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OVERVIEW ON THE WAYS TO LOSSES REDUCTION AND EFFICIENCY OF FISH PROCESSING

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Abstract

A detailed bibliographic study finds that fish is a very important human food, valued by its balanced content of protein, lipids, and biologically active components. From the up-to-date statistics, it finds out that fish represents an important percentage of human food and protein sources. However, fish, like many other animal food sources, represents a future problem. In the food industry, fish can be sold as such, preserved, or processed in different ways. During fish processing technology, fish by-products are also generated and this represents a problem for the food industry and for the environment also. Transformation of these by-products into different products or their use in other industrial applications can solve the problems and may become a sustainable solution for the industry. This bibliographic study represents the starting point of the food innovation process, by analyzing the actual use of the by-products as medicinal products, artificial pearls, fish skin, isinglass, glue, body oil, manure and guano, silage, soluble, flour, fins, biscuits, macaroni, sausage, ham, liver oil and others and finding new paths of developments in order to achieve the goal.

***Key words**: by-products, fish value chain, sustainability, waste management.*

INTRODUCTION

Current fishing practices result in 20 million tonnes of important resources being wasted every year. Even in this situation, vessels must retain on board and bring ashore both target and by-catch species (as required by EU legislation). Therefore, a significant amount of marine biomass of low economic value must be effectively managed to avoid wastage (Antelo et al., 2015).

The fish industry has grown steadily in recent decades and produces massive quantities of by-products. These by-products originate from fish heads, skins, viscera, fins and bones (Marti-Quijal et al., 2020).

Fish is a highly perishable food raw material due to its high moisture and nutrient content. Fish spoilage starts as soon as the fish dies and is the consequence of a series of complex chemical reactions taking place in dead fish, mainly produced by bacteria and enzymes (Subhendu, 2013).

Large quantities of waste, comprising water and solids, are produced in fish processing. The solid waste include 50-70% of the composition of the raw materials, and depending on the technological process used, this waste will constitute a mix of various components: bones, skin, viscera and head that can replace valuable resources (Ahmadi et al., 2021).

Traditional fish by-products are: fish meal, fish glue, fish body oils and fish liver oils, sideful, gelatine etc.

Protein concentrate, gelatine, albumin, glue, pearl sideful, peptones, amino acids, protamine, skin are also by-products obtained from fish and fish waste processing (https://agritech.tnau.ac.in/fishery/fish_byproducts).

MATERIALS AND METHODS

This scientific paper presents a review of the most relevant articles in the literature on reducing the amount of fish waste by obtaining by-products, especially value-added products. The effects of the valorisation of fish by-products on related industries have also been studied.

The fish by-products studied come from the processing of capture fish as well as by-catch fish.

RESULTS AND DISCUSSIONS

During fish processing, fish by-products are generated, which are a problem for the food industry and the environment. Converting by-products into different products or using them in other industrial applications can solve the problems and become a sustainable solution.

This literature study presents new starting points of the food innovation process by analysing the actual use of fish waste and fish by-products.

Fish filleting yields can range from 39% to 55%. Differences in fish filleting yields are a reflection of anatomical and structural differences in processed fish, with effects on fish marketability (Okomoda et al., 2021; Nicolae, 2022).

Several value-added products, such as nutraceuticals or enzymes, might be achieved from a wide variety of fish species through various valorisation processes. Fish enzymes, chondroitin sulphate and biopeptides have been shown to be the most suitable by-products to be obtained due to the relatively low impact on the environment and their high selling price. Solid waste treatment technologies for the manufacture of fishmeal, gelatine and chitin should also be considered, which would reduce economic and environmental costs by exploiting unprocessed biomass (Antelo et al., 2015).

By-products of fish (viscera, skin, scales and bones) have been studied as potential raw materials for the separation of value-added compounds with usages in different domains. Hydroxyapatites and collagen could be produced from bones and scales, corresponding to a complete valorisation of these by-products (Ideia et al., 2020).

Zamora-Apodaca et al. (2020), obtained peptide fractions from by-products of various fish species by hydrolysis of soluble collagen. Because they exhibit functional (solubility, emulsification, foaming) and biological (antimicrobial and antioxidant) activity, these fractions represent an alternative for the production of functional foods and products for the pharmaceutical or medical industries.

The components of fish bones are organic and inorganic in nature. In biocompatibility tests by Adamiano et al. (2023), collagen extracted from bones was shown to have potential for cell regeneration. At the same time, different forms of calcium phosphates were obtained whose biocompatibility recommends them for use in cosmetic and biomedical applications.

