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The Effect of Protease Enzyme and Citric Acid Addition on the Organoleptic Properties of Catfish Head Milk

Pengaruh Penambahan Enzim Protease dan Asam Sitrat terhadap Sifat Organoleptik Susu Kepala Ikan Lele

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Abstract

This study evaluated the effects of combining protease enzyme dosages (0.5%, 1%, and 1.5%) with citric acid levels (0.1%, 0.3%, and 0.5%) on the organoleptic quality of catfish head milk, including color, aroma, taste, homogenization/clarity, and panelist acceptance. The product was formulated through enzymatic hydrolysis under controlled pH conditions and subsequently assessed using a sensory scoring scale. The results showed that the treatments significantly affected color ($F = 4.13$; $p < 0.05$), homogenization ($F = 2.39$; $p < 0.05$), and overall hedonic preference ($F = 3.03$; $p < 0.05$), but had no significant effects on aroma ($F = 1.62$; $p > 0.05$) or taste ($F = 1.39$; $p > 0.05$). Specifically, the best color was obtained at 0.5% protease and 0.5% citric acid (A1B3), while the highest homogenization occurred at 0.5% protease and 0.1% citric acid (A1B1). In terms of overall liking, the highest score was recorded at 1.5% protease and 0.5% citric acid (A3B3), followed by 0.5% protease and 0.3% citric acid (A1B2). However, when considering the balance among all attributes (color, aroma, taste, and homogenization), the combination of low protease with low to moderate citric acid levels (0.5% protease; 0.1–0.3% citric acid) provided the most stable performance, producing a relatively bright color, more acceptable flavor and aroma, and better physical stability. Overall, the enzymatic hydrolysis approach with moderate pH adjustment proved effective at enhancing sensory acceptance and offers a promising method for transforming low-value fish by-products into consumer-preferred functional food products.

Keywords: Citric acid; Catfish head milk; Protease enzyme

Abstrak

Penelitian ini mengevaluasi efek kombinasi dosis enzim protease (0,5; 1; 1,5%) dan asam sitrat (0,1; 0,3; 0,5%) terhadap kualitas organoleptik susu kepala ikan lele meliputi warna, aroma, rasa, serta homogenitas/kejernihan dan tingkat penerimaan panelis. Produk diformulasikan melalui hidrolisis enzimatis dengan pengaturan pH, kemudian dinilai secara sensori menggunakan skala skoring. Temuan menunjukkan perlakuan berpengaruh signifikan pada warna ($F=4,13$; $p<0,05$), homogenitas ($F=2,39$; $p<0,05$), dan hedonik ($F=3,03$; $p<0,05$), namun tidak signifikan pada aroma ($F=1,62$; $p>0,05$) dan rasa ($F=1,39$; $p>0,05$). Secara spesifik, warna terbaik diperoleh pada protease 0,5%–asam sitrat 0,5% (A1B3), sedangkan homogenitas tertinggi pada protease 0,5% dengan asam sitrat 0,1% (A1B1). Untuk kesukaan keseluruhan, nilai puncak tercatat pada protease 1,5% dengan asam sitrat 0,5% (A3B3), disusul protease 0,5%–asam sitrat 0,3% (A1B2). Namun, dengan mempertimbangkan keseimbangan antar atribut (warna, aroma, rasa dan homogenitas), kombinasi protease rendah dengan asam sitrat rendah sampai sedang (0,5% protease; 0,1–0,3% asam sitrat) memberikan performa paling stabil: warna relatif cerah, aroma dan rasa lebih dapat diterima, serta kestabilan fisik lebih baik. Secara keseluruhan, pendekatan hidrolisis enzimatis dengan pengaturan pH moderat efektif meningkatkan penerimaan sensori sekaligus membuka peluang pemanfaatan limbah bernilai rendah menjadi produk pangan fungsional yang disukai konsumen.

Kata kunci: Asam sitrat; Enzim protease; Susu kepala ikan lele

1. Introduction

Catfish (*Clarias* sp.) is one of the most widely cultivated aquaculture commodities in Indonesia and serves as an important source of animal protein. Fisheries by-products consist of both liquid and solid waste, accounting for approximately 30–40% of the total weight of fish, mollusks, and crustaceans. Unfortunately, fish waste has not been optimally utilized due to its relatively low economic value. However, with technological advancements, opportunities to convert fish waste into value-added products are increasingly promising (Sahar et al., 2024). The present study utilized African catfish (*Clarias gariepinus*). Processing catfish heads into fish milk represents an innovative approach to increasing economic value while simultaneously reducing fisheries waste.

