Strategies to Reduce/Manage Fish Waste

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Abstract Recovery of fish waste has taken the priorities of industrialist and scientists, given its richness in high-value products. A better management of this marine resource could increase the profit margin and reduce environmental pollution. During last decade, fish wastes were used as raw material of some marine biopolymers such as chitin/chitosan and its derivatives, gelatin and collagen, mineral compound as hydroxyapatite, and vitamins. Thus, fish waste could transform into animal feed (fish meal or pet feed), fish silage, protein hydrolysates, bioactive peptide, omega-3, biodiesel/biogas, and soil fertilizer. However, their application is limited to the laboratory scale. This chapter will highlight fish waste as feedstock of marine compounds and different strategies to reduce and manage fish wastes. The best management of fish wastes could enhance a circular economy and zero marine waste; consequently, it could open new avenues for natural marine compounds.

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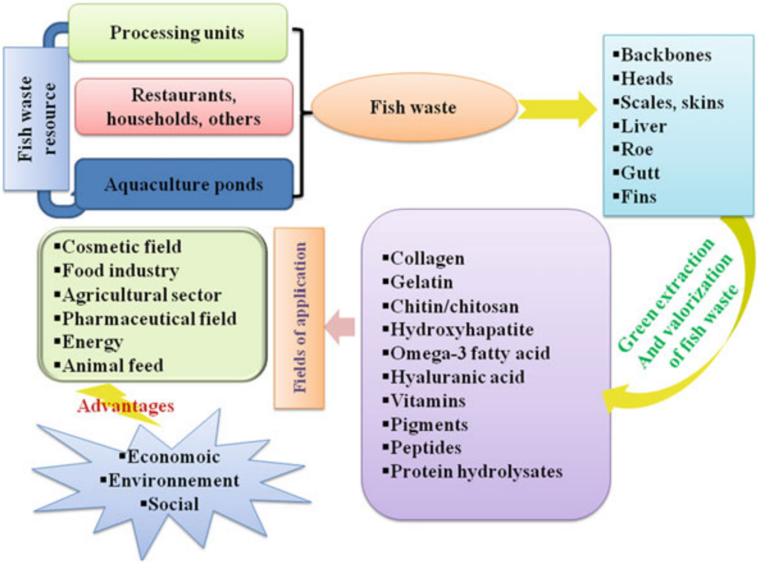
S. Maqsood et al. (eds.), *Fish Waste to Valuable Products*, Sustainable Materials and Technology, https://doi.org/10.1007/978-981-99-8593-7_21

Graphical abstract for fish waste management



Keywords Fish waste · Recovery · Chitin/chitosan · Omega-3 · Collagen · Hydroxyapatite · Gelatin

1 Introduction

With COVID-19, the population is oriented towards the consumption of marine products. Certainly, this high consumption needs supply food demand. In the other side, and despite its primary role in the international and national economy, the fishing sector generates marine litter from processing units, aquaculture, restaurants, households, others. The sustainable management of fish litter produced from seafood processing becomes one of the major worldwide environmental issue. Fish waste could define as various fish species or by-catch products without commercial value and dwarfed or deteriorated commercial species (Caruso 2016). All over the world, the flesh is the most valuable part of the fish. However, after processing, scales, fins, viscera, heads, skeletons, and others are considered fish waste or the non-edible part of the fish. Those parts are less valuable economically and account for approximately 40–60% of the fish weight. The non-valorization of these marine by-products and by-catch could increase the pollution because they contain high contents of organic matter with a very high degradation rate, which influences marine ecosystems and generates greenhouse gas emissions, and offensive odors.

Internationally, half of the catches are consumed directly by humans. Nevertheless, the other half covers by-catch and filleting waste, which is little or no valued, like heads and abdominal parts, which are not edible. Morocco is characterized with vast coastal area, and the fishing sector occupies a primary place in the national economy. In 2022, the Moroccan kingdom provided significant leadership in Africa with a national fish production of 1.55 million tons, which is around 1% of world fish production. The sector mobilizes 19,064 operational units, including 334 active in offshore fishing, 1,800 in coastal fishing and 17,130 in artisanal fishing. The various activities carried out in this sector are freezing, canning, semi-canning, packaging of fresh fish, packaging of shellfish, fish meal, oil, shelling of shrimp, storage, and others. In addition, due to its inland water resources, Morocco is recognized in aquaculture as producer and the leader exporter among the North African countries (Hülya and Tahir 2021). Nationally, despite the significant wealth and the important variety of fishery products and sector activities, the recovery of fish by-products or by-catch is almost rare, and it is related to fishmeal and oil, however, those activities consumed a lot of energy, and exhausted marine resources by producing low-quality of the obtained product.

