Quintessential Utilization of Non-edible Aquatic Biowaste: In Pursuit of a Paradigm Shift Toward Wealth (from Waste) in Aquaculture"

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Abstract Aquaculture plays an increasing role in future food security. Thirty-four calories per person per day are provided by fish and fish products globally. However, the rearing, harvesting, and processing of fish produces enormous amounts of trash, which is an issue for the entire world. For every ton of fish consumed, approximately the same quantity of fish waste (FW) is disposed of either through ocean dumping or land disposal. Unutilized waste has an impact on a larger coastal zone at many ecosystem levels, reducing benthos, plankton, and nekton biomass, variety, and density, and altering the structure of natural food webs. Alternatives to pricey feed additives should be investigated in order to meet the sustainable development goals (SDGs) of preventing the depletion of valuable aquatic resources. Wastes from the fisheries sector could be treated with various methods and can be utilized for pigments, chitosan, and collagen, which can be used in fish feed, biomedical, and

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pharmaceutical industries. Currently, the production of biogas, biodiesel, biofertilizer, and bioplastic from non-recyclable fish waste is widely practiced. The various waste processing activities need additional inputs and outputs in order to recover energy and separate the necessary components from aquatic waste. The primary goal of our study towards sustainable aquaculture is the conversion of these wastes while also recovering important materials before disposal, which would also help in boosting the circular economy.

Keywords Fish waste · Circular economy · Environment pollution · Green technology · Utilization · Bioactive compounds · Sustainable aquaculture

1 Introduction

In the twenty-first century, the fisheries and aquaculture sectors have received greater recognition for their vital role in ensuring global food security and nutrition. Nearly 20% of the average per capita animal protein consumption of the world's 3.2 billion people came from aquaculture (FAO 2021). Thirty-four calories per person per day are provided by fish and fish products globally. Choe et al. (2020) stated that large amounts of trash are produced during fish farming, fishing, and processing, which now became a global concern. Fish trimmings and some particular parts, such as fish heads, fish guts, fish tails and fish fins, fish skins, fish scales, and fish bones, are all included under the concept of "fish waste." The terms "fish waste," "fish processing waste," "by-products," "raw materials," and "rest raw materials" have all been used in various research studies (Choe et al. 2020). According to Illera-Vives et al. (2015) and Karim et al. (2015), for every ton of fish consumed and disposed of via ocean dumping or land disposal, about the same quantity of fish waste (FW) was produced. Fish farm waste has the potential to alter natural food webs by negatively affecting the biomass, density, and variety of benthos, plankton, and nekton. Waste from fish farms can also have an impact on the neighborhood and be directly impacted by the effluent (Gowen 1991; Pillay 1991). To achieve sustainable and equitable global fisheries and aquaculture, revolutionary changes in policy, management, and innovative technology must be accelerated in order to utilize the growing amount of waste produced by the aquaculture industry.

2 Fish Waste as a Secondary Source of Resource

Depending on the region and species, the waste produced by aquaculture has a widely varied range of characteristics. Nearly 32 million tons of waste are produced from the residuals from the total amount of fish caught (more than 50%), which are not consumed as food (Arvanitoyannis et al. 2008). Large volumes of soluble-inorganic excretory waste and particulate organic waste are produced by aquaculture farms

(Ackefors 1994). The average yield in the fish processing industry is calculated using a gutted fish with the head on, which is approximately 40%½ (Marsh and Bechtel 2012). During the processing of fish, only 35–40% of the flesh is edible; the remaining consists of bones, skin/scales, swim bladders, intestines, roes, liver, and blood (Sachindra and Mahendrakar 2015). Fish offals like heads, frames, tails, skin, bones, fins, and viscera are included in the disposal portion. Fishmeal is an essential component of commercial and formulated diets but it is also a major pollution source. Fishmeal contamination looks to be a global issue. Fishmeal can either be, intentionally or accidently, contaminated with heavy metals, persistent organic pollutants (POPs), and pesticides. Alternatives to raw fishmeal protein sources should be researched by utilizing the waste in order to supply the large demand for fish while minimizing the current dependency on marine water and freshwater fishing resources for sustainable aquaculture.

