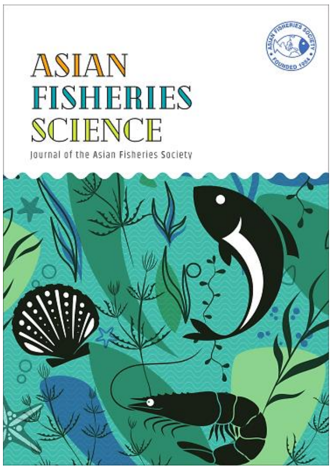

Fish Waste Management: Turning Waste into Healthy Feed with Antimicrobial Properties

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Abstract

Fish processing results in a high volume of by-products that often goes to waste if not converted into value-added products. This review paper aims to present ideas on how to convert these by-products into healthy feed. As a result of fish processing, between 20 and 80 % of the whole fish is not used for direct human consumption. Bigger industrial fish processing units usually process the by-products into fishmeal and fish oil. For small-scale processing units, however, investing in a fishmeal plant is not economically viable unless at least 8 tonnes of raw material is available daily. The preservation of the raw material by acid silage is a simple and inexpensive alternative. Fish silage consists of minced fish by-products or minced whole fish not suitable for human consumption with an added preservative, usually an organic acid such as formic acid, to stabilise the mixture. Fish silage technology can also be used to treat dead fish to prevent the spread of diseases. Fish silage processing methods based on heat treatment at ≥85 °C for ≥25 minutes at pH ≤4.0 will inactivate fish pathogens such as *Salmonella* and *Clostridium perfringens*. This treatment will also degrade DNA and inactivate genes potentially encoding antibiotic resistance. Furthermore, formic acid and the free amino acids and small-chain peptides in the fish silage mixture have antimicrobial properties. Thus, it can be used to reduce the use of antibiotics and promote healthy immune systems of fish. Fish waste can be converted into healthy feed through simple and inexpensive fish silage processing.

Keywords: aquaculture, fish silage, fish processing, value-added products, by-products

Introduction

The utilisation of world fish production for human consumption has increased significantly in recent decades, from 67 % in the 1960s to 87 % in 2014, equivalent to more than 146 million tonnes. The remaining 21 million tonnes were used for non-food products, 76 % of which was converted into fishmeal and fish oil, while the rest was used for different purposes including raw materials for direct feeding in aquaculture. In 2014, 46 % (67 million tonnes) of fish for human consumption was in the form of live, fresh, or chilled fish, 12 % (17 million tonnes) in dried, salted, smoked, or other cured forms, 13 % (19 million tonnes) in prepared and preserved forms, and 30 % (about 44 million tonnes) in frozen form (FAO, 2016).

Fish processing involves several steps: stunning, grading, slime removal, deheading, washing, scaling, gutting, cutting of fins, filleting, and meat bone separation. During processing, the amount of waste generated ranges from 20 to 80 % depending on the level of processing and type of fish (Ghaly, 2013). This residue should not be seen as waste, but as raw material for a range of by-products. With looming food shortages, full utilisation of all resources is a moral and economic imperative. Some by-products containing meat, like heads, frames, and belly flaps, and some parts of the viscera, like liver and roe, can be used for human consumption. They are good sources of high quality proteins and lipids with long-chain omega-3 fatty acids. Furthermore, they are also rich in micronutrients such as vitamins A, D, riboflavin, and niacin and minerals like iron, zinc, selenium, and iodine. All too often, however, the by-products are regarded as low-value items that are best used as feed for farmed animals, as fertiliser or discarded (Olsen et al., 2014).

This paper aims to develop awareness of the large amount of fish waste generated from processing and the existing technologies to utilise it. It introduces fish silage technology as one way to convert fish waste into a value-added product. Aside from being a potential source of income, the use of the fish silage process to treat dead fish can also reduce pathogens and prevent the spread of diseases.

Fish Waste Utilisation

Fish processing by-products can be used for the production of value-added products such as fishmeal, fish oil, fish protein hydrolysates, collagen, biodiesel, and even fish leather. The use of by-products to make fishmeal and fish oil is also an indirect way of providing healthy food since the expanding aquaculture sector is by far the largest user of these products (FAO, 2012). In a report by the World Bank (2013), it is projected that the use of by-products from processing will increase from 5.7 million tonnes under the baseline case to more than 10 million tonnes in 2030. There is an overall increasing trend in the amount of fishmeal and fish oil being obtained from by-products, concluding that the whole fish will be increasingly directed to direct human consumption and marine ingredients will need to be sourced more from by-products (Jackson and Newton, 2016).

