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Effects of Fermentation on the Physico-Chemical Properties of Marine By-Products: A Review

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ABSTRACT

Marine by-products hold significant potential to be utilized as raw materials with added value, particularly in producing high-quality and environmentally friendly fish feed. This study aims to review the impact of fermentation on the physical and chemical properties of marine by-products. The method employed is a narrative literature review, referencing scientific literature from databases such as ScienceDirect and Google Scholar. The literature analysis highlights changes in physical structure, such as alterations in color and odor, that contribute to improved feed digestibility. In addition, fermentation also increases nutrient content, including proteins and essential amino acids, and produces bioactive compounds that act as antimicrobials and antioxidants. This study identifies that fermentation reduces waste and enhances its economic value for various applications, such as fish feed and alternative raw materials. Thus, this review provides innovative solutions for marine by-product management while supporting sustainability and efficiency principles in the fisheries industry.

Keywords: Alternative Feed Ingredients, Fermentation, Marine By-products

1. INTRODUCTION

Indonesia is an archipelagic country with a very large ocean area compared to the mainland. The fishing industry is one of the sectors contributing to the global food supply. However, the sustainability of this sector requires special attention, especially in managing marine by-products and providing environmentally friendly feed. The use of materials sourced from marine by-products is one of the solutions to solve the problem because their availability is quite high, and they have not been utilized optimally. In the research of Aulia et al. (2022), untreated marine by-products can reach up to 50 kg /day, accounting for 10–20% of raw materials. These by-products have significant potential to be processed into value-added raw materials in the fisheries industry, including high-quality fish feed. Feed availability with both good quality and sufficient quantity remains a challenge due to its relatively high cost, driven by the need to import certain feed ingredients from other countries (Sandra et al., 2020; Nasser et al., 2018).

In addition to the high potential possessed by the waste, several shortcomings need to be overcome to increase the nutrient content, shelf life, and quality of the fishing waste through the fermentation process (Andriani et al., 2020). Fermentation is a natural process involving microorganisms to change biomaterials' physical and chemical properties. This process can increase the added value of waste by transforming the physical structure of particles and chemical changes, including enrichment of nutrient content and bioactive compounds (Andriani et al., 2020; Cahya et al., 2023). Fermentation can also remove anti-nutrient compounds and produce beneficial secondary metabolites, such as antimicrobials and antioxidants (Rahmi et al., 2020; Zhao et al., 2021).

The purpose of this study is to examine previous research on the effects of fermentation on the physical and chemical properties of marine by-products. In addition, this article also aims to identify the potential of fermentation in increasing the added value of biomaterials, especially in fishery industry applications. Through this review, it is anticipated that innovative approaches can be identified to support sustainability and efficiency in managing marine by-products from the fisheries sector.

2. RESEARCH METHOD

This study uses the narrative literature review method. This type of qualitative research reviews publications by involving the compilation and presentation of the results of previous studies in narrative form. This method aims to compile a review from previous research on a particular topic to avoid duplication of research and identify research to explore new issues (Nahdiyin, 2023). Literature collection was carried out through academic databases such as Google Scholar, ScienceDirect, SpringerLink, and Researchgate used to search for relevant scientific publications, with keywords such as "Fermentation," "Fishing by-catch," "Physico-chemical quality," “Marine by-product,”, "Alternative feed ingredients." This comprehensive search strategy facilitated the construction of a theoretical framework that aligned with the core subjects discussed in the literature. All relevant journals then reviewed abstract sections and results to identify those discussing fermented marine by-products.

3. RESULT AND DISCUSSION

Potential and Characteristics of Marine By-Products

The production of capture fisheries in Indonesia has steadily increased from 2017 to 2023, with the total value of marine catch production reaching IDR 192,222,345,000 (MMAF, 2023). A large amount of fish production is not in line with the processing industry, which is still fairly stuck, so there is still much fish waste that is a by-product that has not been properly managed by the community (Figure 1). In 2007, the Central Statistics Agency stated that by-products from fish catches at the Fish Auction Place in Semarang City produced 16.28 tons of trash fish (Sofia et al., 2021). These by-products are estimated to have a proportion of around 30-40% of the total weight of fish, mollusks, and crustaceans, consisting of 12.0% of the head, 11.7% of bones, 3.4% of fins, 4.0% of skin, 2.0% of spines and 4.8% of the viscera or entrails (MMAF, 2020).

