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Enhancing fish waste quality through silage production: a review

Yuli Andriani[1,*], Rusky I. Pratama[1], Muhamad Fatah Wiyatna[2], Hasna Nabila Shobihah[3]

[1]Fisheries Department, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran
[2]Animal Production Department, Faculty of Animal Husbandry, Universitas Padjadjaran
[3] Master's Program in Fisheries Science, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran

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ABSTRACT

The untapped potential of fish processing production waste as a source of fish feed ingredients makes it a promising resource due to its widespread availability. This study aims to evaluate the process of producing fish waste silage through probiotic fermentation to assess the resulting quality post-fermentation. Employing an exploratory descriptive method, this research draws from diverse literature sources, encompassing books, national journals, and international publications. The comparison of findings from prior research indicates that fermenting fish waste with microbes, particularly lactic acid bacteria, enhances its protein content, positively impacting fish growth performance. Introducing silage at a 10% dose achieves a tilapia survival rate of 83.33%, while a 25% silage addition yields a relative growth rate of 222.63% for catfish and a feed conversion ratio of 1.06 for tilapia.

Introduction

Feed is a critical aspect of fish farming, constituting a substantial portion, around 60-70%, of total production costs. The challenge lies in the availability of good-quality, affordable feed (Sandra *et al.,* 2020). Importantly, commercial fish feed, often expensive, poses difficulties for developing countries due to the need for imported ingredients such as fish meal, squid meal, crustacean meal, soybean meal, vitamins, and minerals (Nasser *et al.,* 2018). Due to the high cost and limited availability of fish meal, this situation encourages exploring alternative ingredients that are nutritionally rich, abundant, sustainable and cost-effective, where fish silage could be a promising option (Hardy, 2010; Tacon & Metian, 2008).

Utilizing materials from fish processing waste emerges as a viable solution. Solid waste from the fish fillet industry, including fish heads, tail bones, and innards, presents a high-potential alternative feed source, which, unfortunately, is underutilized. Research indicates a significant amount of fish waste generated, ranging from 20% to 60%, with approximately 4.8–14.4 tons of fish waste. Despite the high organic content, especially protein, this waste degrades rapidly, prompting the need for a solution such as microbial (Riza & Ismail, 2017).

Fermentation is known to enhance the shelf life and nutritional content of feed ingredients. This process, commonly referred to as fish silage, can be achieved through chemical or biological means. Fish silage is a semi-liquid product resulting from the preservation of whole fish or parts by the addition of acids (inorganic or organic) or by bacterial fermentation, adding latter a carbohydrates source along with lactobacilli species to convert sugars into lactic acid (Borghesi *et al.,* 2008; Ramirez *et al.,* 2008). Fish silage had been used as alternative to fishmeal in animal feeds, particularly in situations where fishmeal production or preservation by deep freezing is not available or uneconomical (Llanes & Vega, 2008). During the ensilage process, most of the proteins are converted to peptides and a portion of which is hydrolyzed to free amino acids, which they can be used as a high nutritional source for feeding different animals (Vidotti *et al.,* 2003). Additionally, biological fish silage is an important precursor for lactic acid

* Corresponding author.
Email address: yuli.andriani@unpad.ac.id

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bacteria, which act as probiotics providing health benefits (Yin *et al.,* 2005; Gracia *et al.,* 2007). This research aims to provide insights into enhancing fish waste quality through fermentation.

Methods

The approach used is an exploratory systematic and descriptive review method, which combines several previous primary research results to obtain accurate and proven facts, from various literature documented in national and international journals such as Research Gate, Directory of Open Access Journals, and Google Scholar. Key words used to retrieve information ranged from fish feed, fish waste, fermentation methods, fermentation microbes, and fish silage. This comprehensive search strategy facilitated the construction of a theoretical framework that aligned with the core subjects discussed in the literature.