Fish processing industries, aquaculture ponds, restaurants, and households generate large amounts of solid and liquid wastes; that cause environmental pollution. However, better valorization of those fish waste could produce valuable high products such as protein, lipid fractions, minerals, enzymes, peptides, polysaccharides, biogas, biodiesel, omega-3, animal feed, fertilizer, etc. The principal aim of this present chapter is to highlight the necessary strategies to manage or reduce the fish waste impact on the environment.

2 Fish Waste: From Marine Litter to Valuable Compounds

2.1 Fish Waste in Worldwide

The increase in the world's population was followed by an increase in demand for healthy foods, especially seafood, which is the top recommended food for meeting nutritional needs. Seafood can be divided into 25 taxonomic groups (Table 1), and these aquatic groups can be found in 21 fishing areas (Fisheries 2022). Seafood farming is considered among the fastest-growing food sector over the last two decades (Clawson et al. 2022). In addition, this naturally occurring product has different benefits for human health due to its containing high levels of vitamins, especially vitamin D, polyunsaturated fatty acids (i.e., Omega-3), amino acids (i.e., glutamic acid), and minerals (i.e., iodine) (Reames 2012). The composition of seafood can vary between species. For example, high levels of oil can be found under the skin layer of some sea mammals (i.e., seals, dolphins, and whales), in comparison to

Table 1 Taxonomic groups of aquatic species (Fisheries 2022). (https://www.fao.org/fishery/en/aqspecies/search)

Taxonomic group	Species	Taxonomic group	Species
Delphilidae	31	Pleuronectidae	11
Clupeidae	27	Hemiscylliidae	10
Acipenseridae	20	Merlucciidae	10
Scombridae	20	Engraulidae	7
Squalidae	20	Balaenopteridae	6
Penaeidae	19	Orectolobidae	6
Phocidae	19	Parascylliidae	6
Ziphiidae	18	Salmonidae	6
Gadidae	16	Sciaenidae	6
Carangidae	14	Carcharhinidae	5
Otaridae	14	Lamnidae	5
Sparidae	13	Phocoenidae	5
Squatinidae	13		

other seafood species (Saadoun et al. 2015). This oil is stored as a mass of fat cells, which is also called blubber. In fish, Bogard et al. (2015) showed that the levels of fatty acids in *Tenualosa ilisha, Hypophthalmichthys molitrix,* and *Glossogobius giuris* were 183 g kg^{-1}, 41 g kg^{-1}, and 4 g kg^{-1}, respectively.

From 2010 to 2020, an increase in global fish production amounted to over 18% (Boyd et al. 2022). A recent work showed that only 70% of the total fish caught every year is consumed or processed, while the remaining is discarded, on the land surface or water sources, due to its rapid spoilage and storage problems (Nirmal and Maqsood 2022). Also, only one third or half the quantity of the fish is comestible, and the remaining portion, which represents a mixture of scales, skins, vertebrae, dorsal fins, intestines, livers, heads, stick water, and bacteria, is considered waste. In warm conditions, fish waste can be degraded quickly and release carbon dioxide because of the increase in the activity of bacteria that feed on the organic compounds that existed in the raw materials. Therefore, if fish waste is not treated properly it can lead to atmospheric pollution.

Different studies reported that fish waste contains different valuable by-products such as collagen, peptides, chitin, oils, and enzymes (Fernandes 2016; Muthumari et al. 2016; Ivanovs and Blumberga 2017; Abuine et al. 2019; Aboudamia et al. 2020a, b; Aboudamia et al. 2021). Thus, in order that the impact of fish waste on the environment reduced, it would be necessary to reuse it or to extract its by-products for further use in various fields, including agronomy, pharmaceutical engineering, and water treatments.

2.2 Composition of Fish Waste

The isolation of useful substances (collagen, chitin, lipids, fatty acids, enzymes, and hydroxyapatites), as well as the production of other compounds (gelatin, peptides, and chitosan) from discarded parts of fish processing, would have a great interest, especially in the application for boosting plant growth as well as for food and drugs biotechnology (Friess 1998; El Amerany 2020, 2021, 2022).

2.2.1 Collagen, Gelatin, and Peptides

Collagen is a Greek word, which means producing gum (Wang 2021). Also, it is a protein (Fig. 1) that is presented in all human, animal, and fish organs, such as skin, tendons, and ligaments as well as cartilaginous and connective tissues (León-López et al. 2019). It is synthesized after vigorous exercise in order to provide support to connective tissue (Langberg et al. 1999). This protein is characterized by the dominance and the combination of amino acids, especially glycine, proline, and hydroxyproline (Li and Wu 2018).

