

EFFECT OF BODY SIZE ON THE PHYSICOCHEMICAL CHARACTERISTICS OF PROTEIN-RICH POWDERS FROM STRIPED SNAKEHEAD FISH (*Channa striata*) MEAT, BONE, AND SCALE

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Abstract

Striped snakehead (*Channa striata*) are an abundant, high-protein freshwater species in East Kalimantan, and their properties vary with body size. To support complete fish utilization, this study aimed to determine the effect of body size on the physicochemical characteristics (morphology and proximate composition) of powders derived from the meat, bone, and scales of small (500-600 g) and large (1,400-1,500 g) fish. Fish morphometrics were measured, body fractions (meat, bone, and scale) were separated, dried into powders, and analyzed for yields and proximate composition. Comparisons of morphometric characteristics and chemical compositions between the two size groups were statistically analyzed using an independent-samples t-test via the Toolpak in Microsoft Excel. The results showed that the large group exhibited superior morphological traits and higher percentages of edible and non-edible portions. Based on the determination of growth type, both groups exhibited positive allometric growth (where the slope [b]>3), with b-values of 9.5645 (W=160.18L9.5645) for smaller fish and 9.7814 (W=1004.4L9.7814) for larger fish. Proximate analysis revealed significant differences, with the large group consistently yielding higher nutritional values. Comparing the large and small groups across the highest component fractions, protein content reached 87.68% vs. 85.49% in the meat, fat content reached 21.14% vs. 17.30% in the bone, and ash content reached 55.41% vs. 53.55% in the scale, while moisture content remained below 10% for all powders. These findings demonstrate that larger haruan fish yield powders with superior physicochemical qualities, providing a vital guide for sustainable zero-waste processing..

Keywords: allometric growth, fish by-products, fish powder, nutritional composition, resource utilization

Pengaruh Ukuran Tubuh terhadap Karakteristik Fisikokimia Tepung Kaya Protein dari Daging, Tulang, dan Sisik Ikan Haruan (*Channa striata*)

Abstrak

Ikan haruan (*Channa striata*) atau dikenal sebagai ikan gabus merupakan spesies air tawar kaya protein yang melimpah di Kalimantan Timur dengan karakteristik yang bervariasi sesuai ukuran tubuhnya. Guna mendukung pemanfaatan ikan secara utuh, penelitian ini bertujuan menentukan pengaruh ukuran tubuh terhadap karakteristik fisikokimia (morfologi dan komposisi proksimat) tepung dari daging, tulang, dan sisik kelompok bobot yang berbeda, yaitu kelompok kecil (500-600 g) dan kelompok besar (1.400-1.500 g). Penelitian dilakukan dengan mengukur morfometrik ikan, memisahkan fraksi tubuh (daging, tulang, dan sisik), mengeringkannya menjadi tepung, serta menganalisis rendemen dan komposisi proksimatnya. Perbandingan karakteristik morfometrik dan komposisi kimia antara kedua kelompok ukuran dianalisis statistik menggunakan independent-samples T-test melalui Toolpak di Microsoft Excel. Hasil penelitian menunjukkan kelompok besar memiliki karakteristik morfologi yang lebih unggul serta persentase bagian yang dapat dan tidak dapat dikonsumsi yang lebih tinggi. Berdasarkan penentuan tipe pertumbuhannya, kedua kelompok menunjukkan pertumbuhan alometrik positif (jika *slope* [b]>3), dengan nilai b 9,5645 (W=160,18L9,5645) untuk ikan kecil dan 9,7814 (W=1004,4L9,7814) untuk ikan besar. Analisis proksimat menunjukkan perbedaan yang nyata, dengan kelompok ikan besar secara konsisten menghasilkan nilai nutrisi lebih tinggi. Perbandingan kelompok ikan besar dan kecil pada fraksi komponen tertinggi menunjukkan kadar protein mencapai 87,68% dibandingkan 85,49% pada fraksi daging, lemak 21,14% dibandingkan 17,30% pada fraksi tulang, dan abu 55,41% dibandingkan 53,55% pada fraksi sisik, sedangkan air untuk seluruh tepung berada di bawah 10%. Temuan ini membuktikan bahwa ikan haruan berukuran lebih besar menghasilkan tepung dengan kualitas fisikokimia lebih unggul, sekaligus menjadi panduan penting bagi pengolahan industri perikanan yang berkelanjutan dan bebas limbah.

Kata kunci: hasil samping ikan, komposisi gizi, pemanfaatan sumber daya, pertumbuhan alometrik, tepung ikan

INTRODUCTION

The striped snakehead fish (*Channa striata*), also known as the snakehead, is a freshwater fish with a high protein content ranging from 85.32% to 93.98% (Chasanah *et al*., 2015). Communities in regions with extensive freshwater bodies, such as Kalimantan and Sumatra, frequently utilize this fish as a raw material for processed products because of its superior characteristics, including its delicious taste, thick flesh, and minimal bones (Asikin & Kusumaningrum, 2017). The striped snakehead production volume in Indonesia reached 4,432.94 tons in 2024, with a production value of approximately IDR 86,041,612,000.00 (Kementerian Kelautan dan Perikanan Republik Indonesia, 2026).

