Fish Waste and By-Product Utilization: A Circular Economy

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Abstract Significant increase in population growth across the globe followed by the rapid rise in industrialization and urbanization has augmented aquaculture production; consequently, the amount of fish waste generated has also seen a remarkable rise around the globe. The management of waste is one of the main problems that have a great effect on the environment. The utilization of fish waste and fish by-products permits the waste reduction that else would lead to the pollution of both the terrestrial and aquatic ecosystems in the future. The considerable stress of the fishery wastes on the ecosystem puts forward the importance of using it as a potential source compound that helps to promote good health. The nutritive value of fish waste products is almost similar to the edible parts of fish. Collagen, gelatin, bioactive peptides, protein hydrolysates, enzymes, anti-microbial peptides, pigments, chitosan, chitin, lipids, and minerals that have high nutritional value, good flavor, and are suitable for storage can be generated by re-processing the fish waste. The use of this new biological source for generation of the compounds having high value will also prove beneficial for the sustainable use of biotic sources. Utilization of fish by-products symbolizes an important tool in lowering the problem of hunger and food shortage in developing countries. In addition to this, the multifariousness of the productive chains promotes the generation of employment opportunities and as a result, turns out to be advantageous both for the environment and for the upliftment of the socio-economic conditions of human society. The utilization of fish wastes and fishery by-products will also help in improving the economy of fish-processing industries.

Keywords Economy · Fish-processing · Food shortage · Fishery wastes · Sustainable use

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1 Introduction

Fish farming for commercial purposes such as food products is known as aquaculture production. It includes the rearing of fish in tanks or any other enclosures on a commercial scale, generally for the procurement of food. The target of aquaculture management is to increase the output production. The aquaculture sector has shown a fast expansion in recent years as compared to any other livestock sector. This sector has depicted exponential growth over the last few decades as it serves as a fundamental source for fulfilling the rising demand for animal protein, but with the traditional linear model, aquaculture may become unsustainable. This sector generates huge quantities of wastes that have adverse impact on environment. Such effects may be lessened by the utilization of these waste products with implementation of circular economy strategies (Dauda et al. 2019). The circular economy model suggests that wastes generated from the fisheries sector have applicability in agriculture, horticulture, pharmacology, food, and feed industries. Such approaches valorize the fish waste products and reduce the effect on the environment and provide additional benefits.

2 Fish Productivity

At present, the fisheries production is approximately 160 million tonnes across the globe. Aquaculture production is dependent on net primary productivity, the way this yield navigates through food chain network in an aquatic ecosystem and enters the human food chain (Iverson 1990). In 2002, 76% of the production in fisheries sector was used directly for consumption by humans, and the leftover 24% was used for the fish oil and fish meal production (FAO 2004). In 2004, out of the total 164 million tonnes of aquatic production at the global level, about 77% was from the marine ecosystem, and only 23% was contributed from the inland waters. Out of the total production, 32% of molluscs, and fish comes from the aquaculture sector, 66% was from capture production. With the rapid rise in aquaculture production, it has been estimated that by 2030, production from aquaculture will be very close to capture production (Brander 2007). According to the studies done by Jamu and Brummet (2004) and FAO (2011), it has been found that aquaculture received great importance on the global level due to food shortage problems.

Fish farming can be considered as an approach for the development of the economy and to mollify to economic development and mollifying poverty (Mwaijande and Lugendo 2015). Aquaculture production has great potential as it generates employment and establishes food security by providing highly nutritive proteins and other essential micronutrients of animal origin (FAO 2012). A report developed by FAO, in 2012 has also predicted that fish is the source of food for about 3 billion people across the world. Fish farming helps to improve the income of different communities and boost food security at the global level (Shava and Gunhidzirai 2017). In the past few years, the aquaculture industries are rapidly growing in the food industry sector across the globe (Tsani and Koundouri 2018). Production from the aquaculture sector even provides economic benefits to the society and thus forms an important pillar of the Blue Growth targets. Worldwide, 40% of the fish used for consumption by humans are obtained from commercial farms (Goldburg and Naylor 2005). Thus, the fisheries sector has an immense contribution to the economy of any country. In India, fish production has shown an increasing trend and in 2006, it has attained a record of 6.4 million tonnes (Ayyappan and Diwan 2006). According to their study, 1.1% of the total GDP is contributed by the fisheries sector, and India stands at fourth place in terms of total fish production all across the world. Sustainable Development Goals in its Agenda for the year 2030 has set aim for the contribution of fish production towards the nourishment of the world's population. Costello et al. (2020) concluded that 30% of the protein consumed across the globe is derived from edible fish.

