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AQUACULTURE WASTE MANAGEMENT

Abstract
Fish and seafood production has grown steadily in the past five decades. Total world fisheries and aquaculture production reached 167.2 million tonnes in 2014 [1]. Intensive fish production triggers growth in the amount of waste processing, which has serious environmental impacts. Utilization and energy recovery from fish waste have become areas of interest for the global economy. Specialized methods and techniques have been developed to acquire biomethane, biodiesel and biofertilizer from fish biomass. Also, using physical, biochemical and thermochemical processes, relevant substances (such as fish protein hydrolysate, natural pigments, chitosan and collagen) can be obtained.

Key words
fish waste uses, fish waste management, biogas, collagen, chitosan

Introduction

One of the biggest global challenges humanity currently faces is global warming. According to the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) analysis, 15 of the 16 warmest years ever recorded occurred during the last 35 years [2]. Rising surface temperatures on the Earth are caused by the increased emission of greenhouse gases related to human activity. Waste generation and management have serious environmental impacts. Furthermore, the rising human population will produce an increasing amount of waste. Decaying organic waste generates large quantities of carbon dioxide and methane, which contribute to climate change. Industry waste obtained from the fishing sector could be used as a renewable resource.

Fish and seafood are major sources of food and nutrition and are part of a healthy, balanced diet. The fishing sector provides an income and livelihood for hundreds of millions of people around the world. A new record in world fish consumption of 20 kg per capita was reached in 2014 [1]. Unfortunately, the rapid increase in fish production is connected with farm-raised rather than wild-caught fish. The aquaculture waste generated is very heterogeneous in its properties and form, depending on the region and species. Many factors influence the quantity and quality of the waste, such as fish size, season, rearing techniques, husbandry, catching and manufacturing methods. More than 50% of the residuals from the total fish capture is unused as nourishment and involves near 32 million tonnes of waste [3].

The type of culture methods also plays a key role in defining fish waste and in choosing the most effective method to transform them into a usable product [4]. Intensive marine fish farming maximizes the number of fish in the smallest possible area. Big fish farms produce enormous amounts of particulate organic waste and soluble-inorganic excretory waste [5]. After processing or industry treatment, the remainder represents near 50% of the tonnage utilised to production. The disposal consists of fish offal such as heads, frames, tails, skin, lugs, bones, fins and viscera.

Fish industry waste is thought to be the main source of biofuel in near future. The growing production of waste and requirements to use renewable energy sources force governments to implement waste management programs. In addition, the waste management sector is obligated to reduce landfilling for residual disposal. Fish waste might be an important source of environmental contamination, provoking the need for specialized methods for transforming fish disposal into a usable product.

Fortunately, energy recovery from fish processing waste is gaining popularity. Many developed countries use anaerobic digestion as an approach for fish waste treatment. Decaying solid biomass generates a large amount of methane, which can be transformed into thermal and/or electrical energy. In addition to electricity or heat, there is a possibility to obtain selected substrates for the cosmetics, pharmaceutical and food industries from fish waste. The recovery of merchantable by-products from aquaculture wastes plays a key role in waste reduction strategies. In the current study, different fish waste management scenarios were described in the form of a mini-review. The main target of this review is to compare existing solutions for industrial implementation and choose the optimal treatment for fish waste.

Waste management

Fish Waste Management focuses on the generation, treatment, specification, controlling, prevention, handling, reuse and ultimate residual disposition of fish waste. Over the past 30, years many directives were initiated under the auspices of the European Union. These directives refer to the management of aquaculture waste and the environmental impacts of fishery brands [6]. The growing utilization of by-products requires the implementation of guidelines for fishery policies. However, an optimal waste management system depends on both the costs and predicted benefits.