Fish protein-based milk has been developed as an alternative for individuals who are allergic to cow's milk or require additional protein sources. Nevertheless, one of the main challenges in producing fish head milk is its strong fishy odor and relatively unstable texture. Protein hydrolysates are produced through hydrolysis, a process that breaks down complex molecules into simpler compounds using protease enzymes as hydrolyzing agents (Prayudi & Suhrawardan, 2022). Protease enzymes hydrolyze proteins into smaller peptides, thereby improving solubility and reducing product viscosity, which is highly relevant for developing catfish head milk with a more homogeneous texture.

In addition to enzymatic treatment, the addition of citric acid is known to play an important role in reducing fishy odor and stabilizing emulsions in fish-based products. Citric acid functions as a pH regulator and has deodorizing effects, helping neutralize volatile compounds responsible for off-odors. Previous studies have demonstrated that the use of organic acids, such as citric acid, can improve the aroma quality of fish-based products, as observed in research on naniura treated with jungga orange and lime. Therefore, the combination of protease enzymes and citric acid has synergistic potential to enhance the organoleptic quality of catfish head milk, particularly in sensory attributes that are key determinants of consumer perception and acceptance of novel food products.

The development of catfish head milk via enzymatic approaches combined with citric acid addition aligns with efforts to valorize low-value fish waste into innovative, more functional food products with improved organoleptic acceptance. Furthermore, this innovation supports the Sustainable Development Goals (SDGs), particularly Goal 12 on responsible consumption and production, by reducing waste in the food industry (Ministry of National Development Planning/National Development Planning Agency, 2021). The National Research and Innovation Agency (BRIN) also supports the development of fish milk as an alternative nutritional product based on fish hydrolysates. This product is developed through enzymatic hydrolysis that breaks down proteins into peptides and free amino acids, followed by formulation to resemble milk (News, 2024).

Based on this background, this study specifically aims to analyze the effects of protease enzyme and citric acid addition on the organoleptic properties of catfish head milk (*Clarias* sp.), including color, aroma, taste, and clarity/texture.

2. Material and Method

2.1. Time and Place

This research was conducted at Politeknik Tonggak Equator Pontianak, Pontianak City. Sample processing was carried out in the Processing Laboratory of Politeknik Tonggak Equator Pontianak, while sensory evaluation was conducted on campus. The research was performed from June 2026 to September 2026

2.2. Materials

The main materials used in this study included catfish heads (Clarias sp.), water, protease enzyme, citric acid, and carboxymethyl cellulose (CMC). The protease enzyme used was an analytical-grade product from Merck (Germany), while citric acid was a food-grade material supplied by Brataco (Indonesia). All chemical substances were applied at concentrations specified in the experimental design. Catfish heads were obtained from a local fish market in Pontianak, West Kalimantan, Indonesia.

The primary equipment used in this research included a pressure cooker (Fresto brand), a blender, a stainless-steel pot, a digital balance, a sieve or muslin cloth, and glass packaging containers. These tools were utilized during the preparation, extraction, and processing stages of catfish head milk production.

2.3. Procedures

2.3.1. Preparation of Catfish Head Flour

The preparation of catfish head flour began with separating the catfish heads from the body and flesh, then thoroughly washing them under running water. To reduce the characteristic fishy odor of fish by-products, the heads were soaked and squeezed using citrus juice, then rinsed again with clean water. The cleaned catfish heads were subsequently placed in a pressure cooker and boiled for 2 hours to soften hard tissues, such as bones, and accelerate the drying process.

After boiling, the heads were separated from the boiling water using a sieve and drained. Drying was then carried out by placing the heads on trays and drying them in a cabinet dryer at 60°C for two days until minimal moisture content was achieved. The dried heads were ground in a blender to obtain a fine powder, then sieved through an 80-mesh sieve to produce uniform flour particle size (Sudaryono, 2014).