Fish production for food has shown a significant increase during the last few years. The total fish trade across the globe increased from 8 billion US dollars in 1976 to 109 billion US dollars in 2010. In 2014, aquaculture production was recorded to be 3.4 million tons across the globe (FAO 2016). A remarkable rise in the growth of global fish supply was observed in the period between 1961 and 2016, and during this period, the average annual growth rate of the fisheries sector was 3.2%. A similar increase has been observed in the global fish consumption per capita, in which it was reported that in 1916, the consumption per capita was 9 kg, which rose to 20.2 kg in 2015 (FAO 2018). As a result, a dramatic rise in fish waste and by-products has been seen across the globe.

3 Fish By-Products

A substantial quantity of effluents such as feed waste, feces, medications, etc. is discharged from the fish production units, which have a serious impact on the environment. There is a growing need to integrate fish food production with a suitable action for the fish waste and by-products processing. It is need of time to manage fish waste in a better way to control the various environmental-related issues and for the commercial use of fish waste. Fish waste is used for the production of fertilizers, fish oil, and fish meal and some of the fish waste may be used as a feed in aquaculture production practices (Mo et al. 2018; Stevens et al. 2018). Fertilizers derived from the fish waste are suitable for organic farming, generally for the plants grown in gardens. Based on the kind of fish and processing level, 30–70% of the fish is considered as waste (Ahuja et al. 2020). Researchers in aquaculture field have evaluated that the huge amount of waste released from the fishery sector is thrown away which besides having a serious impact on the environment also leads to the loss of valuable commodities, which can be obtained from the fish waste. Production of fish waste has been validated as a pressing issue that has stimulated the research for finding out a feasible solution (Sardà et al. 2013). It has been evaluated that the

Fig. 1 Different fish tissues such as scales, air bladder, flesh, viscera, fins, operculum

different fish tissues such as gut, skin, ovaries, head, operculum, fin, liver, and viscera are disposed of and are categorized as fish waste (Fig. 1).

The composition and the quantity of fish waste vary with the fishing areas and thus the percentage of discarded material is not consistent (Davies et al. 2009). According to the report published by the FAO (2019); it has been estimated that every year approximately nine million tonnes of fish waste are discarded. Kandyliari et al. (2020) carried out a study to find out the percentage of waste products of the meager and gilthead sea bream. They found that the fish waste obtained from these fishes includes 5–9% bones, 2–3% scales, 5–7% intestines, 17–19% heads, 6–7% skin, and 1–2% trimmings. They calculated the nutritional value of such fish by-products and found it similar to the fish fillet.

During the fish filleting, only 30–50% of the meat is obtained while the 45% of the body of a fish includes 4–5% skin, 24–34% bones, and 21–25% head remains unutilized and is discarded (Ghaly et al. 2013). According to Mo et al. (2018), large quantities of fish waste are generated from fish processing industries and this constitutes about 25% of the total productivity. Huge quantities of the scales removed from the body of a fish are part of fish by-products and being less biodegradable their management is difficult and they become a problem for the environment. Waste generated from aquaculture varies that depends upon the fish species and region from where the fish is collected. Fish farms release huge amounts of organic waste and the management of this waste is the need of an hour as it poses a great risk to the environment. Appropriate technologies should be used for the management of fish waste.

In 2018, fishery production reached the volume of 210.9 million tonnes (FAO 2020), which in turn increased the productivity of huge amounts of fish waste and by-products. These fish wastes such as skin, bones, trimmings, head, and intestines are excellent sources of protein, calcium, and lipids. It has been found that fish waste contains approximately 49.22–57.92% protein content, 7.16–19.10% fat content, and 21.79–30.16% ash content (Vidotti et al. 2003; Abbey et al. 2017). Such wastes with good biochemical composition are dumped in the environment, and this leads to various environment-related issues.