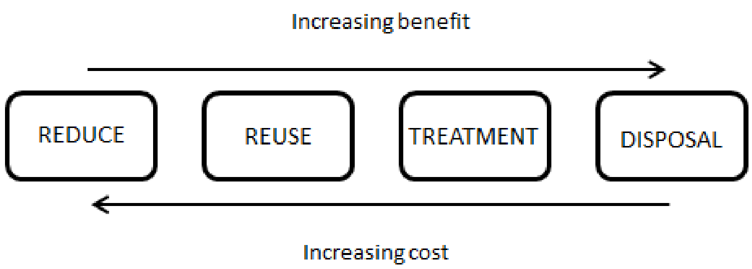

Fig. 1. The priories for fish waste management
Source: Author's

Aquaculture and related industries process waste, which is suspected to pose a significant risk to the ecosystem. To mitigate pollution, appropriate technologies should be used. The conversion of these wastes and the simultaneous recovery of significant materials before disposal become the main aim for fishery management [7].

Biogas

Biogas consists of different compounds, mostly methane CH_4, carbon dioxide CO_2, and a little hydrogen sulphide H_2S and hydrogen H_2, that are produced by the breakdown of using anaerobic digestion. Fish waste is potentially an appropriate source for methane production due to its high content of organic carbon. However, fishery biomass is high in ammonia nitrogen, which limits biogas production. There is a possibility to apply anaerobic treatment of fish disposal using co-digestion. The key issue for the co-digestion process is the proper composition of the co-substrate mixture. It is important to balance the main parameters such as the C:N ratio, macro- and micronutrients, pH, biodegradable organic matter, toxic compounds and dry matter [8].

A general scheme of biogas production is shown below (see Fig 2.) Biogas plants treat different types of biodegradable waste, including energy crops, animal manure, sewage sludge, organic residues and municipal solid waste. The co-substrate mixture requires processing such as chopping, liquefying, mixing and inoculation. Biogas technology involves a fermenter, temperature, hydraulic retention time, amount of substance and shut off from light and air. The quality of biogas is determined by the percentage composition of CH_4, CO_2, NH_3 and H_2S.

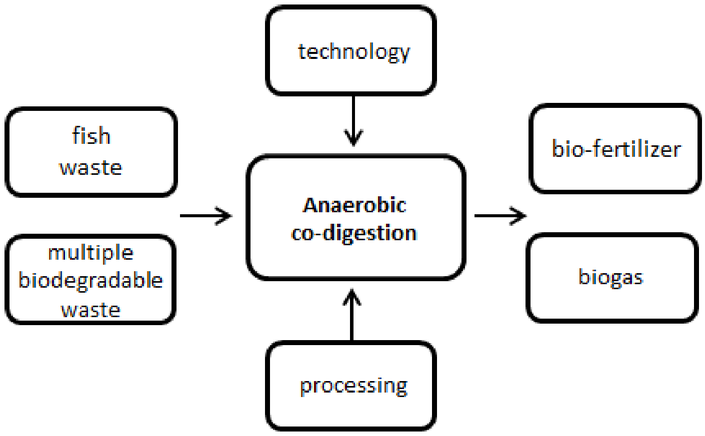

Fig. 2 Anaerobic co-digestion of fish waste
Source: Author's

The most commonly used tool to measure the anaerobic degradability of a feedstock is the Biochemical Methane Potential (BMP) test. The BMP creates batch digestion, in which substrates are incubated with anaerobic microorganisms. An indication of the rate of feedstock digestion is the precisely measured volume of biogas generated [9]. The main advantages of this method are simplicity, cost, repeatability and the short period of time to determine the appropriateness of a substrate for anaerobic digestion. The methane potential is showed in terms of standard temperature and pressure (STP) ml CH_4 per 1 g of VS added (mL CH_4 / g VS) [10].