Despite its great potential, the morphometry and nutritional composition of striped snakehead fish vary with their body weight. Understanding these variations is important because these data are directly related to isometric and allometric growth patterns (Nur *et al*., 2023). Isometric growth is a balance between length and weight growth, whereas allometric growth is an unbalanced growth (one parameter dominates). Analysis of the relationship between length and body weight can show whether fish growth is proportional or whether one parameter (length or weight) dominates. This is an important indicator of the sustainability of fish resources (Rahimnejad *et al*., 2021). Other studies have confirmed that fish size is directly proportional to fat content (Suwandi *et al*., 2014; Asikin & Kusumaningrum, 2017), and that moisture content tends to decrease with increasing weight (Rosmawati *et al*., 2024). This research is important for optimizing the use of striped snakehead fish according to its nutritional composition.

In East Kalimantan, striped snakehead fish have been used to make various processed products, including crackers, fish floss, salted fish, and a traditional product called *amplang*. The use of striped snakehead fish meat has left other underutilized parts of the body, such as bones, scales, and heads. As a perishable commodity, developing appropriate processing methods is crucial for reducing waste and increasing added value (Fatmawati & Mardiana, 2014). One of the most promising approaches is to convert all parts of the fish into powder. Various studies have confirmed that specific parts of the striped snakehead fish are highly nutritious. Fish meat contains approximately 59.24-63.59% protein and albumin (Asikin & Kusumaningrum, 2017; Nurilmala *et al.*, 2020), while fish bones are rich in protein (15.01-15.24%) (Rosmawati *et al.*, 2024), and scales contain collagen protein up to 51.09% (Hussain *et al.*, 2015). This comprehensive utilization can provide significant added value not only for food but also for the feed and cosmetics industries (Niga *et al.*, 2022).

Although various studies have examined the utilization of striped snakehead fish (Dewantara *et al.*, 2019; Adawyah *et al.*, 2024) and albumin extraction (Asfar *et al.*, 2019; Setiawan *et al.*, 2024; Yuniati *et al.*, 2024), research that specifically analyzes the proximate composition of body parts (meat, bones, and scales) in striped snakehead fish of different weight groups is still very limited. Furthermore, detailed information on the morphometric characteristics and growth patterns of striped snakehead fish in different size groups are not yet available. This study aimed to determine the effect of body size on the physicochemical characteristics (morphology and proximate composition) of powders derived from the meat, bone, and scales of small (500-600 g) and large (1,400-1,500 g) weight groups. A comprehensive understanding of these data is expected to guide sustainable fish resource management.

MATERIALS AND METHODS

Striped Snakehead Fish Morphometric Measurement

Fresh striped snakehead fish was obtained from a fish seller in Samarinda, which was caught from the headwaters of the Mahakam River. The fish were grouped into two categories: 500-600 g and 1,400-1,500 g. The striped snakehead fish were sampled randomly and represented the size of the fish caught. The instruments used for morphometric measurements include measuring tapes, rulers, or calipers, which vary depending on the size and shape of the organism being measured (Takacs *et al.*, 2016). The morphometric measurement parameters of the striped snakehead fish are shown in Figure 1.

Determination of Growth Type and Length-Weight Relationship of Striped Snakehead Fish

The determination of the growth type and length-weight relationship of striped snakehead fish was based on the formula established by Cren (1951) as follows:

$$W=aL^b$$

W=fish body weight (g)
L=total fish length (mm)

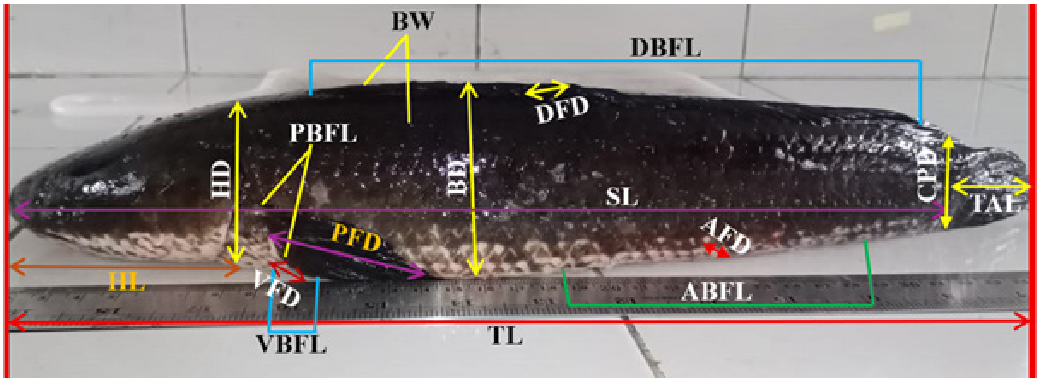

Figure 1 Parameters of morphometric striped snakehead fish (*Channa striata*); TL (total length), SL (standard length), HL (head length), HD (head depth), BD (body depth), BW (body width), CPD (caudal peduncle depth), TAL (Tail length); DBFL (dorsal base fin length), DFD (dorsal fin depth), PBFL (pectoral base fin length), PFD (pectoral fin depth), ABFL (anal base fin length), AFD (anal fin depth), PBFL (pelvic base fin length), PFD (pelvic fin depth).

a=intercept
b=slope

The value of b is used to determine whether fish growth is isometric or allometric. If b=3, then the growth type is isometric; if b<3, then the growth type is negative allometric; and if b>3, then the growth type is positive allometric.

