2023 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 13, Issue 2: 79-88; March 30, 2023 ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2023.13

USE OF FISH WASTE TO SILAGE PREPARATION AND ITS APPLICATION IN ANIMAL NUTRITION

Raziye RAEESI, Bahareh SHABANPOUR, and Parastoo POURASHOURI

Gorgan University of Agricultural Sciences and Natural Resources, Faculty of Fisheries and Environmental Sciences, Department of Seafood Processing, Gorgan, Iran

Email: r.reisi2012@yahoo.com

Supporting Information

REVIEW
PII: S222877012300013-13
Received: December 25, 2022
Revised: March 15, 2023
Accepted: March 17, 2023

ABSTRACT: In recent years, global aquaculture production has increased, leading to an increase in fish waste. These wastes, which in many cases are disposed directly without trying to take advantage of them, are a major environmental and economic problem that may affect the sustainability of the fishing and aquaculture industry. Therefore, their use seems necessary to reduce pollution and make the aquatic industry more efficient. Most of well-known technologies for using fish waste are not economically attractive due to the need for high initial investment. But an easy and inexpensive way to use these wastes is to convert them into silage. Fish silage is a product of good nutritional quality included in animal diets as part of the feed. Fish silage is a liquid product made from whole fish or parts of it to which lactic acid-producing acids, enzymes or bacteria are added, and the liquefaction of the material indicates the action of enzymes present in the fish. Therefore, the purpose of this review is to investigate the use of aquatic waste for preparing silage and the possibility of using it in animal nutrition.

Keywords: Fermentation, Fish by-product, Fish silage, Protein hydrolysis, Silage.

INTRODUCTION

Seafood processing leads to significant amounts of waste (Adeoti and Hawboldt, 2014; Bruno et al., 2019; Nikoo et al., 2019; Ozogul et al., 2021). In some cases, these wastes may be removed from the processing and consumption cycle at no cost (Knuckey et al., 2014). But aquaculture plants will usually have to pay to remove them (Knuckey et al., 2014; Martínez-Alvarez et al., 2015; Etemadian et al., 2021). Therefore, using these wastes and producing new products, in addition to helping to protect the environment, also increases their revenue (Arruda et al., 2007). In most cases, these wastes are used to make fish meal (Shabani et al., 2019), which requires significant amounts of energy to cook, dry and evaporate (Arvanitoyannis and Kassaveti, 2008), and is a costly process (Yamamoto et al., 2005). But fish silage can be produced with a simple process, with the need for simple equipment and machinery (meat grinder, mixer and plastic containers), on a small scale, with low energy consumption and without the need for skilled workers (Vidotti et al., 2002); therefore, the cost of silage production is low (Arruda et al., 2007). Fish silage is a liquid product made from whole fish or parts of it to which lactic acid-producing acids, enzymes or bacteria are added, and the liquefaction of the material indicates the action of enzymes present in the fish (FAO, 2003).

In aquaculture (like any animal husbandry), feed accounts for a high percentage of costs (between 30 and 60% of the total) (Arruda et al., 2007). Currently, the most abundant source of animal protein for the production of animal diets is fish meal (Vidotti et al., 2002), which has no anti-nutritional factors and is a very good source of protein in aquatic feed compared to soybean powder (Martínez-Alvarez et al., 2015); while the global market has always been looking for a suitable alternative, researchers around the world have greatly attempted to identify substitute protein sources in order to reduce nutritional costs (Arruda et al., 2007). On the other hand, increasing demand for fish meal and fluctuations in wild pelagic fish catch (mostly Anchovy) have pushed up fish meal prices over the years. In addition, the effects of thermal damage caused by the drying process on the protein quality and overall protein digestibility, as well as running costs, has increased interest in fish meal substitutes in aquatic feed (such as fish silage, protein hydrolysis and fermentation products) (Martínez-Alvarez et al., 2015). Soybean powder is currently used as a source of protein to reduce the cost of producing aquatic feed (Urán et al., 2009), which can affect growth and feed efficiency due to its anti-nutritional properties (such as phytic acid or lectins; Martínez-Alvarez et al., 2015). The use of fish silage as a protein component in aquatic feed can reduce feed costs and thus improve the profitability of fish farming (Borghesi et al., 2008).

