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Amino acid profile and potential utilization purposes of albumin from four types of freshwater fish in Makassar, South Sulawesi, Indonesia

NURFAIDAH[1,♥], ANDI NOOR ASIKIN[1], KASMIATI[2], ANGRAENI[3]
[1]Department of Fishery Product Technology, Faculty of Fisheries and Marine Science, Universitas Mulawarman. Jl. Gunung Tabur, Samarinda 75123, East Kalimantan, Indonesia. ♥email: nurfaidahanwah@gmail.com
[2]Department of Fishery Product Technology, Faculty of Marine and Fisheries Sciences, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km. 10, Makassar 90245, South Sulawesi, Indonesia
[3]Department of Fisheries Science, Faculty of Science and Technology, Universitas Cahaya Prima. Jl. Jendral Urif Sumoharjo, Bone 92733, South Sulawesi, Indonesia

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Abstract. *Nurfaidah, Asikin AN, Kasmiati, Angraeni. 2024. Amino acid profile and potential utilization purposes of albumin from four types of freshwater fish in Makassar, South Sulawesi, Indonesia. Biodiversitas 25: 4199-4207.* Albumin, a high-quality protein, is known for its complete amino acid profile, which is essential for numerous biological functions, including immune response and nutritional status maintenance. This study investigates the amino acid composition of albumin in four freshwater fish species commonly found in Indonesia: *Cyprinus carpio*, *Pangasius pangasius*, *Channa striata*, and *Trichopodus trichopterus* to asses their potential utilization in sustainable food resources and nutritional and health-related products. Albumin extraction was performed using homogenization and incubation techniques, followed by amino acid analysis using High-Performance Liquid Chromatography (HPLC). The results revealed the presence of 18 amino acids, including 9 essential and 9 non-essential amino acids. The most abundant amino acids were glutamic acid, aspartic acid, leucine, and lysine, with lysine being particularly noteworthy for its role in wound healing and protein synthesis. Significant variations in the amino acid composition were observed across the species, influenced by factors such as diet, habitat, and species-specific physiology. *Pangasius pangasius* exhibited the highest lysine content (12.01%), while *C. carpio* had the highest glutamic acid content (24.55%) of total amino acid. These findings suggest that the albumin from these freshwater fish species is a valuable source of high-quality protein, with potential applications in developing nutraceuticals, functional foods, and dietary supplements aimed at improving health and nutritional status. Importantly, the study highlights the potential of these fish species as a sustainable source of protein, contributing to food security and supporting the development of affordable, protein-rich products that can enhance public health while reducing the reliance on conventional livestock-based proteins. This study provides new insights into the amino acid composition of fish albumin from Indonesian freshwater species, contributing to the broader understanding of the nutritional value of local fish resources and their role in promoting sustainable food systems.

Keywords: Functional food, nutraceutical, nutritional evaluation, protein quality

INTRODUCTION

Protein is an essential component of the body that acts as an antibody to maintain immunity and protect against infections (Watford and Wu 2018). The regulation of protein in the body functions optimally when protein intake is sufficient, thereby stimulating the synthesis of serum albumin-a protein that plays a significant role in various biological functions, including determining an individual's nutritional status (Bharadwaj et al. 2016; Wada et al. 2018). According to the regulation of The Indonesian Food and Drug Authority (BPOM 2019), one method to evaluate protein quality is by analyzing its amino acid profile. Amino acids are the building blocks of protein (Wilson 2003), and high-quality proteins possess a complete and balanced amino acid composition (Huang et al. 2018). Proteins with an amino acid structure closely resembling that of the human body are considered high-quality proteins. The primary sources of high-quality protein are animal proteins, which contain essential amino acids in sufficient amounts and are more easily digested compared to plant-based proteins (Tomé 2013; Gardner et al. 2019).

Animal proteins, including fish albumin, are known for their high quality. Fish albumin, in particular, has a more complete amino acid composition compared to other animal proteins (Mariotti 2017). Albumin belongs to the group of sarcoplasmic proteins, which are water-soluble and easily processed by the body (Ochiai and Ozawa 2020). However, the amino acid composition of fish albumin can vary depending on several internal and external factors. Internal factors include the fish's age, reproductive stage, sex, and species, while external factors are related to the environment in which the fish live, such as water quality, food availability, and habitat (Bogard et al. 2015). Variations in fish populations can also affect the nutritional content and chemical composition. Factors such as energy consumption, feeding habits, food availability, fishing areas, and aquaculture technology contribute to these differences.

Numerous studies have been conducted on the amino acid composition of fish albumin, including notable research by Susilowati et al. (2016), Prastari et al. (2017), and Pratama et al. (2020); however, these studies have not linked the amino acid composition of fish albumin to its potential applications. This study focuses on freshwater fish known for their high albumin content, namely *Cyprinus carpio* Linnaeus, 1758, *Pangasius pangasius* Hamilton, 1822, *Channa striata* Bloch, 1793, and *Trichopodus trichopterus* Pallas, 1770. As identified by Nurfaidah et al. (2021), these species were selected based on their hight albumin content. The focus on albumin was chosen due to its bioavailability and specific roles in health, including its applications in nutraceutical and health products. Albumin has a complete amino acid profile, making it a high-quality protein source crucial for human nutrition. While analyzing the full amino acid profile of the entire edible portion may be useful for general food applications, the emphasis on albumin targets its potential for therapeutic and functional food products, particularly in supporting tissue regeneration and immune responses. This approach aligns with prior research demonstrating the benefits of fish albumin for health-related purposes. In this study, amino acid screening was conducted to determine the albumin profile in these freshwater fish species. This analysis is crucial to understanding the role of albumin in the body, including its potential in developing health products focused on utilizing fish albumin as a key raw material (Nurfaidah et al. 2024; Pratama et al. 2017).