Preparation of Striped Snakehead Fish Bones, Scales, and Meat

Live striped snakehead fish were pithed at the head to reduce stress and hasten their mortality (Yan *et al.*, 2025). The scales were then removed and eviscerated. The flesh was filleted, and all bones (head, frame, and fins) were collected for further processing. The edible (fish meat) and non-edible (bones, scales, and entrails) portions were calculated as a percentage of the whole fish weight. The edible portion (fish meat) and non-edible portion (bones, scales, and entrails) are calculated as a percentage of the whole fish weight. Next, the meat, bones, and scales were separated and chopped into ±2 cm pieces in preparation for the drying and grinding stages.

Production of Striped snakehead Fish Meat, Bone, and Scale Powder

The powder processing method was based on the method described by Wirawan *et al.* (2018). The meat, bones, and scales were dried using a food dehydrator at 60°C for 24 h. The dried meat, bones, and scales were weighed, ground using a blender for approximately 2–4 min, and sieved using a 60-mesh sieve. The meat, bone, and scale powders were weighed to determine the yield and analyzed for proximate composition.

Yield

The yield value is obtained from the ratio of the final weight of the product produced to the initial weight (Ikawati *et al.*, 2024) using the following formula:

$$\text{Yield (\%)} = \frac{\text{Final weight (g)}}{\text{Initial weight (g)}} \times 100$$

Proximate Analysis

The proximate parameters tested included moisture content (Badan Standardisasi Nasional [BSN], 2015), ash (BSN, 2017a), protein (BSN, 2006), fat (BSN, 2017b), and carbohydrate (calculated by difference).

Data Analysis

This study utilized striped snakehead fish from two distinct weight groups: 500-600 g and 1,400-1,500 g. The obtained data are presented as mean and standard deviation from three replicates. Comparisons of morphometric characteristics and chemical compositions between the two size groups were statistically analyzed using an independent-samples t-test via the Data Analysis Toolpak in Microsoft Excel.

RESULT AND DISCUSSION

Striped Snakehead Fish Morphometric Characteristics

Based on the identification results, striped snakehead fish have distinctive morphological characteristics, namely an elongated and sub-cylindrical body with bilateral symmetry. The head of this fish is flat and covered with scales resembling those of snakes. Its mouth is wide and oriented upward, equipped with sharp fangs, thin lips, and a long, pointed snout. The dorsal fin is located behind the head and is not connected to the caudal fins. The pectoral fins are positioned vertically below the dorsal fin, just behind the gill cover, and are shorter than the length of the head behind the eyes. Meanwhile, the position of the pelvic fins is sub-abdominal. The tail fin is rounded, and the anal fin is located just behind it. The scales on this fish are stenoid. Morphometric analysis conducted on two groups of striped snakehead fish weighing 500-600 g and 1,400-1,500 g showed significant proportional differences between the two groups, as presented in Table 1.

Morphometric measurements indicate a direct proportionality between the body weight and morphometric characteristics of striped snakehead fish; fish with greater body weight consistently exhibit higher morphometric traits. This observation aligns

Table 1 Morphometric characteristics of striped snakehead fish

Characteristics	Mean (cm)	
	Weight (500-600) g	Weight (1,400-1,500) g
Total length	38.39±1.43[a]	45.76±1.42[b]
Standard length	31.22±1.28[a]	38.34±1.41[b]
Head length	8.50±0.10[a]	10.52±1.22[b]
Head depth	5.00±0.10[a]	6.00±0.13[b]
Body depth	5.84±0.14[a]	7.32±0.11[b]
Body width	6.22±0.11[a]	7.31±0.10[b]
Caudal peduncle depth	3.23±0.12[a]	5.34±0.12[b]
Tail length	6.81±0.10[a]	7.33±0.12[b]
Dorsal base fin length	17.32±1.41[a]	21.31±1.18[b]
Dorsal fin depth	2.00±0.10[a]	3.00±0.09[b]
Pectoral base fin length	6.24±0.09[a]	6.53±0.07[b]
Pectoral fin depth	3.02±0.11[a]	3.51±0.10[b]
Anal base fin length	16.05±0.21[a]	17.52±1.19[a]
Anal fin depth	2.01±0.06[a]	3.04±0.09[b]
Pelvic base fin length	4.54±0.09[a]	5.03±0.07[b]
Pelvic fin depth	1.54±0.09[a]	2.04±0.09[b]

Data are presented as mean ± SD (n = 3).
Different superscript letters within the same row indicate significant differences based on an independent-samples t-test ($p<0.05$)

with the findings of Muthmainnah (2013), who noted a strong correlation between fish body weight and body length. Specifically, a higher body weight in striped snakehead fish results in a longer body size, and conversely, a lower body weight correlates with a shorter body length (Asikin & Kusumaningrum, 2017). However, the morphometric characteristics of fish are influenced not only by genetic factors but also by environmental factors (Akmal *et al*., 2018). These influential environmental factors include temperature, salinity, dissolved oxygen, radiation, water depth, current velocity, water clarity, food availability, and fish sex. When comparing the growth rate of body weight and body length, the percentage increase in body weight was significantly greater. For example, fish weighing 500 g and 1500 g showed a three-fold increase in body weight, while the average increase in body length, from 38.39 cm to 45.76 cm, was only 19.20%. The relationship between the length and body weight of these fish and their growth type is detailed in Table 2 and Figure 2.