3 Waste Generated from Fisheries Sector

Fish waste is some portion of fish tissue, such as bones, guts, heads, and tails, which is not suitable for human food but can be utilized to make fishmeal. A survey claims that more than half of the fish captured are not consumed (Kristinsson and Rasco 2000). Common by-products of finfish include trims, fish skins, fish heads, fish frames (bones with attached flesh), fish viscera (guts), and blood. According to Stevens et al. (2018), the following by-product fractions were present in the total wet weight of Atlantic salmon: viscera (12.5%), heads (10%), frames (10%), skins (3.5%), blood (2%), and belly flap (2%). Both raw and cooked shrimp, a significant part of the seafood business, are edible. In either event, only around 40% of the shrimp are fit for human consumption, and the remaining 60% are processed trash (shrimp shells) in the commercial shrimp processing sector (Barratt and Montano 1986; Dayakar et al. 2021).

4 Challenges and Negative Impact of Fish Waste

The bulk of by-products and wastes are produced during the processing of large quantities of fish, shrimp, and other aquatic species. Fish and shrimp processing effluents have very high levels of organic matter, nutrients, total suspended particles, fat, oil, pathogenic and other microorganisms. Therefore, the receiving coastal and marine habitats are quite likely to have negative consequences from fish and shrimp processing effluents. There are significant environmental issues as a result of the coastal region receiving about 40% of the oyster shell debris (Zhu et al. 2020). The garbage from shrimp is subsequently put into landfills, dumped in the ground, and dumped into the ocean, which causes significant surface pollution with an unpleasant odor in coastal areas, and raises serious environmental pollution concerns. In any event, it is commonly acknowledged that disposing of shrimp waste has a huge ecological impact (Kelleher 2005). The loss of valuable living resources makes shrimp waste a severe environmental issue. Environmental contamination hampers the healthy ecosystem and curses for endangered species (Morgan and Chuenpagdue 2003). The material's high susceptibility to spoilage is a significant issue with shrimp biomaterial valorization. Within an hour of processing, breakdown starts to occur in tropical temperatures, producing biogenic amines, which have a highly unpleasant odor. The biomaterial decomposes into actual waste if this decay cannot be prevented or stopped and becomes an expensive financial burden if it is not properly disposed of due to its high protein content.

5 Need for Waste Management

It is obvious that appropriate technology should be used to stop degradation and turn the biomaterial into useful goods. This is good for both environmental and economic reasons. Technology ought to offer methods for fractionation as well as techniques for delaying or stopping deterioration. Consequently, there is a lot of interest in recycling fish waste. It's an innovative idea to turn waste from the fish processing industry into marketable organic feed and fertilizer products. After the proper treatment, those biomaterials or biowaste which contain a variety of useful substances, can significantly increase overall profitability. Fishmeal made from fish waste contains crude protein (58%), which is lower than the 60–70% found in high-quality fishmeal, but it is still a wholesome product that might be used as a source of fishmeal for fish at lower trophic levels. According to a study, fish processing waste is currently used to make up to 25% of fishmeal (Chiu et al. 2013). Fish waste does include a lot of monounsaturated, palmitic, and oleic acids and is a good source of fat (19% dry matter) and nutrients (Esteban et al. 2007). When compared to other fish oils, shrimp shell waste contains n-3 fatty acids in lipid that also contains additional beneficial components, like carotenoids (Amiguet et al. 2012; Sowmya and Sachindra 2012). The bulk of the total fatty acids in shrimp oil are polyunsaturated fatty acids (PUFA), particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Gulzar and Benjakul 2019; Takeungwongtrakul et al. 2012). The two main n-3 fatty acids, i.e., EPA and DHA in PUFA are well known for their therapeutic and nutraceutical uses. Shrimp oil contains phospholipids, cholesterol, and carotenoids in addition to fatty acids (Raju et al. 2022). Different species of shrimp have different amounts of lipid components and carotenoids. In comparison to saturated and monounsaturated fatty acids, shrimp oil contains higher polyunsaturated fatty acids (PUFA) (Gulzar and Benjakul 2019). According to some reports, *P. monodon* meat and *L. vannamei* waste both have higher PUFA concentrations such as 44.3 and 43.57%, respectively (Gómez-Estaca et al. 2017). Astaxanthin is present in large amounts in a number of sources of shrimp oil or shrimp processing by-products (SPBP). According to Yang et al. (2022), astaxanthin monoester made up 59% of the carotenoid content in *L. vannamei*, with free astaxanthin making up 33% and astaxanthin diester (8%). Crustacea are an excellent source of the dietary fat-soluble vitamins that adults require (Stancheva and Dobreva 2013). The preservation of human health depends on these fat-soluble vitamins, including vitamin A (retinol), vitamin D, and vitamin E (gamma-tocopherol). López et al. (2006) reported that vitamin A and vitamin E concentrations in oil extracted from the *L. vannamei* cephalothorax ranged from 0.9 to 1.6 mg/100 g. According to Gómez-Estaca et al. (2017), the oil from *Litopenaeus vannamei* waste contains up to 65 mg/g of cholesterol. In this context, shrimp industry by-products must be given to aqua feed as a source of protein and a rich supply of carotenoids (particularly astaxanthin) to promote and augment overall growth, build muscle, improve skin pigmentation, and improve fish health thanks to its antioxidant properties (Haque et al. 2021, 2023). However, the remaining trout intestines from smoking fish were mentioned by Kotzamanis et al. (2001) as a potential source of fatty acids for gilthead bream. Utilizing trout offal in sea bream diets is an alternate, non-polluting method of employing fish industry by-products. The squid protein hydrolysate (SPH) contained 61–64 (%) hydrophilic amino acids, crude lipids, 84–88 (%) crude protein, 6–7 (%) ash, 3 (%) sugar, and trace levels of NaCl, according to Kotzamanis et al. (2001).