Recently, many lab scale evaluations of BMP of fish waste were published. Most of theme relate to co-digestion of fish offal with animal manures, sewage sludge, organic residues and different food industry wastes. The aim of those works was to select optimal co-digestion substrates to improve biogas production from aquaculture waste. The research results demonstrate the optimal ratios of various co-substrates for the enhancement of methane potential [11]. The biochemical methane potential of various solid fish waste was also studied. Feedstock with 1% of total solids (TS) of waste had the highest methane production. It was very similar for sardine, tuna, and needle fish waste, likely due to higher fat content [12].

Despite the fact that research on using fish waste as a source of biogas production has promising results, there are limited industrial applications. High investments costs involved in building biogas plants and the limitation of biogas production due to high concentration of ammonia nitrogen in fish waste are likely factors.

Biofertiliser

As biogas plants grow more popular, the residues after anaerobic digestion are also reused as an essential source of a nutrient-rich substance. After a few unit operations, digestate could be applied as a biofertiliser. The properties of digestate depend on the nature and composition of the digested substrates [13]. Digestate consists of structural plant matter, process intermediaries, dead microorganisms and indigestible material. The total volume consists of more than 90% of the feedstock. Elements such as nitrogen, phosphorous and potassium remain in the digestate. Fish nutrient-rich waste has high-quality digestate, which could be transform into commercial fertiliser. The first step in the transformation is mixing the end-product of digestion together with organic waste using the same minerals to obtain the appropriate level of NPK (Nitrogen, Phosphorous and Potassium). The composition of digestate depends on the source materials and the digestion process, but the average values for nutrients are in a similar level [14]:

- Nitrogen: 2.3 - 4.2 kg/tonne
- Phosphorous: 0.2 - 1.5 kg/tonne
- Potassium: 1.3 - 5.2 kg/tonne

A mixture of thick liquid consistency is then dried using energy from the biogas plant. The last step of the process is to achieve small granulation of biofertiliser, which is important for practical use and for transportation and storage. Even though nutrients are more available for plants from raw slurry, biofertliser releases nutrients slowly and reduces their impact on the environment.

While post-digestion matter is rich in both organic matter and macro- and micronutrients, it can also contain heavy metals. The problem arises from anthropogenic sources as a part of the feedstock. The main origins of the heavy metals are fish farm waste, fat residues, domestic sewage, food industry, animal feed additives and flotation sludge. Research conducted in Europe shows that with respect to heavy metal toxicity, digestate seems to be a good candidate for a fertiliser. Although the total concentration of cooper, zinc and cadmium were at the limit set by European regulation, these elements after digestion were mostly unavailable for direct absorption by plants [15].

Sustainable agriculture is obligated to provide healthy and safe food using post-digestion matter instead of synthetic fertilisers. Residues from biogas plants save energy, reduce our carbon footprint and cut consumption of fossil fuels. Consequently, the quality of biofertiliser is related to co-digested waste. The only condition in using biofertiliser is the rational utilization of such residues [16].

Bio-oil/biodiesel

The fish processing industry generates large quantities of fish oil. This by-product could be used as a renewable energy source. Many studies have been carried out on the properties of fish oil as a fuel because of its high hydrogen and low carbon content. It has much lower kinematic viscosity and a higher flash point [17]. Bio-oil has appropriate properties as a fuel for diesel engines. Compared to traditional diesel fuel, it has a higher heating value and is higher quality than methyl esterificated vegetable oil waste. Biodiesel from fish waste could be used in diesel engines, mainly at low temperatures. The potential for biofuel from fish waste is a function of the location and size of the processing plant, type of fuel requirements, and characteristics of the fish waste. Biofuel is derived from biomass using many different chemical, biochemical, thermochemical, and physical processes [18].

The first process is pyrolysis of biomass. The thermal breakdown takes place at high temperatures (350–700 °C) in anaerobic conditions. Products of pyrolysis consist of biogas (CO, CO_2 and CH_4), biochar (carbon and hydrogen), and bio-oil (organic acids, alcohols, esters, alkenes, ketones, aldehydes, phenols, nitrogen compounds) Nowadays, fast pyrolysis is the most promising thermal conversion technology for biomass.
Fast pyrolysis lasts a few seconds, so heat and mass transfer parameters play key roles in the process. The selection of the apparatus is also important. The process, necessary preparation steps and types of products obtained are shown in the simplified scheme below (see Fig. 3.).