The greatest advantage of fish silage is attributed to its nutritional value; because fish waste (which accounts for half of the processing industry raw materials) is a low-cost source of nutrients. In addition, the production of fish silage does not have the odor and wastewater problems occurring during the production of fish meal (Arruda et al., 2007). The presence of formic acid in the product (if formic acid is used to prepare silage) can promote aquatic growth and health,

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especially under adverse microbial conditions (Olsen and Toppe, 2017). The process of producing silage in tropical climates is fast and it is possible to use the product on site (Arruda et al., 2007), finally it does not attract insects due to its acidic odor and does not contain any pathogens (such as Salmonella) (Vidotti et al., 2002). The purpose of this study is to discuss the use of aquatic waste for silage and to investigate the possibility of using it in aquatic and livestock feed.

History of silage

Fish silage was common in some Scandinavian countries for animal feed (Backhoff, 1976). After World War II, the use of formic acid to protect wastes began to be used in animal diets. Acid silage was developed in the 1920s by A. I. Virtanen using sulfuric and hydrochloric acids to preserve forage (Arruda et al., 2002). Experiments with fish in Sweden began around 1936, using sulfuric acid and molasses, and formic acid. Experiments were performed by Edin in 1940 and a formula based on pH, protein and ash measurements was proposed to calculate the content of acid required by the raw materials ground by him. Olsen set up a table based on this formula, providing the content of acid needed for various Scandinavian ingredients (Tatterson and Windsor, 1974). Production of industrial-scale silage began in Denmark in 1948, and three years later it reached 15,000 tons a year (Backhoff, 1976), and there is still a thriving industry despite a slight modification in techniques (Tatterson and Windsor, 1974). Fish silage has been produced on a commercial scale in Poland and Denmark since the 1960s to produce pig and poultry feed or as a protein supplement in livestock and aquaculture feed (Arruda et al., 2007). In the tropics, although the potential for the use of fish silage has been known, it is less used, which is probably due to the failure of optimal methods of production, use and storage in environmental conditions. Commercial use of fish silage is largely limited in northern Europe, where it is mainly used in the wet feed of pigs, fur-bearing animals and fish (Goddard and AL-Yahyaio, 2001).

Various sources used in the production of silage

Silage can be produced from a variety of raw materials including maize (Hu et al., 2009; Santos et al., 2013; Moloney et al., 2013; Weiss et al., 2016), sugarcane (Ávila et al., 2014; Gandra et al., 2016), casein (Åsgård and Austreng, 1985), silkworm pupae (Rangacharyulu et al., 2003), oats (Gomes et al., 2019), seaweed (Herrmann et al., 2015), poultry slaughterhouse waste (Ashayerizadeh et al., 2017) and aquatic waste. In the following, the use of aquatic waste for silage production is examined.

Use of fish waste

Given the increasing trend of global fish production in recent years (for example, an increase from about 20 million tons in 1950 to 171 million tons in 2016) and an increase in aquatic consumption (from 9 kg in 1961 to 20/2 kg per in 2015), the production of aquatic waste has also increased. By-products are obtained by processing aquatic products on an industrial scale (from fishing or aquaculture) (Marti-Quijal et al., 2020), the amount of which can include 20 to 60% of the total mass, depending on the type of aquatic products (Choi, 2020). Sustainable management of waste from aquatic processing is a global problem (Ivanovs et al., 2018). An important waste reduction strategy for the industry is the recovery of marketable by-products from fish waste (Arvanitoyannis and Kassaveti, 2008). Using these wastes to produce new products, in addition to reducing the environmental and health problems caused by improper use of industrial aquatic wastes, can also increase their revenue (Arruda et al., 2007).

Fish by-products contain large contents of fats, proteins and organic matter that can cause problems such as odor and pest-breeding during their excretion (Choi, 2020). A wide range of high quality compounds can be recovered from these by-products and used for human consumption. Some of these compounds such as proteins, amino acids, oils, hydroxyapatite, enzymes, collagen and gelatin have high added value. Therefore, their study is very important for valuing fish waste (Marti-Quijal et al., 2020). The three most common methods of using fish waste are to produce fish meal/oil, to produce silage, or to use waste in the production of organic fertilizers (Arvanitoyannis and Kassaveti, 2008).