6 Bioactive Compounds from Fish and Shellfish Waste

6.1 Chitin and Chitosan

The shells of crustaceans like shrimp, crabs, and others, as well as fungi, insects, algae, and mushrooms, are plentiful with chitin, the second-most abundant polysaccharide in the world (Arcidiacono and Kaplan 1992). One of the most prevalent renewable biopolymers, chitin resembles cellulose and is mostly made up of unbranched chains of 1,4-N-acetyl-D-glucosamine (Ngasotter et al. 2023a). Chitin is not only an essential component of invertebrates; vertebrates also contain chitin. Contrary to cellulose, chitin has a carbon to nitrogen ratio of 8 to 1 (Struszczyk 2006). Chitin comes in three varieties: chitin A, chitin B, and chitin C. The form, which is usually derived from crab and shrimp shells, is frequently used. Chitin is commercially marketed, too. Chitin's chains are arranged anti-parallel to one another. Strong hydrogen bonds are present in α-chitin due to its anti-parallel structure, which boosts its stability (Sikorski et al. 2009).

Chitin's intermolecular hydrogen bonding prevents it from dissolving in water (Minke and Blackwell 1978). However, derivatives of chitin can be created that are soluble in water, such as chitosan or carboxymethyl chitin. Chitosan, a naturally occurring carbohydrate polymer that has been altered, is produced when chitin is deacetylated (Yeul and Rayalu 2013). Nitrogen makes about 6–7% of chitin and 7–9.5% of chitosan in its deacetylated state. Numerous extremely beneficial features of chitin and chitosan, such as immunological function, hemostasis and wound healing, antioxidant activity, antibacterial activity, and the removal of heavy metals and other impurities, are present in these two substances.

Recently, there has been a lot of interest in the separation and application of chitin in both its micro and nano forms, especially nano chitin in the form of nanocrystals or nanowhiskers (100–800 nm in length and 6–60 nm in width) and nanofibers (several m in length and 10–100 nm in width) (Ngasotter et al. 2022, 2023b; Sampath et al. 2022). There are two methods for converting native chitin into nano chitin: (I) Top-down technique, which uses physical or chemical processes such as acid hydrolysis, high-pressure homogenization, ultra-sonication, grinding, and TEMPO-mediated oxidation. (ii) Bottom-up method, which converts chitin solutions or gels into nano chitin via electrospinning, self-assembly, and dissolution-regeneration (Yang et al. 2020). For some valuable characteristics, it led to an increase in the use of nano chitin in the fields of packaging, food, biomedical, biological, and cosmetics. Chitin nanocrystals, for instance, have been utilized to successfully stabilize Pickering oil-in-water emulsions (Cheikh et al. 2021). Nano chitin, which functions as dietary fiber, can reportedly block the breakdown of fat, according to several in vitro research on digestive systems (Zhou et al. 2020, 2021). Other potential uses for nano chitin in food include enhancing saltiness and serving as a reinforcing nano filler in a variety of packaging films (Somsak et al. 2021).

