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Research Article

Optimized Processing Techniques for Enhancing Fillet Yield from Low-Value Fish in Lamongan, East Java, Indonesia

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Abstract: Fishing activities often yield a bycatch of low-value fish (trash fish) that typically remains underutilized**.** This study aimed to identify the most effective preparation technique to improve the physical and chemical quality of fillets from three types of trash fish: Orangefin ponyfish (*Leiognathus bindus*), chacunda gizzard shad (*Anodontostoma chacunda*), and sardine (*Sardinella fimbriata*). A Randomized Block Design (RBD) was used with two factors: fish species and preparation technique, including mechanical treatment, blanching, immersion in 1% acetic acid, and immersion in 1% papain enzyme. Data were statistically analyzed and presented descriptively in tables and graphs. The results showed that treatment with 1% papain enzyme yielded the highest fillet yield (47.5% to 63.2%) and the shortest processing time. Additionally, the enzymatic treatment produced fillets with favorable chemical characteristics: moisture content (77.46% to 80.13%), protein (7.39% to 9.29%), fat (8.01% to 9.49%), and ash (1.55% to 2.83%). This study demonstrates that enzymatic preparation is effective in enhancing both the efficiency and quality of trash fish fillets, potentially increasing the added value of fishermen's catches.

Keywords: Chemical Composition, Enzymatic Processing, Fillet Yield, Papain Enzyme, Trash Fish.

1. INTRODUCTION

The marine fisheries sector plays a strategic role in supporting economic development and food security in Indonesia. With the second longest coastline in the world and high marine biodiversity, Indonesia holds enormous potential in marine resources [1, 2]. One of the key regions for the development of this sector is Lamongan Regency, East Java, which has been designated as a minapolitan area due to its significant contributions to fish production and processing [3, 4]. In practice, fishing operations yield not only high-value commercial species but also a significant bycatch of small, mixed, and low-quality fish, collectively termed low-value or "trash fish". These fish are often considered waste or by-products and remain underutilized. They are generally used as raw materials for animal feed, salted fish, or even discarded, potentially causing environmental issues such as pollution and foul odors during peak fishing seasons [5, 6]. However, low-value fish actually possess considerable

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potential as food ingredients if processed using appropriate technologies.

Several studies have shown that trash fish can be converted into value-added products such as biodiesel, biogas, food products, and other functional materials [7-12]. One promising form of food product diversification from low-value fish is fish fillet. Several species of trash fish found in Lamongan, such as orangefin ponyfish (*Leiognathus bindus* Valenciennes, 1835), chacunda gizzard shad (*Anodontostoma chacunda* Hamilton, 1822), and sardine (*Sardinella fimbriata* Valenciennes, 1847), are known to have high protein content and suitable characteristics for fillet production [13, 14]. The total marine capture fishery production in Lamongan reaches approximately 74818000 kg, with low-value fish contributing around 3880 kg (0.005%). The market prices are IDR 2000 kg^{-1} for orangefin ponyfish, IDR 3 125 kg^{-1} for chacunda gizzard shad, and IDR 2 300 kg^{-1} for sardine [15].

However, the production of fillets from low-value fish faces several technical challenges. The small size of the fish, varying body shapes, and complex bone and muscle structures complicate the process of separating meat from skin and bones. Both manual and mechanical techniques currently employed are often inefficient, time-consuming, and may compromise the quality of the resulting fillets [16-18]. Therefore, optimized processing techniques are needed to improve the efficiency of the filleting process, reduce processing time, and maintain the physico-chemical quality of the final product.

Various approaches have begun to be explored, including blanching, chemical treatments, and the use of proteolytic enzymes to accelerate the separation of muscle tissue and enhance fillet yields [19]. In this context, the main research question addressed in this study is: What is the most effective and efficient processing technique to improve fillet yield from low-value fish in Lamongan? This study aims to evaluate and optimize various processing methods for trash fish in order to obtain high fillet yields, with shorter processing times and good quality. Ultimately, this effort is expected to enhance the added value of fishery products and support the sustainable management of marine resources in Lamongan Regency, East Java, Indonesia.