Collagen can have different structures; it can be amino acid triplet, α-helix, triple helix, or fibrils (Wang 2021). Regarding collagen size, its molecule can be less than 1.3 nm, whereas the thickness of its fibril can vary from 50 to 500 nm (Fratzl 2008).

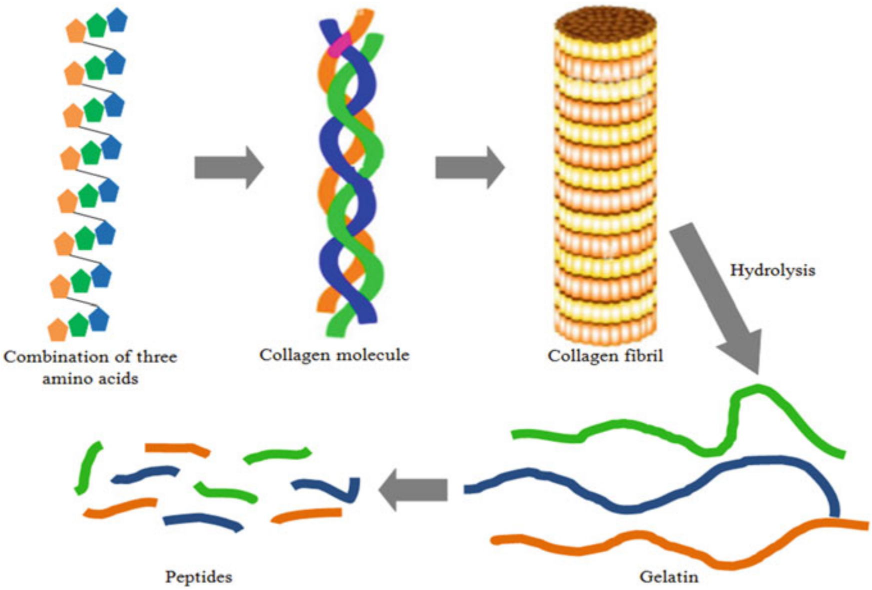


Fig. 1 Collagen structure

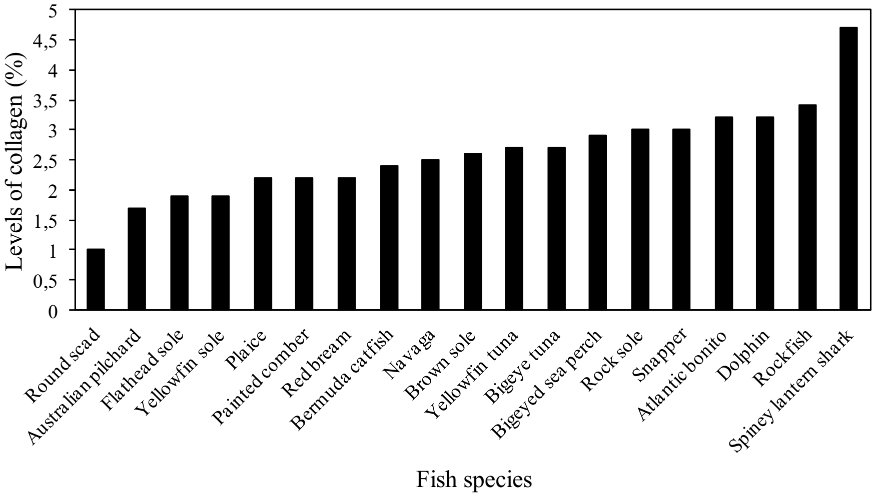


Fig. 2 Collagen levels in fish species

Collagen is often used in the medical field, especially for tissue engineering, wound healing, treating bone defects, and rebuilding teeth (Li et al. 2021). In addition, collagen has other biological properties, including a high capacity in absorbing water and in forming emulsions, which make them a desired biomaterial in the agri-food industry. The levels of collagen in fish muscles are ten-fold lower than in red meat (Sikorski et al. 1984) and as shown in Fig. 2, it can vary between species.

Gelatin is a transparent or slightly yellow, and solid substance, almost tasteless and odorless. It is made from fish waste (epidermis, scales, and bones) (Usman et al. 2022). Even though the level of gelatin obtained from pig skin is up to 80% in the market, in comparison to others made from bovine, this product could not meet the demand for food, especially for Muslim people, who accept only Halal food. Therefore, Gelatin obtained from fish waste can be used as a substitute for those made from other animals like pigs.