Fish proteins can be found in all parts of the fish and can be extracted using chemical and enzymatic processes. Fish proteins can be used as a functional ingredient in many food items due to desirable properties, namely good water holding capacity, oil absorption, gelling activity, foaming capacity, and emulsifying properties. They are often used in food products as milk replacers, bakery substitutes, and in soups and infant formulas. Fish proteins are rich in amino acids which can be used in animal feed and fish sauce or can be used in the production of different pharmaceuticals (Ghaly, 2013).

Fish Silage

Fish silage is a liquid product produced from whole fish or fish parts to which acids, enzymes, or lactic-acid producing bacteria are added resulting in the liquefaction of the mass. This is activated by the action of enzymes from the fish (Babu et al., 2005; Borghesi, et al., 2009; Ferraz De Arruda et al., 2007; Mousavi et al., 2013). The fish silage process converts fish waste into a liquid mix of hydrolysed proteins, lipids, minerals, and other nutrients that are easily digested and absorbed by terrestrial and aquatic animals. The production of fish silage also offers economic advantages as it requires simple and independent scaling technology and low-cost materials (Haider et al., 2015; Vieira et al., 2015; Toppe et al., 2018).

There are two known methods of fish silage production, using either acid or fermentation. Fish silage can be produced by fermentation using lactic acid bacteria such as *Lactobacillus plantarum* as a starter culture (Ramirez-Ramirez et al., 2008). The addition of a carbohydrate source like molasses or fruit processing waste along with a lactobacillus culture converts sugars into lactic acid (Olsen et al., 2014; Carmen Ramírez Ramírez et al., 2016).

Acid preservation is a simple and inexpensive way to preserve by-products from processing. A combination of organic acids like formic acid and propionic acid can be used to turn fish processing by-products into fish silage. Formic acid is considered the best choice because silage made using formic acid is not excessively acidic and therefore, does not require neutralisation before being used (Tanuja et al., 2014). Mineral acids can also be used, however, the product should be neutralised before including in the feed (Pagarkar et al., 2006; Vieira et al., 2015; Olsen and Toppe, 2017). The main disadvantage of this method is the complete destruction of tryptophan and cysteine and the partial destruction of tyrosine, serine, and threonine (Ghaly, 2013).

In the production of fish silage, the material must be fresh and raw. It is important to include fish viscera to ensure sufficient enzymes for hydrolysis. The raw material is minced to a maximum particle size of one millimetre to ensure that acid can penetrate all cells. Then, 2 to 3 % (w/w) of formic acid is added and the mixture maintained at pH 3.5, regularly mixing to maintain the pH and to prevent mould growth (Toppe et al., 2018).

The maturation process of fish silage is affected by temperature. In tropical climates, it will take only 2 to 4 days depending on the amount of viscera. In colder temperatures, the process is longer, maybe a few weeks. The mature fish silage can be stored for years and can be used directly as feed, as a feed ingredient, or as a fertiliser (Toppe et al., 2018).

Benefits of Fish Silage

As healthy feed

According to Ferraz De Arruda et al. (2007), fish silage has long been produced and used in countries like Poland, Denmark, and Norway on a commercial scale. Experimental work using silage as a feed ingredient has been undertaken in several countries. Several studies on the use of fish hydrolysates from acid silage are mentioned by Olsen and Toppe (2017). Other studies include the use of fish silage as a potential protein supplement for growing lambs (Barroga et al., 2004) and pigs (Salas and Ornelas, 2010). Other studies concluded that fish silage could replace fishmeal as a protein source for aquafeeds (Ramasubburayan et al., 2013; Barreto Curiel et al., 2016; Jasim, et al., 2016;). Furthermore, in a study by

Carmen Ramírez Ramírez et al. (2016), the use of fish silage in broiler feed had no significant change in carcass yield, chemical composition, and sensory quality attributes of broiler meat. These studies revealed that low or moderate quantities of hydrolysate might be used in feed for improved feed intake, growth, and other performance indicators. These positive effects can be attributed to the presence of free amino acids and low molecular weight peptides (Ramasubburayan et al., 2013; Espe et al., 2015; Olsen and Toppe, 2017).