Fish silage and its types

Fish silage is a liquid product obtained from the liquefaction of all or part of fish (Tatterson and Windsor, 1974) and has been proposed as a simple and inexpensive substitute for the production of fish meal (van't Land and Raes, 2019). Since this product can be produced using relatively small amounts of raw materials in the isolated spaces, the need for expensive processing and maintenance equipment is eliminated (Goddard and AL-Yahyaio, 2001). In general, fish silage is a product with high biological value and its composition is almost similar to the raw material used (Vidotti et al., 2002). Therefore, the composition and nutritional quality of the product is determined primarily by the composition and freshness of the raw materials. Although processing parameters (such as acid type, pH, additives, storage time and temperature) are more controlled during production, these parameters can also affect the nutritional quality and final composition of fish silage. It is more difficult to control the composition and freshness of raw materials, as it strongly depends on the composition of the catch, the time of transport and the method of processing (Van't Land et al., 2017). Fish silage is divided into three phases during storage, with fish oil at the top, highly soluble proteins, minerals in the middle layer, and semi-soluble materials and bones at the bottom. Proper mixing and stirring is essential to reduce lipid fraction oxidation and maintain product homogeneity (Fagbenro, 1994). Fish silage can be produced in different ways, which are discussed below.

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Acidic (chemical) silage: In making this type of silage, the enzymes in the fish mass are spread throughout it by crushing and mixing, and the acidity is regulated in such a way as to benefit the rapid action of these enzymes and inhibit bacterial function (Tatterson and Windsor, 1974). In fact, liquefaction, which is an autolytic process, is done by enzymes in fish. This process is accelerated by an acid creating the right conditions for decomposing the tissues by enzymes and also limits the growth of spoilage bacteria (Arvanitoyannis and Kassaveti, 2008). Through this process, whole biomolecules are broken down into smaller components (such as proteins into peptides and lipids into fatty acids) (van't Land and Raes, 2019). The substrate is mixed with acid (strong mineral acids or organic acids) to adjust the pH of the mixture to less than 4. At this pH, serine proteases are completely inactive, but the septic enzymes and pepsin are highly active. Primarily, pepsin is responsible for the production of fish silage, the content value of which can be very high in the visceral part of fish (Fagbenro, 1996). In one study, during silage of cod in the presence of 3% (volumetric/volumetric) formic acid, enzymes mainly responsible for liquefaction, enzymes in the intestine, skin and other parts of fish (other than meat) were reported (Backhoff, 1976). In the acidic method, the raw materials should preferably be ground or crushed into small pieces and occasionally stirred to create the desired uniformity and greater contact of the material with the acid; because untreated parts can cause problems. Room temperature is typically used for maintenance, which stimulates the desired biochemical changes (Arruda et al., 2007).

Different acids or combinations of acids can be used. Although mineral acids (such as hydrochloric acid and sulfuric acid) are relatively inexpensive, they are detrimental to the feed component, which must be neutralised before the animals are fed. Formic acid has the advantage of being stored at a higher pH, in which case it does not need to be neutralized for use in feed (Tatterson and Windsor, 1974). However, silages produced with formic acid are more expensive than silages produced with inorganic acids. The liquefaction process with formic acid can be performed in the pH range of 4 to 4/5, which is due to the antiseptic properties of formic acid. But while using mineral acids, the pH of the final product should be around 2 to prevent the growth of bacteria (Tatterson and Windsor, 1974).

Fermented (biological) silage: Fermentation for fish has been used for many years and is a low-level, cost-effective technology for tropical developing countries (Fagbenro, 1996). Fish fermentation is traditionally used to increase the shelf life of fish, which leads to the formation of the desired bacterial metabolites. Fermentation of by-products increases the quality of hydrolysis of proteins, oils and the production of antioxidant compounds. It is a safe, environmentally friendly, low-energy technology (Marti-Quijal et al., 2020). This is a bio-fermentation process performed with the addition of lactic acid bacteria and fermentable carbohydrates to the substrate (Shabani et al., 2019). However, fermentation is also performed without the addition of primer culture, which is called natural fermentation, which has been studied in some studies (Zahar et al., 2002). For proper fermentation, the material must contain lactic acid bacteria and the nutritional needs of these bacteria (including fermentable carbohydrates, amino acids, nucleotides, vitamins, and growth factors) enabling optimal fermentation. Also, the storage temperature should be within the required range for fermenting bacteria (Lindgren and Pleje, 1983).