Gelatin can be applied in agri-food and drug manufacturers either as a stabilizer or as a thickener to modify the viscosity of a solution without altering the whole its characteristics (Saha and Bhattacharya 2010). Gelatin is a polymer of amino acids, produced after the denaturation of collagen (Vázquez et al. 2021) (Fig. 1). This gel is characterized by a lower gelation property than mammalian gelatin due to low levels of proline and hydroxyproline. Therefore, it is recommended to add ionic polysaccharides to gelatin, such as alginate and chitosan to improve its functional properties (Derkach et al. 2020).

To induce the rate of gelatin, collagen can be degraded at pH 4 (Usman et al. 2022). In addition, a high quantity of gelatin can be obtained by using enzymes (i.e., pepsin enzyme) and non-thermal technics such as high pressure and ultrasonication treatment, to break the non-covalent bonds (Usman et al. 2022).

Fish peptides are polymers, characterized by short sequences of amino acids (≤ 20) (Fig. 1) (Ucak et al. 2021). They can be produced under the action of several enzymes, including alcalase and trypsin (Brandelli et al. 2015). Various studies found that strongly charged peptides, isolated from fish waste, had beneficial effects on human health, like building blocks for proteins and fighting cancers, pathogenic agents, and other diseases (Gildberg 2004; Masso-Silva and Diamond 2014). These substances can be found in different fish parts such as muscle protein, bones, and mucous layer (Senevirathne and Kim 2012).

2.2.2 Chitin and Chitosan

Chitin is a material composed of two units' types: N-acetylglucosamine (more than 50%) and N-glucosamine (less than 50%), which are connected by β(1–4) glycosidic bonds (Fig. 3) (Pellis et al. 2022). Chitin can not be dissolved in water and organic solvents because of its crystal structure, which therefore limits its use in several areas (Austin 1973).

Chitin can be isolated from the inner layer of the cell wall of insects (i.e., black soldier fly), microorganisms (i.e., *fusarium oxysporum*), and spores (i.e., arbuscular mycorrhizal fungi), exoskeletons of arthropods (i.e., shrimps), and scales of fish (Elieh-Ali-Komi and Hamblin 2016; Lagat et al. 2021; Aboudamia et al. 2020a, b). This polymer is characterized by three polymorphic crystalline structures, such as alpha (α), beta, and gamma, which differ according to chitin's chains arrangement (Martínez et al. 2001). Regarding the first type, its chains are put in an antiparallel order, however, for the second type, the chains are all parallel (Martínez et al. 2001). However, for the type γ chitin, every one chain is arranged in the opposite direction of two chains that have the same polarity (Martínez et al. 2001). In all chitin's types, the chains are linked together by hydrogen bridge between either the amide group or the carbonyl group of the adjacent chain (Darmon and Rudall 1950). As Aboudamia et al. (2020a, b) demonstrated in their last research, chitin extracted from fish scales has a crystal structure of type β.

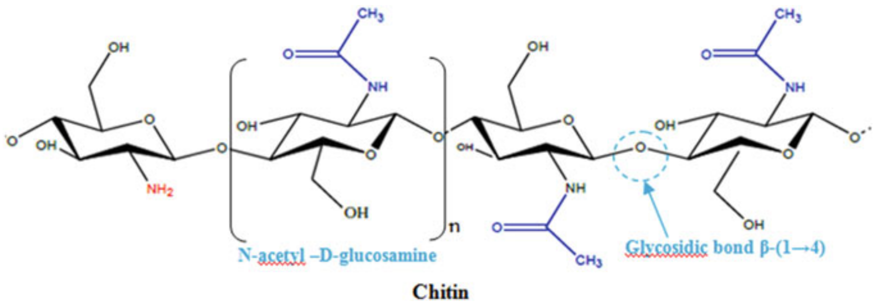


Fig. 3 Chitin structure

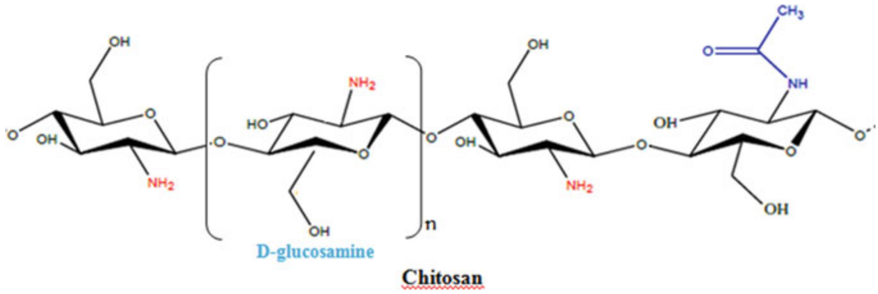


Fig. 4 Chitosan structure

From the hard material covering the skin or the scales of various fish, such as bocachico fish (*Prochilodus magdalenae*), parrotfish (*Chlorurus sordidus*), red snapper (*Lutjanus argentimaculatus*), rohu (*Labeo rohita*), nile tilapia (*Oreochromis niloticus*), and European sardine (*Sardina pilchardus*) the yield of chitin can be 45.2%, 45%, 33%, 22%, 20%, and 10%, respectively (Muslim et al. 2013; Boarin-Alcalde and Graciano-Fonseca 2016; Rumengan et al. 2017; Molina-Ramírez et al. 2021; Aboudamia et al. 2020a, b).