Wastes derived from the aquaculture sector can be grouped into four different categories according to Dauda et al. (2019):

(a) Solid waste materials are derived from unconsumable part of the animal.
(b) Dissolved organic matter includes elements such as nitrogen and phosphorus.
(c) Dissolved chemical compounds.
(d) Pathogens.

Recent studies by Lee et al. (2019) have classified the fish wastes into two categories:

(a) Biological that includes the leftover food and fecal matter.
(b) Waste discharge consists of nitrates and organic waste.

Thus, it is imperative to use the fish by-products to obtain certain value-added products like minerals, chitin, enzymes, collagen, and polyunsaturated fatty acids, thus reducing the adverse impact of fish by-products on the environment and maximizing the economic benefits (Shahidi et al. 2019; Parvathy et al. 2018).

4 Utilization of Fish Waste

Various products can be processed out of the fish waste, which can contribute to the economic growth of any nation and even lessen the problems generated due to the accumulation of the fish waste. Composition of the by-products of fish is similar to fish fillet that is consumed as a food product. The fish by-products are an essential source of fatty acids, proteins, and minerals. Studies carried out by Kandyliari et al. (2020) had disclosed that revealed that head, viscera, and bones are significant sources of lipids and calcium, skin is the rich source of protein. Fish by-products are an important source of proteins and fatty acids, which are known to have antioxidant, anti-tumor, anti-hypertensive, and anti-bacterial activities. The use of fish by-products is procuring significant attention these days as different bio-compounds are extracted from such by-products as oil, enzymes, peptides, collagen, chitosan, biofuel, biogas, fertilizers, fish insulin, fish meal, and fish sauce. Valorization of various fish by-products has been depicted in Fig. 2.

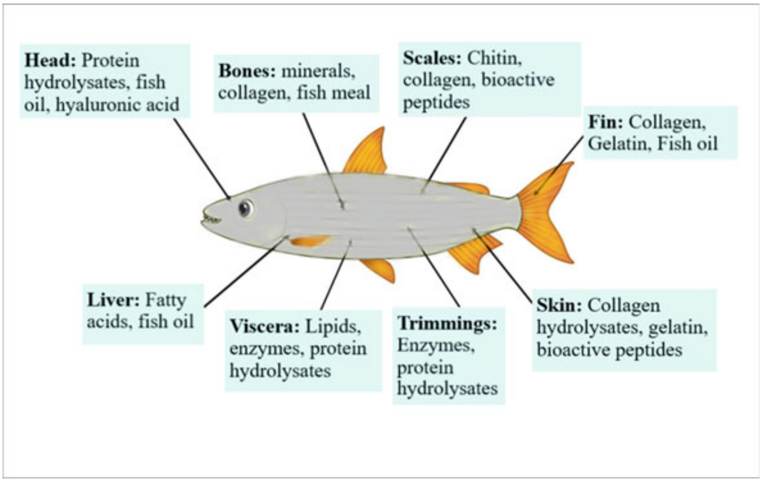

Fig. 2 Valorization of various fish by-products

4.1 Collagen

Collagen extraction from fish skin ameliorates usefulness of the byproducts derived from fish. Extraction of the collagen from the scales of fish has numerous applications in the medical sciences (Rodríguez et al. 2018). It has been used in various cosmetic products and medicines due to its property of decreased immunogenicity (Sionkowska et al. 2020). Based on structural features, Type 1 and Type 2 collagen are found in the fish, which have wide applications in the field of cosmetics and wound healing medicines (Karim and Bhat 2009). By weight, approximately, 30% collagen is present in the bones, skin, and fins of fish. Fish waste symbolizes the inexpensive and huge sources of collagen (Jafari et al. 2020). Nagai and Suzuki (2000) proposed that the bones, fins, and skin of fish are responsible for the extraction of 36–54% of collagen. Scales of the sardines are important sources of collagen (Belouafa et al. 2018). Scales of various species of fish such as *Pagrus major, Catla catla, Oreochromis nilotics, Hypophthalmichthys nobilis, Cirrhinus mrigala* (Ikoma et al. 2003; Fengxiang et al. 2011; Mahboob 2015) have been used for the collagen extraction.