2. MATERIALS AND METHODS

2.1. Material

The primary raw materials consisted of fresh trash fish, including orangefin ponyfish, chacunda gizzard shad, and sardine, with an average individual weight ranging from 50 g to 100 g. These fish were obtained from the fish auction site in Lamongan regency, East Java, Indonesia. After purchase, the fish were stored in a refrigerator and transported to the Agroindustrial Technology Laboratory, Faculty of Agricultural Technology, University of Jember, using a cooler box for approximately ±5 h. Upon arrival at the laboratory, the fish were stored in a freezer at −18 °C until analysis. Prior to use, the fish were thawed at room temperature, thoroughly washed, eviscerated, and uniformly chopped using a mincing machine. The additional materials used in the filleting preparation process included unripe papaya fruit (as a source of papain enzyme, a proteolytic enzyme derived from papaya- *Carica papaya* L.), lime juice, cooking oil, and chemical solutions such as acetic acid (CH_3COOH). Other analytical-grade chemicals used for laboratory analysis included TCA, NaOH, H_2SO_4, selenium, 3% boric acid, SDS (0.1% and 2%), and petroleum benzene [20].

2.2. The Preparation of Trash Fish Fillets

The fillet preparation procedure began with a deodorization step by adding lime juice equivalent to 15% ($v\ w^{-1}$) of the fish's weight for 10 min. After being thoroughly cleaned, the fish were prepared using four different preparation techniques: (i) Mechanical Method, based on the method by Fu *et al*. [21]: The fish were manually filleted using a knife from the tail to the head after being descaled and eviscerated. The process was conducted on fresh fish and immediately followed by chilling after filleting; (ii) Blanching Method, adapted from Nguyen *et al*. [22]: Cleaned fish were boiled at 100 °C for 5 min. After cooling to room temperature, the fish were manually filleted and stored in a freezer; (iii) Chemical Method, based on Moniharapon *et al*. [23]: The fish were soaked in acetic acid solutions at varying concentrations (0.25%, 0.5%, 0.75%, and 1%) for 30 min, followed by filleting and weighing of the resulting fillet; iv) Enzymatic Method, adapted from Ma *et al*. [24]: The fish were soaked in a papain enzyme solution (a proteolytic enzyme derived from unripe papaya) at the same concentration levels as the chemical treatment (0.25%, 0.5%, 0.75%, and 1%) for 30 min prior to filleting. All preparation techniques were conducted under identical conditions. The fillet yield from each method was weighed and stored in a freezer for further analysis. Flowchart for the trash fish preparation process is presented in Figure 1.

2.3. Chemical Properties

The analyses conducted on the fillet products included: i) Fillet yield and flesh color, which followed the method by Urgessa *et al*. [25]; ii) Moisture, fat, ash, and crude protein content, which were analyzed based on standard AOAC procedures as described by Gukowsky *et al*. [26]; iii) Carbohydrate analysis was not performed, as carbohydrates are not considered a primary component in the chemical composition of fish, in accordance with findings by Eden and Rumambarsari [27], Elliott [28], Caulton and Bursell [29], and Weatherley and Gill [30].

2.4. Data Analysis

Quantitative data from the analyses were processed using Microsoft Excel for initial tabulation and visualization. Statistical analysis was performed using one-way ANOVA with the DSAASTAT software. If significant differences were found ($P \leq 0.05$), the analysis was followed by Duncan's Multiple Range Test (DMRT) to determine differences between treatments [31].

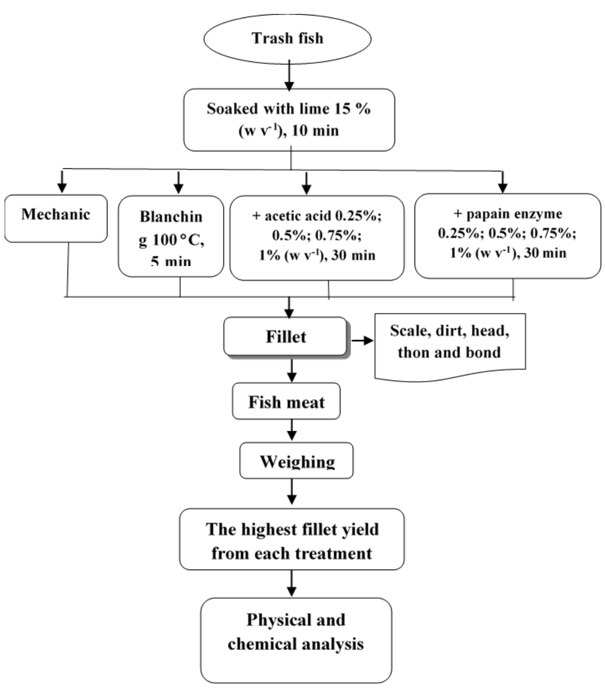

Fig. 1. Flowchart of trash fish preparation technique.