Results and Discussion

Potential and Characteristics of Fish Waste

Waste, often overlooked in various sectors such as agriculture, industry, plantations, animal husbandry, and fisheries, encompasses by-products, discarded materials, and unused resources (waste products) (Mastika, 1991). Within fisheries, an untapped resource lies in by-products like trash fish or leftover catch with economic value. Unfortunately, these by-products are frequently deemed useless and discarded, contributing to environmental pollution. Underutilized fish, however, holds immense potential as a raw material for fish feed or meal, serving as a primary protein source for fish. Effectively harnessing abundant underutilized fish could significantly reduce feed production costs. In 2020, the Central Statistics Agency reported 1.826.3 tons of fish caught at the Mataram City Fish Auction Place, generating 104 tons of trash fish by-products. Trash fish by-product landed at Ampenan Beach, Mataram, have a protein content ranging from 71.52% to 72.34% (fillet) and 54.80% to 70.60% (whole fish), while the fat content of the trash fish by-product is 0.65 % to 4.23% (fillet) and 0.96% to 6.31% (whole fish) (Diamahesa *et al.,* 2023).

Figure 1. Fish Head, Bone and Gut from the Fish Processing Industry (Luhur *et al.,* 2016)

Beyond by-products from catches, fish waste originates from the fisheries processing industry, involving unused or discarded fish parts like heads, fins, and innards (Figure 1). This waste constitutes approximately 30-40% of the total weight of fish, mollusks, and crustaceans, including heads (12.0%), bones (11.7%), fins (3.4%), skin (4.0%), spines (2.0%), and stomach contents/innards (4.8%) (Bhaskar et al., 2008). The fishing industry disposes of an estimated 20 million tons (20% of total production) of fish waste (Bhaskar *et al.,* 2008). Properly processed, this waste retains significant nutrients, including protein, fat, and various minerals. Fish bone waste processed into fish meal contains 47.34% protein, 2.62% calcium, and 12.72% fat (Sihite *et al*, 2013). Utilizing this waste in feed production can profoundly impact the growth of farmed fish or shrimp due to its high calcium, protein, and fat content, contributing to the production of healthy farmed products (Sihite *et al.,* 2013).

Fish Waste Fermentation

Fermentation is an energy production process occurring in cells under anaerobic (without oxygen) and some aerobic conditions (Sihite *et al.,* 2013). It involves changing complex compounds into simpler ones by utilizing enzymes from the activity of secondary metabolites of fermenter microbes, conducted under controlled conditions (Llanes & Vega, 2008; Sandra *et al.,* 2020). Fermentation microbes, due to their catabolic properties, can break down complex compounds and synthesize various complex vitamins (Pamungkas, 2011). The fermentation process is classified into solid substrate fermentation with 40-75% water content and liquid substrate fermentation with around 90% water content (Stephanie & Purwadaria, 2013). Liquid substrate fermentation is performed in a medium with a liquid consistency using a bioreactor, such as an aerated flask, a shaker-flask, or a fermenter.

One example of liquid substrate fermentation is the production of fish silage. This process involves two methods: chemical, where strong acids are added (organic or anorganic), and biological, where fermentation occurs using specific microbes like lactic acid bacteria alongside carbohydrates such as bran, pollard, or molasses (Handajani, 2014). Silage made with inorganic acids is highly corrosive and requires neutralization before use, incurring additional costs and reducing effectiveness. Lactic acid bacteria (LAB), including genera like *Aerococus, Allococcus, Carnobacterium, Enterococcus, Lactobacillus, Lactococcus, Leuconostoc, Pediococcus, Streptococcus, Tetragenococcus,* and *Vagococcus*, are part of this fermentation process (Vidotti *et al.,* 2003). The most commonly used LAB as starter cultures in the production of biological silages are *Lactobacillus spp., Carnobacterium spp., Leuconostoc mesenteroides, Pediococcus acidilactici.* Certain LAB strains are considered probiotic due to their beneficial effects on the digestive tract and immune system of fish (Libonnatti, 2023).

Figure 2. Underutilized fish waste (Handajani, 2014).