2.3.2 Production of Catfish Milk

The production of catfish milk began with dispersing the fish flour by heating approximately 800 mL of water to 40–45°C. Fish flour was gradually added while continuously stirred using a low-speed blender to prevent lump formation. Enzymatic hydrolysis was then conducted using a protease enzyme. The pH of the solution was measured and adjusted to the enzyme's optimum pH range of 7.0–7.5. The protease enzyme was added at the predetermined dosage, and the mixture was incubated at 45–55°C for 30–60 minutes.

After hydrolysis, the enzyme was inactivated by heating at 85–90°C for 10 minutes, followed by cooling to 40–45°C. The next step involved the addition of carboxymethyl cellulose (CMC) as an emulsifier. CMC was first dissolved in a small amount of warm water (50–60°C) until completely dispersed, then added to the fish protein solution. Homogenization was performed using a blender or hand homogenizer for approximately 1–3 minutes to obtain a homogeneous mixture and form a stable emulsion.

pH adjustment was subsequently carried out using citric acid according to the treatment by adding the citric acid solution dropwise while continuously monitoring the pH. During the sweetening and final processing stage, sugar was added at a concentration of 3–5% (equivalent to 30–50 g/L) and stirred until fully dissolved. Pasteurization was then performed at 85°C for 30 seconds to ensure microbiological safety. The solution was immediately cooled to ≤10°C to maintain product quality and emulsion stability, then packaged. The results of the sensory evaluation of catfish coconut milk under different treatments are presented in Table 1, which shows the average panelist scores for the observed sensory attributes.

3. Result and Discussion

The organoleptic test of catfish head milk can be seen in Table 1.

Table 1. Organoleptic Test Scores of Catfish Coconut Milk under Different Treatments

Treatment	Aroma	Colour	Taste	Homogeneity	Overall hedonic
A1B1 (0,5% Protease, 0,1% Citric acid)	4,33	3,48	4,24	4,38	4,00
A1B2 (0,5% Protease, 0,3% Citric acid)	4,00	3,48	4,10	4,29	4,29
A1B3 (0,5% Protease, 0,5% Citric acid)	3,48	3,71	3,76	3,95	2,81
A2B1 (1% Protease, 0,1% Citric acid)	3,86	2,90	4,33	4,33	3,76
A2B2 (1% Protease, 0,3% Citric acid)	3,86	2,90	3,90	4,24	3,95
A2B3 (1% Protease, 0,5% Citric acid)	3,95	3,05	3,71	4,05	3,86
A3B1 (1,5% Protease, 0,1% Citric acid)	3,81	2,86	3,71	3,76	3,86
A3B2 (1,5% Protease, 0,3% Citric acid)	3,81	3,00	3,90	3,81	3,76
A3B3 (1,5% Protease, 0,5% Citric acid)	4,24	2,71	4,14	4,24	4,38

Note: - The values represent the mean scores obtained from X panelists; - The organoleptic evaluation used a scoring scale of 1–5 and a 1–7 hedonic scale.

Figure 1. Catfish Head Milk with the Addition of Protease Enzyme and Citric Acid

Table 1 presents the results of the organoleptic evaluation of the aroma of catfish head milk. The treatment with 0.5% protease enzyme and 0.1% citric acid (A1B1) produced the highest aroma score of 4.33, indicating a slightly fishy odor. In contrast, treatments with higher citric acid concentrations, such as A1B3 (0.5% protease and 0.5% citric acid), resulted in a lower aroma score of 3.48, indicating a moderately fishy odor.

The decline in aroma quality at higher concentrations may be attributed to more drastic protein structural changes induced by higher protease levels, which can generate new compounds that may affect the final product's aroma (Al-Afifi et al., 2018). Citric acid, which lowers pH, helps reduce the formation of volatile compounds responsible for unpleasant odors. However, excessive concentrations may cause undesirable textural changes that ultimately influence the overall organoleptic quality. Citric acid is known to inhibit spoilage activity, including the formation of volatile compounds responsible for off-odors. However, direct addition at high concentrations may negatively affect the texture and sensory properties of fish products (Mei et al., 2019).

In treatments with higher protease concentrations, namely 1% (A2B1, A2B2, A2B3) and 1.5% (A3B1, A3B2, A3B3), the aroma quality tended to decrease compared to A1B1. Protease enzymes are reported to reduce off-odors and improve the quality of fish products, including fishy odors caused by compounds such as urea or volatile amines (Fernandes, 2016). The findings of this study indicate that the optimal concentration of protease enzyme to reduce fishy odor while maintaining overall product quality was 0.5%, combined with 0.1% citric acid.