3. RESULTS AND DISCUSSION

3.1. Process Time

The analysis of variance showed a significant interaction between fish species and preparation techniques on fillet processing time ($P < 0.05$). Further analysis using Tukey's HSD test revealed significant differences among each treatment combination, as presented in Table 1.

Table 1 demonstrates that morphological differences among fish species affect the duration of the fillet process. Chacunda gizzard-shad has a relatively flatter and softer body shape, allowing faster separation of flesh from the bones. In contrast, orangefin ponyfish and sardine required longer processing times, with orangefin ponyfish consistently showing the longest fillet duration, likely due to its denser bone structure and firmer flesh texture. The 1% acetic acid treatment resulted in the shortest fillet times across all fish species, indicating its effectiveness in softening connective tissues by breaking peptide bonds, thereby facilitating easier flesh separation. Papain enzyme (proteolytic enzymes from papaya) exhibited a similar effect, particularly at concentrations of 0.25% and 1%, which statistically yielded significantly shorter fillet times compared to mechanical and blanching treatments. Papain acts by degrading myofibrillar proteins and connective tissues, aiding the filleting process [32]. Conversely, mechanical and blanching techniques tended to require longer fillet times, especially in fish with tougher or smaller body morphologies. This suggests that chemical or enzymatic pretreatments are more effective in reducing processing time for trash fish fillet production.

3.2. Yield

The analysis of variance revealed a significant interaction ($P < 0.05$) between fish species and preparation technique on fillet yield. The average fillet yields of the three types of trash fish under various treatments are presented in Figure 2.

Table 1. Average fillet processing time of three types of low-value fish in different preparation techniques (minutes).

Sr. No.	Treatment	Chacunda gizzard-shad	Orrangefin ponyfish	Sardine
1	Mechanics	2:52 g	6:49 a	6:23 b
2	Blanching	2:19 h	3:25 d	4:59 c
3	Acetic acid 0.25%	2:11 i	3:22 de	2:09 i
4	Acetic acid 0.50%	2:10 i	3:08 f	2:05 ij
5	Acetic acid 0.75%	2:57 g	3:06 f	1:58 k
6	Acetic acid 1%	2:00 ij	2:57 g	1:55 k
7	Enzym papain 0.25%	1:55 k	3:03 f	2:16 hi
8	Enzym papain 0.50%	1:52 k	3:09 f	3:22 de
9	Enzym papain 0.75%	1:55 l	3:20 de	3:08 f
10	Enzym papain 1%	1:53 k	3:10 f	2:11 i

Description: Different letters in the same row/column indicate significant differences (DMRT), $P < 0.05$).

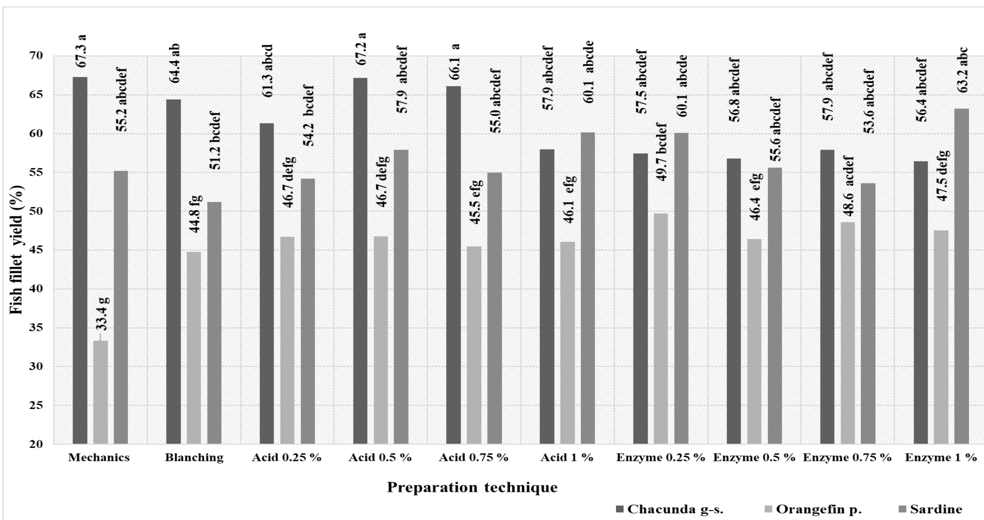

Fig. 2. Average fillet yield of three types of low-value fish in various preparation techniques (%).
Description: Different letters in the same row/column indicate significant differences (DMRT), $P < 0.05$).