Chitosan, an aminopolysaccharide, is derived from the copolymerization of two monomers: glucosamine (or 2-amino-2-deoxy-beta-d-glucopyranose) and N-acetylglucosamine (or 2-acetamide-2-deoxy-beta-d-glucopyranose) (Fig. 4), which are joined together by glycosidic bonds (Domínguez-Delgado et al. 2014). This biopolymer is characterized by the dominance of the D-glucosamine unit (more than 50%) in the polymeric chains (Fig. 4), which allows them to be part of different organic acids, including lactic acid, chloride acid, and acetic acid (Rinaudo 2006). In 1859, chitosan was discovered for the first time by Rouget (Ruiz and Corrales 2017) who found out that heating chitin in an alkaline solution produces a soluble material.

Chitosan is a substance that is not widely available in nature. It can be isolated only from the cell wall of some microorganisms, such as fungi (e.g., Mucor Rouxii) (White et al. 1979; Zamani et al. 2007; Tayel et al. 2011) and yeasts (e.g., Candida Albicans) (Pochanavanich and Suntornsuk 2002) and in the abdominal wall of the termite queen (Pillai and Ray 2012). It is, moreover, obtained through the complete or incomplete deacetylation of chitin that is seen anywhere and available in large quantity (Baxter et al. 1992).

Chitosan's yield produced from fish sources can be varied depending on the extraction method applied. For instance, Ooi et al. (2021) showed that chitosan's yield produced from the scales of red snapper (*Lutjanus johnii*) can be 49% and 33% if the raw material was treated with 0.05% and 3% HCl, respectively.

2.2.3 Lipids and Fatty Acids

Lipids are considered the main components of the cell membranes. They can act as regulators of membrane layer permeability, cellular signaling and responses, and gene expression (Calder 2012). Many researchers have demonstrated that fish oil, especially Omega-3 fatty acid, can be beneficial for patients with high cholesterol and heart disease (Chaddha and Eagle 2015), and this oil can be found in fish meat as well as its waste. A study has shown that the oil isolated from the waste of the *Atlantic salmon*, especially heads, and soft tissues, contains high levels of saturated (11% palmitic acid), monounsaturated (47% oleic acid), and polyunsaturated (15% linoleic acid) fatty acids and antibiotics (i.e., nafcillin, oxacillin, and penicillin). This oil has as well as bactericidal activity against *Pseudomonas aeruginosa* (Inguglia et al. 2020). Regarding *Sardinella lemuru* waste, the highest level of lipids, which was up to 5%, can be found either in heads, intestines, and livers (Khoddami et al. 2009). In addition, this waste is composed of saturated (36% palmitic acid and 9% steric acid), monounsaturated (22% oleic acid), and polyunsaturated (16% docosahexaenoic acid) fatty acids.

In addition, Suriani and Komansilan (2019) have reported that increasing the yield of mono- and poly-unsaturated fats and reducing the levels of saturated fats, which lead to cancer and gaining weight, is possible through using the process of urea crystallization.

2.2.4 Enzymes

Fish wastes contain diverse kinds of enzymes (i.e., collagenases, peptidases, proteases) (Table 2) that can modify macromolecules and accelerate the deterioration of waste (Venugopal 2016). The isolation of these enzymes required four main steps: (i) collection of the enzyme extract, (ii) metabolite fractionation, (iii) enzyme purification, and (iv) enzyme activation through biochemical modification of their shape (Daboor et al. 2012).

To produce different and high-quality products for human and animal consumption, enzymes are becoming a crucial element of the production processes applied by the food and medical industry (Shahidi and Kamil 2001). For example, enzymes isolated from cold fish species can be used to protect pharmaceutical and food products (Venugopal 2016).

2.2.5 Hydroxyapatite

Hydroxyapatite is a mineral species that can be found in bone, teeth, and scales, and it is mainly composed of two elements, such as calcium (Ca) and phosphate (P) (Mustafa et al. 2015). This material is considered stable only if Ca/P ratio is more than 1.67 (Fiume et al. 2021).