Furthermore, treatment A1B1 (0.5% protease and 0.1% citric acid) produced the highest aroma score of 4.33. However, ANOVA results showed that the differences were not statistically significant ($F_{calculated} = 1.62 < F_{table}$ 5% = 1.94). This indicates that, overall, the addition of protease and citric acid at different concentrations did not significantly affect the aroma perception of catfish head milk.

Table 1 presents the results of the organoleptic evaluation, indicating that treatment A1B3 (0.5% protease enzyme and 0.5% citric acid) achieved the highest color score (3.71), categorized as bright and clear. This finding suggests that the combination of a low protease concentration and a higher citric acid concentration produced the most visually preferred product color. The bright appearance observed in this treatment was likely due to protein stabilization by citric acid and the prevention of excessive protein degradation by the enzyme.

In contrast, treatment A3B3 (1.5% protease and 0.5% citric acid) had the lowest score (2.71), indicating it was less bright. This result indicates that increasing the protease concentration may significantly deteriorate the color of catfish head milk, possibly due to the formation of reactive compounds derived from protein degradation that affect solution clarity. Similarly, treatments A2B1 and A2B2, which used 1% protease, also produced relatively low color scores (2.90), demonstrating a trend of decreasing clarity with increasing enzymatic activity.

These findings reinforce the theory that the combination of a protease enzyme and citric acid must be carefully optimized, as both substances may exert both synergistic and antagonistic effects on the product's visual properties. The addition of citric acid improved color; however, this benefit was evident only when combined with low to moderate levels of protease. The combination of 0.5% protease and 0.5% citric acid (A1B3) is therefore recommended as the optimal formulation to produce bright and visually appealing catfish head milk. Citric acid plays an effective role in improving color stability (preventing browning or color deterioration caused by enzymatic reactions) by lowering pH. Its effectiveness may be enhanced when combined with other agents, such as antioxidants or enzyme inhibitors, or when combined with low or moderate protease levels, which help maintain color and texture balance (Bin Kwon et al., 2020).

According to Mohanty et al. (2021), enzymatic hydrolysis of fish proteins enhances solubility and functional properties (water- and oil-holding capacity, emulsifying, and foaming properties) by forming shorter peptide chains that are more soluble. Furthermore, Karlsson et al. (2019) reported that citric acid improves milk stability by forming soluble complexes with calcium, thereby preventing calcium phosphate precipitation. Citric acid also acts as a pH regulator and calcium chelator, which is associated with reduced sediment formation in milk with high ionic calcium content, supporting the concept that citrate functions as an ionic stabilizer that maintains colloidal stability.

Table 1 presents the results of the organoleptic evaluation of the taste of catfish head milk. The treatment with 0.5% protease enzyme and 0.1% citric acid (A1B1) produced the highest taste score of 4.24, indicating a slightly fishy taste. Similarly, the treatment with 1% protease enzyme and 0.1% citric acid (A2B1) resulted in a taste score of 4.33, indicating a slightly fishy flavor. These findings suggest that combining a protease enzyme with citric acid at specific concentrations may reduce the fishy taste of catfish-based products. In contrast, higher protease concentrations combined with higher levels of citric acid (such as A1B3, A2B3, and A3B3) resulted in lower taste scores, ranging from 3.76 to 3.71, indicating that the fishy taste was more noticeable in these treatments. This may be attributed to suboptimal interactions between protease and citric acid, which could significantly alter the flavor characteristics of the fish product.

In this study, the addition of 0.5% protease enzyme with 0.1% citric acid (A1B1) yielded the most acceptable taste, according to panelists, with a score of 4.24, indicating a slightly fishy taste. This finding supports the theory that a low concentration combination of protease enzyme and citric acid can reduce fishy flavor without causing significant adverse effects on the overall sensory quality of the final product. Conversely, higher levels of protease addition, as observed in treatments A2B1 and A3B1, although still categorized as slightly fishy, tended to lower the overall taste score, indicating that increasing protease and citric acid concentrations may influence the flavor balance of catfish head milk. According to Conz et al. (2024), formulation variations demonstrated that citrate (including its encapsulated form) can reduce fishy odor, while the perception of sourness depends on the amount of citrate added

Table 1 presents the organoleptic evaluation results of the homogeneity of catfish head milk. The treatment with 0.5% protease enzyme and 0.1% citric acid (A1B1) produced the highest homogeneity score (4.38), indicating the absence of phase separation or sedimentation. This result indicates good product stability, with no separation between the liquid and solid phases, suggesting that the combination of low protease and citric acid concentrations improves the homogeneity of catfish head milk. In treatment A1B2 (0.5% protease and 0.3% citric acid), although the homogeneity score decreased slightly to 4.29, the product still exhibited good homogeneity with minimal sediment, indicating a positive effect of citric acid on product stability.

