acids, lipids with large amounts of polyunsaturated fatty acids (PUFA), carotenoids, and minerals are abundant in the discards, effluents, and by-catch. Therefore, the loss of nutrients and major environmental risks are caused by fish wastes. To solve the issues, it is crucial to subject the waste to secondary processing and valorization. However, biological treatments are cost-efficient, secure, and favourable to the environment. Bioconversion techniques, which are the foundation of biological treatments, assist in recovering important ingredients from by-catch, industrial effluents and discards without losing their inherent bioactivities. Nutrients are converted by biological processes into single cell proteins that can be used as a source for biodiesel production and essential components. It is now possible, thanks to the recent advancements in algae biotechnology.

Key words: Bioconversion, Environmental impact, Fish processing, Fish processing waste

Highlights

- Loss of nutrients and major environmental risks are caused by fish wastes.
- The waste can be utilised through secondary processing and valorisation.
- Biological treatments are cost-efficient and favourable to the environment.

INTRODUCTION

Fish is one of the highly perishable and preferred staple food commodities which plays a vital role in balanced diet and nutritional requirements of people from developing countries. The choice of fish product consumption is substantially expanding due to its high content of essential dietary nutrients like amino acids, fatty acids and other essential minerals, which are beneficial to keep human health in good condition. To cope with the increasing human demand, global fish production is rapidly increasing day by day. According to FAO (2022), global fisheries and aquaculture production have created a whooping record of 214 million tons in the year 2020 which is around 3% more than the production recorded in 2019. In Asia and Africa, the production of fish food especially seafood products contribute in large spectrum in the betterment of socio-economic condition of the rural and urban population.

Today, seafood comprises one of the major parts of food industry. It is highly preferred in many countries due to its high content of essential fatty acids, amino acids, good quality proteins, several growth promoting minerals and trace elements, vitamins etc. which promote healthy lifestyle and maintains nutrition in human beings. Also, seafood helps in some biological functions like development of nervous system and brains in human. As a result, in developing countries, fish is considered as one of the prime functional foods, and the per capita consumption of seafood increased from 9 kg in 2018 to 20.5 kg in 2020, respectively (FAO, 2022).

The seafood industry is, however, associated

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with production of significant quantity of fish processing waste or fish discards (Karkal and Kudre, 2020). Fish waste includes many fish species that have lesser economic values or damaged parts which cannot be sold in large scale. According to Caruso *et al.* (2020), several fish body parts like skin, head, fins, viscera, and scales are referred to as fish processing wastes. Globally, the range of fish wastes exceed 25% of the total marine catch annually, which is weighted as around 20 million tons. In addition, a large quantity of water is required for fish processing operations; thus, the used water is also recognized as fish processing wastewater. Presently, there are approximately 1000 fish processing plants existing in India, out of which 400 are major processing plants, which have daily capacity to process 10,000 tons of fish; rest 500 plants are engaged with pre-processing practices of fish; some canning and surimi units (Ahmad and Bhuimbar, 2019). Every year a large amount of waste from fish processing industry is discarded. According to the report given by the Ministry of Commerce and Industry, Government of India, the country is the 5th largest exporter of fish and fishery products with 4.1% share in the world seafood exports, and total export volume was 12,89,651 million tons in 2019-20. Half of the total quantity was disposed of as fish wastes (Ahmad and Bhuimbar, 2019). Among the seafood industries, the highest amount of fish waste is generated from shrimp processing itself (Mohanty *et al.*, 2020).

Nowadays, one of the major issues of processing industry is the effect of fish discards or fish wastes to the aquatic environment which can alter the biodiversity and community structure as well (Mirto *et al.*, 2012). Direct disposal of fish wastes in the aquatic environment can create severe environmental pollution due to its high organic load and creates an environment which is suitable for disease outbreak. Also, fish wastes can create a significant economic loss as it can be utilized as feed for fish species. Fish meal is one of the major products obtained from fish processing wastes which are generally not consumed by human. However, these fish processing wastes can positively be utilized for human as cheap alternative resources by using recent biotechnological advances. A promising area of research and development for the use of fish waste by-products is the recovery of chemical components from fish processing units that can be used for other food applications. The ideal alternative is to transform these wastes into high-value, bioactive products for human and animal use. This review paper delineates the environmental impact and utilization of wastes from fish processing industry.

Fish processing

A series of processing techniques are applied in most of the Indian fish processing industries to process finfish and shellfish. This includes grading, slime removal, scaling, washing, heading, gutting, fins removal, slicing, filleting, meat bone separation, packaging, labelling and distribution (Fig. 1).