During fish silage production, the enzymes present in the acidic medium breaks down fish proteins into peptides, while the acidic environment helps to speed up their activity and prevent bacterial spoilage (Ghaly, 2013), The review of Harnedy and FitzGerald (2012) summarises the protein-derived bioactive peptides identified in marine processing waste, which have different functional properties such as antioxidant and antimicrobial.

The use of organic acids in fish silage has some additional benefits. Organic acids have antimicrobial properties, acting both as bacteriostats and bacteriocides (Suiryanrayna and Ramana, 2015). Each acid has its own antimicrobial potential (Rurangwa et al., 2014). Organic acids are also one of the most efficient feed additives for mould prevention (Coskuntuna et al., 2010). Organic acids in the diet can have beneficial effects on the performance of poultry by decreasing pathogenic bacteria Khan and Iqbal (2016). Given the weak acid nature of short-chain organic acids in their undissociated forms, they can easily diffuse through the cell membranes of the microorganisms. Once internalised in the neutral pH of the cell's cytoplasm, the organic acids dissociate into anions and protons and lower intracellular pH, thus affecting the enzyme-catalysed reactions and transport systems (Ricke, 2003; Olsen and Toppe, 2017).

Organic acids, when used as acidifiers in poultry feeds, can improve nutrient digestibility and stimulate natural immune response. Furthermore, organic acids also enhance apparent total tract digestibility and improve growth performance in pigs (Suiryanrayna and Ramana, 2015). The actions of organic acids include stimulating the secretion of pancreatic enzymes, lowering gastric pH, inhibiting pathogens, acting as an energy source during GI-tract intermediary metabolism, improving mineral utilisation, enhancing the apparent total tract digestibility, and improving growth performance (Suiryanrayna and Ramana, 2015).

The maturation process of fish silage is influenced by the amount of viscera and temperature. The high storage temperature results in faster maturation, usually 2 to 4 days in tropical climates. With the use of simple and unsophisticated equipment, the fish silage produced is rich in amino acids and peptides that have antimicrobial properties. Furthermore, the presence of organic acids in the fish silage can improve nutrient digestibility, stimulate immune response, and improve growth performance when used as a feed ingredient for livestock.

Prevention of spread of disease

Fish silage can also be used to treat and prevent the spread of pathogenic microorganisms found in dead fish or fish killed for disease control due to the antimicrobial properties of the organic acids. The fish silage processing method (FSPM) in Norway is based on mincing to a ≤10 mm particle size, ensiling at pH 4.0 with formic acid, and heat treatment at ≥85 °C for ≥25 minutes. The process has been assessed for its potential to reduce the microbial risks of category 2 and 3 animal by-products of fish origin. Category 2 includes dead and clinically ill fish with external signs of disease and fish killed for disease control purposes. Category 3 includes animal by-products originating from the slaughtering of fish for human consumption (Norwegian Scientific Committee for Food Safety, 2010).

An ad hoc group appointed by the Norwegian Scientific Committee for Food Safety concluded that the FSPM would inactivate non-spore forming bacteria, *C. perfringens*, moulds, *Saprolegnia*, parasites, and viruses. Furthermore, *Clostridium botulinum* and preformed toxins of type E can be destroyed by the method. The FSPM can also degrade DNA and thus can inactivate the genes that encode antibiotic resistance. The method will not inactivate mycotoxins and prions. These are unlikely, however, to pose any hazard to animal or human health. The fish silage produced using this method can be safely used as agricultural fertiliser, biofuels, and feed for fur, zoo, pet, or circus animals (Norwegian Scientific Committee for Food Safety, 2010).

The Norwegian Institute of Food, Fisheries, and Aquaculture Research (Nofima) later verified the method, concluding that the process will adequately reduce the risks related to pathogens present in fish by-products from aquaculture. The process can inactivate *Salmonella*, *Enterobacteriaceae*, *C. perfringens* and *Clostridium sporogenes* spores (Nygaard, 2013).

Conclusion

Fish processing leads to a high volume of by-products that can be converted into value-added products like fish hydrolysates, fish collagen, fish sauce, fish oil, fish biodiesel, and fish leather. Most importantly, fish silage technology, using 2 to 3 % (w/w) of formic acid to treat fish processing by-products, can convert potential waste into valuable feed ingredients, thus transforming fish waste into profit. The resulting products also have antimicrobial properties, making the process advantageous for the treatment of diseased fish.

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