Underutilized fish silage feed products are liquid, fermented fish products derived from whole fish or leftovers from the fish processing industry. Fish remnants are liquefied by enzymes found in the fish themselves through fermentation, aided by lactic acid or deliberately added microbes. The use of yeast in the fermentation process has been shown to increase protein content from 3.41% to 5.53% (Muhiddin *et al.,* 2001). Thus, underutilized fish has considerable potential to be processed into fish silage feed products.

Underutilized fish, as shown in Figure 2, refers to small-sized fish obtained from fishermen's by-catch. Underutilized marine fish and freshwater trash fish are two types based on their habitat. Examples of underutilized marine fish include sardines, yellowtail fish, trevally fish, and similar species (Selpina *et al.,* 2013). Underutilized freshwater fish, belonging to the Cyprinidae family, include catla, common carp, silver barb, and bonylip barb (Haryono, 2006).

The fish silage fermentation process with the addition of 5% *Lactobacillus Plantarum* bacteria led to increased amino acid composition in freshwater fish silage. For instance, lysine, histidine, threonine, and serine increased from initial values of 7.48 g/100g, 2.65 g/100g, 3.18 g/100g, and 3.39 g/100g to 9.92 g/100g, 3.08 g/100g, 5.12 g/100g, and 3.52 g/100g, respectively (Vidotti *et al.,* 2003). In tilapia fish fillet waste silage, amino acid composition increased in histidine, arginine, aspartic acid, threonine, serine, glutamic acid, glycine, and alanine levels (Vidotti *et al.,* 2003). In research Erfanto *et al.,* (2013), revealed that underutilized fish silage contains higher protein content, specifically 57.49%, compared to artificial feed (Table 1).

Table 1. Proximate Analysis of Artificial Feed and Underutilized Fish Silage (%)

Sample	NNFE	Protein	Fiber	Fat	Ash
Feed	13.88	6.56	15.14	34.30	30.12
Silage	30.12	6.22	1.78	57.49	4.39

NNFE : Non Nitrogen Free Extract (Erfanto *et al.,* 2013).

Physiologically high protein underutilized fish silage products could be produced using probiotics + 20% molasses with a fermentation time of 14 days, resulting in silage protein of 45.76%. For a fat content of 5.84%, a 14-day fermentation with 30% protein and molasses is required. To achieve a sour aroma and color in silage, probiotics + 30% molasses for 7 days can be utilized (Handajani, 2014). Fermented food products, known since ancient times, serve various purposes such as preservation, taste enhancement, and the creation of new products. The involvement of lactic acid bacteria in fish silage production necessitates additional carbohydrates to support bacterial growth. This aligns with the perspective of Malaka & Laga, (2005), indicating that dissolved carbohydrates in water undergo fermentation by lactic acid bacteria, generating lactic acid, CO_2, ethanol, and heterofermentative acid. The acid produced during fermentation lowers the pH of the silage, extending its shelf life by reducing the number of non-acid-resistant bacteria like *Salmonella* sp., *Escherichia coli*, and *Clostridium* sp., which typically thrive in a pH range of 4-9. Apart from carbohydrates, microorganisms also require water and fatty acids for growth.

Adding a lactic acid solution to fish initiates fat degradation due to decreased water and fat content in the silage liquid. Rapid multiplication of lactic acid bacteria during fermentation leads to swift aerobic respiration, triggering an ensiling process in the raw material. The fermentation-induced heat raises the temperature of the fish silage, imparting a blackish-brown color (Wahidah *et al.,* 2018). Beyond temperature elevation, color changes in silage result from biochemical processes facilitated by microorganisms, as described by (Llanes & Vega, 2008). Enzymatic activity in fermentation induces biochemical alterations in taste, color, shape, caloric content, and other aspects of food ingredients Handajani (2014).

Probiotics Incorporation in the Fish Waste Fermentation Process

In order to prevent environmental pollution, by-products from fish processing can be repurposed as raw materials for crafting fish probiotics, thereby enhancing fish farming production. According to Salminen *et al.,* (1999), probiotics encompass live microbial cells or components thereof that exert a beneficial influence on the health and vitality of their hosts. Lactic acid bacteria (LAB) are gram-positive, non-sporulating bacteria, coccus or bacillus contained in probiotics that can ferment carbohydrates and produce lactic acid as the main product of fermentation (Hayek & Ibrahim, 2013). The incorporation of probiotics into fish farming is integral to effective management, offering advantages such as heightened growth, bolstered non-specific immune responses, enhanced disease resistance, and improved fish survival (Balcazar *et al.,* 2006; Wang & Xu, 2006).