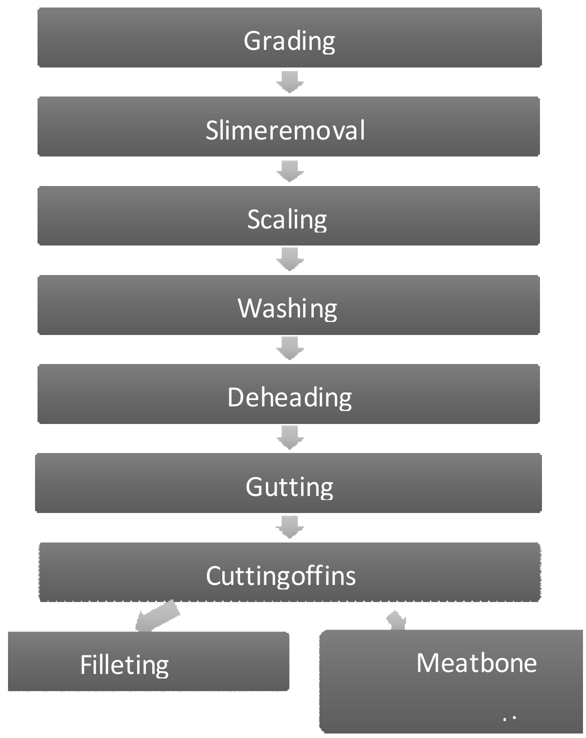

Fig. 1. Fish processing stages (Adapted from Ghaly *et al.*, 2013)

Grading of fish is one of the preliminary stages of processing based on species and size. Generally, two types of grading techniques are employed in processing industry, manual grading or grading by hand and automated grading. The automated grading system is more superior than the manual grading due to its high efficiency (Ramakrishnan, 2013).

Removal of slime is a step which reduces the qualitative degradation of fish as slime formulates a perfect environment for growth of pathogenic bacteria like *Pseudomonas* (Hebert, 2010). Also, during processing, anaerobic bacteria, with the help of sulfur compounds present in the slime, generates hydrogen sulfide (Granata, 2012). For that reason, a thorough washing is necessary to remove the slime from the surface of the fish.

Scaling is one of the major steps in lowering bacterial proliferation in fish during refrigerated and cold storage. Generally, the process is much more labour intensive, but recent day developments of descaling machine can perform the task easily at faster rate (Ringo *et al.*, 2010).

The main objective of washing is to remove bacterial load and clean the fish for further processing operations. In processing industries, washing can be done in a vertical drum or horizontal drum. Generally, chlorinated potable water is used for washing, and the process does not cause any physical loss to the fish (Mahawanich, 2008).

Many researchers like Waterman (2001) stated that the fish head constitutes around 20% of the total body weight of the fish and it is generally considered as inedible. Generally mechanical de-heading machine is used for de-heading of large-sized fishes.

One of the most potential processes to reduce the microbial content of fish is gutting. Also, it helps in retention of the qualitative parameters during processing. Gutting is a process of removing the internal organs of the fish, which is a main source of microbial growth.

Fins of fish are removed by two ways; either manually by using knives or by using machinal devices like rotating drums knives (Listrat *et al.*, 2016). Fish fins make up between 1% and 2% of the total weight of the fish (Arvanitoyannis and Kassaveti, 2008).

Only the dorsal and abdominal muscles are present in fish fillets. The processing of fillets can be manual or mechanical. Small freshwater fish enterprises employ manual filleting, and processing marine fish uses mechanical filleting. During filleting, between 30% to 50% of the meat is often released along with the bones. Since meat is lost more frequently in smaller fish, minced fish meat is becoming more popular (Ghaly *et al.*, 2013).

Fish processing waste

The fish production in India is estimated to be 14.73 million metric tons (FAO, 2022) in the financial year of 2020-21, out of which inland fisheries sector contributes 11.25 million metric tons and the rest 3.48 million metric tons of production is contributed by marine fisheries. Presently, India contributes 7.96% of global fisheries production, which makes India as the 3rd largest fish-producing country in the world. Fish production has shown a rapid increase over time (Fig. 2), and fisheries play a major role in national economy of India and contribute to foreigne xchange.

Fish processing industry regularly releases a large amount of wastes in terms of solid discards and also in the form of wastewater. According to Gustavsson *et al.* (2011), an estimated 1.3 billion tons or roughly one-third of the food produced worldwide each year is lost or squandered. In fish processing industry, all the harvested species are not properly utilized as food. Customers only favour a few specific types of seafood. Due to intrinsic issues with undesirable colour, smaller size, and high fat content, a sizeable amount of the whole harvest is thus wasted or used inefficiently. As a result, a large amount of catch is referred to as by-catch, which is nothing but a group of non-targeted fish species. Generally, in case of seafood industries, freezing, chilling, smoking, drying, fermenting, marinading are the frontline