Food industry

By-products and waste products from fish processing are important sources of protein and various nutrients. When exploiting them, one can consider obtaining myofibrillar fish proteins, homogenized and concentrated (Cercel et al., 2015; 2016).

Antioxidant peptides have been identified in solid waste from fish sauce industrialization. The results showed that fish sauce as a by-product contains a high amount of proteins, i.e. peptides with antioxidant activity.

Most of the peptides in proteins have relatively low molecular weight and strong antioxidant activity (Choksawangkarn et al., 2018).

Fish waste is considered to be a source of high nutritional value due to its rich protein and essential amino acid content. Benhabiles et al. (2012), researched the possibilities of optimizing the process of obtaining fish protein hydrolysate (FPH) from solid waste using enzymatic hydrolysis and crude pepsin.

Hydrolysates of fish proteins can be used as food additives and food ingredients that impart desirable properties to processed foods. These include emulsification, increasing storage stability, foaming or dispersion in creams, sausages, beverages, salad dressings, mayonnaise, etc. Studies on bioactive compounds of hydrolysed proteins are recommended for establishing potential market share, pharmacology and human nutrition, feed additives and/or supplements (Halim et al., 2016).

In a study conducted by Garcia-Moreno et al., in 2014, on five fish species from the Mediterranean Sea, it was found that these species have a lipid content between 4.6 and 25.3%. These can be used as raw material to obtain protein hydrolysates with antioxidant activity.

Three antioxidant peptides were extracted from grass carp skin (*Ctenopharyngodon idella*) by hydrolysis and the use of Alcalase. The peptides obtained, consisting of 5 or 6 amino acids, showed free radical scavenging activities. Grass carp skin protein hydrolysate has the potential to be used for medicinal purposes and food preservation (Cai et al., 2015).

Ahn et al., in 2014, identified an octapeptide from salmon pectoral fin proteins that exhibited antioxidant activity. The octapeptide has the capacity to remove 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals and significantly protect against liver damage produced by hydrogen peroxide in Chang liver cells and DNA damage produced by hydroxyl radicals.

The proteins of fish by-products represents an important bioactive peptides source, and alternatives as ingredients of functional food.

Ennaas et al., in 2015, demonstrated that Gram-negative (*Escherichia coli*) and Gram-positive (*Listeria innocua*) bacterial strains can be totally inhibited by antibacterial peptides from Atlantic mackerel (*Scomber scombrus*) by-products. These results showed that this protein hydrolyzate can be used as an antimicrobial ingredient in both nutraceutical and functional food applications.

The use of oyster mushrooms (*Pleurotus ostreatus*) in making fish burgers from salmon (*Salmo salar*) and striped catfish (*Pangasianodon hypophthalmus*) as a by-product of filleting has proven to be a suitable strategy for technologisation. Thawing losses and thermal processing yield of the products were improved by incorporating 10-15% mushrooms, as the polysaccharides contained in mushrooms improve water retention capacity in frozen products. When mushrooms were added the textural properties (especially hardness) change due to retained water. An improvement in the oxidative stability of frozen burgers was achieved and the acceptability of the products to consumers was not affected. The use of mushrooms resulted in a higher number of microorganisms, but maintained at an acceptable level (Pachekrepapol et al., 2022).

Abdollahi et al., in 2020, evaluated the potential of cross-processing salmon or herring by-products with lingonberry press cake, shrimp peeling by-products and brown seaweed (called "helpers") to minimize lipid oxidation process during alkaline/acid protein isolation with pH change. It was observed that using lingonberry press cake and changing pH significantly reduced aldehydes and hydroperoxides in salmon and herring by-products. The cross-processing concept has the advantage that by using berries and seaweed, lipid oxidation is reduced and the 'clean label' requirements of the food industry are met.

Medicine and pharmaceutical products

Fish by-products is considered an important source of proteins and amino acids with high potential for new nutraceuticals development who can substitute or minimise the possible harmful effects of synthetic drugs. Peptides from protein hydrolysates obtained from fish waste and by-products show bioactivities with antihyperglycemic, anti-inflammatory, antihypertensive, antimicrobial or antioxidant actions. The use of fish waste proteins can minimise the potential pollution of fish waste and develop a high value-added product from a abundant and cheap raw material (Zamora-Sillero et al., 2018).