6.2 Pigment Composition

Carotenoid is obtained after processing shrimp, crab, trout, lobster, crayfish, salmon, snapper, and tuna industry waste. The most common pigments found in both plants and animals, ranging from red to yellow, are carotenoids, which are found in the lipids of fish waste. In a racemic combination, astaxanthin contains three stereoisomers that combine to create a complex with a protein that builds up in the exoskeleton of crustaceans (Haque et al. 2021). Due to its unique binding properties, astaxanthin is primarily found in crustacean waste in combination with other substances. With proteins (carotenoproteins) or lipoproteins (carotenolipoproteins), the pigment forms a chemical compound (Higuera-Ciapara et al. 2006). Carotenoids are extracted from the head, body carapace, and leftover shrimp waste using a variety of organic solvents (Sachindra 2006). The extracted residue can be used to create chitin and/or chitosan, and the recovered carotenoids can successfully substitute synthetic carotenoids in formulations for aquaculture feed (Haque et al. 2021). The level of redness in seafood directly affects its price or quality. The antioxidant action is reportedly ten times more powerful than carotene (Naguib 2000). It is utilized in the culinary, cosmetic, and salmonid and crustacean feed industries (De Holanda and Netto 2006).

6.3 Polyunsaturated Fatty Acids

Shrimp waste has a substantial amount of mono- and poly-unsaturated fatty acids, which combined account up 34% of the product’s total fatty acids, according to the fatty acid composition of the waste. Furthermore, it seems to contain a lot of saturated fatty acids. According to reports from India, the acetone extract made from shrimp waste contains a lot of saturated fatty acids (Sachindra et al. 2006). According to Bragagnolo and Rodriguez-Amaya, penaeid shrimp from the Brazilian region had a significant concentration of unsaturated fatty acids, demonstrating that the composition of fatty acids varies depending on the kind of shrimp (2001). According to Senphan and Benjakul (2012) and Takeungwongtrakul et al., the cephalothorax and hepatopancrease of shrimp are important sources of highly unsaturated omega-3 fatty acids, such as eicosapentaenoic acid (EPA, 20:5n3) and docosahexaenoic acid (DHA, 22:6n3) (2012). Following these acids, saturated fatty acids and monounsaturated fatty acids (which together constituted up 37.5% of the lipid extracted from the cephalothorax of the Pacific white shrimp, *L. vannamei*) are found (Gulzar and Benjakul 2019).

6.4 Essential Amino Acids

All necessary amino acids, with the exception of tryptophan, are present in both the original shrimp waste and the powder created after fermented shrimp waste was lyophilized (Bhaskar et al. 2010). Glutamic acid and aspartic acid were found to be dominated as amino acids in caratenoproteins, extracted from shrimp waste using enzymatic extraction (Simpson and Haard 1985). In aquaculture, by-product from fish waste can be utilized as an immunostimulant and growth promoter (Amar et al. 2000). Fish waste protein hydrolysates are known to be superior in terms of nutrition as feed ingredients because they contain a high concentration of important amino acids (Gildberg and Stenberg 2001). These traits obviously indicate the material's potential relevance as a dietary element that will support wellness in the diets of young fish and penaeid shrimps.