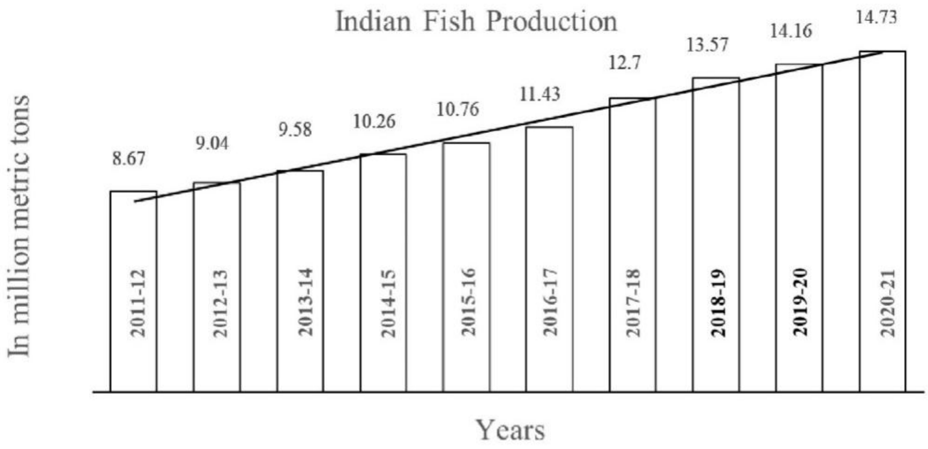

Fig. 2. Year wise production data of fisheries, India

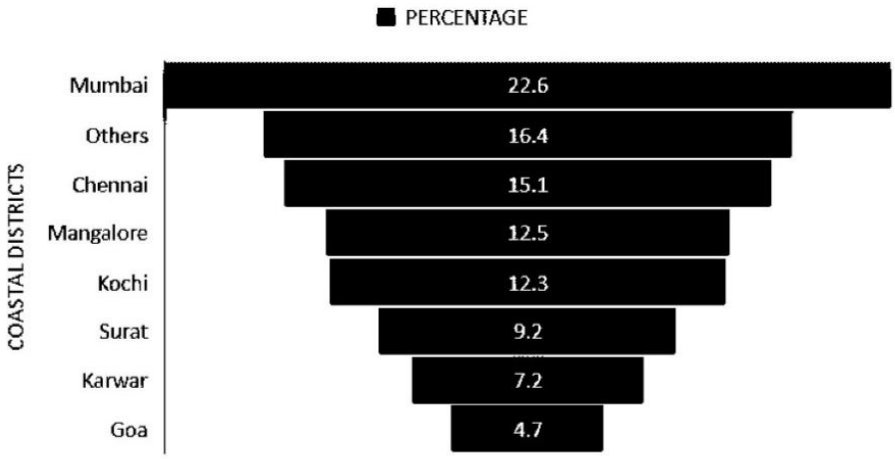

Fig. 3. Fish waste producing major coastal districts in India (Adapted from Ahmad and Bhuimbar, 2019)

operations which process 80% of the total harvested fish species (Venugopal, 2021). However, pre-processing procedures such as grading, scaling, gutting, filleting, and washing produce a sizable amount of solid waste and wastewater as effluents. Chandrasekharan (2015) informed that a large quantity of shellfish waste accounting to 80,000 metric tons is generated in India annually.

The coastal cities of India provide a large volume of fish processing discarded annually. The major coastal cities contributing to the overall fish waste production in India includes Mumbai, Chennai, Mangalore, Kochi, Surat, Karwar and Goa, contributing 22.6%, 15.1%, 12.5%, 12.3%, 9.2%, 7.2% and 4.7%, respectively (Fig. 3). These wastes are utilized for larger spectrum of applications like production of fishmeal, fish oil, collagen, chitin-chitosan, other bioactive peptides etc.

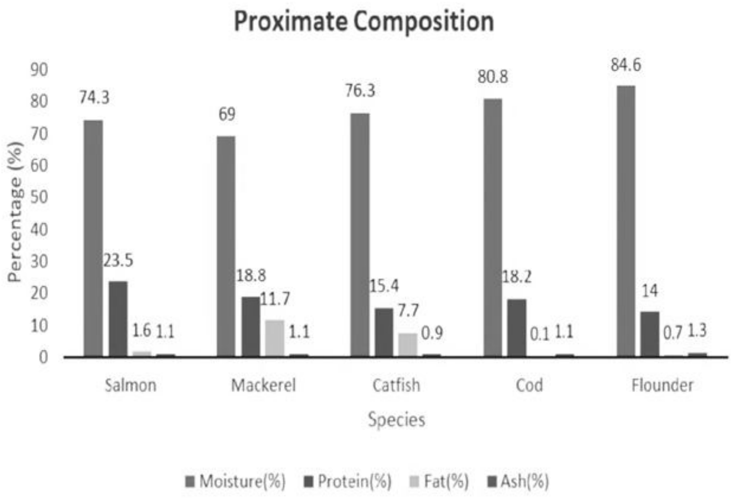

Fig. 4. Proximate composition of different fish species (Adapted from Suvanich *et al.*, 2006)

Composition of fish waste: Species, type, size, sex, age, and nutritional profile is the basic factors by which the composition of fish varies significantly. Generally, fish contains 15-30% protein content, 0-25% fat content and 50-70% moisture content, respectively (Arana, 2012). Also, Suvanich *et al.* (2006) reported the proximate composition of different fishes like, catfish, cod, flounder, mackerel and salmon vary according to species type (Fig. 4).