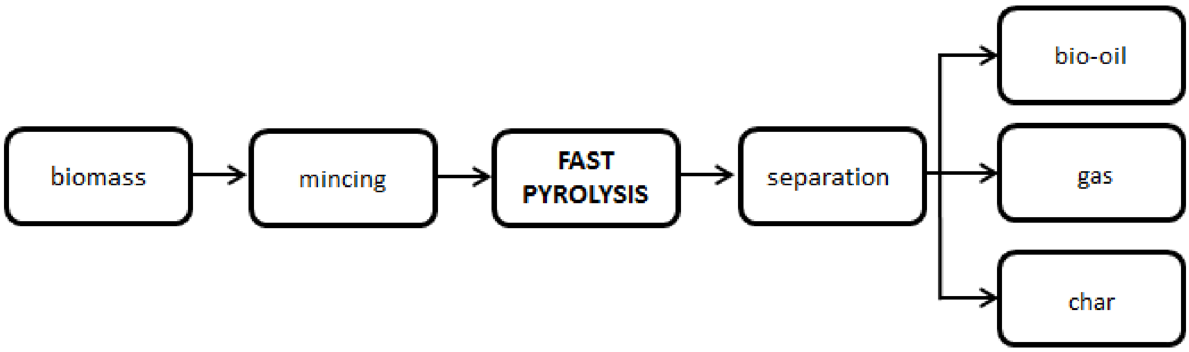

Fig 3. Fast pyrolysis process
Source: Adapted from IEA [19]

Afterward, the recovery of oil from waste biomass can be used in the fermentation and hydrolysis processes. Bacteria generate silage during the utilization of sugars or organic acids, where oil could be recovered as a by-product. Different steps are involved in oil extraction and oil refining to obtain purified bio-oil. They consist of various operation units as pressing, filtering, degumming, neutralizing, bleaching, hydrogenation and deodorizing [19].

The interest in processing of biomass for biofuel is steadily growing. Fish processing oil is predicted to be an alternative source for biodiesel. Despite the great potential of biofuels, there are technical and economic challenges. The specialized methods and very specific parameters of every unit process make the production problematic and relatively expensive.

Protein hydrolysate

Protein hydrolysis means breaking protein into peptides and free amino acids. Protein recovery became one of the main target for enzyme technologies due to the growing production and wide use of protein ingredients in the food industry. The main purpose of producing protein hydrolysates is to improve nutritional and biological value and to produce added value merchandise because of a wide variety of applications such as milk replacers, stabilizers in beverages, protein supplements and flavour enhancers [20]. The key process is to form specific size peptides, either by enzymatic or chemical methods [21]. Biological methods using enzymes are prevalent, and products of enzymatic hydrolysis have higher nutritive value and functionality.

To obtain hydrolysates from aquaculture industrial waste, the process is as follows: isolation or pre-treatments, hydrolysis, protein recovery (see Fig 4.). In each process, specific parameters should be fulfilled.

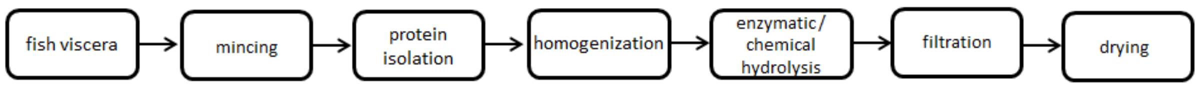

Fig. 4 Fish protein hydrolysate production
Source: Based on [22]

Proteins from animal sources are more nutritious than from plants due to the better balance of the dietary essential amino acids. A continuous development in protein hydrolysis resulted in obtaining the desired products for various applications. Many studies of amino acid composition and lipid profile confirm the high quality and nutritional value of fish protein hydrolysate. The food, pharmaceutical, agricultural, cosmetic, and nutraceutical industries commonly use protein hydrolysate. It could be employed as a protein source in diets for aquatic organisms and other farmed animals [23]. Finally, the solid material from enzymatic hydrolysis can be used as a fertiliser [24].