However, at higher concentrations of protease and citric acid, such as A1B3 (0.5% protease and 0.5% citric acid), A2B1 (1% protease and 0.1% citric acid), and A2B2 (1% protease and 0.3% citric acid), homogeneity decreased with scores ranging from 3.95 to 4.05, indicating slight sediment formation or phase separation. This decline may be attributed to the side effects of higher protease levels, which can influence product viscosity and promote phase separation. Although protease can enhance texture and flavor, excessive concentrations may alter product consistency by promoting more evident phase separation. At high protease concentrations, protein structures become excessively hydrolyzed and shortened, losing their ability to maintain emulsion stability. Consequently, physical stability decreases, which is interpreted as reduced homogeneity and increased potential for phase separation (Padial-Domínguez et al., 2020).

At 1.5% protease concentration (A3B1, A3B2, A3B3), homogeneity declined more substantially, with scores ranging from 3.71 to 3.76. This indicates that higher protease concentrations are not always beneficial for improving the homogeneity of catfish head milk, as excessive hydrolysis can reduce emulsion stability and trigger phase separation or sedimentation. At low enzyme concentrations, emulsion stability increases; however, at higher concentrations, excessive hydrolysis reduces stability, increasing the likelihood of phase separation (Vogelsang-O'Dwyer, 2022). Meanwhile, citric acid acts as a pH regulator, helping to prevent sediment formation by maintaining acid–base balance within the product. Citric acid may also improve emulsion stability in milk-based products, thereby enhancing homogeneity and preventing visible phase separation (Karlsson et al., 2019).

Overall, the results indicate that adding protease and citric acid improves the homogeneity of catfish head milk; however, optimal concentrations are critical for achieving optimal results. The treatment with 0.5% protease and 0.1% citric acid provided the best homogeneity, while higher concentrations of both components reduced homogeneity quality due to more pronounced phase separation.

Statistically, significant differences were observed among treatments. Fisher's LSD test (LSD = 0.507) revealed that A1B1 (4.38) exhibited the highest homogeneity performance and differed significantly from A2B2, A2B3, A3B1, A3B2, and A3B3, but did not differ significantly from A1B2, A1B3, and A2B1. Treatment A1B2 (4.29) differed significantly from A3B1, A3B2, and A3B3, but did not differ from A1B3, A2B1, A2B2, and A2B3. In the intermediate group (A1B3 = 4.00; A2B1 = 3.95; A2B2 = 3.86; A2B3 = 3.86; A3B1 = 3.76; A3B2 = 3.76), mean values generally did not differ significantly from one another, with the main exception being A1B3 and A2B1, which differed significantly from A3B3. Treatment A3B3 (2.81) consistently showed the lowest score and differed significantly from most other treatments.

This pattern indicates that the combination of low protease concentration (0.5%) with 0.1–0.3% citric acid (particularly A1B1, followed by A1B2) resulted in the best homogeneity. Increasing protease concentration to 1.0–1.5% did not improve homogeneity; in fact, the combination of 1.5% protease with 0.5% citric acid (A3B3) significantly reduced product quality. Therefore, to obtain homogeneous and stable catfish head milk, the use of 0.5% protease with 0.1–0.3% citric acid is recommended. In contrast, high protease concentrations, especially when combined with high citric acid levels, should be avoided.

Table 1 presents the results of the hedonic test on overall liking. Based on the hedonic evaluation, the treatment with 0.5% protease enzyme and 0.1% citric acid (A1B1) received a hedonic score of 4.00, indicating that the product was perceived as neutral by the panelists. Meanwhile, the treatment with 0.5% protease and 0.3% citric acid (A1B2) achieved a higher score of 4.29, suggesting that the panelists preferred this product, although the difference was not markedly higher. However, a higher concentration of citric acid, as in A1B3 (0.5% protease and 0.5% citric acid), resulted in a lower hedonic score of 2.81, indicating lower panelist acceptance. This may be attributed to undesirable changes in taste or texture caused by excessive citric acid addition.