Solid waste of fish comprises of head, skin, scale, tail, fins, guts and frames. The proximate composition of fish wastes comprises of essential nutrients like protein, moisture, fat, ash and other essential minerals which are very much useful for further processing (Table 1).

Outputs of different fish processing industries: Generally, fish waste comprises of head, bones, scales, fins, guts and other debris and large amount of wastewater. The common outputs of different processing industries are shown in Table 2.

Introspection of fish processing waste

Nutrient losses through processing waste: Fish is a nutritionally enriched staple food item which contains essential amino acids, fatty acids, vitamins and minerals (James, 2013; Venugopal and Gopakumar, 2017). Jamieson *et al.* (2017) reported the average content of protein, fat and ash in fish processing waste is 57.92±5.26%, 19.10±6.06% and 21.79±3.52%, respectively, which is reflected in Table 1. On

Table 1. Composition of fish processing waste (Venugopal, 2021)

Sl.No.	Nutrient	Fish waste (dry weight basis)
1	Crude protein (%)	57.92±5.26
2	Fat (%)	19.10±6.06
3	Crude fiber (%)	1.19±1.21
4	Ash (%)	21.79±3.52
5	Calcium (%)	5.80±1.35
6	Phosphorus (%)	2.04±0.64
7	Potassium (%)	0.68±0.11
8	Magnesium (%)	0.17±0.04
9	Sodium (%)	0.61±0.08

Table 2. Wastes generated from different fish processing industries (Adapted Ghaly *et al.*,2013)

Industry type	Processing operations	Input (kg)	Output	
			Wastewater (m^3)	Solid waste (kg)
Fish canning industry	Canning	1000	15	Head: 250; Bone: 100-150
	Unloading fish for canning	1000	2-5	-
	Precooking of fish to be canned	1000	0.07-0.27	Inedible parts: 150
	Nobbing and packing	1000	0.2-0.9	Head and entrails: 150; Bone and meat: 100-150
	Draining of cans with precooked fish	1000	0.1-0.2	-
	Filling sauce	1000	-	Oil and sauce spillage occurs
	Can sealing	1000	-	-
	Can washing	1000	0.04	-
	Autoclaving of cans	1000	3-7	-
Fish production industry	Oily fish filleting	1000	5-8	400-450
	White fish filleting	1000	5-11	Skin: 40-50; Bone: 240-340; Head: 210-250
	Thawing of frozen fish	1000	5	-
	Washing and removal of ice	1000	1	0-20
	Grinding	1000	0.3-0.4	0-20
	Whitefish scaling	1000	10-15	Scale: 20-40
	De-heading	1000	1	Head and Debris: 270-320
	Filleting of de-headed fish (white)	1000	1-3	Frame: 200-300
	Oily fish filleting (un-gutted)	1000	1-2	Head, gut, frame, tail: 400
	White fish skinning	1000	0.2-0.6	Skin: 40
	Oily fish skinning	1000	0.2-0.9	Skin: 40
	Trimming and cutting (whitefish)	1000	0.1	-
	Packaging	1000	-	-
	Freezing and storage	1000	-	-
	Handling and storage	1000	-	-
	Fish unloading	1000	2-5	-
Fishmeal production industry	Fishmeal and fish oil	1000	-	-
	Cooking of fish	1000	-	-
	Processing cooked fish	1000	Water: 750 kg; Pressing cake: 100 dry matter Oil: 150 kg	
	Drying of press cake	1000	-	-
	Polishing fish oil	1000	0.05-0.1	-
	Evaporation of stickwater	1000	-	Concentrated stickwater: 250; Dry matter: 50

the other hand, a head waste of shrimp species comprises of 65% protein, 21% ash and 18% chitin, according to Yan and Chen (2015). The total suspended solids (TSS), fats, oils, grease, pigments, and minerals content are the distinguishing characteristics of effluents from the processing of fish. The TSS consists of proteinous material in soluble, colloidal, or particulate state. TSS, fat, chemical oxygen demand (COD), and biochemical oxygen demand (BOD) were all present in tuna processing effluents at concentrations of 1,570, 450, 11,100, and 6,600 mg/g, respectively (Achour *et al.*, 2000). Thus, the nutrient losses are caused by processing effluents as well as solid waste and by-catch.