Since aquatic wastes are high in unsaturated fatty acids, they are very sensitive to fat oxidation and spoilage, which reduces the quality of fish meal during storage (Shabani et al., 2019). Yano et al. (2008) stated that the fermentation of aquatic waste by microorganisms can improve their quality by reducing their fat content. Biologically prepared silage may have improved nutritional value (compared to fish meal) due to increased digestibility and biological activity and the removal of undesirable and anti-nutritional compounds. This product can contain some functional compounds (such as lactic acid bacteria) and organic acids (mainly lactic acid) preventing pathogen contamination by creating acidic conditions in the silage causing a longer shelf life (Shabani et al., 2019).

Enzymatic silage: Liquid fish products (such as silage) can be produced by adding other enzymes (Tatterson and Windsor, 1974; Borghesi et al., 2008; Borghesi et al., 2008; Hevrøy et al., 2005; Khosravi et al., 2015). These exogenous enzymes used can be obtained from various animal, plant or microbial sources (Ovissipour et al., 2009; Hathwar et al., 2011). In general, various studies have shown that the use of these hydrolyses can be used successfully in feed. In some cases, improved cellular immunity and growth (Goosen et al., 2014), increased growth performance, feed utilization, digestibility, innate immunity, and resistance to fish disease (Khosravi et al., 2015) have been reported.

Problems related to silage

Fish silage is usually produced and stored as a liquid close to where it is used (Goddard and AL-Yahyaio, 2001). But the high water content of this product makes its transportation for long distances uneconomical. Therefore, the production of fish silage on an industrial scale is limited (Backhoff, 1976). Drying liquid fish products reduces storage and transportation costs, facilitates the inclusion of fish silage in the diet, and also limits microbial growth (Van't Land and Raes, 2019). Drying, however, means an additional cost (Arruda et al., 2007); because conventional drying methods are often expensive, energy-consuming and tedious, and require harsh conditions (Van't Land and Raes, 2019). Drying can be done by adding agricultural by-products commonly used in animal feed (Vidotti et al., 2002). Freeze-drying and spray drying of protein products are also recommended, as bioactive compounds maintain functional properties (such as emulsification and water holding capacity) and nutritional quality. However, considering the long time spent in freeze-drying and the application of high temperatures in spray drying, both of these processes can cause unwanted structural changes in the product (Van't Land and Raes, 2019).

V'ant Land and Raes (2019) conducted a study to investigate the drying potential of silage using refractance window drying. In this method, the products are dried by transferring them in a thin layer, on a polyester film, on a hot water bath,

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and convection, conduction and radiation heat transfer occurs (Nindo et al., 2003). Due to the application of low drying temperatures and short storage times, this method was introduced with high potential to maintain quality when concentrating silage. Mild conditions also indicate the potential for sustainable yield and biological activity of hydrolyzed fish products (Van't Land and Raes, 2019). This method also has the advantages of improved energy efficiency and lower costs than spray and freeze drying methods (Nindo et al., 2003; Baeghbali et al., 2016).

Due to its high content of unsaturated lipids, fish silage is prone to oxidation and the formation of toxic products (Fagbenro, 1996) that can jeopardize the nutritional value of the diet (Arruda et al., 2007), reduce product quality, especially during storage, and may reduce the nutritional performance of animals (Fagbenro, 1996). The lipid oxidation process also changes the taste, color and texture of the silage, and the oxidation process can be accelerated if the fish silage comes in contact with light and air. Therefore, in order to achieve a more uniform and stable product, it is recommended to remove the fat part of the silage during its preparation (Arruda et al., 2007). In addition, lipid oxidation can be prevented by adding a variety of antioxidants, including ethoxyquinone, butylated hydroxytoluene (BHT), and butylated hydroxy anisole (BHA). However, since these synthetic antioxidants are expensive and are slowly metabolized in animal muscle, they are banned from many meat and fish products (Fagbenro, 1996).