The data presented in Figure 2 indicate that the mechanical filleting technique produced the highest yield significantly in chacunda gizzard-shad (67.3%). This is attributed to the fusiform and elongated body morphology of chacunda gizzard-shad, which has relatively thick flesh, making it easier to cut using mechanical methods. However, for sardine, the best result was achieved with 1% papain enzyme treatment, yielding the highest value (63.2%) and significantly differing from most other treatments. Similarly, in orangefin ponyfish, the 0.25% enzyme treatment produced the highest yield (49.7%), indicating the effectiveness of papain in softening connective tissues and facilitating the separation of flesh from bones. The enzyme papain can tenderize muscle tissue, simplifying the fillet process and increasing yield.

The general trend shows that increasing the concentration of papain enzyme tends to improve fillet yield, especially in fish with more complex muscle and connective tissue structures, such as sardine and orangefin ponyfish. This mechanism is supported by the proteolytic activity of papain, which breaks down myofibrillar proteins and connective tissues, resulting in softer flesh that is easier to fillet [33]. Previous studies have also supported these findings. For instance, papain has proven effective in increasing gelatin yield from bovine hides [33]. This supports previous findings by Zhang *et al*. [34], who reported a 20% increase in tenderization yield using papain on low-grade meat, and also on crocodile meat (*Crocodylidae* Cuvier, 1807 [35]. Although mechanical filleting produced the highest yield in chacunda gizzard-shad, this approach is not optimal for small and flat-bodied fish like orangefin ponyfish. Therefore, enzyme- or acid-based treatments should be tailored to the specific morphology of the fish. Based on the best average yield for each technique and fish species, the general treatment recommendations are as follows: i) 1% papain enzyme treatment: consistently delivers high yield, especially for sardine and orangefin ponyfish, making it the most effective overall treatment for various types of trash fish; ii) 0.5% to 0.75% acetic acid treatment: yields relatively high results in chacunda gizzard-shad, though less effective than enzymes in other fish species; iii) Mechanical filleting: optimal for thick-fleshed fish such as chacunda gizzard-shad, but less suitable for smaller fish. This study extends current understanding by demonstrating that enzyme-based methods are not only effective in high-value fish but also improve processing of underutilized species, thus supporting sustainable fisheries.

3.3. Lightness

Lightness (L*) indicates the brightness level of the fillet color, where a value of 0 represents black and 100 represents white. The lightness values of trash fish fillets across different preparation techniques ranged from 18.83 to 25.01 (Figure 3). Based on the analysis of variance, a significant interaction was found between fish species and preparation technique ($P < 0.05$), indicating that the effect of one factor depends on the other.

The fillet with the highest lightness value was from chacunda gizzard-shad treated with 1% enzyme solution (25.01), which was significantly different from the mechanical treatment of the same species (21.52). The lowest lightness value was recorded in sardine under mechanical treatment (18.83). The 1% acetic acid treatment resulted in lightness values above 20 for all fish species, indicating that this method tends to preserve brightness [36].

The variation in lightness values indicates that both treatment type and fish species influence the visual quality of the fillet, particularly color. The 1% enzymatic treatment on chacunda gizzard-shad yielded the highest brightness value, possibly due to proteolytic enzyme action softening the surface tissue and breaking down proteins, which enhances light reflectance. In contrast, mechanical treatment of sardine fillets resulted in the lowest brightness value, likely due to physical damage, oxidation, or release of endogenous pigments during cutting and washing. Acetic acid soaking produced relatively stable and brighter results. Acetic acid is known for its antimicrobial and antienzymatic effects, inhibiting the decomposition of histidine into histamine [37-41], and lowering pH, which may slow down color changes caused by oxidation. This may explain why the acid treatments maintained lightness values above 20 across all fish types. The highest lightness value (25.01) was observed in chacunda gizzard-shad fillets treated with 1%

