

# Fish Meal Production Optimization From Fish Processing Solid Waste Using Lipase And Protease Enzymes Addition

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**Abstract.** Fish meal derived from solid waste in the tuna processing industry presents a sustainable opportunity to increase the value of by-products and manage waste. However, the quality of fish meal from solid waste processing is still poor, especially its relatively high fat content. This study investigated the quality changes of fish meal produced from tuna processing waste during various incubation periods (30, 60, and 90 minutes) before and after the addition of crude extracts of lipase and protease enzymes. The fish meal quality parameters tested were protein, moisture, fat, Total Volatile Basic Nitrogen (TVBN), and ash content. The results showed that the addition of crude extracts of lipase and protease enzymes and the incubation duration significantly affected the quality of fish meal. The fat content in fish meal was successfully reduced, which is good for product stability. The highest protein content reached 56.7%, but this value did not fully meet the industry standard of a minimum of 58%. In addition, the Total Volatile Basic Nitrogen (TVBN) value increased with longer incubation times, and the resulting value still exceeded the maximum standard of 130mg/100g. Ash content remained stable within an acceptable range (maximum 22%), indicating consistent mineral retention. Furthermore, physical observations showed that more extended incubation periods resulted in a denser and smoother texture, which is advantageous for applications requiring consistency. These findings emphasise the need to optimise incubation conditions to improve the nutritional and physical properties of fish meal while addressing challenges related to protein degradation and freshness.

## 1 Introduction

The global fish processing industry is expanding rapidly, contributing significantly to both the global economy and environmental challenges. In 2024, the industry reached a production volume of approximately 178.8 million tonnes, with Asia-Pacific leading production [1]. This growth, however, generates large quantities of waste, including fish heads, bones, skin, scales, fins, guts, frames, and trimmings. These fish processing by-products, which typically contain valuable nutrients such as proteins (averaging about 58% dry weight), lipids (around 19%), and essential minerals like calcium and phosphorus, represent a significant environmental burden due to their high organic load [2]. If not properly managed, this waste can lead to substantial pollution risks, contributing to ecological degradation and straining waste management systems, particularly in regions with high fish processing activity. Consequently, a sustainable approach to handling this waste is urgently needed.

Despite the significant amount of fish waste generated, these by-products are rich in bioactive compounds, making them valuable substrates for producing high-quality fish meal [3], [4]. The challenges in efficiently converting these materials into usable products that meet the nutritional and functional standards required by industries such as aquaculture and nutraceuticals. Traditional fish meal production methods typically rely on mechanical techniques like pressing and grinding, which yield meals with high residual fat content and comparatively low protein levels. Additionally, these methods employ high temperatures that can lead to the denaturation of proteins, lipid oxidation, and a reduction in the bioavailability of essential nutrients, particularly omega-3 fatty acids [5].

An alternative to these mechanical methods is enzymatic hydrolysis, which uses enzymes like lipases and proteases to break down proteins and lipids under controlled, mild conditions. Lipases catalyze the hydrolysis of triglycerides into free fatty acids and glycerol, facilitating the extraction of high-purity lipids, particularly omega-3 fatty acids, which are highly valued for their anti-inflammatory and cardiovascular health benefits [6]. Proteases on the other hand, break down complex proteins into smaller peptides and amino acids, enhancing the protein content of the resulting fish meal and potentially yielding bioactive peptides with health-promoting properties [7]. Unlike traditional mechanical processes, enzymatic hydrolysis can reduce the risk of lipid oxidation, preserving the stability and quality of omega-3 fatty acids in the final product, thus ensuring a higher nutritional value.

Moreover, enzymatic removal of lipids by lipase treatment has been shown to improve subsequent protease hydrolysis rates and yields of functional peptides, offering a more efficient method for extracting high-value components from fish waste. Enzymatic hydrolysis is generally preferred for producing high-value functional ingredients from fish waste due to its specificity and superior product quality compared to other bioconversion methods like microbial fermentation or chemical hydrolysis, which take longer, require additional microbial management, and can lead to nutrient degradation [8]. This method is thus not only more efficient but also more environmentally sustainable.