6.5 Alpha-Tocopherol

Tocopherol content in fish waste varied depending on the species, age, sex, fish waste component, and type of extraction process (Afonso et al. 2016; Gómez-Estaca et al. 2017; Gulzar and Benjakul 2018). Brown shrimp meat and fermented shrimp waste (head and cephalothoraxes) had tocopherol values of 7.73 mg per 100 g and 50.5 mg per 100 g, respectively (Merdzhanova et al. 2018). Gomez-Estaca et al. (2017) found a greater tocopherol concentration (1.26 g/100 g) in the waste extract from the cephalothorax, cuticles, tails, and pleopods of *L. vannamei*. Fish's muscular and reproductive systems need tocopherol, a fat-soluble vitamin with antioxidant properties (vitamin E) (Afonso et al. 2016). Additionally, tocopherol is necessary to prevent lipid peroxidation in the food system as well as the oxidation of low-density lipoprotein in living things (Mathur et al. 2015).

6.6 Fish Calcium

Calcium deficiency in the diet can be treated with calcium powder made from the tuna's backbone. The main calcium-containing ingredients are dolomite, bone meal, and oyster shell. In the building business, calcium is utilized to generate early strengthening agents. In the culinary and agricultural industries, calcium is used as a food antiseptic to keep fruits and vegetables from going bad and to make cheese-making simpler.

6.7 Carotenoproteins

The processing waste from shrimp and other crustaceans can be utilized to make carotenoproteins, which are high-density lipoproteins connected to stable carotenoid complexes (Dayakar et al. 2022). In their ovaries and eggs, carotenoprotein is found as carotenolipoproteins, while in the exoskeletons of crustaceans, it is found as chitinocarotenoids and crustacyanins (Pattanaik et al. 2020). According to research by Sowmya et al. (2011), carotenoproteins are bioactive natural colorants that have the ability to boost farmed species' growth, coloration, and immunity (Pattanaik et al. 2021). In order to fully use these species, carotenoprotein can be produced from shrimp shells and head debris and used as a functional addition in foods, drinks, and animal feeds to promote growth (Dayakar et al. 2023).

7 Role of Bioactive Substances from Fish Waste

7.1 Antioxidant Activity

Oxidation is the term for the typical physiological process that occurs in living organisms. Chitosan, protein hydrolysate, carotenoprotein, astaxanthin, and tocopherol are examples of bioactive fish waste products that exhibit potent antioxidant effects via a variety of methods (Ambigaipalan and Shahidi 2017; Chintong et al. 2019). Chitosan demonstrated lowering potential, DPPH radical scavenging activity, and prevention of carotene bleaching (Younes et al. 2014). By using shrimp shell hydrolysates (SSH) and shrimp shell protein hydrolysates (SPH), researchers were able to lessen the oxidative deterioration of cholesterol, the bleaching of beta-carotene caused by cupric ions, and the DNA damage brought on by peroxyl and hydroxyl radicals (Ambigaipalan and Shahidi 2017). Likewise, Pangasius viscera spray-dried protein hydrolysate showed strong antioxidant activity (Hassan et al. 2019). According to Sila et al. (2013), deep-water pink shrimp shell waste-derived astaxanthin showed superior antioxidant activity to commercial antioxidant BHA. Astaxanthin demonstrated strong anti-oxidant activity against the DPPH and ABTS radicals, as well as the ability to prevent the bleaching of β-carotene and quenched singlet oxygen. The amount of conjugated double bonds, the hydroxyl (OH) group, the keto (C=O) group, and the chemical makeup of astaxanthin all have an impact on the antioxidant activity (Chintong et al. 2019).

7.2 Activities Against Microbes

Chitosan from the shell of *L. vannamei* has demonstrated antibacterial efficacy against Gram-positive and Gram-negative bacteria, according to Vilar et al. (2016). *S. maltophilia*, *B. subtilis*, and *E. cloacae* can all be inhibited by chitosan at concentrations as low as 78, 625, and 156 g/mL, respectively. Astaxanthin showed a strong inhibitory impact on *E. coli*, *S. mutans*, *P. auriginosa*, *S. typhi*, and *S. aureus*. Astaxanthin's ability to interact and break bacterial cell membranes due to its lipophilic nature may contribute to its ability to have an antibacterial impact (Sukmawati et al. 2020).