The antioxidant properties of spices and plant extracts on fish and meat products have been proven to be generally available at low cost. Therefore, they are offered as cheaper substitutes to synthetic antioxidants (Fagbenro and Jauncery, 1998). In some studies, onion extract has been used as a natural antioxidant in fermented silages of shrimp head (Fagbenro, 1996) and tilapia (Fagbenro and Jauncery, 1998), which has acted effectively as a fat antioxidant.

The use of acids to produce fish silage can potentially eliminate essential amino acids (especially tryptophan) and reduce the nutritional value of silage (Martínez-Alvarez et al., 2015). In addition, total deamination can be caused by prolonged hydrolysis, which is reflected by a decrease in essential amino acids and an increase in volatile nitrogen. Therefore, there is a possibility of many changes in the final product (Van't Land et al., 2017).

Processing fish silage with organic acid and storing the product may, due to hydrolysis, change proteins into smaller protein fragments, more peptides, and free amino acids (Nørgaard et al., 2015). High contents of free amino acids can interfere with the mechanisms of amino acid and polypeptide uptake in fish (Goddard and AL-Yahyaio, 2001). Optimal maintenance can be achieved by inhibiting the activity of endogenous proteolytic enzymes by limiting the proteolysis rate (Fagbenro, 1996). Salt can be used to inhibit protein hydrolysis in fish silage (Fagbenro and Jauncey, 1993). Inhibition of protein hydrolysis by the addition of trona (Sodium sesquicarbonate) has also been reported (Fagbenro, 1996). In addition, the process of silage autolysis can be stopped by cooking raw fish before fermentation (Fagbenro and Jauncey, 1993) or before adding acid (Espe et al., 1992), pasteurizing (Hardy et al., 1984) or subsequently lowering the pH (Stone and Hardy, 1986). The use of fish waste silage in feed formulations may be significantly limited due to its unpleasant odor (Arvanitoyannis and Kassaveti, 2008). In addition, the problems associated with bitterness in hydrolyzed silage can make the product extremely unpleasant for animals fed with fish-enriched silage (Kristinsson and Rasco, 2000).

Use of fish silage

Fish silage can have various applications, including substituting fish meal in animal and aquatic feed, and using the oil extracted from it to be included in aquatic diets, which are addressed below.

Use of fish silage in fish feed

Aquaculture is the biggest contributor to increasing fish production, which is one of the fastest growing agricultural activities in the world (Arruda et al., 2007). Today, more than a quarter of the world's seafood is sourced from aquaculture, and the FAO forecasts that by 2030 it will be closer to 50 percent (Arvanitoyannis and Kassaveti, 2008). Given this rapid growth of global aquaculture, this industry needs high quality food (Olsen and Toppe, 2017), and future demand for fish farming largely depends on the availability of suitable, inexpensive, and sufficient quantities of feed (Martínez-Alvarez et al., 2015). Fish meal is often used as a source of protein in animal feed, which reduces the stocks of wild fish (as a raw material) leading to stiff competition and rising prices (FAO, 2016). Access to it is also seasonal (Vidotti et al., 2002). Therefore, there is a growing concern to identify substitute protein sources in order to minimize the use of fish meal in feed formulations (Samaddar et al., 2015). Fish silage is known as a simple and inexpensive substitute to fish meal (van't Land and Raes, 2019). Fish silage can be fed directly into wet diets or dried or squeezed as part of animal feed (Goddard and AL-Yahyaio, 2001). However, the use of fish silage in aquatic feed depends on its apparent digestibility coefficients (Borghesi et al., 2008). It is important to know that international feed law in Europe does not allow fish products or components to be used in the same feed (Borghesi et al., 2008). In different studies, fish silage has been studied in the diets of different aquatic species, which has been presented in the table below with a summary of the results of each of them.

Application of oil extracted from fish silage in aquatic feed

Oil extracted from fish silage can also be used in aquatic feed, which was examined in some studies, and benefits such as improved cellular immune function in South African abalone (*Haliotis midae*) (Goosen et al., 2014) and antimicrobial properties in the diet and digestive tract of Mozambique tilapia (*Oreochromis mossambicus*) have been reported. It was also introduced as a good source of polyunsaturated fatty acids and a cost-effective substitute to some

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common fish oils (Goosen et al., 2014). However, it was stated that the optimal content of oil in the diet should be determined in order to avoid negative effects on production efficiency (Goosen et al., 2014).