4.2 Gelatin

Fish gelatin consists of both non-essential and essential building blocks of proteins; thus, it can be used in various food industries. In food sources, bovine and porcine gelatin acts as alternative source for fish gelatin. Gelatin obtained from fish waste can be utilized in bakeries, dairy, cosmetics, shampoos, photography, tablets, capsules, and syrups (Lin et al. 2017; Ishaq et al. 2020). Collagen present in the fish skin is an important source of gelatin production (Jamilah and Harvinder 2002). According to Ahmad et al. (2017); five different steps viz., cleaning, isolation, purification, concentration, and drying are used for converting fish waste to gelatin. Both the acid and alkali processes are involved in the hydrolyzation of collagen into gelatin. At acidic pH, gelatin is isolated from the skin of fish by hydrolyzation of collagen at acidic (Baziwane and He 2003). Because of the high concentration of collagen in the bones and skin of fish, the production of gelatin from the waste of the fish is done on extensive level these days (Alfaro et al. 2015).

4.3 Chitin

Fish waste especially the scales of the fish are excellent source of chitin and its derivatives. Chitin was isolated for the first time by Zaku et al. (2011) from the common carp scales. They dried, macerated, washed the scales with acid, rinsed them with de-mineralized water, and then de-proteinized. This way they obtained the chitin from the fish waste. Chitin and chitosan were obtained from the scales of a fish, *Tilapia nilotica* by Uawonggul and Ruksakulpiwat (2002) and Alcalde and Fonseca (2016). Approximately, 20% of the chitin was obtained from 50 gm of the scales of fish by them. Similarly, 45% chitin yield was obtained from *Chlorurus sordidus* by Rumengan et al. (2017). Chitin obtained from the waste of fish products was utilized in numerous fields such as nutraceuticals, pharmaceutics, bioremediation, and cosmetic industry. The chitosan derived from the *Papuyu* fish scales has been used for ameliorating process of removal of iron from groundwater (Irawan et al. 2018). Chitin finds its huge applications in the field of pharmaceutical industries as they have anti-bacterial, anti-oxidant, anti-cholestremic, and anti-thrombogenic properties. Several authors have also reported the antibacterial activities of chitosan (Zheng and Zhu 2003; Benhabiles et al. 2012). Chitosan is ideal for the storage of easily perishable commodities such as vegetables, meat, eggs, dairy products, and sea food as the films developed from the chitosan can form oxygen barriers (Coppola et al. 2021). Chitosan is isolated from the fish scale waste mainly by following three steps, i.e., deprotonation, demineralization, and deacetylation (Aichayawanich and Saengprapaitip 2019). Suresh et al. (2022) revealed that from the 100 gm of fish scale; 12% of the chitosan can be extracted. Deacetylation of the chitin using the chitin deacetylase produces chitosan (Santos et al. 2020).