Environmental impact of fish processing waste: Fish processing industry comprises large amount of solid waste, by-catch and wastewater which makes it a high potential to cause environmental hazards. A large amount of by catch is disposed of annually in the ocean by the processing industries, which causes a reduced oxygen level at sea. The reduction of oxygen level is detrimental for the survival of other valuable fish species (US EPA, 2017). On the other hand, solid fish processing wastes are disposed as landfills. Two major techniques are widely used for solid waste, one is composting, and the other one is ensilage of wastes. Though these techniques have some advantages over fish processing wastes, still it has some limitations like high processing cost, longer time to process and emission of volatile substances. In landfilling process, the decomposition of solid wastes can generate environmentally detrimental methane, hydrogen sulfide and ammonia gases (Xu *et al.*, 2018). According to Gao *et al.* (2018), the landfilling process can cause much higher disruption of climatic conditions than other waste removal processes. The processing wastewater or effluent has a higher amount of TSS levels, which can directly alter the BOD and COD levels of the aquatic environment. The change in the aquatic environment can cause several problems like eutrophication, algal bloom, scarcity of drinking water, natural habitat destruction, disease outbreak and many more (Hall, 2011).

Promotion of sustainable processing using fish wastes: In general context, sustainable fish processing helps to increase the productivity in processing sector by utilization of the wastes derived during the process. To reduce environmental impact due to fish processing, an effective and improved waste utilization technique is essential (López-Pedrouso *et al.*, 2020). To overcome environmental issue and nutritional losses, some measures like solid waste and effluent treatment, waste valorization and selective trawling can be used effectively. Reducing the environmental risks, conserving water, isolating substances with high commercial value, and boosting the economy are the main benefits of waste treatment.

Fish processing waste disposal processes

Fish waste has a high organic content, making disposal expensive. Most of the processed solid waste is disposed of rigidly using the procedures that are outlined below for (i) landfilling, (ii) incineration, and (iii) disposal or dumping in water bodies.

Land-filling: According to Venugopal (2021), aerobic bacteria are generally used in this process of waste disposal, which converts the organic matter into value-added products. Well-designed landfill operations are crucial to overcoming the effects of hazardous gases and minimizing their effects. Additionally, the usage of landfills for waste disposal greatly increases greenhouse gas emissions.

Incineration: An approved waste management technique called incineration involves burning fish waste in a particular combustion chamber with fuel to reach the right temperature. Finally, the result of this method is ash, which may be landfilled. Indirect heat recovery occurs during this process when heat is transferred into hot water or steam. Since setting up an incinerator to treat fish waste, which often has high moisture, low energy content, and excess chloride that impacts the process, is expensive, this strategy is not economically viable (Venugopal, 2021).

Dumping: One of the oldest methods of eliminating fish waste involves simply dumping massive amounts of waste into water, such as the sea and ocean, which has a detrimental effect on the health of the marine ecosystem. Multiple pollution hazards associated with ocean dumping include reduced oxygen levels at the ocean floor, aquatic organism burial or suffocation, and the development of pathogenic illnesses from putrefying organic debris (Venugopal, 2021).

Bioconversion of fish processing waste

The cycle of bioconversion reactions is used to first separate food components from their substrates. By using the right methods, the separated components can be recovered and purified. There are two main bioconversion processes that have been identified; they either use externally introduced enzymes or microorganisms. These aid in separating the parts from the food matrices. The conversion of biomass of the food's components occurs as a result of microbial fermentation of the waste, which leads to the production of hydrolytic enzymes. On the other hand, exogenous enzymes result in a direct release of nutrients from the food matrix. Fermentation has been performed with a wide range of microorganisms, primarily lactic acid bacteria (LAB). In this regard, using algae is an innovative strategy. The bioconversion caused by algae not only aids in the treatment of wastewater but also in the creation of nutrient-rich biomass, which has a range of uses.

Microorganism-assisted bioconversion: Fermentation is the word for microorganism-assisted biotransformation, which is secure, eco-friendly, and energy efficient. Live microorganisms (bacteria, fungi, or microalgae) are used in the process to transform raw materials into finished goods with highly adaptable properties. According to Anihouvi *et al.* (2012), LAB fermentation has been utilized as a common technique for the preparation of fermented fish and fishery products. Some parameters like organism type,