Table 2 Enzymes isolated from fish species

Family enzyme	Compounds	Fish species	Properties	References
Collagenases	Collagenases	Smooth weakfish (*Cynoscion leiarchus*)	Activity increased when the temperature is around 55 °C whereas the pH is equal to 8	de Melo Oliveira et al. (2017)
Peptidases	Chymotrypsin A	Atlantic salmon (*Salmo salar* L.)	Activity reduced when temperature is more than 38 °C Activity increased in low pH	Zhou et al. (2011)
	Chymotrypsin B			Rungruangsak-Torrissen et al. (2006)
	Trypsin		Not shown	
Proteases	Caspase-3	White amur (*Ctenopharyngodon idella*)	Activity decreased during cold temperatures	Jiang et al. (2022)
	Calpain			
	Cathepsin B		Activity increased only during the first day of ice storage	
	Cathepsin L		Activity increased only during 3 days of ice storage	
	Cathepsin	Yellow pike (*Congresox talabon*)	Activity increased when the temperature is around 50 °C and the pH is equal to 5	Pertiwi et al. (2020)
	Chymosin	Atlantic tuna (*Thunnus obesus*)	Activity of enzyme is less sensitive at pH values above 6.4	Tavares et al. (1997)
	Pepsin	Catfish and milkfish	Activity of enzyme is more important when the temperature range of 20–40 °C, whereas the pH is less than 3	Nurhayati et al. (2020)

Hydroxyapatite that existed in nature is better than synthetic one because of its higher metabolic activity and stability as well as its biocompatibility and non-toxicity (Granito et al. 2018). Hydroxyapatite from fish bone and scales is cheap and easy to produce. Based on many different protocols, the production of hydroxyapatite from fish waste can be done through 4 main steps: (i) heating the raw material to remove lipids and meat surrounding the material used, (ii) drying and crushing, and (iii) calcinations (Kerian 2019). Hydroxyapatite isolated from natural resources is mainly used for bone tissue engineering after controlling its microstructure to allow blood flow through the material.

2.2.6 Vitamins and Pigments

Carotenoid pigments, specifically carotene and astaxanthin, are the cause of the appearance of yellow, orange, and red stains in the meat and skin of fish (Simpson 2007). In addition, fish liver stores high levels of vitamins such as vitamin D (Lock et al. 2010).

3 Strategies to Reduce and Manage Fish Wastes

The Moroccan government inaugurate various sustainability initiatives as the National Roadmap for Biomass Energy Valorization (BEV) to 2030, the National Energy Efficiency Strategy to 2030, the Green Hydrogen Roadmap, the Low Emission Development Strategy for 2050 (LEDS), and others. In order to achieve the objectives of those initiatives, the National Ministry of the Environment, national laboratories, and municipalities are looking for green solutions to decrease the negative impact of fish by-products in the environment, while applying eco-friendly technologies. The choice and the application of these strategies require a great challenge, and the collaboration of several actors (environmental, scientific, industrial, financial), and civil society. During the last decade, several governments have oriented and encouraged fish companies to valorize their marine by-products. Circular business models aim to find a solution to environmental problems by incorporating new scientific knowledge and green technologies into a new economic system (Rosa et al. 2019). To decrease fish waste generated, various eco-friendly solutions could be adopted. Fish companies and aquaculture should apply the traditional hierarchy of waste management from the best choice to the least favorable one. The model of the inverted pyramid or 5R gives optimal solutions for human and environment from prevention to disposal (Fig. 5).

Romero-Hernández and Romero (2018) reported that the circular economy is established on sale, disposal, and prevention compared with waste management. Thus, it is recommended to make a framework for each processing plant and aquaculture in order to integrate the economic, environmental, and social. In addition, the application of a circular bioeconomy which is an integral part of the circular

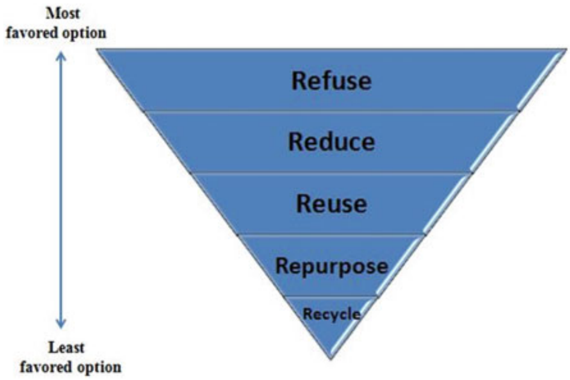


Fig. 5 The inverted pyramid for fish waste management

economy is primordial to achieve sustainability in terms of resources and environmental sustainability (Coppola et al. 2021). The European Commission, defined bioeconomy as "the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, including food, feed, bio-based products and bioenergy" (Commission, E. A Sustainable Bioeconomy for Europe). The application of circular bioeconomy in the fisheries sector could increase the awareness by society and companies, sustain production and consumption, increase valorization of resources and zero waste, contribute to stakeholders and policymakers, and support of politics (Fig. 6).