Despite the promising potential of enzymatic hydrolysis for fish waste valorization, there remains a significant gap in the literature regarding the direct comparison between mechanical and enzymatic methods in the context of tuna processing. Most studies focus on either lipase or protease in isolation, without examining their combined effects on tuna waste. Additionally, many studies overlook key nutritional parameters such as the preservation of omega-3 fatty acids and the generation of bioactive peptides. This study aims to bridge this gap by evaluating the combined enzymatic method's ability to produce high-quality fish meal

while also minimizing environmental impact, thus providing a comprehensive solution to the challenges of fish waste management.

This research will compare the quality of fish meal derived from tuna processing waste using both traditional mechanical methods and enzymatic processing with lipase and protease enzymes. The primary objectives are to evaluate the nutritional and functional qualities of the resulting fish meal, focusing on key metrics such as protein content, lipid profile, and fatty acid composition. Furthermore, the study will explore the potential of enzymatic processing to generate high-value products such as omega-3-rich fish oil and protein-rich meal, while minimizing the environmental impact of fish processing. By optimizing the extraction of lipids and proteins, enzymatic hydrolysis could offer a sustainable and economically viable alternative to mechanical processing, contributing to the development of circular economy models within the seafood industry.

Moreover, by optimizing fish meal production through enzymatic hydrolysis, this research could provide a viable, environmentally friendly alternative to traditional methods. This would not only offer a solution to the challenges of fish waste management but also contribute to more sustainable practices in the aquaculture sector. The findings will be highly relevant not only for the aquaculture industry, which relies on high-quality fish meal for feed production, but also for nutraceutical applications, where the high-quality lipids and proteins extracted from fish waste could have significant health benefits. Ultimately, this study aligns with global efforts to reduce waste, promote sustainable practices, and advance the circular economy within the seafood sector, offering new insights into how fish waste can be efficiently valorized for broader applications.

## **2 Methodology**

### **2.1 Chemicals and Materials**

The chemicals used in this study include nutrient agar (Merck), nutrient broth (Merck), methyl red, olive oil, Tween-80, NaCl 0.85% (Merck), peptone (himedia),  $\text{KH}_2\text{PO}_4$  (Merck),  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$  (Merck),  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  (Merck), *p*-Nitrophenyl palmitate (*p*-NPP), *p*-Nitrophenol (Merck), Triton X-100, phosphate buffer, isopropanol, Bovine Serum Albumin (BSA) (Merck), Folin-Ciocalteu reagent (Merck), iodine solution (Merck), crystal violet (Merck), 95% alcohol, safranin (Merck). Medium used for production, includes molasses, monosodium glutamate, and tofu wastewater.

The equipment used including pH meter (*Lutron PH-208*), Vortex Thermolyne Maxi Mix II type 37600 mixer, Hot Plate Thermolyne Cimarec 2, Microscope model BX43F, UV-Vis Spectrophotometer Genesys 20 (Thermo Scientific), Autoclave Tomy SX-700, and Refrigerated Centrifuge Tomy MX-105.

### **2.2 Sample Collection and Physical Characterization**

This study begins with the collection of solid waste samples from fish processing at PT. Aneka Tuna Indonesia. As a research partner, PT. Aneka Tuna Indonesia collaborates to provide consistent and representative samples. Prior to processing, the physical characteristics of the raw materials were evaluated visually. This characterization included observations of texture, color, and moisture content to document the initial condition of the

waste. The waste used consists of fish flesh, bones, and entrails, which will be further processed in the subsequent stages.