Use of fish silage in feed of other animals

Fish meal has been considered a source of high quality protein in diets for many years. In recent years, in northern Europe, fish silage has gradually replaced fish meal in pig diets, as it has as good an effect on as fish meal (Nørgaard et al., 2015). Other studies have shown that fish silage, as a protein component, can be replaced with fish meal in the diet of various animals such as Omani sheep (Al-Abri et al., 2014), rats (Espe et al., 1992), broilers (Vizcarra-Magaña et al., 1999; Santana-Delgado et al., 2008), and Japanese quail (Panda et al., 2017).

Table 1 - Summary of some reported studies on silage processing, use it in diets and it outcomes.

Raw material	Treatment	Fish specie	Percentage of silage in diet	Outcome	References
Whole Pacific whiting (*Merluccius productus*) and its wastes	2% sulfuric and 0/75% propionic acid	Rainbow Trout (*Salmo gairdneri*)	50%	Apparent digestibility values were higher for the fish silages than for fish meal.	(Stoneand Hardy, 1989)
Whole Pacific whiting	2% sulfuric and 0/75% propionic acid	Rainbow Trout	50%	Growth and feed conversion were significantly affected by feeding diets containing silage.	(Hardy et al., 1983)
By-products of shelled shrimp (*Pandalus borealis*)	4/8% sulphuric and 1/2% propionic acid	Rainbow Trout (*Salmo Gairdneri*)	10/5%	The digestion of the astaxanthin was improved by ensiling. The rate of accumulation of the pigment in the fish muscle was markedly higher in fish fed the silage diet than those given fresh or dried shrimp waste.	(Torrissen et al., 1981)
Enriched poultry by-product meal with silage of tuna by-products	2/5% citric and 2/5% phosphoric acid	Rainbow Trout (*Oncorhynchus mykiss*)	21, 40 and 62%	Growth of rainbow has been improved.	(Barreto-Curiel et al., 2016)
Marine fish processing by-products	3% formic acid	Rainbow Trout (*Oncorhynchus mykiss*)	20, 40 and 60%	Silage had potential to replace fish meal up to 20% in diets (without adverse effects on growth performance, fatty acid composition and serum biochemical variables).	(Güllü et al., 2014)
Fish processing waste	-	Rainbow Trout (*Oncorhynchus mykiss*)	25, 50 and 100%	Replacing the fish meal with 50% fish silage had a positive effect on growth.	(Guzel et al., 2011)
Spiny Atlantic dogfish *(Squalus acanthias)* offal Herring	3/5% formic acid	Atlantic Salmon (*Salmo salar*)	24/6% 22%	The palatability of both silage diets fed to the smaller fish was decreased.	(Heras et al., 1994)
-Freshwater and saltwater commercial fish waste -Tilapia filleting residue	-15% sugar cane molasses, 5% *Lactobacillus plantarum* -Acid silage: 2% formic and 2% sulfuric acid	Pacu (*Piaractus mesopotamicus*) Fingerlings	The different ratios	Apparent protein digestibility and protein productive values were significantly different.	(Vidotti et al., 2002)
Fish by-products	60% fish by-products, 30% rice bran, 5% dried molasses and 5% of *Lactobacillus plantarum*	-Nile Tilapia (*Oreochromis niloticus*) -African Catfish (*Clarias gariepinus*)	25, 50,75 and 100%	Dried fish silage successfully replaced up to 25 and 50% of fish meal in diets. While, the higher levels of replacement reduced growth performance, feed utilization parameters as well as significant effect on fish body composition of fishes.	(Soltan and Tharwat, 2006)
-Seeds of Jatropha curcas kernel meal (JCK) and tilapia waste silage (FS) -Tilapia byproducts	1/5% of formic acid	White Shrimp (*Litopenaeus vannamei*)	The different ratios	A combination of 18/75% fish silage and 39/75% JCK meals is a potential alternative to fish meal in practical diets for *L.vannamei*.	(Rodríguez-González et al., 2018)
Raw heads of the river prawn (*Macrobrachium vollenhovenii*)	*Lactobacillus plantarum* at 30°C using molasses or cassava starch	Fingerlings Catfish (*Clarias gariepinus*)	15%	Apparent digestibility coefficients of dry matter, crude protein, gross energy and essential amino acids in the silage by catfish fingerlings was high (>70%).	(Fagbenro and Bello-Olusoji, 1997)
Shrimp heads	17% acetic acid	Tilapia (*Oreochromis niloticus* Linnaeus)	10, 20 and 30%	Proximate composition of the feeds (except for a higher protein content than the commercial feed) did not differ statistically.	(Cavalheiro et al., 2007)
Filleting by-products and 80% whole Nile tilapias	AS: 1/5% formic and 1/5% propionic acid BS: 1/4% *Lactobacillus plantarum*, 18% sugarcane molasses were added to AS ES:10 g of protease to AS	Nile Tilapia (*Oreochromis niloticus*)	30%	The highest amount of apparent digestibility coefficient (ADS) and the highest average ADC of amino acids were related to ES.	(Borghesi et al., 2008)
Shrimp (*Penaeus* spp) head waste	10% refined sugar cane and 5% *lactobacillus* spp.	Nile Tilapia (*Oreochromis niloticus L*)	10, 15, 20, 25 and 30%	Growth ratio was improved at dietary inclusion levels as high as 15%. The diets containing shrimp silage were well accepted by the fish.	(Plascencia-Jatomea et al., 2002)
-Heated and unheated mackerel, S. *juponicus* -Heated abalone viscera	2/6% phosphoric and 2/6% citric acid	Juvenile Abalone (*Haliotis fulgens*)	31/8 31/8 20	Significantly higher growth rates occurred when abalone were fed artificial diets containing both fish silages (compared with the kelp, *Mucrocystis pyrifera*).	(Viana et al., 1996)
Nile tilapia (*Oreochromis niloticus*) filleting residue	2% Formic and 3% Phosphoric acid	Pacific White Shrimp (*Litopenaeus vannamei*)	1/5, 3/0, 4/5 and 6/0%	Shrimp final weight was statistically influenced by biofloc system ($P<0.05$) but not by the diet.	(Neto et al., 2019)
Nile tilapia (*Oreochromis niloticus*) processing waste	The acid silage was produced	Pacific White Shrimp (*Litopenaeus vannamei*)	1/5, 3/0, 4/5 and 6/0%	After 45 days, water quality parameters remained within the recommended range for *L. vannamei* culture. Regarding to the production performance survival was above	(Lobato et al., 2019)