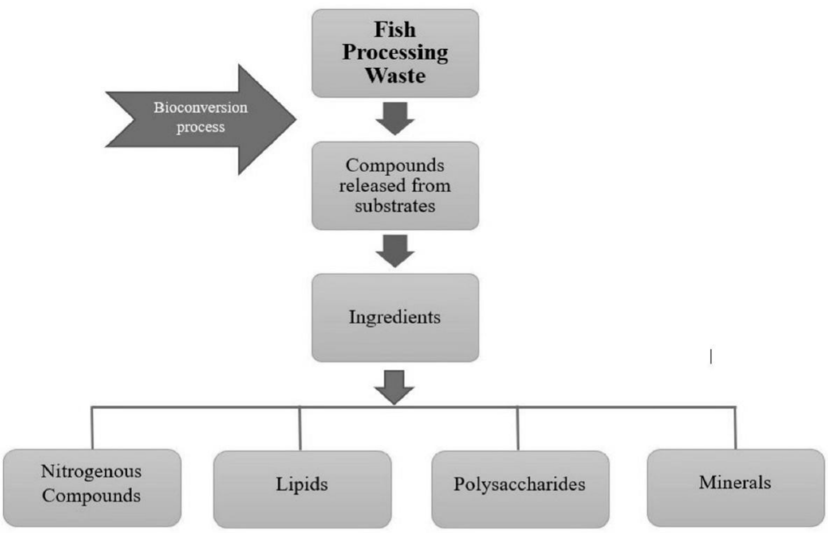

Fig. 5. Schematic diagram of bioconversion of fish processing waste (Adapted from Venugopal, 2021)

inoculum quantity, starting pH, and pH obtained during fermentation reflect the efficacy of fermentation. Low pH is produced by the lactic acid during the breakdown of sugar, which in turn inhibits the growth of microorganisms that cause spoilage and increases the activity of acid protease enzymes. Acid proteases then act best on the proteins in seafood, many of which are still bound to chitin and lipids. The use of bacteria and their aggregates in bioremediation is acknowledged as an effective, low-cost green technique. A prospective method of isolating and using substances with biotechnological potential is also made available through the technology of microbial conversion (Wang *et al.*, 2019). Aquafeed and fertilizer production, in addition to the bioremediation of waste from the preparation of seafood, are all excellent uses for microbe-assisted bioconversions. When fermentation is used on fish by-products, it yields high-quality protein hydrolysates and oil as well as antioxidant chemicals (Marti-Quijal *et al.*, 2020). Fermentation transformed the solid waste into a significant nutrient fertilizer with a nitrogen level as much as 12%. (Wang *et al.*, 2019). Effluents from the processing of seafood can be treated by microorganisms in reaction systems such activated sludge, aerobic lagoons, trickling filters, and rotating disc contactors.

Enzyme mediated bioconversion: Waste management has a lot of possibilities with enzyme processing. Enzymes can assist in the creation of novel chemicals, reduce the risks associated with traditional chemical transformations for the elimination of food waste-related environmental issues, and serve as analytical tools for the evaluation of food quality. Enzymes can be utilized exclusively to improve current seafood processing technologies or as supplementary processing aids in conventional processes. The major advantages of using enzymatic technology are less costly processing, conservation of product safety, low energy consumption etc. (Fernandes, 2016; Yang and Yan, 2018). Proteases, glycoside hydrolases, lipases, transglutaminases, and other enzymes are developing as specific, energy-efficient, and easily controllable enzymatic procedures for the processing of seafood (Shah *et al.*, 2016; Huang *et al.*, 2017).

Modern biotransformation: Microalgae has great potential for transforming fish processing waste into biomass rich in bioactive chemicals (Das, 2015). In order to produce microalgae as single cell protein, comparable volumes of effluents from the seafood sector could be

Table 3. Microorganism-assisted bioconversion of fish processing wastes

Type of waste	Product	Microorganism	Reference
Fish waste	Liquid fertilizer	Mixed microorganisms	Dao and Kim, 2011
Tuna waste	Aquafeed	*Lactobacillus plantarum*;	Hena *et al.*, 2009
	Lipase	*Bacillus licheniformis*	
Tuna condensate	Glutamic acid	*Staphylococcus epidermidis*	Esakkiraj *et al.*, 2010
Fish discards	Peptones	*Lactobacillus futsaii*	Sanchart *et al.*, 2018
Cod by-products	Oil	lactic acid bacteria	Vazquez *et al.*, 2020
Shrimp waste	Chitin, protein	Proteolysis	Dumay *et al.*, 2004
hydrolysate		*Lactobacillus acidophilus*	Duan *et al.*, 2012
Shrimp head	Antioxidant	*Bacillus licheniformis*	Mao *et al.*, 2017
Crab shell	Chitin	*L. paracasei*	Jung *et al.*, 2007
Shell waste	Astaxanthin	Fermentation	Routray *et al.*, 2019
Shrimp shell waste	Chitin	*Pseudomonas aeruginosa*	Ghorbel-Bellaaj *et al.*, 2011
Seafood effluents	Single cell protein	Microalgae	Shahid *et al.*, 2020