## 2.3 Enzyme Activity Test

### 2.3.1 Protease Enzyme Activity

Protease activity is measured using a non-specific method developed by Sigma. Protease enzyme was produced from three bacterial isolates: AP-1, AP-13, and AP-16. It used 3 types of production medium including Molase, MSG, and Tofu. The test begins by mixing 5 mL of 0.65% casein as the substrate with 0.5 mL of crude enzyme extract obtained from the centrifugation process. The substrate and enzyme mixture is vortexed and incubated at 37°C for 10 minutes. The reaction is then stopped by adding 5 mL of 10% TCA solution, followed by another vortex and incubation at 37°C for 30 minutes. After incubation, the mixture is centrifuged at 10,000 rpm for 10 minutes at 4°C. A 2 mL sample of the supernatant is pipetted into a test tube, followed by the addition of 5 mL Na<sub>2</sub>CO<sub>3</sub> 0.4 M and 1 mL Folin-Ciocalteu reagent 1 N. The homogenized mixture is then incubated at 37°C for 30 minutes, and absorbance is measured at a wavelength of 660 nm. Enzyme activity is calculated based on the difference in absorbance between the sample and the blank. A negative activity value indicates that the absorbance of the sample is lower than that of the blank control, representing no detectable enzyme activity.

### 2.3.2 Lipase Enzyme Activity

Lipase activity is measured by a spectrophotometric method using *p*-nitrophenylpalmitate (p-NPP) as the substrate. The p-NPP solution is prepared by dissolving 30 mg p-NPP in 10 mL isopropanol, then mixing it with 90 mL of 0.1 M phosphate buffer with pH 7 until homogenized. A 0.5 mL sample of enzyme supernatant is then mixed with 2 mL of the substrate and incubated at 37°C for 30 minutes. Afterward, 50 µL of Triton X-100 is added to the mixture. Absorbance is measured using a UV-Vis spectrophotometer at a wavelength of 410 nm.

### 2.3.3 Determination of Protein Concentration and Specific Activity Enzyme

Protein concentration of the crude enzyme extract was determined using the Lowry method with Bovine Serum Albumin (BSA) as the standard. The specific activity of the enzyme was then calculated to determine the *purity* of the enzyme extract using the following formula:

$$\text{Specific Activity Enzyme (U/mg)} = \frac{\text{Enzyme Activity (U/mL)}}{\text{Protein Concentration (mg/mL)}} \quad (1)$$

## 2.4 Processing of Fish Processing Industry Solid Waste

The collected solid waste is first ground using a crusher machine until it becomes a smooth slurry. This crushing process is repeated to obtain a soft and homogenous texture. The resulting slurry then undergoes a pressing stage to separate water and oil from the waste. Next, a mixing process is conducted by combining the solid waste slurry with a mixture of lipase and protease enzymes in a 1:1 ratio. This mixture is homogenized at room temperature

with incubation variation 30, 60, and 90 minutes. The solid waste that has been mixed with enzymes is then dried in an oven at a temperature of 65-80°C. The dried waste is then milled into fishmeal.

## 2.5 Chemical Analysis of Fish Meal

The final product, fishmeal and fish oil, is analyzed to determine its quality. The parameters studied include protein content, fat content, moisture, Total Volatile Basic Nitrogen (TVBN), and protein level. This quality analysis is conducted by PT. Aneka Tuna Indonesia using standard laboratory procedures to ensure the product's characteristics meet the desired quality criteria.

## 3 Result and Discussion

### 3.1 Solid Waste Characteristic

The solid waste samples were obtained from the tuna processing industry at PT. Aneka Tuna Indonesia. The types of fish processed belong to the family *Scombridae*, tribe *Thunnini*, which includes the genus *Thunnus* (Bluefin tuna and Yellowfin tuna) and the genus *Katsuwonus* (Skipjack tuna). The solid waste obtained is a by-product such as leftover meat, bones, and fish entrails that are not included in the next stage of processing.



**Fig. 1.** Solid Waste include bones, leftover meat, and fish entrails

Different types of solid waste naturally have different physical and chemical characteristics. Solid waste in the form of fish bones and meat has a coarse, brown texture (**Figure 1**). The brown color of the meat waste is the result of cooking processes prior to separation. The waste from fish entrails tends to be wetter, mixed with blood, red-brown in color, with a chewy and slightly oily texture (**Figure 1**). The difference in physical characteristics are due to different processing methods. Entrails are separated from the fish body before cooking, while meat waste is produced after cooking.