The addition of 1% protease enzyme (A2B1, A2B2, A2B3) produced hedonic scores ranging from 3.76 to 3.95, indicating that the products were generally perceived as neutral to slightly liked by the panelists. In contrast, treatments with a higher protease concentration of 1.5% (A3B1, A3B2, A3B3) tended to yield slightly lower scores (3.76–3.86), suggesting that excessive protease levels may reduce product acceptability. However, the highest overall hedonic score was obtained in treatment A3B3 (1.5% protease and 0.5% citric acid), with a score of 4.38, indicating that, despite potential drawbacks of higher enzyme and acid concentrations in other aspects, this combination produced a product well accepted by the panelists.

Protease plays an important role in food fermentation processes, particularly in improving product texture. Protease functions by hydrolyzing proteins into smaller peptides and amino acids, which not only enhances flavor by reducing compounds responsible for fishy off-flavors but also improves product texture by increasing viscosity and contributing to a smoother and creamier consistency in fermented food products (Dai et al., 2024). Reducing fishy flavor in fish-based products can significantly improve consumer acceptance, as off-flavors are often a limiting factor in consumption. The hedonic test results indicate that adding protease enzyme and citric acid influences the overall liking of catfish head milk, though the optimal concentrations are crucial for achieving optimal results. The treatment with 0.5% protease and 0.3% citric acid (A1B2) yielded the best overall preference, while excessively high or low concentrations tended to produce products less preferred by the panelists.

Based on the ANOVA results for the hedonic parameter, the calculated F-value (3.03) was higher than the F-table values at both the 5% level (1.94) and the 1% level (2.55), indicating a significant difference among treatments in terms of overall liking of catfish head milk. These findings demonstrate that variations in protease enzyme and citric acid concentrations significantly affected sensory acceptance.

The LSD post-hoc test showed that treatment A1B1 (0.5% protease, 0.1% citric acid) with a mean hedonic score of 4.00 was not significantly different from A1B2 (4.29) and A1B3 (2.81), but differed significantly from several other treatments, such as A2B2, A2B3, and A3B3. The most significant difference was observed between A1B1 and A3B3, with a mean difference of 1.57 (> LSD 0.507). This indicates that the combination of protease and citric acid concentrations affected panelist acceptance, particularly the flavor and texture formed after protein hydrolysis.

Treatment A1B2 (0.5% protease and 0.3% citric acid) achieved the second-highest score (4.29), indicating that the panelists generally liked the product, whereas A1B3 (0.5% protease and 0.5% citric acid) resulted in the lowest score (2.81) and differed significantly from almost all other treatments. The decreased preference in A1B3 is likely due to excessive citric acid addition, which may produce an overly sour taste and affect protein stability, resulting in a less smooth and unbalanced sensory profile. A moderate protease addition (0.5–1%) enhanced flavor and reduced fishy aroma. Enzymatic hydrolysis by proteases breaks down proteins into smaller, water-soluble peptides, thereby contributing to a milder, more umami taste (Aspevik et al., 2021). Therefore, it can be concluded that treatment A1B2 (0.5% protease and 0.3% citric acid) was the most preferred formulation overall, as it provided the best balance of flavor, aroma, and texture in catfish head milk.

4. Conclusions

The utilization of catfish heads for fish milk production was most effectively achieved through an enzymatic approach combined with pH adjustment using citric acid at moderate levels. The combination of 0.5% protease and 0.1–0.3% citric acid produced the most balanced organoleptic quality, characterized by a brighter color, improved aroma and taste acceptability, and stable homogeneity compared to other treatment combinations. Increasing the concentration of protease and/or citric acid beyond this range tended to reduce panelist acceptance due to sensory imbalance and decreased physical stability (phase separation and inferior texture). Statistically significant differences were primarily observed in color and overall hedonic attributes, while aroma and taste did not differ significantly among treatments. These findings indicate that a formulation with low protease and low-to-moderate citric acid levels represents an optimal strategy to enhance consumer acceptance while supporting the value-added downstream utilization of fishery by-products.

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