7.3 Anti-inflammatory Activity

The body's physiologically necessary defense mechanism against pathogens, free radicals, and dead cells is inflammation. Pro-inflammatory cytokines including NF-, IL-1, and IL-6 are blocked by anti-inflammatory substances (Santos et al. 2015). The inflammatory response of astaxanthin isolated from L. vannamei waste in rat alveolar macrophages stimulated by phorbol myristate and lipopolysaccharide (LPS) was studied (Santos et al. 2015). Astaxanthin was isolated from the shell of an Asian tiger shrimp using a solvent extraction approach, and it demonstrated anti-inflammatory effects that increased the stability of the erythrocyte membrane (Sukmawati et al. 2020).

8 Green Technologies for Efficient Utilization of Fish Waste

8.1 As Feed Ingredients

According to Yang et al. (2006), lactic acid fermentation of biowaste could cause the fiber to be broken down and increase the amount of water-soluble carbohydrates in the fermented products. Biowaste frequently contains biological components such as chitin, protein, lipids, pigments, flavorings, and calcium carbonate (Bueno-Solano et al. 2009). "Fish waste to Wealth" is an approachable way to deal with fish processing waste and turn it into organic fertilizer and feed additives that are self-stabilizing. The use of fish waste in animal feed is currently a highly sought-after alternative because it not only lowers the cost of animal feed and production but also benefits the environment and ecosystem (Westendorf 2000). Fish waste can be added to poultry feed as a probiotic supplement and nitrogen source (Hammoumi et al. 1998).

8.2 Fish Protein Concentrate (FPC)

A stable protein concentration made from entire fish is called fish protein concentrate (FPC). Removing water, oil, bones, and other materials increased the protein concentration. A variety of whole fish may now be processed into protein concentrate, which has little similarity to the original raw material.

Types of FPC: There are mainly three major types of FPC, which were defined by the Food and Agriculture Organization of the United.

Type A: A powder with a maximum total fat concentration of 0–75% that is almost tasteless and odorless. **Type B**: A powder with a maximum fat level of 3% and an odor or flavor that is unrestricted but unquestionably fishy. **Type C**: Common fish meal produced in an environment that meets acceptable hygiene standards.

8.3 Bioremediation Agent

Diverse aquatic pollutants can be removed from water and wastewater using derivatives of chitin and chitosan, which has proved to have good potential. Metal cations, metal anions, radionuclides, dyes, phenol-substituted protein anions, and other contaminants are removed by using derivatives of chitin and chitosan (Bhatnagar and Silanpaa 2009).

8.4 Nutraceuticals and Flavoring Agent

Leucine, an important amino acid, has been found in shrimp head hydrolysates, which are suitable in the animal feed industry. Glutamic acid, aspartic acid, alanine, and glycine in shrimp head hydrolysates also act as flavor enhancers (Randriamahatody et al. 2011).

8.5 Removal of Metal and Dye from Wastewater

Wastewater from a range of industries, including mining, textile, leather, paper, and plastic, contains metal, acid, and dye (He et al. 2020). Through the food supply chain, these heavy metals can be consumed by living things and passed on to people, posing health risks (Nunez-Gomez et al. 2017). Since these poisons are poisonous and challenging to remove from contaminated water, they represent a serious risk to living things and the ecosystem as a whole (Druzian et al. 2019). To remove Fe, Al, Mn, Co, and Ni from mine-affected water, the idea of using shrimp shell powder as a biopolymer was taken into consideration (Nunez-Gomez et al. 2017). Due to the high chitin and calcium carbonate content of shrimp shell powder, it successfully removed heavy metals from mine-affected water (Nunez-Gomez et al. 2017). A cheap and efficient adsorbent for extracting heavy metals from wastewater may be debris from shrimp shells. Shrimp waste was used to extract chitosan, and ionic gelation techniques were used to create chitosan nanoparticles (Ali et al. 2018). The efficiency of the freshly created nano-chitosan particles in removing Fe (II) and Mn (II) ions from water was tested. The outcomes demonstrated that nano-chitosan had a 99.8 and 95.3% efficiency in removing Fe (II) and Mn (II) ions, respectively, with adsorption capacities of 116.2 and 74.1 mg/g (Ali et al. 2018). Shrimp shell waste was processed into hydro char (SHC) utilizing the deproteinization and deacetylation method, then hydrothermal carbonization (Nirmal et al. 2020). This carbon-rich hydrochar created from shrimp shell waste has the potential to be a starting point for energy- and carbon-sequestering technologies (Kannan et al. 2017). Additionally, shrimp shell waste and its active components have a variety of uses. For example, shrimp waste's chitosan can be used to remove radioactive materials, create artificial fish bites, destroy benzene, and act as an oil spill dispersion (Rostamian et al. 2019).