The solid waste from the fish processing industry is obtained in a frozen state to maintain the quality of the waste in fresh condition during transport and to reduce the degradation of important compounds in the waste. The transport process is also carried out using special containers to slow down the melting of the ice within the solid waste.

### 3.2 Protease and Lipase Enzyme Activity

The main component of the solid waste processing in the fish processing industry involves not only mechanical processes but also enzymatic aspects. The use of enzymes with appropriate specific activity values will help optimize the conversion process. This study investigates the specific activity of several enzymes, including AP-1, AP-13, and AP-16. The protease and lipase activity of bacterial isolates AP-1, AP-13, and AP-16 were evaluated on three types of substrate media: molasses, MSG (monosodium glutamate), and tofu.

**Table 1.** Protease Enzyme Activity

Production Medium	Bacterial Isolate	Enzyme Concentration (U/mg)	Specific Activity (U/mg)
Molase	AP-1	8,31	9,14
	AP-13	4,42	4,86
	AP-16	-8,57	-9,43
Monosodium Glutamate	AP-1	-127,27	-140,00
	AP-13	54,55	60,00
	AP-16	-101,30	-111,43
Tofu Wastewater	AP-1	-0,62	-0,69
	AP-13	-2,57	-2,83
	AP-16	-2,83	-3,11

The results show significant variation in enzyme concentration and activity, depending on the media used and the type of bacterial isolate. This indicates that substrate composition and bacterial specificity play a crucial role in optimizing enzyme activity for industrial applications. Evaluation of the protease activity from bacterial isolates AP-1, AP-13, and AP-16 on three types of media (molasses, MSG, and tofu) showed varied results (**Table 1**), highlighting the importance of selecting the appropriate media to optimize enzyme production. In molasses media, the AP-1 isolate showed the highest protease activity of 9.14 units with an enzyme concentration of 8.31, followed by the AP-13 isolate with moderate protease activity of 4.86. The high activity in AP-1 suggests that molasses provides nutrients that support protease expression and stability in this isolate, making it a potential candidate for applications requiring protein hydrolysis. On the other hand, in MSG media, the AP-13 isolate recorded the highest protease activity of 60.00 with a concentration of 54.55. The high activity of AP-13 in MSG media may be due to the monosodium glutamate content, which tends to produce higher protease enzyme activity due to efficient induction by MSG as a nitrogen source and growth simulator [9]. Overall, these results suggest that molasses and MSG are potential media for protease production in specific isolates (AP-1 in molasses and AP-13 in MSG), whereas tofu is less suitable as a substrate. These variations emphasize the importance of selecting appropriate substrate and isolate combinations to maximize enzyme production, where nutrient composition and the presence of inducers or inhibitors in the media significantly influence protease expression and activity.

**Table 2.** Lipase Enzyme Acitivity

Production Medium	Bacterial Isolate	Concentration (U/mg)	Specific Activity (U/mg)
Molasse	AP-1	-18,75	-0,02
	AP-13	12,50	0,02
	AP-16	6231,25	7,61
Monosodium Glutamate	AP-1	-593,75	-0,73
	AP-13	500,00	0,61
	AP-16	656,25	0,80
Tofu Wastewater	AP-1	-1,50	0,00
	AP-13	-0,88	0,00
	AP-16	-2,44	0,00