4.4 Fish Oil

The volume of fish waste augments with an increase in the production of fish. In 2016, out of the fish oil produced in total, 26% was obtained from the waste products of the fish (Jackson and Newton 2016). Fish oil is obtained from the head, viscera, fins, tail, and skin of the fish. The viscera of the fish waste contains a considerable quantity of fat, oil, and proteins (Kudre et al. 2017). Yasin et al. (2021) extracted the fish oil from waste products of a fish, *Pangasius hypophthalmus* using the modified Soxhlet method. The nutrients present in the fish waste especially fatty acids increase its demand in the market. Various techniques are utilized for the extraction of fish oil from fish by-products and the selection of the technique for the fish oil extraction (Kerton et al. 2013; Bonilla-Méndez and Hoyos-Concha 2018). Khoddami et al. (2012) utilized the various organs of the fish, *Euthynnus affinis* for the extraction of oil. They concluded that the predominant fatty acids in the tuna wastes were stearic acid, docosahexaenoic acid, and oleic acid. According to their studies, the head of the tuna contains a suitable amount of omega-3 fatty acids, ratio of ω-3/ω-6, and lipid content so it is suitable for consumption by humans. Different methods utilized for the extraction of the fish oil from the waste products of the fish include Goldfisch, chloroform–methanol, Bligh and Dyer, and acid digestion (Shahidi 2003). Fish oil contains a long chain of fatty acids and can be used in the food and feed industry, nutraceuticals, and aquaculture. Fish oil has high value as it consists of essential polyunsaturated fatty acids viz., eicosapentaenoic acid, docosahexaenoic acid, and omega-3 fatty acids, which are advantageous for the health of humans (Khoddami et al. 2009). The omega-3 fatty acids are known to have positive impacts such as reducing blood pressure, symptoms of asthma, improving learning ability and the survival of a person suffering from cancer, prevent arrhythmias and atherosclerosis (Kim and Park 2006; Tawfik 2009). Extraction of the fish oil was done from the liver waste of ray species by Sellami et al. (2018) and the fatty acid profiling revealed that the unsaturated fatty acids were present in the major concentration in all the samples. Besides this, various carotenoids and phenolic compounds were also found in these oils that are known to have antioxidant activity. Inguglia et al. (2020) evaluated that the waste products of *Salmo salar* can be used to treat various pathogenic infections.

4.5 Biofuels

Biofuels can be used as an alternative to conventional energy sources as they are free from pollution and so are advantageous over conventional fossil fuels. Oil extracted from fish waste acts as a basic material for biodiesel production (Samat et al. 2018). Research studies have shown that more than 50% of the fish is transformed into fish waste. Extracted fish fat from the fish waste was subjected to saponification and then transesterification. This process resulted in the production of biodiesel (Girish et al. 2017). Results of studies done by Zhang et al. (2020) revealed that *insitu* transesterification of the waste of fish can be done for the production of biodiesel. Lin and Li (2009) suggested that the biodiesel extracted from the marine fish has high hydrogen and carbon content, low oxygen content, high heating value, and cetane index. They obtained a high yield (>97%) from the fish waste. The various physico-chemical parameters of biodiesel obtained from waste of *Tilapia* were evaluated by Martins et al. (2015), and it was found to have all the characteristics of good fuel. Moroccan fish oil waste was used as a raw material by Kara et al. (2018) for the production of biodiesel, and this fuel was found to be free from glycerol, and in accordance with international standards. Wastes of the fish can be utilized for the production of biodiesel as they are non-toxic and biodegradable. When compared with conventional fuel, biodiesel is less toxic and produces fewer amounts of carbon dioxide and other particulates. The efficiency of biofuels can be confirmed by the usage of various techniques such as gas chromatography-mass spectrometry (GCMS), Fourier-transform nuclear magnetic resonance (FT-NMR), and proton nuclear magnetic resonance (H-NMR) (Yuvaraj et al. 2019).

4.6 Enzymes

Enzymes have numerous applications and are utilized in agriculture, textile, pharmaceuticals, various other manufacturing units. Fish wastes are good sources of enzymes such as elastase, alkaline phosphatases, lipases, hyaluronidase, proteases, transglutaminases, acetylglucosaminidase, etc. Enzymes isolated from the wastes of the fish inhabiting cold waters are more useful as they work at low temperatures and thus save energy and provide protection to the food items (Venugopal 2016). Various proteolytic enzymes, viz., elastase, collagenase, and pepsin have been isolated from the viscera of fish. Gildberg (2004) utilized the process of autolysis for the isolation of pepsin from the fish silage. Generally, protease enzyme is found in fish waste. Fish viscera is the rich source of various enzymes, viz., hyaluronidase, chitinase, and alkaline phosphatase (Shahidi and Kamil 2001). Pepsin isolated from the viscera of fish is highly active under acidic conditions (Morrissey and Okado 2007). Sriket (2014) isolated collagenase enzyme from the muscles of *Scomber japonicas, Paralichthys olivaceous*, common carp, and rainbow trout. Myrnes and Johansen (1994) isolated the lysozyme from the waste of Arctic scallops, which was found to inhibit the growth of both the Gram negative and Gram positive bacteria (Guérard et al. 2005). Harikrishna et al. (2017) reported that the fish scale waste is used as a raw material for the alkaline protease production by *Bacillus altitudinis* GVC II. Pepsin described from the viscera of fish waste can be used as an alternative for the hog-derived pepsin (Kim and Dewapriya 2014).