Cudennec et al. (2008) analyzed the effect of hydrolysates protein extracted from brown shrimp (*Penaeus aztecus*) and blue whiting (*Micromesistius poutassou*) on cholecystokinin released from intestinal endocrine cells. Peptide molecules in fish hydrolysates have been observed to strongly increase cholecystokinin secretion from intestinal endocrine cells. In order to industrially use protein hydrolysates as potential appetite suppressants, should be further studied in both lab rats and humans. The endogenous enzymes obtained from bluefin tuna (*Auxis rochei*) viscera were used to produce bioactive hydrolysates. Ben Maiz et al. (2018) analysed the bioactive and functional characteristics of hydrolysates made at different degrees of hydrolysis. The endogenous enzymatic hydrolysates obtained by low-cost treatment were compared to those made with subtilisin (a commercial enzyme). Functional characteristics of endogenous enzyme hydrolysates were similar or better than subtilisin hydrolysate. Endogenous enzyme hydrolysates have demonstrated antioxidant properties such as free radical scavenging activity and metal reducing activity.

Since hypertension is a high frequency condition and synthetic angiotensin I inhibitors have undesirable side effects, research has been undertaken to obtain angiotensin I inhibitory peptides from fish by-product proteins.

Qian et al., in 2007, isolated angiotensin I, a converting enzyme inhibitory peptide from dark muscle of tuna hydrolysate processed with papain, pepsin, neutrase, alkalase, α-chymotrypsin and trypsin. The pepsin derived hydrolyzate showed the highest angiotensin I inhibitory activity compared to those of the other enzymatic hydrolysates. The peptide had an antihypertensive effect with a maximum decrease in blood pressure detected, 3 hours after oral administration at a dose of 10 mg/kg body weight in hypertensive rats. The results suggest that the peptide derived from dark tuna muscle is a beneficial ingredient for pharmaceuticals or functional foods with an effect against hypertension and its related diseases.

Collagen extracted from Atlantic salmon skin (*Salmo salar*) was hydrolyzed with papain and Alcalase and treated by multi-step isolation. Major fractions of the obtained collagen peptides were collected and their inhibitory activity on angiotensin I converting enzyme was tested. Only two fractions showed inhibitory activity on the conversion enzyme. The results suggested that collagen peptides may be useful as antihypertensive agents and in functional foods (Gu et al., 2011).

Choonpicharn et al. in 2015 demonstrated that gelatin hydrolysate from the skin of Nile tilapia (*Oreochromis niloticus*) can be used as a potential functional antihypertensive agent. Research has shown that trypsin and aromatic hydrolysates have high antihypertensive activity.

Chuesiang and Sanguandeekul, in 2015, evaluated the inhibitory and antioxidant activities of angiotensin I converting enzyme according to hydrolysis time in the production of a protein hydrolysate from tilapia and the effect of varying aminopeptidase concentration. Hydrolysis time and enzyme concentration significantly affected the inhibitory and antioxidant properties of the converting enzyme. 1hour use of 2% (g/g) Flavourzyme® 1000 L for produced the highest levels of free radical scavenging (90.4%), angiotensin I converting enzyme inhibition (83.8%) and metal chelating (91.8%). The functionality of food products can be improved by using protein hydrolyzate as an ingredient.

Ahn et al., in 2012, showed that peptide hydrolysates from by-products salmon of may be useful as an ingredient in functional foods and/or pharmaceuticals. Peptide hydrolysates exhibited antioxidant activity, significantly inhibited the generation of intracellular reactive oxygen species, lipid peroxidation and improved glutathione levels in Chang liver cells and did not show cytotoxic effects on Chang liver cells or macrophage cells. They also exhibited anti-inflammatory activity by inhibiting the formation of nitric oxide and pro-inflammatory cytokines, including tumor necrosis factor-α, interleukin-6 and -1β in macrophage cells.

An important source of omega-3 polyunsaturated fatty acids with many benefits for human health is fish oil. It is obtained from by-products of the fishing industry or fish from whole fisheries, from various extraction methods. The oil must be purified to meet acceptable quality standards for human consumption. The refining process removes unwanted compounds: proteins and their degradation products, hydrocarbons, carbohydrates, pigments, mono- and diglycerides, phosphates, steroids, guaranteeing the purity and stability of the oil. During the refining process, phospholipase enzymes are used in the oil degumming process to hydrolyse phospholipids without hydrolysing triglycerides and releases fatty acids into the oil, resulting in less loss. This procedure has been proven to have no negative impact on the environment and has a higher yield compared to chemical degumming. Based on the results obtained, the refining process by enzymatic degumming as the initial stage, is considered a beneficial alternative for improving the physical-chemical characteristics of the oil, while also maintaining the nutritional characteristics (Lamas, 2022).