Evaluation of the lipase enzyme activity from bacterial isolates AP-1, AP-13, and AP-16 on three types of media (molasses, MSG, and tofu) showed significant variation, emphasizing the critical role of media in supporting enzyme production and activity. In molasses media, the AP-16 isolate showed the highest lipase activity of 7.61 with an enzyme concentration of 6231.25, while AP-13 showed the minimum activity (0.02). The high lipase activity in AP-16 is due to its rich carbon content and ability to effectively induce lipase production in microorganisms, making it a promising medium for applications requiring lipid hydrolysis or oil extraction. The minimal activity in AP-13 in molasses media may be due to the mismatch between molasses nutrient composition and the metabolic needs of these two isolates for lipase production. In MSG media, isolates AP-13 and AP-16 showed identical lipase activity of 0.61. The positive activity in AP-13 and AP-16 in MSG indicates that MSG can support moderate lipase activity in these two isolates, although the activity is lower compared to molasses. MSG is more related to impacting metabolic enzyme expression rather than directly acting as an efficient substrate for lipase production. Meanwhile, in tofu media, all isolates (AP-1, AP-13, and AP-16) showed zero lipase activity, indicating that tofu is ineffective for lipase production. This low activity may be due to the lack of lipid sources or the presence of inhibitors in tofu media that hinder lipase enzyme activity [10]. Overall, these results suggest that molasses is the most effective medium for lipase production in the AP-16 isolate. In contrast, MSG supports moderate lipase activity in AP-13 and AP-16, and tofu is not suitable as a substrate for lipase production. These variations underline the importance of selecting appropriate media for lipase production, where nutrient composition and the presence of inducing or inhibiting factors significantly influence the effectiveness of lipase production and activity. Negative values in enzyme activity measurements typically indicate issues related to experimental or measurement errors caused by a few possible problems, including blank errors, instrumental noise, improper reaction, or substance interference.

The protease and lipase enzyme activities of bacterial isolates AP-1, AP-13, and AP-16 vary significantly depending on the media used. The best specific enzyme activity for lipase was found in the AP-16 isolate, while for protease, it was found in the AP-13 isolate. These two isolates, with specific activity for each enzyme, will serve as starters for solid waste processing.

### 3.3 Solid Waste Processing

After completing the design and construction of the equipment, testing was carried out to evaluate its efficiency in processing tuna fish waste and producing valuable byproducts. Real solid waste from the tuna processing industry was used in this trial, specifically 2.5 kg of meat/bone waste and 0.5 kg of entrail waste. The first step in the process involved grinding the waste using a grinding machine, which successfully converted the coarse, water-laden texture of the bones and entrails into a finer material, facilitating further processing. This initial grinding stage was essential for breaking down the physical structure of the waste, preparing it for the subsequent mixing and enzyme treatment phase.

In the second stage, a mixture of lipase and protease enzymes was introduced to the ground waste to improve the yield of both fishmeal and fish oil. The enzymatic addition likely enhanced the breakdown of complex proteins and fats, making it easier to separate and recover valuable components. This enzymatic treatment is critical as it not only aids in converting the waste into fishmeal and oil but also contributes to increased overall efficiency of the process. Following the enzymatic treatment, the pressing stage was conducted to separate the solid waste from the water content in the fish waste. This step effectively reduced the moisture content in the solid waste, thus preparing it for the drying phase.

The third stage of the process involved drying the solid waste in an oven at a controlled temperature between 65-80°C until the moisture content was reduced to below 10%. This drying stage was crucial for stabilizing the solid waste, making it suitable for long-term storage and further processing. The low moisture level also improves the grinding efficiency in the next stage. Meanwhile, the liquid waste generated from the pressing stage was analyzed for oil and protein content. This analysis was essential for evaluating the potential oil yield, which is crucial for the fractionation phase. The results from this analysis provide insight into the effectiveness of the pressing and enzyme treatment stages in releasing extractable oils and proteins.

The final stage focused on processing the dried solid waste into fishmeal powder using a milling machine. This stage successfully produced a dry, brown fishmeal powder, a valuable byproduct for various applications, including animal feed and nutrient supplements. The color and consistency of the fishmeal powder indicate effective processing and stabilization through drying and milling. Overall, the testing results demonstrate that the equipment effectively processes fish processing waste into valuable byproducts through a series of mechanical, enzymatic, pressing, drying, and milling stages. The results also highlight the importance of each step, notably the enzyme addition, in enhancing yield and quality. This approach provides a sustainable solution for waste management in the tuna processing industry by transforming waste into high-value products.