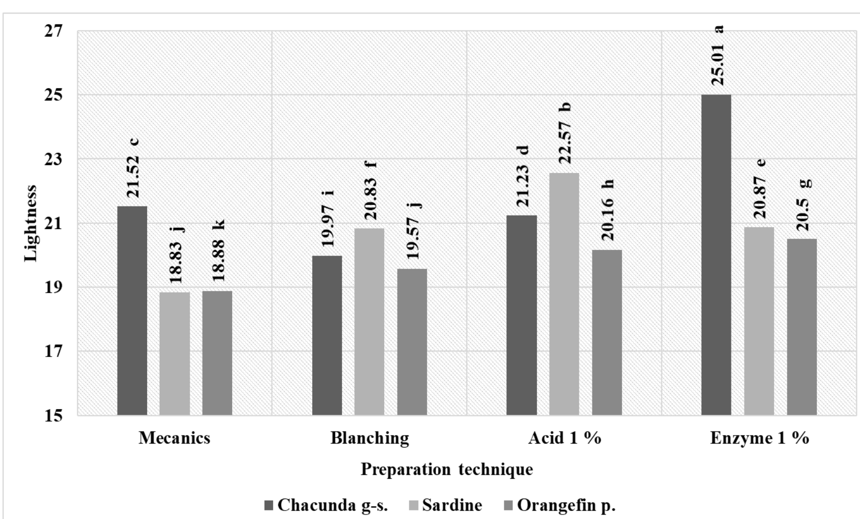

Fig. 3. Average brightness value of fillets of three types of low-value fish in various preparation techniques (scale: 0 to 100).

Description: Different letters in the same row/column indicate significant differences (DMRT, $P < 0.05$).

enzyme immersion. This value is relatively low compared to fresh tilapia (*Oreochromis niloticus* Linnaeus, 1758) fillets (40.85 ± 0.32) [42], which indicates that trash fish fillets have a darker color intensity, possibly due to higher muscle pigment concentrations or post-capture stress. Factors such as myoglobin content, fish age, habitat, and post-harvest handling methods also influence the lightness value of fish flesh.

3.4. Water Content

The moisture content of fish fillets in this study ranged from 72.86% to 80.13%. Results from the two-way ANOVA showed that the preparation technique had a significant effect on moisture content (*P* < 0.05, whereas fish species had no significant effect, and there was no significant interaction between the two factors. This indicates that differences in moisture content were more influenced by the preparation methods than by the type of fish.

Figure 4 shows that the 1% enzyme treatment on sardines resulted in the highest moisture content (80.13% ± 0.36%), which was not significantly different from the acid treatment (78.94% ± 0.29%) and mechanical treatment (77.75% ± 0.31%), but was significantly different from the blanching treatment (76.57% ± 0.25%). Although the moisture content range among treatments was relatively narrow, the differences were statistically significant, indicating the effect of treatment on water retention in the fillet meat. High moisture content in fillet products has a direct impact on shelf life and susceptibility to microbial spoilage. The highest moisture content was observed in the 1% enzyme treatment, likely due to the enzyme's ability to break down connective tissue between muscle fibers, thereby enhancing the tissue's water-holding capacity. Previous studies have shown that proteolytic enzymes such as papain can increase water retention by breaking down the structure of myofibrillar proteins, allowing water to be more effectively trapped within the muscle matrix [43, 44]. In contrast, the blanching treatment resulted in the lowest moisture content. The rapid heating during blanching causes protein coagulation, leading to a loss of free water from the muscle tissue [45, 46]. This process also deactivates endogenous enzymes that help maintain tissue structure, further facilitating water loss during treatment.

The moisture content range in this study (72.86% to 80.13%) is comparable to the moisture content of several other fish species. For example, fillets of Baltic cod (*Gadus morhua* Linnaeus, 1758) contain about 79.5% to 79.7% moisture [47], while crescent grunter (*Terapon jarbua* Fabricius ex Forsskål in Niebuhr, 1775) fish from Pakistan have a moisture content of 73.22% [48]. In contrast, Atlantic salmon (*Salmo salar* Linnaeus, 1758) is reported to have a lower moisture content of 61.8% to 63.9% [49], likely due to its higher fat content and denser muscle structure. Other factors that influence moisture content in fish include species, body size, age, physiological status, habitat, and diet [50, 51]. However, in this study, fish species did not

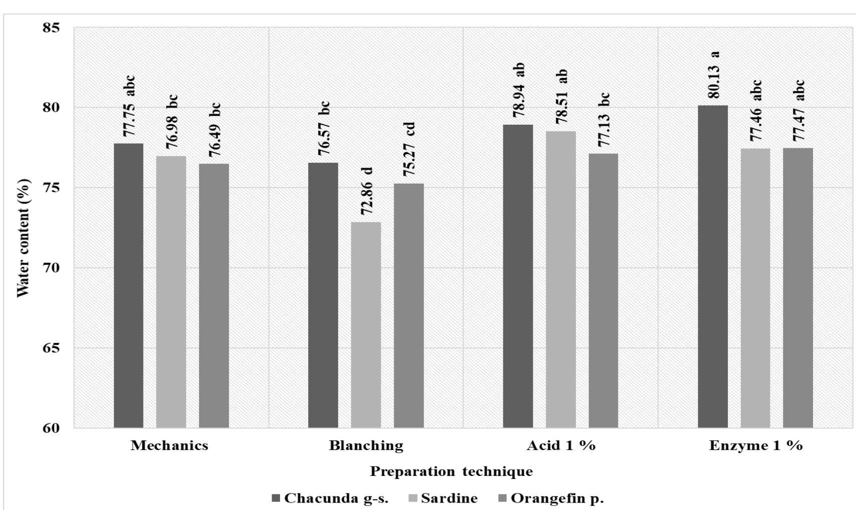

Fig. 4. Average water content of fillets of three types of low-value fish in various preparation techniques (%). Description: Different letters in the same row/column indicate significant differences (DMRT, *P* < 0.05).