Natural pigments

Fish and aquaculture products have a diverse range of colour, which influences customers' decision to purchase them. One of the most important sources of natural carotenoids are shrimps and prawns. The increasing production of these types of seafood generates large quantities of processed industrial waste. The yellow, orange and red colour of the shell, skin, and exoskeleton of sea creatures is caused by carotenoids, one of the most commonly known natural pigments.

It is also present in yeasts, all green plants, bacteria, many animals and has various functions [25]. For humanity, the most important aspects of carotenoids are colour and their impacts on food and environment.

Carotenoids could be obtained from industry waste after shrimps, crabs, trout, lobster, crayfish, salmon, snapper and tuna processing. The pricing or grading of seafood is directly connected to the intensity of its red hue. Head and body carapace and the rest of shrimp waste are used for carotenoids extraction with different organic solvents such as methanol, isopropyl alcohol (IPA), hexane, ethyl acetate, ethyl methyl ketone, ethanol, petroleum ether and solvent mixtures like IPA and hexane or acetone and hexane at diverse extraction conditions [26]. Many directives instruct which colorants are safe for the food industry, what sources could be used for obtaining a particular colorant, what solvents might be applied and what purity degree of the pigment can be expected. Colorants are added to make food and drinks more attractive and to improve their stability [27].

The level of environmental awareness is still growing, more and more consumers avoid foodstuff containing synthetic colourants, which forces food industries to use natural pigments. Shrimps waste is a significant source of natural pigments, which could be applied in various products.

Collagen

Collagen is one of the most abundant proteins present in all living organisms and comprises nearly 30% of total protein content. This fibrous protein is responsible for the physiological functions of tissues in skins, bones, tendons and cartilages. Collagen has many applications in the food, cosmetic, pharmaceutical and biomedical industries. The commonly used gelatine is collagen that has been irreversibly hydrolysed. The popularity of collagen results from its excellent biodegradability, biocompatibility, and weak antigenicity [28]. Collagen is isolated mostly from by-products from animals, such as pigs, cows and poultry. Unfortunately, the high price severely limits its use, and there are also problems with sources of collagen according to religious beliefs such as those that forbid pork or cow by-products.

Aquaculture waste processing is a promising source of collagen, which reduces the costs of production and has a positive impact on the environment. Additionally, this type of an alternative source solves the problem with religious beliefs. Preparations of collagen from aquaculture by-products could satisfy kosher and halal requirements [29]. The increasing attention to fish industry waste (skin, scale, bone and others) is due to its high quality of collagen and its ability to serve as a good substitute for mammals.

Collagen from fish waste processing is generally obtained by the methods mentioned and described below:

- Acid and alkali extraction:

The skin prepared for the process is mixed with sodium hydroxide to remove proteins which are not collagenous. The skin is deproteinized and then demineralized using hydrogen chloride. The demineralized skin is then swollen by mixing the skins with acetic acid. After these processes, the skin is mixed with distilled water for various times and at different temperatures. Collagen is obtained from the mixture using filtration.

- Acid and enzyme extraction:

The scales and bones are soaked in sodium hydroxide. The insoluble substances are extracted with acetic acid. Centrifugation of the solution, sodium chloride addition and dialysis against acetic acid result in collagen obtainment. This method takes a long time (near 200h) and requires a large amount of chemicals.