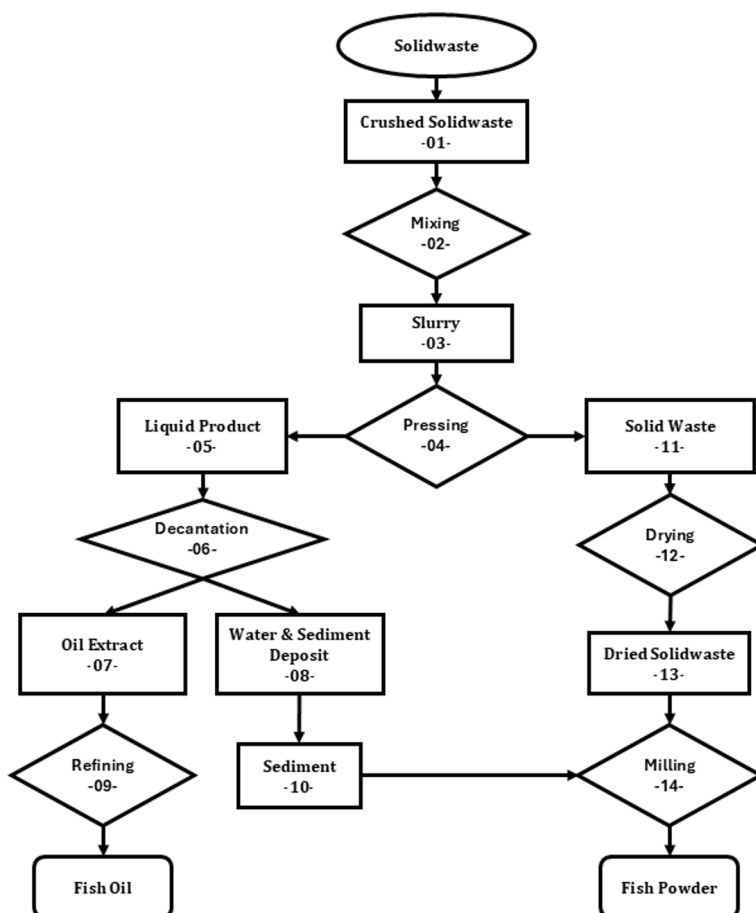






Fig. 2. Flowchart of Solid Waste Processing

### 3.4 Fish Meal Physical and Chemical Characteristic

This study evaluated the quality of fishmeal produced from solid waste in the fish processing industry over four incubation periods: 0 minute (TI 01), 30 minutes (TI 30), 60 minutes (TI 60), and 90 minutes (TI 90). The analysis focused on key quality parameters, including protein content, moisture, fat, Total Volatile Basic Nitrogen (TVBN), and ash, comparing the results with industry standards for fishmeal. The findings indicate a significant impact of incubation duration on fishmeal quality, driven by enzymatic and microbial processes occurring during incubation.

Physically, the texture of the fishmeal changed as the incubation period increased (**Table 3**). The TI 0 appeared coarser and less compact, while samples with longer incubation times (TI 30, TI 60, and TI 90) showed a denser and more uniform texture. This change is likely due to enzymatic degradation and microbial activity, breaking down particles into finer and more consistent forms. The thicker and more homogeneous texture is advantageous for applications requiring consistency and stability in fishmeal products.

**Table 3.** Fish meal Physical Characteristic

Sample	TI 0	TI 30	TI 60	TI 90
Physical form				
Incubation time	0	30	60	90

The results of the study reveal the impact of lipase and protease enzyme treatment on various sample components, with noticeable changes in protein, moisture, fat, TVBN (Total Volatile Basic Nitrogen), and ash content (**Table.4**). The protein content in the samples before enzyme addition ranged from 48.1% to 53.7%, which was below the industrial standard minimum of 58% protein required for the sample. After enzyme addition, protein content increased in all samples, particularly in TI 90, which showed the most significant increase from 53.7% to 56.7%. This increase suggests that enzymatic degradation may have led to the formation of protein breakdown products, which might not be detected as intact proteins in standard protein assays. This indicates that the protease enzyme effectively contributed to breaking down larger, less accessible protein molecules, potentially enhancing the nutritional profile of the sample [11]. However, the protein content still did not meet the required standard, indicating that further enzyme optimization, such as adjusting enzyme concentration or incubation time, may be needed to achieve the 58% target.