As mentioned in the first axis of this chapter, the fish marine waste contains a valuable compound of high-commercial added as minerals, polysaccharides, proteins,

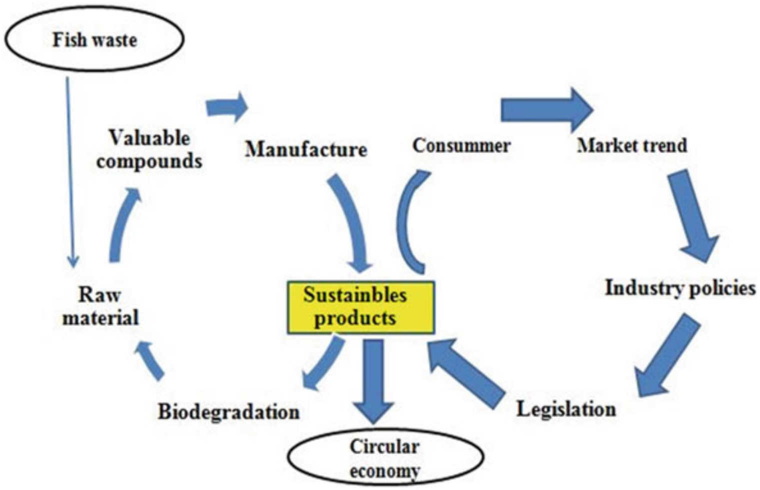


Fig. 6 The inter- and multi-disciplinary process for fish wastes

lipids, and others. In general, fish by-products and by-catch might be applied in various fields from agriculture to pharmaceutic. In this section, we will highlight various scenarios that might be used to reduce or manage fish waste in energy, and agriculture as vital sectors.

3.1 Energy

3.1.1 Biodiesel

Fossil fuels are considered as non-renewable energy, which causes the depletion of natural resources by the emission of greenhouse gases, as well as atmospheric contaminants, some product of incomplete combustion such as NOX, SOX, CO, volatile organic elements with particles of atmospheric matter (Kannahi and Arulmozhi 2013). Recently, biodiesel might produce from fish litter, and among the most used parts are the head, spine, skin, stomach, and tail. Fish by-products as marine litter might be the inexpensive resource of biodiesel (Yahyaee et al. 2013) or bio-oil (Wisniewski et al. 2010). Fish oil obtained from marine fish contains higher rate of omega-3 polyunsaturated fatty acids and its use as source of biofuels will minimize greenhouse gases and preserve biofuel feedstock for the future generation. According to the study of Mata et al. (2014), it is demonstrated that residual biodiesel properties as density, flash point, heat of combustion, acide value depends on waste fat (ester profile). In addition, fish oil could enhance fuel flow fluidity at low operating temperatures, due to its composition which consists mainly from unsaturated fatty acids as PUFAs (Karkal and Kudre 2020). However, the high rate of mineral and moisture in fish by-products requires adequate technologies for energy conversion (Fig. 7).

The biodiesel production could be obtained using various methods such as pyrolysis (Wisniewski et al. 2010), transesterification (Jung et al. 2019), mico-emulsion, and direct blending (Behçet 2011) with diesel fuel. Bhaskar (2018) reported that transesterification chemical process is one of the best processes to decrease the viscosity of the vegetable or animal fat oil and to increase the cetane number of biodiesel. In addition, a simple transesterification of fish oil was done by Sharma et al (2014) who converted fish waste into biodiesel of high FAME content using a single-step transesterification by alkaline catalyst (CH_3ONa). The production of biodiesel from marine fish litter as an alternative of fossil fuels could solve environmental and political problems.

3.1.2 Biogas

Biogas could be obtained from various organic sources and wastes during anaerobic digestion. Fish waste is rich source of proteins considered as biodegradable organics, making it a proper substrate for anaerobic digestion (Yulisa et al. 2022). The production of biogas from fish by-products and by-catch is among the simplest processes for