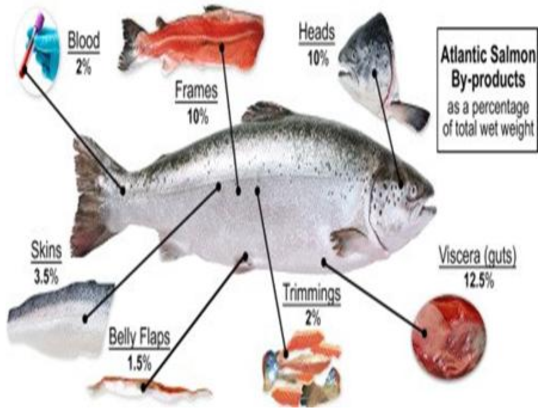

Figure 1. Atlantic salmon by-products

Source: IFFO (2018)

Waste from shrimp (Figure 2), i.e., shrimp heads that account for 40 to 48% of the total shrimp, is a significant component that is discarded if not utilized properly (Xin et al., 2020; Gao et al., 2020). A large amount of shrimp residues are disposed of without any beneficial processing during the shrimp processing process, even though shrimp residues have significant potential to be utilized in the food industry to recover bioactive compounds and add value (Silva et al., 2021). Deep-sea shrimp are known to contain high levels of omega-3 fatty acids, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Misir et al., 2017).

Fishery by-products often contain valuable nutrients such as proteins, fats, and minerals. Riyanto et al. (2012) reported that tuna viscera contain 17.11 ± 0.18% protein and 1.63 ± 0.30% fat. Meanwhile, the protein content of shrimp shell waste ranges between 33-40%, with the remaining material being chitin, which is difficult to degrade and has a content of 15-40% (Widyastuti, 2023). Examples of fishery by-products with potential for use as raw materials for feed production are presented in Table 1.

In addition to the many potentials this waste possesses, several shortcomings need to be overcome. Fish waste that is rich in protein and fat will quickly undergo a decay process (Marantika, 2017), so it can produce an unpleasant odor if left to rot without proper treatment (Masse et al., 2011). According to Ghaly et al. (2013), the fat content in fish waste is also susceptible to oxidation, producing harmful compounds such as peroxide and aldehyde, which can accelerate deterioration. So, to improve the quality of the fishing waste, it is necessary to carry out a processing process through fermentation.

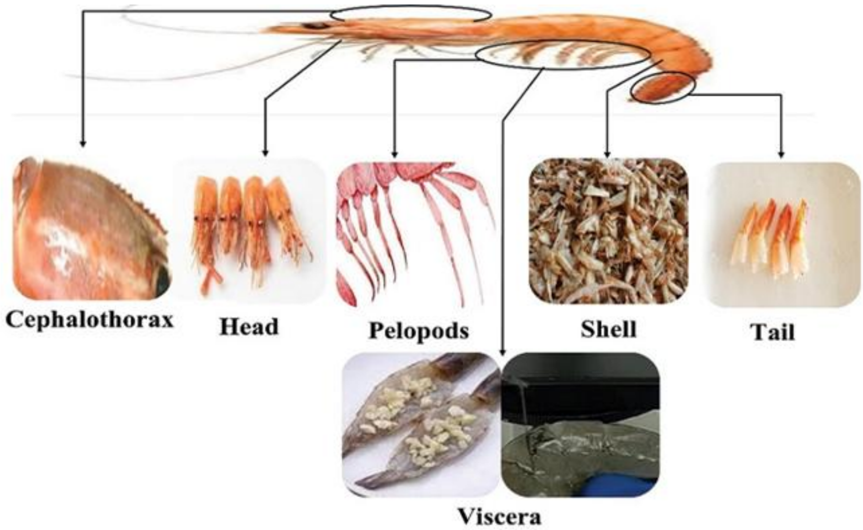

Figure 2. Valuable parts of shrimp waste
Source: Abuzar et al. (2023)

Table 1. Nutritional potential of marine by-products

Types of Waste	Nutrient Content (%)			
	Protein	Fats	Crude Fiber	Moisture
Tuna Viscera	17.11	1.63	0	75.42
Marine Fish Scales	48.57	4.98	0	9.81
Tuna Fish Bone	17.18	5.04	0	5.37
Skipjack Fish Bone	32.27	8.00	0	6.95
Shrimp waste	45.29	6.62	17.59	0
Codfish waste	38.54	12.75	0	0
Milkfish Scales	65.94	2.64	0	4.94
Milkfish Bones	38.39	20.43	0	6.38

Sources: Andriani et al. (2020), Riyanto et al. (2012), Fahrizal & Ratna (2018), Nurhayati et al. (2024)

Fermentation of Marine By-products

Fermentation is a process of breaking down or decomposing organic matter into simpler forms, both aerobic and anaerobic, to increase the value of nutrient content in waste. It can be done through a biotransformation process using the help of microorganisms, which generally aim to increase the level of crude protein and easily digestible carbohydrates and reduce crude fiber in an ingredient (Mo et al., 2019; Wong et al., 2016; Andriani et al., 2021). One of the main chemical reactions that occur in fermentation is glycolysis, which is the process of breaking down sugar and carbohydrate molecules with the help of organisms such as *Leukonostoc*, *Streptococcus*, and *Lactobacillus* bacteria into pyruvic acid, which is then converted into the final product of lactic acid (Ghaffar et al., 2014).