This study revealed distinct morphometric differences based on weight groups. Generally, based on the independent sample T test, differences in fish weight significantly affected the morphometric characteristics of striped snakehead fish. Striped snakehead fish weighing between 500-600 g exhibited a total length ranging from 36.10 to 41.50 cm, whereas those in the 1,400-1,500 g group had a total length of 40.20 to 50.50 cm. Analysis of the length-weight relationship resulted in the equations $W=160.18L^{9.5645}$ for the 500-600 g group and $W=1004.4L^{9.7814}$ for the 1,400-1,500 g group. Since the b values for both groups (9.5645 and 9.7814) were greater than 3, the growth type was classified as positive allometric, indicating that the fish body weight increased faster than body length.

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Table 2 The correlation of length and body weight of striped snakehead fish

Parameters	Weight (500-600) g	Weight (1,400-1,500) g
Total length range (cm)	36.10-41.50	40.20-50.50
Total length (cm; mean±sd)	38.39±1.60[a]	45.76±3.08[b]
Body weight range (g)	500.70-552.40	1,405.20-1,499.20
Body weight (g; mean±sd)	527.32±15.70[a]	1,452.00±30.52[b]
Intercept (a)	160.18	1,004.4
Slope (b)	9.5645	9.7814
Correlation coefficient (r)	0.9490	0.9765
Regression equation	$W=160.18L^{9.5645}$	$W=1004.4L^{9.7814}$
Growth type	Positive allometric	Positive allometric

Different superscript letters within the same row indicate significant differences based on an independent-samples t-test ($p<0.05$)

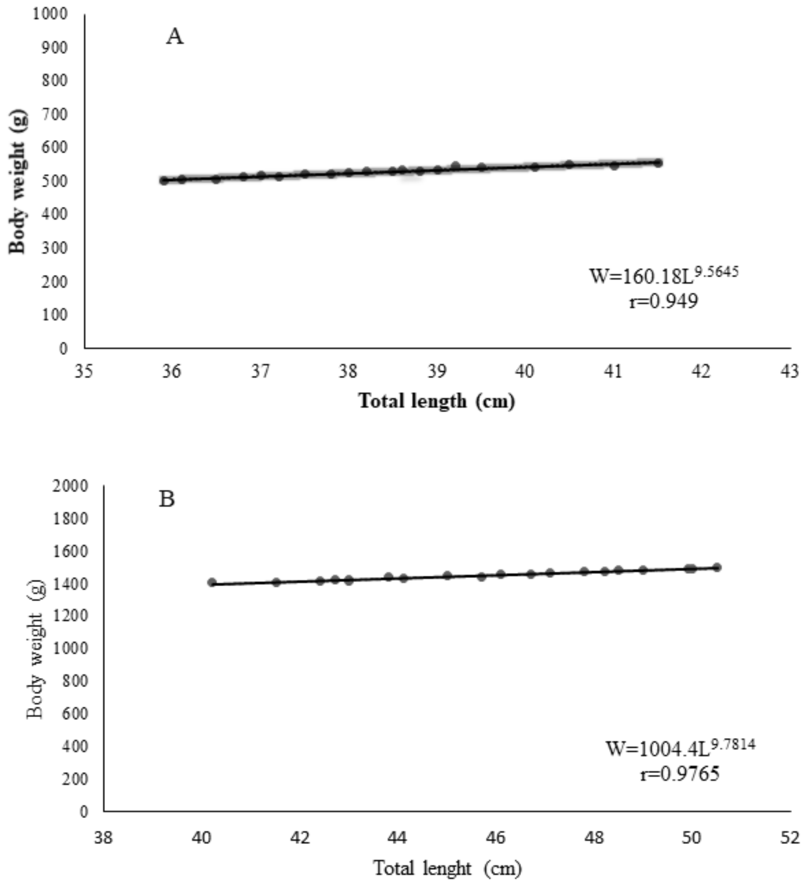

Figure 2 The length-weight relationship of striped snakehead fish categorized by weight groups: A (500–600 g) and B (1,400–1,500 g)

This positive allometric growth in *C. striata* aligns with the findings of Amanpokptis (2018), who observed similar b-values (b>3) in wild snakehead populations and attributed this growth strategy to the high carnivorous nutrient intake and optimal muscle tissue accumulation. Conversely, a negative allometric growth pattern (b<3) in *C. striata* has been reported by Ahmadi (2022) and Asyhari & Machrizal (2023), wherein environmental stressors, seasonal feed limitations, and high energy expenditure for reproduction constrained lateral body weight gain. This allometric growth pattern is consistent with reports suggesting that it can be influenced by internal factors (such as genetics, sex, hormones, and foraging ability) and external factors (including adaptation to environmental conditions, exploitation levels, feed availability, resource competition, and water temperature) (Nur *et al.*, 2023; Hamed *et al.*, 2024). The strong correlation coefficients (r>0.94) observed in both weight groups further confirmed that body length is a highly reliable predictor of body weight and total muscle mass accumulation in *C. striata*, thereby offering advantages for industrial processing and yield efficiency.