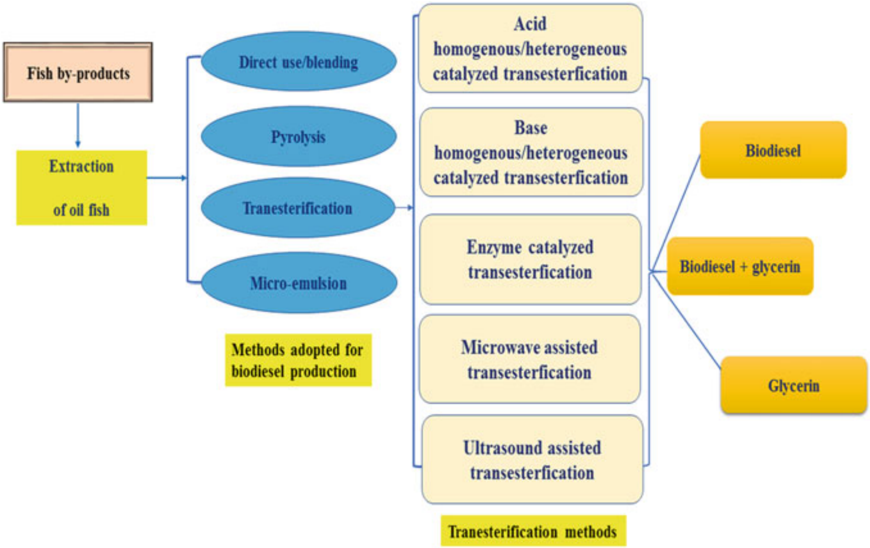


Fig. 7 Outline of various methods applied for the production of biodiesel from fish by-products and its perspective of use (Karkal and Kudre 2020)

energy conversion, and it could be viable and sustainable feedstock and alternative biofuels. However, methane as accumulated intermediate from protein degradation could affect negatively system stability and even process failure (Solli et al. 2018). The study of Cadavid-Rodríguez et al. (2019) reported that fish waste could be an alternative source of biomethane production, the produced biogas was used as an alternative energy for artisanal fishing communities in Tumaco city, Colombia. According to Bücker et al. (2020), industrial fish processing waste can be efficiently converted to methane in a mono-digestion process and produced methane at 540.5 CH_4 mL gVS_1. In addition, the fish waste had the best daily methane production performance and produced biogas with higher methane content than fish crude oil waste in less time.

As already mentioned in Sect. 3.1, the production of biogas from fish waste could minimize the greenhouse gases and increase economic incomes.

3.2 *Biofertilizer*

Biofertilizers are defined as the microorganisms (bacteria/fungi) that help the plants to grow by ameliorating the nutrient supply to the host plant when given to seeds, plants, or the soil (Daniel et al. 2022). According to the FAO 2016, the application of biofertilizers enhances soil fertility and sustains plant growth, thus enhancing crop yields. Biofertilizers are classified within various classifications according to their functions and their mechanisms of action. The study of Nosheen et al. (2021) showed that nitrogen-fixers (N-fixers), potassium solubilizers (K solubilizers), phosphorus solubilizers (P solubilizers), and plant growth-promoting rhizobacteria (PGPR) are the most favorable nutrient for the plant. Fish by-products and by-catch are the among source for the production of biofertilizers, due to their richness of Ca, N, P (Illera-Vives et al. 2015). The production requires the blending of acids to neutralize the pH to eliminate fungal growth, and the process of maturation demands between 3 and 4 days to achieve maturation. Moreover, organic matter ameliorates the soil fertility. It plays as a natural fixation to the soil physical, chemical, and biological properties which sustain the use of soil for long term (Jubin and Radzi 2022). Previous studies revealed that fish waste as abdominal parts, heads, outer shells, scales, or skins have a higher influence on growth and crop yields. (Hepsibha and Geetha 2021; Shahsavani et al. 2017). The application of bio-fertilizer from fish by-products and by-catch could mitigate the environmental pollution caused by using chemical fertilizer.

Finally, we can mention that several constraints may confront the industrials in the sector of the recovery of fish by-product /by-catch and among them are the absence of knowledge, lack of finance, lack of awareness, low skilled workers. In addition, the recovery of fish waste will be a new sector that is in line with the principles of the blue economy using environmentally friendly and sustainable technologies, and while producing high-value substances applicable in different fields.

4 Conclusion and Future Perspective

For the greater benefits of our environment, it is mandatory to elaborate strong collaborations between scientists and industrials to learn from their depth experiences. In addition, the government should support the industries that make use of fish by-products; because they have great economic and environmental potential in the country Furthermore, it is essential to include civil society and the mass media to show the major interest of fish by-products. In schools and universities, students must be involved in workshops or congresses by showing different documentaries about valuables products that can be made using from fish by-products, thus by mentioning the major interest of recovery in the depollution. It is also necessary to organize workshops for professionals to increase their knowledge in the field of marine waste recovery. Finally, the recovery of fish by-products is a great deal with important advantages for our society, economy, and environment.

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