handled (de Farias and Barbera, 2018). Due to their quick growth and high lipid content, microalgae have the main benefit of producing third generation biofuel (Shuba and Kifle, 2018; Koyande *et al.*, 2019). Biodiesel is distinguished by having fewer emissions of toxic air pollutants, carbon dioxide, and sulphur dioxide when compared to petroleum diesel. Single cell protein oil makes a good candidate for biofuel. So, oleaginous microbe cultivation may be a fruitful strategy for valuing inexpensive organic waste for energy production (Cho and Park, 2018). Thus, effluents from seafood waste can be a promising alternative feedstock for the environmentally friendly production of biodiesel and biogas (Jayasinghe and Hawboldt, 2012).

Recovery of functional components from fish processing waste

The waste products from fish processing industries are a rich source of nitrogenous compounds like protein, collagen, enzymes, lipid, polysaccharide components and essential minerals. By combining the various bioconversion processes, these can be recovered (Table 4).

Recovery of nitrogenous compounds: Fish processing waste have a maximum protein

Table 4. Major functional components derived from fish processing wastes (Adapted from Venugopal, 2021)

Type of fish	Compound type	Derived components
Finfish	Nitrogenous compounds	• Protein, • Gelatin, • Collagen, • Protein hydrolysates • Bioactive peptides • Enzymes (Proteases, Collagenases, Transglutaminases, Chitinases, β-1,3-Glucanase, β-Galactosidase, Lysozyme, Catalase, Glutathione, Peroxidase)
Shellfish	Nitrogenous compounds	• Protein, • Gelatin, • Collagen, • Protein hydrolysates • Bioactive peptides • Enzymes (Lysozyme from crab, scallop)
Finfish	Essential minerals	• Calcium • Phosphopeptides • Hydroxyapatite
Shellfish	Essential minerals	• Calcium carbonate • Calcium lactate • Calcium acetate
Finfish	Lipids	• PUFA rich oil • Squalene, Squalamine
Shellfish	Lipids	• Carotenoids • PUFA rich oil • Astaxanthin • B-carotene

Table 4., Cont. ...

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Type of fish	Compound type	Derived components
Finfish	Polysaccharide compounds	• Hyaluronic acid • Glycosaminoglycan • Chondroitin • Dermatan sulfate
Shellfish	Polysaccharide compounds	• Chitin, Chitosan, Chitosan derivatives • Glucosamine • Oligosaccharides

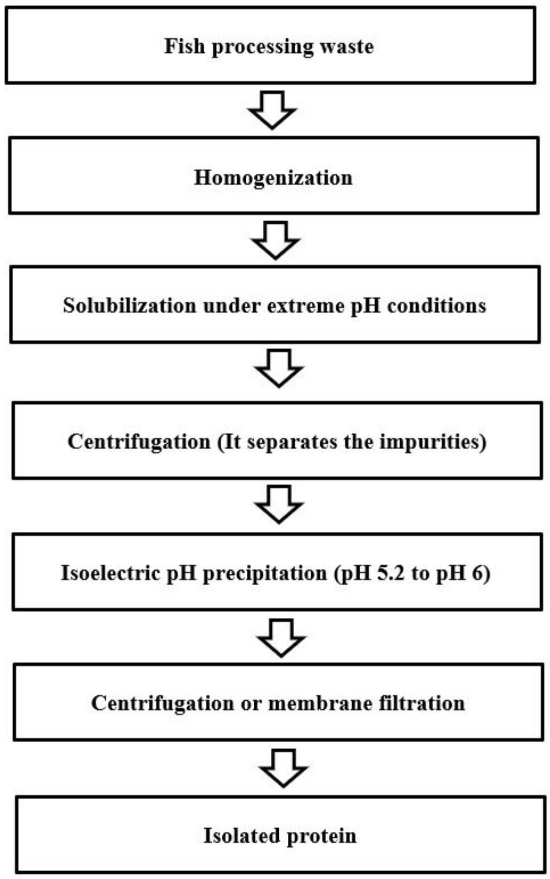

Fig. 6. Protein recovery from fish waste by isoelectric solubilization precipitation (Adapted from Hultin *et al.*, 2005)

content of roughly 60%, which can be retrieved while keeping the majority of their natural qualities. The recovery of myofibrillar protein from several finfish and shellfish waste by applying isoelectric solubilization precipitation technique has been suggested by Sasidharan and Venugopal (2020) (Fig. 6).

Apart from structural proteins, collagen and collagen residues are present in large numbers in fish wastes. Silver carp bone and skin residues that emerged during the ISP process contained collagen, which was recovered. Type I collagen was defined as isolated collagen that still had its triple-helical structure. The collagen found in the skins and bones of many marine and freshwater fisheries sources is used to make gelatin, which has excellent gelling qualities.