The graph illustrating the length-weight relationship of the fish yielded a strong correlation coefficient (r) for both the groups. Specifically, the striped snakehead fish in the 500–600 g weight group showed an r-value of 0.949, whereas the 1,400–1,500 g group exhibited an even higher correlation of 0.9765. These results confirm a strong correlation between body weight and body length in striped snakehead fish, aligning with the criteria established by Papageorgiou (2022), where an r-value near 1 indicates a strong relationship. This strong relationship is likely attributed to the sufficient availability of food and supportive environmental conditions within the fish habitat. Furthermore, seasonal changes influence food availability; during periods of scarcity, fish migrate in search of sustenance and better living conditions, and this increased activity contributes to the observed increases in both weight and length. Different parts of an organism's body grow at different rates as size and age increase, which is a common phenomenon in allometric growth (Rosenfeld *et al.*, 2015; Phillips *et al.*, 2018; Balikci, 2024).

Proportion of Striped snakehead Fish Body Parts

Striped snakehead fish of different weights showed different proportions of edible and non-edible parts. The edible portion is the part of the fish that can be consumed, such as the flesh, while the non-edible portion is the part of the fish that is generally not consumed, such as the bones, scales, and entrails (Coppola *et al.*, 2021; Abasubong *et al.*, 2025). The proportion of striped snakehead fish body parts can be seen in Figure 3.

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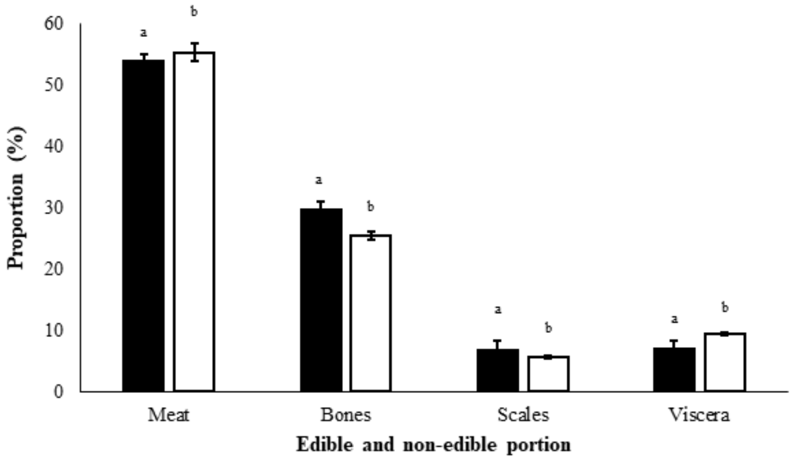

Figure 3 Proportion of striped snakehead fish; ■ 500-600 g, □ 1,400-1,500 g. Values represent the mean ± standard deviation (n = 3). Different superscript letters indicate significant differences based on an independent-samples t-test (p<0.05).

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Striped snakehead Fish Powder Yield

The yields of powders derived from the meat, bone, and scales of striped snakehead fish across the two weight groups are presented in Table 3. Overall, the powder yields increased with larger fish body weights across all fractions, although a statistically significant difference ($p<0.05$) was exclusively observed in the scale fraction. These variations in recovery efficiency highlight the practical advantage of processing larger fish to maximize powder production, particularly from by-product fractions.

In this study, the yield was 23.90% for fish weighing 500–600 g, whereas fish weighing 1,400–1,500 g yielded 25.17% powder. These results indicate a higher proportion of flesh, bone, and scales in striped snakehead fish weighing 1,400–1,500 g than in those weighing 500–600 g. This was also statistically confirmed based on the independent sample t-test. This finding indicates that larger fish possess a more optimal raw material composition for processing.

The significant increase in yield in larger fish (1,400–1,500 g) is attributed to their biological maturity. As striped snakehead fish grow, their bones and scales undergo a more complete mineralization process, resulting in a higher mineral content and lower water content (Jaya *et al.*, 2024). Furthermore, the increase in meat powder yield suggests that larger fish have a higher protein-to-fat ratio and a slightly lower water content than smaller fish (Breck, 2014; Ahmed *et al.*, 2022). Asikin & Kusumaningrum (2017) previously reported that larger striped snakehead fish have lower water content than smaller fish. This collectively confirms that larger fish not only have a heavier total weight but also exhibit better raw material quality, which consequently leads to more efficient processing yields. The appearance of the fish meat, bone, and scale powders is shown in Figure 4.