Ozyurt et al. in 2017 analysed the fatty acid composition and lipid quality of fish oils recovered from sea bass (*Dicentrarchus labrax*) waste, produced with five different strains of bacteria (*Streptococcus* spp., *Lactobacillus brevis, Lactobacillus plantarum*, *Enterococcus gallinarum* and *Pediococcus acidilactici*) and formic acid, in terms of safety for human consumption. In general, it was found that there were no appreciable differences in the unsaturated fatty acid content of the fish oils. Fermented fish waste silage was shown to have a better initial lipid quality than acid fish waste silage lipids. Thus, fish oils recovered from fermented silages can be used as food supplements for humans and animals or food additives.

Fish viscera are a significant source of biomolecules, such as lipids and proteins. Studies have been conducted to evaluate fermentation ensiling as a method of oil recovery from freshwater fish viscera. The total recoverable fat content of the viscera ranged from 19% to 21%; up to 85% of it by fermentation. Regarding oil recovery and fatty acid composition of the recovered oil, fermentation with added lactic cultures (*Pediococcus acidilactici* K7 and *Enterococcus faecium* HAB01) did not differ from natural fermentation. During fermentation the activity of neutral alkaline and acidic protease decreased. Although the degree of protein hydrolysis increased during fermentation, no differences in oil recovery were noted, the highest degree being recorded in the *Pediococcus acidilactici* K7 fermentation (62.3%). The rate of change in degree of hydrolysis decreased as protease activity decreased (Rai et al., 2010).

Ahmadkelayeh et al. in 2022 they studied the extraction, using fish oil depending on the process conditions (temperature, time and oil-to-waste ratio) and pretreatment (drying) of astaxanthin from by-products of Atlantic shrimp (*Pandalus borealis*). A higher yield of astaxanthin in the extract is a consequence of the lower water content in the by-products.

A source of valuable compounds such as hydroxyapatite is the solid waste generated during industrial fish processing. This calcium phosphate is used in the development of biomedical materials due to its biocompatibility with biological and physicochemical properties similar to those of human bone. To improve their bioactive, mechanical and structural properties, hydroxyapatite has been combined with many other chemical compounds. It has outstanding application benefits in the fields of dietary supplements, dentistry, medicine, bone implants and cosmetology. The isolation of hydroxyapatite and the development of products with health benefits are being studied. Hydroxyapatite derived from industrial fish processing, obtained by hydrolysis and calcination, reduces the environmental risks caused by dumping aquatic waste in landfills and adds value to the by-products. (Hernandez-Ruiz et al., 2022).

Animal husbandry

For the production of animal feed (fish meal and fish oil), the aquaculture sector still depends on marine fishing. In 2006-2007, a worldwide survey was conducted on the use of fish oil and fish meal in aquaculture. This survey was started in more than 50 countries and involved 800 feed producers, fishing specialists, researchers, farmers and other people of interest. The survey carried out in 2006 estimated that the use in the aquaculture sector was 835,000 tons of fish oil and 3,724,000 tons of fish meal, respectively 16,600,000 tons of small pelagic forage fish, with a total fish-in fish-out ratio of 0.70. The ratio of small pelagic forage fish per unit of farmed crustacean or fish production showed a steady decrease for all farmed fish species from 1995 to 2006. The biggest declines were in carnivorous fish species such as eel, trout, salmon, salt-water fish and, to a lesser extent, shrimp (Tacon et al., 2008).

Since fishmeal is a major source of protein in aquaculture diets, Saadaoui et al. in 2019 aimed to optimize the hydrolysis of tuna protein to obtain ingredients for these feeds. Free amino acids and fish protein hydrolysates (FPH) have been shown to be useful in increasing feed assimilation and larval development. By optimizing the operating parameters, a fish protein hydrolyzate with the desired molecular weight profile (depending on the specific needs of the farmed species) was made.

The use of tuna by-products as a protein source in tilapia (*Oreochromis niloticus*) aquaculture represents an option to reduce feed costs. Kim et al. in 2019 conducted a study to identify the concentration of heavy metals in tuna by-products. These were found to be safe for use as fishmeal as the safety levels of cadmium and mercury in their composition were not exceeded.