Big eye tuna skin gelatin extract included glycine, up to 32% of the total amino acids, and hydroxyproline along with proline and alanine. Newtonian and shear thickening properties of the gelatin were discovered through rheological investigations. The production of functional foods, nutraceuticals, and biomedical applications may benefit from the use of tuna gelatin (Dara *et al.*, 2020). Transglutaminases, lipases, phospholipases, chitinases, -1, 3-glucanases, carrageenases, and other enzymes can be found in the viscera, liver, and head of seafood (Murthy *et al.*, 2018). (Table 5)

Recovery of polysaccharide compounds: Dry squid skeletal pen and krill shells have a lower chitin level of 40%, but the dry shell discards of crab, shrimp, and lobster may have up to 70% chitin. Three procedures are used in the commercial extraction of chitin from crab and shrimp shells: demineralizing dried and ground-up shells with diluted hydrochloric acid; deproteinizing with diluted alkali; and decolorizing, washing, and drying. Utilizing 30 to 60% (w/v) sodium or potassium hydroxide at 80-140°C, chitin is deacetylated to yield chitosan. Chitin yields around 25% of dry shell, whereas shrimp chitosan yields roughly 77% of crude chitin (Dima *et al.*, 2017).

Recovery of mineral based components: Minerals are abundant in fish wastes, especially in the frames. The principal component of bone is minerals (about 70%), additionally, collagen, a few types of carbohydrates, and lipids are also present too. Biomedical sciences are successfully utilizing the bone implant components like hydroxyapatite and calcium phosphate. Animal studies have demonstrated that calcium is bioavailable and can thus boost growth, proposing that it can be used as a calcium supplement (Tang *et al.*, 2018). Salmon frames are hydrolysed by a combination of commercial proteolytic enzymes followed by centrifugation that finally resulted a bone fraction (62% ash), mostly containing a significant amount of copper, iron, selenium, zinc, and the trace minerals calcium, phosphorus, and magnesium (Liaset *et al.*, 2003).

Recovery of lipid: Fish processing waste is a good source of oil, especially the livers of some important finfish species like tuna, salmon, cod

Table 5. Enzymes generated from fish processing wastes (Adapted from Venugopal, 2016)

Enzymes	Fish waste resources
Proteases (pepsin, trypsin, chymotrypsin, collagenases, acid and alkaline proteinases, cathepsins, peptidases	Seafood processing discards (finfish intestines, shrimp heads
Lipases	Discards of Atlantic cod, seal, salmon, sardine, Indian mackerel, red sea bream.
Chitinases	Shellfish, squid liver, octopus
Amylase	Abalone
β-1,3-glucanase β- galactosidsase	Abalone, scallop, tilapia, sea cucumber
Lysozyme	Arctic scallop shell, crab shell
Catalase, glutathione peroxidase	Marine mussel and other organisms
Transglutaminases	Various fishery sources

(Falch *et al.*, 2006). Traditionally, fish oil is derived by using the wet reduction method, which involves some conventional processes like cooking, crushing, and purification. It results in two components, the press liquor which contains high amount of proteins which is used in feeding of livestock, and the crude oil which is further purified via alkali purification, deodorization, carbon treatment and anti-oxidant stabilization (Venugopal, 2008). Fish viscera is a significant source of lipids as it contains 19-21% of the total lipids.

Conclusions

In India, fish processing is one of the primary food formulating industries. Processing generally includes some stages like stunning, grading, removing slime, de-heading, washing, cutting of fins, meat bone separation, scaling, gutting, steaks, and fillets. A significant amount of trash is produced during these steps. The paper highlighted the significant issues caused by wastes and effluents produced during industrial fish processing. The discards and effluents cause environmental damage as well as significant losses of nutrients and other vital substances. The issues can be solved via microorganism and enzyme-assisted bioconversion processes. Unlike other chemical conventional waste removal processes, bioconversion technique is eco-friendly, cost-effective and safe. Microalgae-based biotransformation processes are gaining popularity as environmentally friendly and cost-effective methods of recovering biologically active substances and fuels. Microalgae are a viable platform for the recycling of fish processing waste and the conversion of waste into energy because of their remarkable qualities, including their rapid growth, their capacity for photosynthetic activity, and the nutrient-rich nature of their cells.

Conflict of interest: Authors have no conflict of interest in this study.

Author's contribution: AB: Involved in investigation, design, data generation, and preparing the original manuscript; SC: Engaged in conceptualization, data curation, supervision and final editing; AI, PM. SN: Involved in final checking and editing.

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Received- 19.10.2022, Accepted- 26.11.2022, Published- 01.12.2022 (Print)

Section Editor: Dr. D. Kamilya, Member, Editorial Board