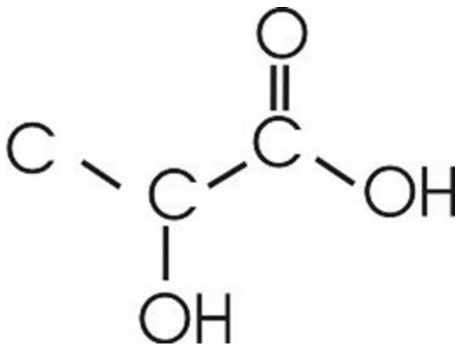

Figure 3. *Lactic acid*, $C_3H_6O_3$
Source: Soult (2024)

Anaerobic respiration performed by bacteria (such as Lactobacillus and others) converts the 3-carbon pyruvate into 3-carbon lactic acid ($C_3H_6O_3$) (Figure 3) while regenerating NAD+ in the process, allowing glycolysis to continue to make ATP in low-oxygen conditions.

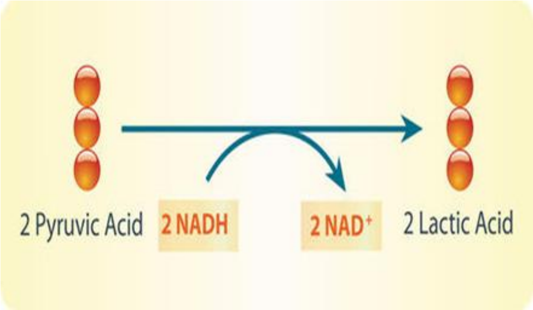

Figure 4. Lactic acid fermentation makes ATP in the absence of oxygen by converting glucose to lactic acid
Source: Soult (2024)

Since a limited supply of NAD+ is available in any given cell, this electron acceptor must be regenerated to allow ATP production to continue. To achieve this, NADH donates its extra electrons to the pyruvate molecules, regenerating NAD^+. Lactic acid is formed by the reduction of pyruvate (Mckay & Baldwin, 1990; Soult, 2024). This reaction can be expressed as follows (Figure 4):

$C_3H_3O_3$ pyruvate + NADH → $C_3H_6O_3$ lactic acid + NAD^+

This process creates anaerobic conditions and high acidity levels, which help extend the waste's shelf life and inhibit pathogenic microorganisms' growth.

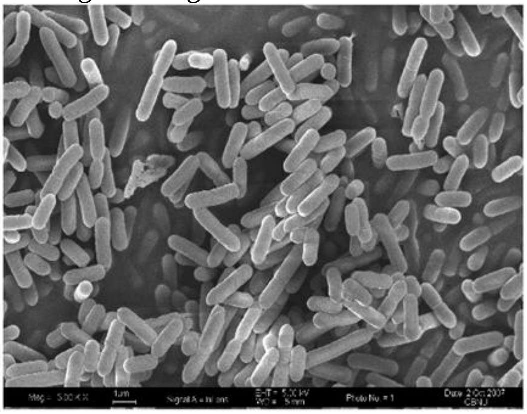

Figure 5. *Lactobacillus sp.* is one of the lactic acid bacteria
Source: Shin et al. (2012)

In the case of fish by-products, the fermentation process is carried out using a type of lactic acid bacteria (Figure 5). *Lactobacillus* sp and *Bacillus* sp are the lactic acid bacteria that are often used in the fermentation of fish by-products because they can degrade various compounds, break down anti-nutrient compounds that can inhibit the absorption of nutrients in fish, and produce protease enzymes (Putri et al., 2012). According to Tamang et al. (2016), the transformations during fermentation can produce antioxidant and antimicrobial components and enrich healthy bioactive components. The utilization of shrimp by-products as fish feed is limited by the high chitin content, which reduces protein bioavailability. Several studies have shown that fermenting shrimp by-products with *Aspergillus niger* (Rosyidi et al., 2009) and *Trichoderma viridae* (Palupi & Imsya, 2011) can reduce chitin content, thus improving the quality of the resulting shrimp by-products.

Physical and Chemical Changes in Marine By-products

The quality changes in marine by-products through fermentation can alter their texture and odor while increasing nutritional content and reducing antinutritional factors. The increase in protein content in fermented materials is due to the activity of fermenting microbes such as *Lactobacillus* sp, which enhance protein hydrolysis, increasing free amino acids. This is because proteins are broken down into simpler forms like amino acids and peptides, which are then re-used to form proteins, thus increasing protein content in the fermented material (Mukherjee et al., 2016).