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				70% in all treatments.	
Rainbow trout viscera	2/5% formic acid	Mozambique Tilapia (*Oreochromis mossambicus*)	16%, 28/5%	Low silage inclusion improved phagocytic activity of leucocytes (compared with the reference). High silage inclusion significantly decreased growth and led to higher mortality. Formic acid had no effect on growth.	(Goosen et al., 2016)
Ungutted tilapia	5% sugar beet molasses and 2% *Lactobacillus plantarum*	-Juvenile *Oreochromis niloticus* -*Clanas gariepinus*	25, 50 and 75%	Apparent protein digestibility decreased with increasing dietary level of CO-dried fish silage: soybean meal blend	(Fagbenro et al., 1994)
Indian oil sardines (*Sardinella longiceps*)	1/5% mixture of formic and propionic acid (1:1)	Tilapia (*Orenchromis aureus*)	30%	Essential amino acids were present at levels exceeding the requirements for tilapia. The apparent digestibility coefficients of crude protein, dry matter and gross energy for silage were equivalent to those of fishmeal.	(Goddard and AL-Yahyaio, 2001)
Discards from snapper (*Lutjanus* spp.), grunt (*Haemulon plumieri*) and grouper (*Epinephelus* spp.) filleting	1/5% formic acid	Juvenile *Litopenaeus vannamei*	294/6 and 604/0 (g/kg)	Waste fish silage was beneficial for the white shrimp *L. vannamei*. It sustained reasonable weight gain combined with soybean meal in practical diets.	(Gallardo et al., 2012)
Tilapia (*Oreochromis* spp.) by-products	4% formic acid	Hybrid Red Tilapia (*Oreochromis mossambicus×Oreochromis niloticus×Oreochromis aureus*)	25, 50 and 75%	Less expensive dried fish silage with rice bran is an alternative protein source for tilapia feed up to 50% of fishmeal replacement.	(Madage et al., 2015)
-	-	Eel fingerlings (1.7 g)	10, 15 and 20%	The food conversion efficiency, the protein efficiency ratio and the specific growth rate have been Increased.	(Gonçalves et al., 1989)
Residue from the processing of Nile tilapia fillets (*Oreochromis niloticus*)	2% Formic and 3% Phosphoric acid	Pacific White Shrimp (*Litopenaeus vannamei*)	1/5, 3/0, 4/5 and 6/0%	The combination of the biofloc system and tilapia silage feed-based were reported as good options to increase the sustainability of intensive shrimp culture and the overall shrimp quality and shelf life.	(Gonçalves et al., 2019)
Whole whiting (*Merlangius meriangus*)	3% Formic acid	Mirror Carp (*Cyprinus Carpio*)	43/4%	Intake of the fish silage diet was slow compared with diets containing cooked fish and fish meal whilst mortality reached 40% in one replicate.	(Wood et al., 1985)
Stunted tilapia (*O reochromis niloticus*) brooders culled	15% Sugar beet molasses and 5% *Lactobacillus plantarum*	Tilapia (*Oreochromis niloticus*)	66%	Moist fish silage pellets were physically stable and highly digestible to *O. niloticus*, and suitable as farm-made feeds for fish.	(Fagbenro and Jauncery, 1998)
-Fresh hake -Hake stored for 48 h at 17°C	Eight different *Lactobacillus* cultures and whey powder, molasses and sugar	-Calves -Cattle -Pigs	65/4% 90%	The final quality and stability of fermented silage relates to the choice of *Lactobacillus*, the quality and age of the fish material.	(Van Wyk and Heydenrych, 1985)
Fish body viscera	Lacto bacillus bacteria 5% Molasses, 5% yogurt, 30% orange peels and 60% minced body viscera	*Labeo rohita*	50, 75 and 100%	Fish silage had reasonable concentration of nutrients. Fermented fish silage contains high concentrations of mono-unsaturated fatty acids which has positive impact upon growth.	(Haider et al., 2017)
-Muscle of Pacific creole-fish (*Paranthias colonus*) -Humboldt squid (*Dosidicus gigas*)	10% carbohydrate source and 5% an overnight-wet pellet of *L. sakei* strain 5-4	Pacific Red Snapper (*Lutjanus peru*)	44/733% 43/361%	The marine silages with squid enriched or combined with *L. sakei* 5-4 increased the body weight and stimulated the physiological and humoral immune parameters in fish infected with *A. veronii*.	(Reyes-Becerril et al., 2012)