In China, processing fish waste yields up to 650,000 t fishmeal. Even though its protein content is lower (58%) than that of high-quality fishmeal (70%), it can be used to feed low trophic fish. Fishmeal derived from waste of fish is a good source for the culture of various tilapia (*Oreochromis niloticus*) and carp species - common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*). Trout guts from evisceration are a good source of fatty acids for sea bream (*Sparus aurata*). Prior to processing, thermal sterilisation of fish waste is recommended to inactivate microorganisms or pathogens present (Mo et al., 2018).

Ozyurt et al. in 2019 he investigated the impact of the fermentation stage by spraying with strains of lactic and acid bacteria (*Streptococcus* spp*., Enterococcus gallinarum, Lactobacillus plantarum, Pediococcus acidilactici* and *Lactobacillus brevis*) on the formation of biogenic amines in dry and wet fish silos. The silages studied were produced from the processing of whole ponyfish (*Equulites klunzingeri*), crucian carp (*Carassius gibelio*) and by-products of sea bass (*Dicentrarchus labrax*) processing. The results showed that among the biogenic amines, agmatine, spermine, dopamine, spermidine, cadaverine, serotonin and putrescine were predominant in all groups. Wet fish silage and raw fish contained low levels of histamine. No histamine was found in dried fish silage, and a small amount of histamine was found in sea bass by-products. In both wet and dry form, fermented fish silage has potential for use as a protein source and possibly as a probiotic ingredient for animal feed.

An alternative process for the use of fish waste is the use of fish silage, obtained by fermentation with lactic acid, in quail feed. The introduction of this silage in the diet of quails did not negatively modify the production indices, the sensory quality of the meat or the carcass yield. With the inclusion of silage in the diet, the polyunsaturated fatty acid content of quail meat increased. For the reduction of environmental problems and the use of fish waste, the biological production of fish silage is a beneficial biotechnological process (Ramirez et al., 2013).

The valorization of waste of fish in insect rearing is a unique approach that helps aquaculture in achieving the lasting purpose of replacing fishmeal in aquaculture. Chaklader et al. in 2021, showed that Asian perch (*Lates calcarifer*) can better utilize nutrients from diets containing poultry by-product meal mixed with meal from larvae reared on fish waste. Negative effects on the amino acid composition of fish muscles were not recorded, and total protein and albumin were qualitatively increased by these diets. Incorporation of larval meal and poultry meal allowed for the complete substitution of fishmeal in the diet of Asian sea bass, potentially easing the pressure to eliminate marine fisheries and use fish waste, which is much more cost-effective from a circular economy point of view.

Agriculture

Fish waste is a suitable material for composting to ensure sustainable agriculture and its integration into the circular economy.

Radziemska and Mazur in 2015 followed the effects of composting fish waste with manure and mineral fertilizer on the performance and chemical composition of aboveground parts of maize (*Zea mays*). Compost variants composed of fish waste (79.3-80%) to which sawdust, straw, pine bark, lignite were added in varying proportions were made. The highest yield in maize harvesting was obtained from composts containing fish waste, straw and lignite, and fish waste, bark and lignite.

Increased yield and mineral composition of lettuce (*Lactuca sativa*) using compost consisting of 80% fish waste and 20% pine bark was studied by Radziemska et al. in 2018. It was found that adding the fertilizer to the soil increased lettuce leaf production and resulted in significant increases in the nitrogen, magnesium, calcium, sodium, potassium and phosphorus content of the plant leaves.

A potentially valuable use of fish waste is its composting in combination with seaweed and pine bark. This results in a natural and non-limiting fertilizer that can be used successfully in organic farming systems (Lopez-Moschera et al., 2011).

Chemical industry

Artists and craftsmen have used fish glue as a natural adhesive since ancient times. Fish glue can be extracted from various parts of the fish, including the skin, bones, and swim bladder. The Egyptians, as far back as 3500 years ago, briefly described the process of obtaining glue from fish by thermal melting and brush application. Since the 8th century fish glue has been recorded as a painting material for illuminating parchment manuscripts. This product has been used in the preparation of adhesives and binding media, the raw material being commonly available fish protein. Published scientific materials and practical recipe books focus on the use of fish and animal adhesives in the restoration and making of objects, illuminated parchment manuscripts, paintings, icons and other artefacts (Petukhova, 2000).

Fish glue obtained from the swim bladders of tropical fish is used to clarify alcoholic beverages. It is obtained by solubilisation in organic acids and has predominantly collagen in its composition. Because thermal denaturation of collagen in fish glue occurs at 29ºC, it is less used than mammalian collagen (Hickman et al., 2000).