significantly affect moisture content, reinforcing that post-harvest treatment (preparation technique) is the dominant factor. Besides being a nutritional parameter, moisture content also determines the physical properties, texture, and shelf life of fillet products. Foods with high moisture content tend to deteriorate more easily due to microbial growth and chemical reactions [52]. Therefore, processing strategies that reduce moisture content (such as blanching) may be considered to improve product stability, though their impact on other attributes like texture and color should also be taken into account.

3.5. Protein Content

The protein content of fillets from the three types of low-value fish studied ranged from 7.39% to 10.59%. Two-way ANOVA results showed that both fish species and preparation techniques had a significant effect ($P < 0.05$) on protein content. However, there was no significant interaction between fish species and preparation techniques ($P > 0.05$), indicating that the effects of each factor were independent.

Figure 5 shows the effect of preparation techniques on the average protein content. The blanching treatment yielded the highest protein content (9.55 % ± 0.21%), which was not significantly different from the mechanical treatment (9.39 % ± 0.18% , but significantly higher than the 1% enzymatic treatment (8.31 % ± 0.14%), which had the lowest protein content. Figure 6 shows the effect of fish species on fillet protein content. Fillets from the orangefin ponyfish showed the highest protein content (9.55 % ± 0.19%), but this was not significantly different from the chacunda gizzard-shad (9.39% ± 0.17%). In contrast, the protein content of sardine (8.46 % ± 0.15%) was significantly different from the other two species. The differences in protein content among preparation techniques can be explained by the thermal and biochemical mechanisms occurring during the treatments. Although blanching involves heating, it actually helps preserve higher protein content [53]. This may be due to the blanching process inactivating proteolytic enzymes that could break down proteins, as well as inhibiting oxidation and nutrient degradation [54]. Additionally, blanching can improve color stability and antioxidant properties, which also contribute to the overall quality. [55, 56].

On the other hand, treatment with 1% papain enzyme significantly reduced protein content. This is consistent with literature stating that proteolytic enzymes like papain hydrolyze peptide bonds, producing smaller protein molecules (oligopeptides or free amino acids), some of which dissolve into the soaking medium and are lost from the fillet meat [57, 58]. As a result, the measured protein content appears lower due to the loss of these soluble fractions. In terms of fish species, chacunda gizzard-shad exhibited the highest protein content, likely due to its muscle tissue composition and habitat. This species tends to have denser muscle mass and higher motor activity, which generally correlates with higher protein levels [59]. The lower protein content observed in sardines may be attributed to their smaller body size and higher fat content, which can reduce the proportion of protein in the tissue. However, the protein content of fillets

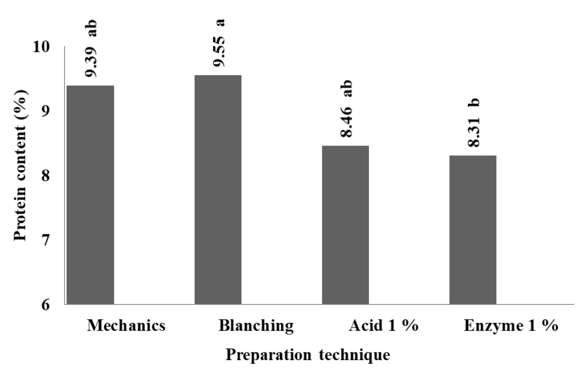

Fig. 5. Average protein content of fillets in various preparation techniques (%).
Description: Different letters in the same row/column indicate significant differences (DMRT, $P < 0.05$).