- Extrusion cooking

The key parameters in this method are high temperature, short reaction time and high shear force. Many reactions take place during the extrusion process, such as protein denaturation, gelatinization, hydrolysis of protein, grinding, mixing, shearing, hydration, shaping, partial dehydration, expanding, texture alteration, destruction of microorganisms and other toxic compounds. Collagen extracted from fish scales has a weaker odour than from fish bone and skin. Fish scales consist of collagen and hydroxyapatite, which are tightly linked together [30] and are difficult to separate [31]. The extrusion–hydro-extraction process utilizes the typical extrusion which decomposes the intimate linkage between hydroxyapatite and collagen and simplifies the release of collagen from fish waste extrudes using water extraction. Extrusion cooking is an easy operation that requires little labour and costs and offers continuous production, high yield and multiplicity of products [32].

Fish processing waste clearly has potential to be an alternative source of collagen. It is characterized by high physicochemical functionalities and could be used in various applications, but increases economic returns for the fishery branch.

Chitosan

According to the great diversity of aquaculture waste, different types of disposal could be used in various applications. Shellfish by-products, which consist of crustacean exoskeletons, constitute the main source for chitin production. Chitin is a polysaccharide, which contains N-acetyl-D-glucosamine units. It is a specific component of the cell walls of fungi, the exoskeletons of crabs, lobsters, shrimps, insects, as well as the beaks and internal shells of cephalopods [33]. There is currently a high interest of chitosan, a deacetylated derivative of chitin. Chitosan has many biological properties, such as anti-cancer, antioxidant, and immune-enhancing and thus can be applied in various ways [34].

Present-day polymers are mostly synthetic materials, which are not as biodegradable as the environment's opportunity to degrade. Natural polymers are a bio-replacement for a portion of synthetic polymers [34]. Chitosan has relevant properties such as non-toxicity, biodegradability, biocompatibility and adsorbability [35].

Other useful features of chitosan are anti-bacterial properties [36]. These parameters make chitosan a suitable functional material that could be used in food, biomedical, cosmetics and pharmaceutical applications [37]. The most popular processes using chitosan are binding, thickening, gelling, and stabilizing.

The multidimensional utilization of chitosan in the medical, cosmetic, food, and textile industries requires the development of extraction methods [38]. Isolation of chitin from shellfish waste and conversion of chitin to chitosan require the following steps:

1. Demineralization - calcium carbonate and calcium phosphate separation
2. Deproteinization - protein separation
3. Decolorization - removal of pigments
4. Deacetylation – removal of acetyl groups.

To remove some or all acetyl groups from the chitin and obtain chitosan, the process should be conducted with a concentrated sodium hydroxide solution at high temperature [39]. Many studies have proved that the physicochemical properties of chitosan depend on preparation methods, crustacean species, temperature, autoclaving, and concentration of sodium hydroxide solution.

Marine biowaste processing is the main source of chitosan, but chemical extraction with existing methods is wasteful and expensive. To produce one kilogram of chitosan from shrimp shells, more than one tonne of water is required. Due to costs, legal restrictions and environmental problems, many studies have been conducted to make chitosan production profitable, sustainable and environmentally friendly. Fortunately, new technologies are emerging. Methods using bacteria to prepare chitosan from aquaculture waste minimize environmental pollution [40]. Physical and solvent-free methods for shell fractionation should be available in the next decade.

Advantages and disadvantages of described methods

Table 1. Advantages and disadvantages of described methods

Type of utilization of aquaculture waste	Advantages	Disadvantages
Fish Biogas	• Renewable energy source and cost efficient tool to approach greenhouse gas reduction • Cheap recycling of organic waste that could be harmful to human existence • High content of organic carbon in fish waste effect on high methane potential • Ability to co-digestion • Odour regulated production • Regulated pathogen and diseases vectors e.g. flies in fishing ports [41]	• High content of ammonia nitrogen in fish waste limits biogas production • High investments costs involved in building biogas plant
Biofertliser from fish waste	• Cost effective, eco-friendly product for agriculture • Complete fertiliser contains all the essential minerals • Dramatic stimulation to the soils beneficial microorganisms which consume, digest and release the abundant nutrients in the fish when it is applied to the soil. • Amino acids present in 'Fishlizer' will enhance flowering and fruit setting in plants, favoring enhanced production. [42]	• The composition of fish fertilizers is variable. • Risk of infections • Effectiveness deepened on Moisture, temperature, pH and other environmental variables. • High transportation and labor costs
Fish Bio-oil/biodiesel	• High quality biodiesel • Larger acid number, a greater increase in the rate of peroxidization	• Higher emission of oxides of nitrogen • Generally higher production cost