Probiotics, when integrated into feed, have been demonstrated to elevate growth and immune responses in fish (He *et al.,* 2011). In a study by Herry *et al.,* 2019 on probiotic production from Jambal Roti (local salt fermented fish) processing waste, non-pathogenic bacteria, including *Lactobacillus* sp. and *Bacillus* sp. (Figure 3), were identified with probiotic bacteria counts falling within the recommended range of 10^5 CFU/ml for commercial probiotics. Incorporating probiotics containing *Lactobacillus* sp. into commercial feed has proven effective in enhancing growth among catfish fry (Ahmadi *et al.,* 2012). The application of 15% probiotics resulted in a 95% survival rate and a feed efficiency ratio (FCR) of 0.82, signifying lower FCR and higher survival rates (Herry *et al.,* 2019). Similarly, introducing probiotics with *Bacillus* sp. into feed has been shown to enhance feed efficiency and protein retention in Pangas catfish (Setawan *et al.,* 2013). For common carp (*Cyprinus carpio*), the addition of probiotics to the feed was associated with a 5% increase in growth (Sakamole *et al.,* 2014), and in tilapia, incorporating probiotics with *Lactobacillus* sp. in feed enhances digestibility and growth with the highest values of 68.09% and 42.56% respectively (Ramadhana *et al.,* 2012).

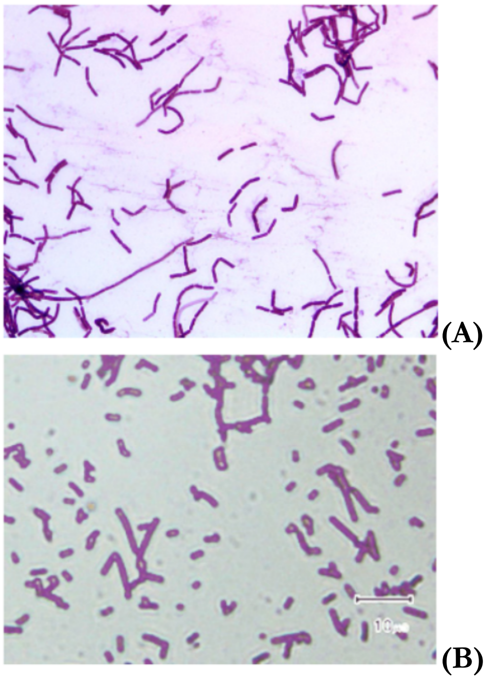

Figure 3. *Bacillus* sp. (A) and *Lactobacillus* sp. (B)
Source: (a) Jumaah *et al.,* 2014; (b) Wirama *et al.,* 2015

Utilization of Fish Silage as a Feed Ingredient

The incorporation of fish silage derived from both freshwater and marine fish into fish farming feed significantly impacts fish physiology and growth. In Kusuma *et al.,* (2017), the feeding of silage made from freshwater and seawater trash fish to snakehead fish fry (3-5 cm) demonstrated notable effects on the fry's weight, absolute length, survival rate, growth in absolute length and weight, and feed efficiency. The combined silage of freshwater and seawater trash fish, each at 50%, influenced survival rate (83.33%), absolute length (1.90 cm), absolute weight (0.498 g), and feed efficiency (71.85%) of snakehead fish fry. Similarly, Erfanto, *et al.,* 2013 reported a significant relative growth rate (RGR) of 5.02 ± 0.26% in goldfish fry fed with trash fish silage. In Madage *et al.,* 2015 on tilapia feed, the addition of 25% silage resulted in the highest final weight (36.35 g) with a feed conversion ratio of 1.06 (Table 2).