The yields of meat, bones, and scales were higher in striped snakehead fish weighing 1,400–1,500 g than in those weighing 500–600 g. This suggests that larger fish possess a more optimal raw material composition for processing. The significant increase in yield in

Table 3 Striped snakehead fish powder yield

Weight group (g)	Yield (%)		
	Meat	Bone	Scale
500-600	23.90±1.38[a]	39.54±1.27[a]	47.26±1.19[a]
1,400-1,500	25.17±1.11[a]	41.95±1.25[a]	52.65±1.28[b]

Data are presented as mean \$\pm\$ standard deviation of three replicates (n = 3).
Different superscript letters within the same column indicate significant differences based on an independent-samples t-test ($p<0.05$)

(A) (B) (C)

Figure 4 Visual characteristics of striped snakehead fish powders derived from (A) meat, (B) bone, and (C) scale

larger fish (1,400–1,500 g) can be attributed to their biological maturity. As striped snakehead fish grow, their bones and scales undergo a more complete mineralization process, leading to a higher mineral content and lower water content (Jaya *et al*., 2024).

The meat yield of striped snakehead fish is lower than that of bones and scales. This difference in yield between the meat and bone/scale powders can be attributed to their respective water contents. Fish meat naturally has a very high-water content, ranging between 60% and 80% of its total weight, which results in significant weight loss during the drying process. Consequently, the meat powder yield was relatively low, specifically 23.90% for fish weighing 500–600 g and 25.17% for fish weighing 1,400–1,500 g. In contrast, bones and scales have much higher mineral content and lower initial water content, meaning their weight does not decrease drastically when dried. Arsih *et al.* (2022) reported that striped snakehead fish meat has a moisture content of 81.6%, whereas Jaya *et al.* (2024) reported that the moisture contents of striped snakehead fish bones and scales are 71.88% and 57.33%, respectively.

Chemical Composition of Powders derived from Meat, Bone, and Scale of Striped snakehead Fish

The proximate compositions of the powders derived from the meat, bone, and scales of striped snakehead fish across two different weight groups are presented in Table 4. Overall, the chemical components exhibited significant variations ($p<0.05$) influenced by both fish body size and the specific body fraction evaluated. These proximate profiles provide essential insights into the nutritional quality and functional potential of each fraction for zero-waste fishery product development.

Moisture content

The moisture content of striped snakehead fish meat, bone, and scale powder in this study showed a difference in moisture content between the two weight groups (500-600 g) and (1,400-1,500 g). The moisture content of snakehead fish meat powder was lower in the heavier weight group, but in snakehead fish bone and scale powders, the higher the body weight, the higher the moisture content. The complete data are presented in Table 4.

The moisture content of meat powder from the 1,400–1,500 g weight group (5.95%) was lower than that of the 500–600 g weight group (6.87%). The independent-samples t-test results confirmed a significant difference in the moisture content of striped snakehead fish meat powder between the two weight groups. This difference is thought to be due to the naturally higher water content in the flesh of striped snakehead fish in the smaller group (500–600 g) than in the larger group (1,400–1,500 g). Fish in the smaller weight group generally possess a higher proportion of muscle relative to fat (Pyz-Łukasika *et al.*, 2020). During this growth phase, the fish body prioritizes muscle mass formation without

Table 4 Chemical composition (%) of powders derived from meat, bone, and scale of striped snakehead fish across two weight groups

Weight group (g)	Source of powder	Parameters			
		Moisture	Ash	Fat	Protein
500-600	Meat	6.87±0.07^{a}	6.11±0.40^{a}	4.88±0.19^{a}	85.49±0.06^{a}
	Bone	6.42±0.28^{a}	42.05±0.12^{a}	17.30±0.32^{a}	37.68±0.33^{a}
	Scale	7.50±0.61^{a}	53.55±0.77^{a}	3.71±0.58^{a}	38.12±0.37^{a}
1,400-1,500	Meat	5.95±0.04^{b}	8.38±0.09^{b}	6.50±0.01^{b}	87.68±1.09^{b}
	Bone	8.23±0.23^{b}	44.72±0.11^{b}	21.14±0.17^{b}	40.51±0.13^{b}
	Scale	9.59±0.27^{b}	55.41±0.19^{b}	5.70±0.69^{b}	41.82±0.66^{b}

Data are presented as mean ± standard deviation of three replicates (n = 3).
Different superscript letters within the same column indicate significant differences based on an independent-samples t-test (p<0.05)

excessive fat accumulation, leading to a higher moisture content in the meat. Conversely, as fish increase in weight and approach gonadal maturity, they begin accumulating fat. This fat accumulation can displace some of the water within the muscle tissue (Wang *et al*., 2025), resulting in lower water content in the flesh of larger fish (Ahmed *et al*., 2022). This finding aligns with several previously reported studies (Asikin & Kusumaningrum, 2017; Sudirman *et al*., 2018; Ullah *et al*., 2022), which reported that fish with lower weights exhibit higher flesh water content. Furthermore, the results are consistent with those of Suwandi *et al*. (2014), who found that the moisture content of 500 g snakehead fish was higher (80.41 %), likely referring to the meat before drying. However, the water content of striped snakehead fish meat powder in this study was slightly higher than the 5.68% reported by Mahardika *et al.* (2017) for snakehead fish meat powder.