**Table 4.** Fish Meal Analysis

	Sample	Incubation Time (Minutes)	Protein (%)	Moisture (%)	Fat (%)	TVBN (mg/100g)	Ash (%)
Before Enzyme Addition	TI 01	0	50,2	11,7	13,7	354,9	15,9
	TI 30	30	49,4	9,2	14,9	338,7	19,2
	TI 60	60	48,1	8,8	13	313,9	19,2
	TI 90	90	53,7	5,7	11,1	289,8	17,4
After Addition	TI 01	0	52,47	13,05	11,52	397,65	15,17
	TI 30	30	51	14,3	8,47	524,53	15,37
	TI 60	60	50,2	12,3	11,58	476,95	15,51
	TI 90	90	56,7	13,95	13,41	581,4	6,78
Industry Standard			Min 58%	Max 10%	Max 20%	Max 130 mg / 100 g	Max 22%

Moisture content showed a similar trend, with initial values ranging from 5.7% to 13.05%, some of which exceeded the maximum moisture limit of 10%. Moisture is a critical factor in determining the texture and shelf life of the final product. After enzyme treatment, moisture content increased significantly, particularly in TI 90, which saw an increase from 5.7% to

13.95%. This increase could be attributed to the breakdown of hydrophobic components in the sample, making it more water-absorbent. According to Seyed (2021), enzymatic hydrolysis of proteins and lipids disrupts the matrix or network in the substrate, loosening the structure and allowing it to hold more water physically, thus increasing moisture content [12].

Fat content before enzyme addition ranged from 11.1% to 14.9%, all of which were within the acceptable maximum of 20%. The fat content decreased significantly in TI 30, where lipase activity likely broke down triglycerides into free fatty acids and glycerol, reducing the overall fat content from 14.9% to 8.47%. However, in TI 90, fat content increased from 11.1% to 13.41%, suggesting a more complex enzymatic interaction that may have released other lipid compounds or affected the fat retention in the sample.

TVBN (Total Volatile Basic Nitrogen), a key indicator of protein degradation and spoilage, was significantly decreased before enzyme addition. Before enzyme treatment, TVBN levels in the samples ranged from 289.8 mg/100g to 354.9 mg/100g, indicating the presence of nitrogenous breakdown products. After enzyme treatment, TVBN increased for most samples especially in TI 60 and TI 90, where it went up from 476.95 mg/100g to 581.4 mg/100g, respectively. This high increase in value is because proteolytic enzymes degrade proteins and release volatile nitrogen compounds, an expected biochemical reaction reflecting protein breakdown and potential spoilage or enzymatic processing progress [13], [14]. However, the TVBN levels in all samples still exceeded the maximum standard of 130 mg/100g, highlighting the need for further enzyme optimization or an extended incubation time to fully meet this target.

Ash content, which is a measure of mineral content, remained relatively stable across all samples, with slight fluctuations before and after enzyme treatment. The initial values ranged from 15.7% to 17.4%, which are within the maximum 22% ash limit. These results suggest that the enzyme treatment did not significantly affect the mineral composition of the samples, as ash content remained relatively constant despite changes in other parameters. The fluctuations in ash content may be due to the breakdown of organic material, which could concentrate the mineral content in the final sample. These findings underscore the importance of optimizing enzymatic treatments to not only improve protein and fat content but also to maintain acceptable levels of ash and other mineral components.

In conclusion, lipase and protease enzyme treatments were effective in improving the protein content with an increase in moisture and fat content of the samples, though none met the required standards for protein and TVBN.

## 4 Conclusion

This study shows that the use of lipase and protease extracts is effective in changing the nutritional composition of fish meal. Enzymatic treatment successfully increased protein yield, moisture retention, and fat breakdown. However, the resulting protein content did not meet the minimum commercial requirements (58%) and the Total Volatile Basic Nitrogen (TVBN) level still exceeded the standards limit of 130mg/100g. Therefore, further process optimization is needed to meet these standards. These findings highlight the potential of the enzymatic process in improving the nutritional quality of fish meal, with further research needed to refine enzyme dosage, incubation conditions, processing time, and post-treatment drying methods.

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