4.7 Bioactive Peptides

Fish waste contains high-quality protein, thus representing an important source of biofunctional peptides. Peptides isolated from the fish wastes depict HIV protease inhibitory, anti-microbial, and calcium binding activity. Biopeptides and protein hydrolysates derived from the scales of seabream, the skin of pollack, bones, and scales of yellowtail are known to inhibit the action of the main component of renin-angiotension system under *invitro* conditions. Thus, it acts as a natural inhibitor and helps in the treatment of hypertension (Harnedy and FitzGerald 2012). Biopeptides produced by the process of protein hydrolysis of fish waste possess anti-oxidant activity, besides having various functional and nutritional activities (Tacias-Pascacio et al. 2021). Peptides derived from the skin waste of *Ctenopharyngodon idella* were found to have anti-oxidant properties (Cai et al. 2015). Vázquez et al. found that fish hydrolysates derived from the head, trimmings, and viscera of *Scophthalmusmaximus* have anti-hypertensive and anti-oxidant properties. Peptides derived from skin of *Magalapis cordyla* and *Otolithes ruber* reduce the peroxidation of polyunsaturated fatty acids (Kumar et al. 2012).

4.8 Fertilizers

Fertilizers can be manufactured from the fish waste, which are then used in the horticultural fields, and they help to ameliorate the quality of soil and plants. Fertilizers prepared from fish waste can be used in gardens, field crops, and vegetable production as they increase the nutrient content of the soil, decrease the incidence of diseases in plants and eliminate unwanted plants (Jayvardhan and Arvind 2020). Kusuma et al. (2019) prepared a compost by placing 2 kg of fish waste in a porous container having 15.08% of moisture content and kept it as such for 2 weeks. This fish waste was then mixed with the remaining fruits and vegetables and compost was prepared. They recorded high levels of carbon, nitrogen, potassium, and phosphorus in the compost made from fish waste. The results of the experiment carried out by Radziemska et al. (2019) revealed that compost made from fish waste is suitable for use in agricultural fields. They observed that compost made from fish waste increased the dry and fresh matter of the leaves of *Lactuca sativa*. Significant rise in concentration of different elements like nitrogen, potassium, calcium, sodium, and phosphorus was observed in the leaves of this plant. Ranasinghe et al. (2021) explained that liquid organic fertilizers can be produced by the hydrolysis of fish waste, which can be utilized in agricultural fields.

5 Role of Fish Waste in the Circular Economy Era

Every year, extraction of 90 billion tonnes of primary materials is done and only 9% material is recycled (UNEP 2019). This process upsets the ecological balance and has an adverse effect on climate, ecosystem, and the health of humans. By enhancing the utility of any resource and incorporating the circularity concept during the process of production and utilization, the circular economy elevates. A circular economy is pivotal in securing future prosperity and economic benefits. It is an alternative economic model that aims to reduce the waste to minimum levels by reusing and recycling the waste products. Across the globe, our economy is 8.6% circular and the remaining 91.4% is wasted according to the Circularity Gap Report, 2021. The main aim behind the circular economy is to design out the waste products and the environmental problems caused by them by keeping the products in use and aid in regenerating the natural systems. This involves the maintenance of the value of the products as far as possible by giving them back into the nature at the end of their utilization and this way helps in decreasing the waste generation. And thereby declines the over-use of raw materials, greenhouse gas (GHG) emission, and the loss of biodiversity. Management of fish waste in an efficient manner should be aligned with the concept of circular economy. Recycling and reusing of the fish waste into new products can lessen the dependence on virgin resources. The model of circular economy in aquaculture is based on re-utilization of fish waste and by-products, in which the outputs of one cycle become inputs for any another cycle. For example, processing of fish produces left over wastes such as scales, viscera, fins, gills, skin, trimmings, etc. These waste products generated from the fish processing can be used in feedstock, as a fertilizer for growing crops, and this way helps to support the other forms of biodiversity. This way the circular economy helps in the valorization of the fish waste and by-products that may otherwise cause various environmental problems. The principles of circular economy revolve around the reduction of waste, increase of efficiency and favoring of more sustainable ecosystems. As far as the perspective of circular economy is concerned, the reutilization of the products in the foodservice industry is considered as most popular in declining the waste (Tola et al. 2023).