Table 2. Effect of Different Doses of Fish Silage on Fish Performance

Amount of Silage in Feed	Results	References
10%	- The highest tilapia survival rate was 83.33% and a feed conversion ratio of 1.57. - Adding silage to Bass Fish feed obtained a feed conversion ratio of 1.19 and an increase in fish weight of 17.81 g.	(Tobigo *et al.*, 2022; Arruda *et al.*, 2007)
15%	- Obtained tilapia survival rate of 70.00% and a feed conversion ratio of 1.61. - Adding silage to Bass Fish feed obtained a feed conversion ratio of 1.47 and an increase in fish weight of 14.64 g.	(Tobigo *et al.*, 2022; Arruda *et al.*, 2007)
20%	It was found that the survival rate of tilapia fish was 66.67% and the feed conversion ratio was 1.67.	(Tobigo *et al.*, 2022)
25%	- The results of the study showed that the highest relative growth speed (%) value for catfish was 222.63%. The value of the Feed Conversion Ratio (FCR) in treatment C obtained relatively low results with a value of 1.09. - Research on the use of fish silage in tilapia feed resulted in the highest final weight of 36.35 g with a feed conversion ratio of 1.06. - The addition of fish silage meal to the feed of Nile Tilapia and African Catfish resulted in weight gain of 36.99 g and 53.89 g respectively. - Replacing fish meal with fish silage by 25% for shrimp *Litopenaeus vannamei*, produces a specific growth rate of 5.56% and final weight 4,95 g.	(Madage *et al.*, 2015; Ratnasari *et al.*, 2020; Soltan & Tharwat, 2006; Shao *et al.*, 2020)

Amount of Silage in Feed	Results	References
50%	- The results of the research showed that the relative growth speed (%) value of catfish was 164.7%. The Feed Conversion Ratio (FCR) value obtained relatively low results with a value of 1.38. - Replacing fishmeal in the feed used to feed trout with 50% fish silage had a positive effect on growth, with a final weight of 178.7 g. - The addition of fish silage meal to the feed of *Labeo rohita* fingerlings resulted in weight gain of 5,94 g. The proximate results of the fish body contain 58.53 protein.	(Ratnasari *et al.*, 2020; Guzel *et al.*, 2011; Haider *et al.*, 2015)

In Handajani, (2014), underutilized fish waste exhibited a protein content of 28.83% and fat of 4.75%. Following fermentation using molasses and probiotics, trash fish silage products displayed a protein content ranging from 31.78% to 45.76%. Compared to the initial protein content in underutilized fish porridge (28.83%), all treatments exhibited an increase in protein content ranging from 2.95% to 16.93%. Meanwhile, in research Ramirez *et al.*, (2013), fish silage contained 39.9% protein and 14.5% lipid.

Table 3. Proximate Analysis of Silage Addition in Feed (%)

Feed with Addition	Protein	Fat	Ash	Fiber
0% Silage	34.30	7.56	10.88	13.14
5% Silage	35.45	8.68	11.29	10.35
10% Silage	36.62	8.73	11.27	10.59
15% Silage	37.77	8.87	11.47	10.65

Source: Erfanto *et al.*, 2013

In Erfanto *et al.*, (2013), the addition of trash fish silage to artificial feed significantly affected the Protein Efficiency Ratio (PER) of common carp seeds. Treatment B (5%) demonstrated the highest PER result of 1.40 ± 0.12%, aligning with common carp feed protein requirements (31-36%) (Table 3).

Conclusion

Drawing from a comprehensive analysis of various studies, it is evident that enhancing the quality of fish waste through fermentation, specifically utilizing lactic acid bacteria from the genera Aerococus, Allococcus, Carnobacterium, Enterococcus, Lactobacillus, Lactococcus, and Vagococcus, yields fish silage products characterized by elevated protein content, thereby influencing the growth performance of fish. Notably, incorporating silage at a 10% dosage remarkably achieves a survival rate of 83.33% for tilapia. Moreover, a 25% silage addition results in the highest observed relative growth rate for catfish, reaching an impressive 222.63%, alongside a commendable feed conversion ratio of 1.06 for tilapia.

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