8.6 Plankton Production in Aquaculture Ponds

Using a natural fermentation technique, the underutilized fish processing waste was cost-effectively converted into fish hydrolysate. Utilizing them as bio-organic manure, liquid organic fertilizer, feed additive, feed supplement, and feed binder during feed technology has improved their value. According to Sahu et al. (2014), the nutrients include calcium (2.24%), magnesium (1.75%), phosphorus (1.98%), potassium (0.65%), sulfur (1.52%), boron (10.4 ppm), and nitrogen (2.95%). For growth and optimal production, plankton and fish food organisms need both macronutrients and micronutrients. A liquid organic fertilizer called fish hydrolysate (Planktofert) has all the necessary nutrients in exactly the right amounts. Micronutrients and macronutrients used in pond ecosystems at the recommended fertilization rate are economical, environmentally benign, and have no negative effects on the water's quality or fish growth (Sahu et al. 2014). Both macro and micronutrients are present in fish hydrolysate in a balanced way. It has macronutrients like N:P:K::1.5:0.5:0.4

and micronutrients like copper, magnesium, iron, and zinc (Sahu et al. 2014). At low inclusion levels, the application of fish hydrolysate generally has a positive impact on growth performance and feed consumption.

8.7 Energy Conversion Strategy

Because it offers a significant surface area for electrochemical processes, the porous carbon material is a useful electrode material for energy applications (Kannan et al. 2017). Chitin is a nitrogen-based polymer found in large quantities in shrimp shell waste that may be a rich source of porous carbon. The inclusion of heteroatoms (such as S and P) may also boost the electrochemical activity, catalytic effectiveness, and adsorption capacity of this supply of carbon with nitrogen (Zheng et al. 2021). Waste from shrimp shells was used to produce catalysts with a high specific surface area that were co-doped with phosphorus (Zheng et al. 2021). Moreover, the catalyst made from shrimp shells demonstrated superior long-term stability compared to its commercial counterpart. Therefore, N, P-doped catalysts based on shrimp shells may be effective in air–cathode microbial fuel cells for generating electricity (Zheng et al. 2021).

8.8 Biodegradable Plastic Production

Polyethylene and polypropylene, two plastic materials generated from petroleum, take a very long time to break down and are particularly bad for the environment (Elhussieny et al. 2020). It is therefore exciting to create biodegradable plastic from a natural biopolymer that may be broken down by bacteria, such as chitosan (Wang et al. 2018). In this case, glycerol was employed as a plasticizer while shrimp shell waste that had been extracted for chitosan and cassava peel starch were combined to create bioplastic (Saridewi and Malik 2019). The freshly created bioplastic was mechanically and physically robust and included 7% chitosan (Saridewi and Malik 2019). In a different study, Thammahiwes et al. (2017) used either calcified or uncalcified shrimp shell powder (2.5%) as filler for the production of bioplastics based on wheat gluten (WG). Consequently, trash from rice straws and shrimp shells could be used to produce biodegradable bioplastic from natural sources (Elhussieny et al. 2020).

8.9 Biogas Production

Biogas is made up of a variety of substances that are broken down during anaerobic digestion, namely methane CH_4, carbon dioxide CO_2, hydrogen sulfide H_2S, and hydrogen H_2. Due to its high level of organic carbon, fish waste has the potential to be an acceptable source for the creation of methane. Biogas generation is however constrained by the high ammonia nitrogen content in fishery biomass. Co-digestion can be used to handle fish waste anaerobically. The right co-substrate mixture composition is the main problem with the co-digestion process. The C:N ratio, macro- and micronutrients, pH, biodegradable organic matter, hazardous chemicals, and dry matter are a few of the critical factors that must be in balance (Tomczak-Wandzel et al. 2013).