CONCLUSION

Using fish waste to prepare silage, in addition to solving the major problem of disposing of this waste and reducing the environmental effects caused by them, can improve the overall productivity of animal protein consumption, add nutritional benefits to diets prepared from these materials and also reduce the cost of diets. If fish silage can be a substitute to fish meal in the formulation of diets, the effect of fat content on the taste of the final product should be investigated. There is also a need to standardize and maintain the nutritional quality of silage. Further studies are needed to evaluate the appropriate amount of silage input in diets.

DECLARATIONS

Corresponding author

E-mail: r.reisi2012@yahoo.com

Authors' contribution

R. Raeesi had the idea for the article and drafted it, and performed the literature search.
B. Shabanpour performed Supervision and editing.
P. Pourashouri critically revised the work.

Conflict of interests

The authors declare that they have no conflict of interest.

Citation: Raziye R, Bahareh SH, and Parastoo P (2023). Use of fish waste to silage preparation and its application in animal nutrition. *Online J. Anim. Feed Res.*, 13(2): 79-88. DOI: https://dx.doi.org/10.51227/ojafr.2023.13

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Citation: Raziye R, Bahareh SH, and Parastoo P (2023). Use of fish waste to silage preparation and its application in animal nutrition. *Online J. Anim. Feed Res.*, 13(2): 79-88. DOI: https://dx.doi.org/10.51227/ojafr.2023.13

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Citation: Raziye R, Bahareh SH, and Parastoo P (2023). Use of fish waste to silage preparation and its application in animal nutrition. *Online J. Anim. Feed Res*., 13(2): 79-88. DOI: https://dx.doi.org/10.51227/ojafr.2023.13