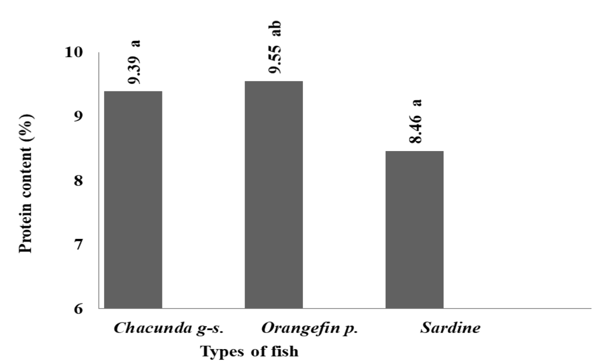

Fig. 6. Average protein content of fillets of three types of low-value fish (%).
Description: Different letters in the same row/column indicate significant differences (DMRT, $P < 0.05$).

in this study remains relatively low compared to values reported for fresh species, such as orangefin ponyfish in India (12.4%) [60]. This discrepancy may be due to the condition of the raw material (trash fish), freshness status, or post-harvest handling methods. Protein tends to degrade more rapidly in fish of lower initial quality, which affects the final yield [61].

3.6. Fat Content

The fat content of the treated Trash fish fillets ranged from 5.87% to 9.49% (Figure 7), with the highest value found in orangefin ponyfish treated with 1% papain enzyme (a proteolytic enzyme derived from papaya) (9.49%), and the lowest value observed in the blanching treatment (5.87%).

The results of the two-way analysis of variance showed that the preparation technique had a significant effect on the fat content of the fillet ($P < 0.05$). Fish species and the interaction between fish species and preparation technique had no significant effect on fat content ($P > 0.05$). Thus, differences in fat content are more influenced by the preparation method than by the fish species used. The 1% papain enzyme treatment resulted in the highest fat content, likely due to the softening of muscle tissue caused by protein hydrolysis, which facilitates lipid extraction during testing. This aligns with the study by Imaizumi *et al*. [62], which stated that structural changes in tissue due to biochemical or thermal treatments can affect the release of nutrients, including lipids. Conversely, the blanching treatment produced the lowest fat content (5.87%). This may be due to partial dissolution of lipid content into hot water during the boiling process. A reduction in fat content due to blanching was also observed in boiled salmon fillets, which were reported to have lower fat content compared to other processing methods [63].

Overall, the fat content observed in this study was higher than that of Indian orangefin ponyfish (3.58%) as reported by Jeyasanta and Patterson [64], which may be influenced by differences in local species, environment, or post-catch handling methods. Fat content is also affected by moisture content, where fish with lower moisture levels tend to show higher percentages of crude fat [65]. A similar study on fish species in Iraq also showed fat content variation ranging from 0.97% to 6.46% [66], confirming that fish fat content can be strongly influenced by species and environment. Although high fat content can enhance the nutritional and caloric value of a product, it is not desirable for products such as surimi, since fat can interfere with gel formation [67]. Therefore, blanching can be recommended for gel-based industries, while enzymatic treatments are more suitable for high-energy products such as baby food or specialized diet products.

3.7. Ash Content

The ash content of fillets from the three types of low-value fish ranged from 1.55% to 3.19% (Figure 8). The results of the two-way analysis of variance showed that neither fish species, preparation technique, nor the interaction between them had a

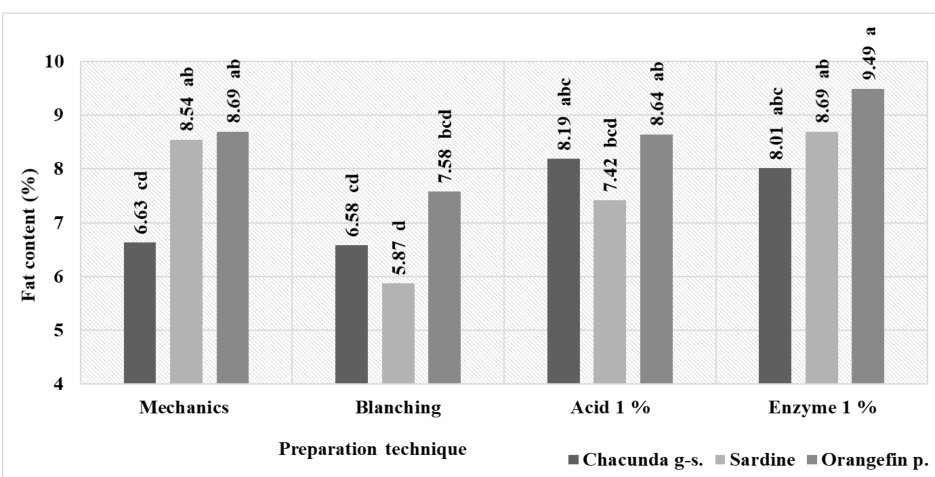

Fig. 7. Average fat content of fillets of three types of low-value fish in various preparation techniques (%). Description: Different letters in the same row/column indicate significant differences (DMRT, $P < 0.05$).