8.10 Biofertiliser Production

Anaerobic digestion waste is also recycled as a vital supply of a nutrient-rich substance as biogas facilities which become more popular. Digestate can be used as a biofertilizer after a few unit operations. The digestate still contains elements like nitrogen, phosphorus, and potassium. Fish waste contains high-quality digestate, which can be used to make fertilizer for farms. To acquire the proper level of NPK, the final by-product of digestion is mixed with organic waste using the same minerals as the original transformation (nitrogen, phosphorous, and potassium). Biogas plant waste enables us to conserve energy, lessen our carbon impact, and use fossil fuels less frequently. As a result, co-digested waste and biofertilizer quality are connected (Koszel et al. 2015). Fish hydrolysate, also known as "Planktofert" and "Shelfifert," is a natural liquid fertilizer for fish that contains more than 40 trace minerals and elements. The underutilized fish processing waste is a great resource for making organic fertilizer with additional value and bio-additives.

8.11 Bio-oil/biodiesel Production

Fish oil is produced in significant amounts by the fish processing sector. This waste product might be converted into renewable energy. Due to the high hydrogen and low carbon content of fish oil, a lot of research has been done on its potential as a fuel. Fish bio-oil is a viable fuel for diesel engines due to its properties. It is higher quality and has a higher heating value than methyl-esterified vegetable oil waste, which is conventional diesel fuel. Diesel engines could be able to run on biodiesel made from fish waste, especially at low temperatures.

9 Recent Trends and Future Prospects in Aquaculture Research

The development of biotechnologies for the complete utilization of shrimp wastes still faces challenges and is constrained. The technical limitations of biocatalysts, biotransformation, and fermentation technologies include the restricted stability and reuse of enzymes, the difficulty of maintaining continuous reactions, and the constrained overall sample capacities. Although most shrimp waste is currently converted into animal feed, some of it is also turned into bioactive substances with additional value including chitin, chitosan, carotenoid, and protein. The fish meal, which was prepared from fish heads, skin, intestines, fins, gills, livers, kidneys, and scales, was determined to be mercury-free by Murthy et al. (2013). These compounds have also shown promise as base materials for catalysts, energy conversion, and wastewater remediation. Despite the fact that the recovered bioactive chemicals are known to provide a variety of biological benefits, including applications in food and medicine, their extraction calls for dangerous materials such as powerful acids and bases. Once more, the extraction procedure results in some dangerous wastes and effluents that endanger the environment. Therefore, the complete exploitation of waste without producing any new garbage is the direction that shrimp processing waste will go in the future.

10 Conclusion

Aquaculture waste can be treated by following a lot of techniques. Making biogas, biodiesel, and biofertilizer from non-recyclable fish waste is the best approach to handle sick or dead fish as well as mixed rubbish. The harmful biomass is also recycled and transformed into useful heat, power, or fuel. Fish viscera-based waste has the most potential for producing protein hydrolysate. Pigments, chitosan, and collagen separation for the cosmetics, culinary, biomedical, and pharmaceutical industries are some of the most well-liked contemporary uses of aquaculture waste. The various waste processing activities need additional inputs and outputs in order to recover energy and separate the necessary components from aquatic waste. A wide range of bioactive substances, such as chitin, chitosan, protein, carotenoids, polyunsaturated fatty acids, -tocopherol, and minerals, can be found in fish waste. These bioactive compounds, according to the literature, exhibit a variety of bioactivities, such as antioxidant, antimicrobial, anti-hypertensive, anti-inflammatory, and anti-proliferative ones. However, the feed industries frequently use these active substances to improve the nutritive content and practical qualities of foods. Functional foods can be made from bioactive ingredients that have healthful nutritional and nutraceutical properties, such as protein hydrolysate and astaxanthin. Fish waste has recently been transformed into hydro char, porous carbon, and nanopowder, all of which have uses in biochemical engineering fields such bioremediation, energy conversion, and the creation of bioplastics. Therefore, it is more likely that future fish waste use will concentrate on producing environmentally friendly energy and wastewater remediation.

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