The utility and maximum value of products are maintained in the circular economy by increasing the use of resources and extending the lifetime of any product. The main idea of circular economy is based on regenerative development, which means that the cycling of earth's resources restores and enhances the economy instead of depleting it. In aquaculture, the adoption of a circular economy addresses the problem of fish waste by the creation of value-added products from these waste products, thus contributing to the development of a healthy ecosystem and providing employment opportunities. The proper management of fish wastes by the use of a circular economy has a positive influence on the economy and reduces the generation of waste, thereby, protecting both the health and the environment (Fraga-Corral et al. 2022). The most efficacious approach to reusing the fisheries by-products and wastes is the recovery of important biomolecules such as gelatin, lipids, collagen, and pigments, which can be used in the food industry, pharmaceuticals, and cosmetics. The circular economy helps in the sustainable development and the maintenance of the resources and products for a long period of time and this way minimizes the generation of waste (Carus and Dammer 2018). According to the studies conducted by Angouria-Tsorochidou et al. (2021), the circular economy helps in the conservation of environment and alleviated poverty so as to ameliorate the well-being of individuals and significantly decline the risks posed by the fish waste for the environment. The main challenge behind the blue economy is to generate the power of products obtained from the sea, which can then be utilized as a raw material for various applications. Circular economy focuses on the preparation of value-added product from the waste so that it gets recycled and has no harmful effect on the environment. The waste generated from the different parts of the fish supply chain can be processed and utilized in the pharmaceutical units.

The circular economy focuses on expanding the rate of reuse of fish waste products and this way helps in the reduction of pressure on the various natural resources. As far as sea food is concerned, large amount of biomass is being lost through the discard or by-catch from aquaculture such as sludge, and by-products that are produced by the fish processing such as offal and trimmings. All these can be valorized and used for the generation of value-added products, production of food and feed generation for the pets. Awareness, communication, and interaction with the collaborators play a key role in development of circular economy as education and acceptance among the local people will increase the demand for the valorization of fish waste (Cooney et al. 2023). In general, the circular production system will have a great impact on the production efficiency and it will lessen the demand of natural resources and food production and all this will address the different goals of the United Nations Sustainable Development Programme and thereby contributing a lot to the food security and maintenance of the life on the Earth.

6 Conclusion

The fish by-product exploitation will be helpful in the sustainability of aquaculture. The valorization of fish waste, which is considered to be useless, is known to play a key role in resolving impact of waste on environment. The principle aim of fishery management is to convert the fish wastes and recover the significant product before their disposal. Conversion of the biodegradable fish waste into different bio compounds is the most effective method for the processing of fish waste. Fish waste finds its prominent use in cosmetics, pharmaceutical, and textile manufacturing units. Processing of fish waste products is essential for conservation of natural resources. Sustainable use of fishery waste expands the potential of the aquaculture sector by providing employment and thus generates income for the local communities. It is necessary to manage the fish wastes in a better way to overcome the environment-related issues and concomitantly ensure the use of by-products. For this, the government should build up several regulations and policies along with requisite infrastructure and facilities. The present paper illustrates the production process of different value-added products with several applications that can be extracted from fish wastes. The utilization and the minimization of the fish waste and its conversion into numerous useful products are beneficial both from an economic and environmental point of view. Fishery wastes have numerous uses, and this industry can play an important role in ameliorating the livelihoods, creation of employment, increasing the environmental sustainability, and this way it can contribute a lot in the economy of a nation (Mozumder et al. 2022).

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