The large amount of packaging polluting the environment has prompted the search for innovative solutions. As a result, Florentino et al., in 2022, found that myofibrillar by-product proteins of sawfish (*Pristis pectinata*) and yellow passion fruit peel pectin have suitable chemical characteristics as feedstocks for bioplastic production. The film thus developed can be used as biodegradable primary food packaging.

Scottish researchers have investigated obtaining adipic acid from salmon waste using biological enzymes and then genetically modified bacteria. Adipic acid is a basic ingredient in nylon, but it is also used in other products, including polyurethane-based products used in construction, furniture upholstery, lubricants and pharmaceuticals (https://www.thechemicalengineer.com/news/research-could-see-fish-waste-used-for-nylon-production).

Bioenergy

As the fish farming industry expands rapidly, the by-products resulting from fish oil refining are enjoying increased interest, offering opportunities for bioenergy generation. Some of the by-products of fish oil refining have been studied, such as ethyl monoesters, glycerol and soap. Sarker (2020) investigated the profitability of anaerobic digestion of these by-products as co-substrates with silage of fish (acidified waste of fish). During the experiment, it was found that the volumetric yield of biogas produced (in milliliters) from the co-digestion of monoesters and silage of fish was much higher than that of the monodigester made only with silage of fish. The highest specific biogas yield was obtained of the co-digester with soap stock. The average calculated biogas methane content for all digesters used throughout the experiment was approximately 61%.

Freitas de Medeiros et al. (2019), produced biodiesel using oil resulted from fish processing waste. The experiments conducted used two different methods of biofuel production. Fish residue was thermally treated to extract fatty material, and biodiesel was made by heating it, stirring it, and ultrasonic wave-assisted heating and stirring methods. The best quality biodiesel was produced with heating and stirring, the method having reaction times of 30 and 60 minutes and the yields being 92.37% and 97.95%. The highest biodiesel yield for the ultrasonic method was at a frequency of 20 kHz, with a sonication time of 2 minutes. High concentrations of sodium, potassium and magnesium were found in biodiesel produced from fish waste. In addition, the production of biodiesel from a waste with a high probability of contamination for the environment, such as fish waste, promotes economic and social development.

The possibility of producing biogas from waste of fish as a source of renewable energy was also evaluated. Four concentrations of fish waste (1%, 1.5%, 2% and 2.5%) were used and fermented for 28 days under mesophilic conditions. The economic and energy analyzes estimated an annual production of energy thus produced of 489 MWh. The research results demonstrated that biogas production from waste of fish is a sustainable and viable choice for the proper management of this material and the provision of renewable energy (Cadavid-Rodriguez et al., 2019).

Choi, in 2020, investigated the consequences of anaerobic co-digestion of fish by-product broth mixed with sewage sludge on sludge reduction and biogas production. The 5:5 mixing ratio of broth and sewage sludge produced a recovered energy of 4.1 kWh and generated the highest removal of total solids, volatile solids and chemical oxygen demand. The 5:5 mix ratio is proposed because it can recover the largest amount of energy, can handle larger amounts of fish by-products and is the most efficient. Biogas produced by mixing sewage sludge with fish by-product broth increases the possibility of biogas production using organic waste due to the increased content of methane contained.

Currently, only a fraction of fish waste is used for biofuel production, and most of the waste is dumped on land and in water. Waste fish oil can be used as a potential source for biofuel production after its recovery. Biofuels from fish waste could ease congestion caused by other potential sources of biofuels, due to their low cost. The fatty acid composition of fish varies depending on the type and season, so the quality of the resulting biofuels can vary. The technique used for biofuel production is catalytic esterification, as it can be operated efficiently in a shorter time and at low temperatures. Glycerol is a by-product with extensive requirements in various industries and an extraordinary use in them. In addition, research has demonstrated that biofuels derived from waste of fish have characteristics comparable to biodiesel used according to international standards. Transesterification is a method used to make biofuels and has proven to be a cost-effective method by producing a large amount of biofuel in a short time. However, new strategies need to be developed and implemented to support businesses and fish marketing units by decreasing the amount of discarded waste (Saravanan et al., 2023).

CONCLUSIONS

Fish by-products have great potential for use.

Fish is an important food source for mankind. After processing, a number of by-products are obtained that can become waste or value-added products.

Making more efficient use of by-products of fish is a long-term strategy in the context of increasingly limited resources, high levels of pollution and the desire to increase economic profitability by exploiting unconventional resources.

More research is needed to increase the efficiency of fish by-product recovery and decrease or eliminate existing losses in the fish processing industry.

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