The moisture content of striped snakehead fish bones and scales was significantly higher in the 1,400–1,500 g weight group, as demonstrated by the t-test results. Specifically, the moisture content of striped snakehead bone and scale powder in the 500–600 g weight group was 6.42% and 7.50%, respectively, whereas in the 1,400–1,500 g group, it was 8.23% and 9.59%, respectively. It is hypothesized that the structure of bones and scales in younger fish tends to be less dense and more porous because of incomplete mineralization (Seidel *et al*., 2021). This less dense structure allows water to evaporate more easily during the drying of the bone and scale powders. Conversely, larger fish possess denser and more compact bone and scale structures as a result of a more intensive mineralization process (Kague *et al*., 2024). A dense structure can absorb and retain water within its matrix, making it more difficult to evaporate during drying. This structural difference is thought to be the reason why the moisture content of bone and scale powder from striped snakehead fish weighing 1,400–1,500 g is higher. The moisture content of striped snakehead bone powder in this study was lower than the 10% reported by Wirawan *et al*. (2018). However, the moisture content of striped snakehead scale powder in this study exceeded the 6.67% reported by Widagdo (2016).

Ash content

Ash content serves as a primary indicator of the total mineral content in various parts of the fish body. As summarized in Table 4, ash levels varied significantly among the different parts, with scale and bone powders exhibiting much higher concentrations than the flesh. Furthermore, a significant increase (p<0.05) in ash content was observed in the group of heavier fish (1,400-1,500 g) across all tested fractions, reflecting a greater accumulation of inorganic minerals as the fish increased in body size.

The ash content of the striped snakehead fish powder in this study ranged from 6.11% to 8.38% (db). Specifically, the higher ash content was observed in the 1,400–1,500 g weight group, while the lower content was observed in the 500–600 g weight group. Based on the T-test results, a significant difference was established in the ash content between the two weight groups. Variations in ash content can be attributed to the differing primary functions of various fish body parts, such as their structural and metabolic roles (Sudirman *et al*., 2018). Ullah *et al*. (2022) also noted that differences in ash content between several types of freshwater and marine fish of different sizes may be influenced by the type of feed consumed and the mineral content of the fish habitat. The increase in ash content observed in larger fish is typically due to mineral accumulation during growth (Naqvi *et al*., 2021).

The striped snakehead fish bone and scale powders consistently exhibited a higher ash content than the fish meat powder. This is because fish bones and scales are naturally rich in minerals, particularly calcium and phosphorus (Rozirwan *et al*., 2025). As fish mature and grow from the 500–600 g group to the 1,400–1,500 g group, the mineralization process continues, causing the bones and scales to accumulate substantial amounts of minerals, making them denser and harder. Consequently, when these parts are processed into powder, their ash content is significantly increased. The ash content of the striped snakehead fish bone powder in this study was higher than that reported by Rosmawati *et al*. (2024), which was 29.82% and 32.05% for fish weights of 300–400 g and 900–1,000 g, respectively. Meanwhile, the ash content of the scale powder in this study was slightly higher than the 53.16% reported by Widagdo (2016). The reason scale powder has the highest ash content among the parts is that one of the main components of scales is the hydroxyapatite mineral, which is quite high, often ranging from 16 to 59% of the total scale weight (Zhu *et al*., 2012).

Fat Content

Fat content plays a crucial role in determining the energy density and susceptibility to lipid oxidation in fishery products. Based on the proximate analysis results in Table 4, fat distribution showed significant differences among body parts; the bone fraction contained the highest proportion of lipids, followed by the flesh and scales. Furthermore, the powder derived from the larger fish group (1,400–1,500 g) exhibited a significant increase ($p<0.05$) in fat content across all body parts, indicating higher lipid deposition in large striped snakehead fish.

The analysis of fat content in various parts of striped snakehead fish (meat, bone, and scale) processed into powder revealed that a higher body weight of the fish correlated with a higher fat content. The fat content of striped snakehead fish meat powder in this study ranged from 4.88% to 6.50% (db). Furthermore, the fat content of the striped snakehead fish bone powder ranged from 17.30% to 21.14% (db), while that of the scale powder ranged from 3.71% to 5.70% (db).

This study demonstrated a significant difference in fat content between the two weight groups of striped snakehead fish based on the independent-samples t-test. A higher fat content was observed in the meat, bones, and scales of striped snakehead fish weighing 1,400–1,500 g. The variation in fat content can be attributed to physiological factors such as feeding habits, sex, reproduction, and the environment where the fish are caught (Balikci & Özcan, 2023; Shim *et al*., 2025). Based on their feeding behavior, striped snakehead fish are carnivorous and predatory, relying on shrimp, frogs, worms, insects, and various fish as their primary food sources (Hasan *et al*., 2023). Striped snakehead fish consume food more frequently and in greater amounts, allowing them to accumulate larger fat energy reserves. This trend was particularly evident in larger fish, consistent with the findings of Asikin and Kusumaningrum (2017), who reported higher fat levels in larger specimens.