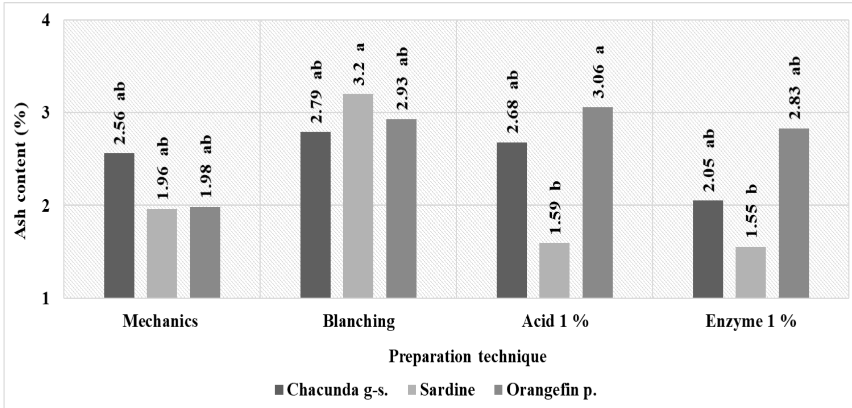

Fig. 8. Average ash content of fillets of three types of low-value fish in various preparation techniques.
(%) Description: Different letters in the same row/column indicate significant differences (DMRT, $P < 0.05$).

significant effect on the ash content of the fillets. However, descriptively, the lowest ash content was recorded in *orangefin ponyfish* treated with 1% papain enzyme (a proteolytic enzyme derived from papaya) (1.55 % ± 0.08%), followed by the 1% acetic acid treatment (1.59 % ± 0.09%). Meanwhile, the highest ash content was observed in the blanching treatment applied to *orangefin ponyfish* (3.19 % ± 0.11%) and *chacunda gizzard-shad* (2.85 % ± 0.10%).

The ash content of the fish fillets in this study ranged from 1.55% to 3.19%, which is within the typical range for tropical fish products, and there were no significant statistical differences between treatments. This value is quite comparable to the ash content of Indian mackerel (*Rastrelliger kanagurta* Cuvier, 1816) at 1.75% [68], but lower than that of fresh Tilapia at 4.80% [69] and *Scomberoides commersonnianus* Lacépède, 1801, from Pakistan (3.58%) [70]. The blanching treatment tended to increase the ash content of the fillets. This is likely due to the relatively higher concentration of minerals remaining after water and dissolved substances are lost during the heat treatment. Conversely, the use of acetic acid and papain enzyme appeared to reduce the ash content, which may be linked to tissue softening and the possible dissolution of some mineral components during the soaking process [71]. Additionally, ash content is influenced by biological and environmental factors of the fish, including diet, age, and habitat. The mineral composition that forms the ash is correlated with the physiological and ecological characteristics of the fish, as explained in the study by Qubay *et al*. [72], which noted that fish from different environments show significant variations in mineral content and other inorganic elements. Thus, although not statistically significant, the trend in this data suggests [73, 74] that enzymatic and acid treatments can be used as alternatives to produce fillets with lower ash content, which is particularly relevant for processing industries such as surimi or gel products that require low mineral content.

4. CONCLUSIONS

This study shows that the enzymatic preparation technique using 1% papain is the most effective method for achieving the highest fillet yield and the fastest processing time for all three types of trash fish, namely: chacunda gizzard-shad by 56.4%, orangefin ponyfish by 47.5%, and sardine by 63.2%. This technique also produces stable chemical composition results, water content (77.46% to 80.13%), protein levels (7.39% to 9.29%), fat content (8.01% to 9.49%), and ash levels (1.55% to 2.83%). A novel finding from this study is that the enzymatic treatment consistently produces fillets with superior physical and chemical quality compared to mechanical, blanching, and acid soaking techniques. Therefore, the enzymatic technique is recommended as the optimal preparation method to enhance the added value and processing efficiency of trash fish.

5. ACKNOWLEDGEMENT

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6. ETHICAL STATEMENT

This study did not involve any human participants or live animal testing. All fish samples used in the experiment were obtained from local fishermen as part of regular fishing activities, and the handling procedures followed standard post-harvest practices without causing unnecessary harm. Therefore, ethical approval was not required for this research.

7. CONFLICT OF INTEREST

The authors state that they have no conflicts of interest.

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