Type of utilization of aquaculture waste	Advantages	Disadvantages
	with the increase in the time that it was stored, greater kinematic viscosity, higher heating value, higher cetane index, more carbon residue, and a lower peroxide value, flash point, and distillation temperature than for e.g. cooking-oil biodiesel If produced chemically: • high conversion • ratio of triglycerols (TAG) to methyl esters (biodiesel) • low reaction times (4-10 h). If produced enzymatically: • there is no soap formation, • low temperature requirement, • no waste generation • high quality of glycerol [43]	• Less oxidation stability than diesel [44.] If produced chemically: • high reaction temperature, • soap formation, • waste generation and contamination of glycerol with alkali catalysts. If produced enzymatically: • high reaction times (12-24 h) high cost of enzymes
Fish protein hydrolysate	• Highly nutritious and easily digestible • Wide range of applications as milk replacers, stabilizers in beverages, protein supplements and flavor enhancers If produced chemically: • High recovery yields • Fast process • Inexpensive process If produced enzymatically: • Higher nutritive value and functionality • High recovery yields • High selectivity • Low-salt final product • Low contamination of wastes	If produced chemically: • Complete destruction of tryptophan and cysteine and partial destruction of tyrosine, serine and threonine • Difficulty in process control If produced enzymatically: • Bitterness • High-cost enzymes (except autolysis) • Long-time process • Potential decrease of protein functionality [43]
Natural pigments	• Great variety of colours in aquaculture waste • Carotenoids from shrimps have low impact on food and environment	• Higher price than artificial pigments • Lower quality than pure synthetic pigments
Fish Collagen	• Fish collagen peptides have best absorption and bioavailability due to their smaller particle sizes compared to other animal collagens • Type I collagen - best source for medicinal purposes • Tasteless and odourless or have a neutral, non-fishy taste.	• Contains allergens for users with allergic to fish
Chitosan	• Chitosan from shellfish by-products is the most commonly available • Methods using bacteria to prepare chitosan from aquaculture waste minimize the environmental pollution	• Chemical extraction with existing methods is wasteful and expensive • Properties of chitosan depend on preparation methods, crustacean species, temperature, autoclaving, concentration of sodium hydroxide solution

Source: Author's

Summary and conclusions

In the future, the aquaculture sector will need to produce more with less. This means an effective usage of resources, growing earnings and sustainability practices on the one hand, and on the other hand inputs, pollution and waste reduction. Different types of aquaculture waste could be treated with various methods. The conversion of non-recyclable fish waste materials into biogas, biodiesel and biofertiliser is the most appropriate method for sick or dead fish and mixed waste processing. Additionally, the hazardous biomass is recycled and converted to usable heat, electricity, or fuel. Waste, which consist mostly of fish viscera, has the biggest potential to obtain protein hydrolysate. Among the most prominent current uses of aquaculture waste are pigments, chitosan and collagen isolation for cosmetics, food, biomedical and pharmaceutical industry. Energy recovery and obtaining the essential compounds from aquatic waste need extra inputs and outputs of the various activities involved in waste processing. The development and industrial implementation of the best alternative treatment process for specific type of waste should predate lab-scale evaluation. However, it is important to estimate the benefits of processes not only in terms of economic income, but also considering the environmental impacts. Recycling and processing of fish by-products play a key role for marine resources conservation.

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