The fish bone powder analyzed in this study exhibited fat content ranging from 17.30% to 21.14% (db). The fat content in the bone powder increased proportionally with an increase in fish body weight. The fat content of the bone powder here was higher than the results obtained by Rosmawati *et al.* (2024), who reported 2.54% and 4.19% for degreased bones from fish weighing 300–400 g and 900–1,000 g, respectively. Furthermore, Ama-Abasi and Ogar (2013) reported that Nigerian snakehead fish (*Parachanna obscura*) weighing 130–195 g had a fat content of 17.10–17.40%. Similarly, the fat content of striped snakehead fish scale powder in this study was 3.71%–5.70% (db), which also increased with fish body weight.

Smaller fish are typically in an active growth phase, utilizing more energy for muscle mass formation and overall growth, resulting in lower fat content in their muscle tissue (Sudirman *et al.*, 2018). As fish grow larger, most of the energy obtained from food is not only used for growth but is also stored as fat between the muscle fibers (Hastarini *et al.*, 2012). Fat accumulation is not limited to muscle tissue; it is also trapped within the fish tissue surrounding the bones and beneath the scales. In larger fish, fat storage is observed across the entire supporting structure (Scharnweber *et al.*, 2021).

Protein Content

Protein content is a key indicator of the nutritional value and functional quality of the resulting powder. As detailed in Table 4, the highest protein concentration was found in the flesh fraction, exceeding 85%, while the bone and scale powders also maintained relatively high protein levels, primarily derived from the structural collagen matrix of the fish. Furthermore, the heavier weight group (1,400–1,500 g) exhibited a significant increase ($p<0.05$) in protein content across all fractions compared to the lighter group. This confirms that body size positively influences protein density in striped snakehead fish tissues.

The protein content in the powder derived from the meat, bone, and scales of striped snakehead fish increased significantly (based on independent sample t-test) with the body weight of the fish. Specifically, fish weighing 500–600 g exhibited lower protein content than those weighing 1,400–1,500 g. The highest protein content in the fish meat powder was recorded in the 1,400–1,500 g weight group, reaching 87.68% (db), whereas the lowest was found in the 500–600 g weight group at 85.49% (db).

Protein levels increase as fish grow, and the protein content in striped snakehead fish meat powder was higher than that in bone and scale powders. These differences in fish protein content can be influenced by the type of feed, feeding habits, sexual maturity, habitat, and feed availability (Balikci, 2024). Smaller fish are generally thought to be in their active growth phase, resulting in muscle tissue with a higher water content and lower density (Pyz-Łukasika *et al.*, 2020). Conversely, larger fish have denser and more fully developed muscle tissues, resulting in a higher protein concentration per unit weight. Sroy et al. (2021) reported that the average protein content of large species is higher than that of small species. Additionally, larger striped snakehead fish tend to prey on small fish, frogs, and shrimp (Hasan *et al.*, 2023). These types of prey have a higher protein content and richer nutritional profile, and a protein-rich diet can support the formation of denser muscle tissue, consequently increasing its protein content. The protein content of the meat powder in this study was higher than that reported by Mahardika et al. (2017), who found it to be 86.13% (db), and Asikin & Kusumaningrum (2017), who reported a range of 17.28–18.12% (db) for fish weighing between 200 and 500 g and 800–1,100 g.

The protein content of striped snakehead fish bone powder in this study ranged from 37.68% to 40.51% (db). Bone powder had a higher protein content in the 1,400–1,500 g weight group and a lower content in the 500–600 g weight group. The protein content of the bones in this study was significantly higher than that reported by Rosmawati *et al.* (2024), which showed a protein content of 15.01–16.09%. Bones are composed of 90% organic material, primarily collagen. Collagen accounts for 20% of all body proteins and acts as an organic structure that builds bones, joints, muscles, and skin (Barzkar *et al.*, 2023).

The protein content of striped snakehead fish scale powder increased with an increase in the body weight of striped snakehead fish. The striped snakehead fish scale powder from the 1,400–1,500 g weight group had a higher protein content of 41.82% (db), while the protein content of the scale powder from the 500–600 g weight range was 38.12% (db). The results of this study are higher than those of Widagdo (2016), who reported a protein content of 19.72%. The protein contained in fish scales is a fibrillar protein with a triple helix structure called collagen. The amount of collagen in fish scales varies greatly depending on the type, age, habitat, and sex of the fish (Pamungkas *et al*., 2018).

CONCLUSION

This study demonstrates that body size significantly affects the morphometric characteristics, yields, and proximate profiles of powders derived from striped snakehead fish meat, bone, and scales. Larger fish (1, 400–1, 500 g) consistently produced powders with superior nutritional qualities compared to smaller fish (500–600 g), characterized by higher protein content in meat powder, higher lipid content in bone powder, and higher ash content in scale powder, while maintaining moisture levels below. These findings confirm that utilizing larger striped snakehead fish maximizes the functional and nutritional value of both edible and non-edible fractions, providing a practical foundation for zero-waste processing in the fisheries industry.

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