Meanwhile, the decrease in crude fiber by 14.31% after the fermentation process is due to the activity of the cellulase enzyme produced by *Lactobacillus* sp, which can break down crude fiber into simpler compounds that can be utilized as energy in cellular metabolism. The transformation of cellulose into short-chain fatty acids is responsible for the decrease in oil fiber content in the fermented by-product (Suryani et al., 2017). In the research of Handajani (2014), fermentation in the waste of catch in the form of trash fish produces silage products with a protein content of 45% and fat of 5.85%. Meanwhile, in the study of Palupi & Imsya (2011), the fermentation of shrimp waste using *T.viridae* produced a crude protein content of 41.27% with a protein digestibility of 81.24%. The nutritional composition of the fermentation of marine by-products can be seen in Table 2.

In addition to changing the nutritional content, the fermentation process can also improve the physical quality of fish waste in terms of color and odor. According to Handajani (2014), the results of the physical test of fermentation of trash fish using probiotics and molasses can be seen in Table 3.

Table 2. Nutritional composition of marine by-products after the fermentation process

Type of Waste	Results	References
Tuna Fish Guts	The nutrient content of fermented tuna fish guts meal is 66.53% protein, 7.43% fat, and 0.69% crude fiber.	Marantika (2017)
Trash Fish	Fermentation of trash fish was conducted using probiotics and 20% molasses with a fermentation time of 14 days, resulting in silage with a protein content of 45.76% and fat content of 5.84%.	Handajani (2014)
Solid Waste Surimi of Swanggi Fish (*Priacanthus macracanthus*)	Fermented swanggi surimi waste has a protein content of 46.32%.	Aunurrofiq et al. (2017)
Trash fish	The results of fermentation of trash fish with treatment using molasses plus probiotics had a crude protein content significantly different from all treatments (P < 0.05), with protein content ranging from 31.78–45.76%. When compared to the initial protein of the ingredient, namely fish porridge, with a protein content of 28.83% from all treatments, there was an increase in protein content, which ranged from 2.95 to 16.93%.	Handajani (2014)
Shrimp Waste	Fermentation with *T.viridae* 4% with a fermentation period of 2 days resulted in a crude protein content of fermented shrimp waste flour of 41.27% with a protein digestibility of 81.24%.	Palupi & Imsya (2011)
Shrimp Waste	The nutritional content of shrimp waste flour after fermentation has improved in quality, namely crude protein 45.09%, crude fiber 21.23%, crude fat 3.64%, calcium 8.26%, phosphorus 2.52%, and chitin 10.82%. Meanwhile, unfermented shrimp waste contains lower crude protein at 30.2% and higher chitin content at 11.92%.	Mulyadi et al. (2017)

Table 3. Physical test of fermented trash fish using probiotics and molasses

Treatment	Odor and Color Responders			
	Fishy	Sour	Dark Brown	Light Brown
Probiotics + Molasses 20% + 7 days fermentation	27	60	10	20
Probiotics + Molasses 20% + 14 days fermentation	27	40	10	20
Probiotics + 30% Molasses + 7 days fermentation	0	97	3	0
Probiotics + 30% Molasses + 14 days fermentation	20	77	5	6

In Table 2, the effect of molasses combined with probiotics (*L.casei* and *S.cerevisiae*) shows that the fermented trash fish produced a sour odor, with the percentages of respondents reporting the odor as sour being 60%, 40%, 97%, and 77% throughout the fermentation process. This sour odor is suspected to result from the metabolic activity of the fermenting microorganisms.

Application of Fermented Marine By-products in Feed Materials

Utilizing marine by-products as fish feed can serve as a solution to reduce waste accumulation in the environment while also decreasing costs associated with raw material procurement for feed production. Organic waste from fisheries activities can be used as feed ingredients in fish farming, positively impacting fish physiology and growth. Kusuma et al. (2017) stated that the addition of 50% fermented trash fish in the feed had a significant effect on the growth of snakehead fish fry, resulting in a survival rate of 83.33%, absolute length growth of 1.90 cm, absolute weight growth of 0.498 g, and feed efficiency of 71.85%. Meanwhile, in the Madage et al. (2015) study, the use of fish waste fermentation of as much as 25% in tilapia feed resulted in the highest final weight of 36.35 g with a feed conversion ratio of 1.06. Adding fermented tuna viscera meal to a dose of 20% in feed causes an increase in survival up to 100%, lowering the lowest feed conversion ratio of 1.54 and the best protein efficiency ratio of 2.47 g (Marantika, 2017).

4. CONCLUSION

The fermentation process significantly affects the physical and chemical properties of marine by-products, making it more valuable to be applied in various fisheries sectors, primarily as raw materials for fish feed.

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