This research builds on existing studies of amino acid composition in fish albumin, offering further insights into the analysis of freshwater fish species in Indonesia, an area that has received limited attention. By focusing on local species such as *C. carpio*, *P. pangasius*, *C. striata*, and *T. trichopterus,* this study contributes valuable data to the growing body of research in this field. The diversity of these species provides new insights into the variations in albumin quality and amino acid composition, which may influence the functional properties and nutritional value of the protein (Pichl 1976). In the context of food and health industry development, a deep understanding of the amino acid composition of fish albumin can open new opportunities. For example, albumin with a complete amino acid profile can be used in formulating nutritional supplements or pharmaceutical products designed to support overall health, particularly in enhancing the immune system and improving nutritional status. Furthermore, this research may contribute to increasing the added value of freshwater fish products, which can be economically beneficial for both the fisheries sector and public health.

Thus, this research has broad implications, not only in understanding the quality of protein in fish albumin but also in supporting the development of health products based on natural ingredients sourced from Indonesia's abundant freshwater fish resources. The potential of these findings lies in their ability to drive innovations in affordable nutraceuticals and functional foods, utilizing local ingredients to improve community welfare. By tapping into these natural resources, this research could contribute to enhancing public health and fostering economic opportunities in the region.

MATERIALS AND METHODS

Collection and preparation of samples

This study examined four freshwater fish species: *Cyprinus carpio*, *Pangasius pangasius*, *Channa striata*, and *Trichopodus trichopterus* were selected based on their availability in Makassar and their relevance to local dietary patterns. These species are commonly consumed and represent a variety of protein sources important to the region's diet. Furthermore, previous studies have identified these species as having among the highest albumin content (Nurfaidah et al. 2021; Prastari et al. 2017; Romadhoni et al. 2016; Susilowati et al. 2015), making them particularly suitable for this research focused on protein and albumin analysis. The fish samples analyzed were live specimens obtained from wet markets around Makassar, specifically from cultivated stocks rather than wild populations, which are generally caught from the waters of Pangkep District and Lake Tempe. The collected fish ranged in size from 340 to 824 g for *C. carpio*, 116 to 162 g for *T. trichopterus*, 276 to 497 g for *P. pangasius*, and 243 to 640 g for *C. striata*. The variation in size occurred because the sampling was based on a total sample weight of approximately 3 kg per species, which was then divided into three equal replicates. To account for the variation in fish size and weight, these differences were carefully considered during the sampling process to ensure that the results remained representative. While there was some variation in weight, these differences reflect the natural biological diversity within each species. The fish samples were pooled based solely on species, meaning that all individuals of a given species were combined for analysis without regard to size or weight. Therefore, the number of individual fish used in each sample was determined by their total combined weight rather than a fixed number of specimens.

This study did not require formal ethical approval for animal research, as the fish samples were obtained from wet markets where they were already designated for human consumption. However, all procedures involving live fish, such as transportation and euthanasia, were conducted following widely accepted humane practices to minimize stress and suffering. All fish were transported alive to the laboratory, where they were immediately euthanized using thermal shock at 10°C in a bucket containing water and crushed ice. The fish samples were then scaled, gutted, deboned, and filleted, followed by thorough washing with clean running tap water and left to drain. The meat was then minced, pre-homogenized in a commercial blender, placed in High-Density Polyethylene (HDPE) zip-lock bags, and stored at -20°C until further analysis. This method ensured that the fish was sourced ethically from cultivated environments and reflected typical market conditions rather than wild populations, addressing concerns about environmental sustainability and validity in sample sourcing.

Albumin extraction

After thawing the pre-homogenized fish meat at room temperature, 50 g of the meat was precisely weighed using a calibrated analytical balance and transferred into a 250 mL glass beaker. The meat was then diluted with distilled water at a 1:4 ratio (50 g of fish meat to 200 mL of water) and stirred manually to ensure even distribution. The mixture was homogenized for 1 minute using a laboratory homogenizer until it became uniform. The homogenized sample was incubated at 50°C for 1 hour in a continuously shaking water bath to maximize albumin extraction. After incubation, the sample was filtered under reduced pressure to separate the filtrate from the solid residues, and the volume of the filtrate was measured. The filtrate was transferred to a dark glass bottle to protect it from light and degradation and stored at -20°C until further analysis.

Amino acid analysis

Amino acid analysis was performed according to the AOAC (2023) method using High-Performance Liquid Chromatography (HPLC) with a C18 column (reverse phase) with dimensions of 4.6×150 mm. The mobile phase consisted of a mixture of water and the organic solvent methanol, with Trifluoroacetic Acid (TFA) added to enhance separation efficiency. The gradient elution profile included an initial phase of 95% water and 5% methanol, gradually shifting to 30% water and 70% methanol over 30 minutes. The injection volume was 5 µL, and the mobile phase flow rate was set at 0.5 mL/min. Detection was carried out using a UV-Vis detector at a wavelength of 280 nm. To ensure accuracy and precision, the HPLC system was calibrated with an albumin standard, and amino acid standard solutions were used to validate both separation and detection. A calibration curve was constructed using varying concentrations of amino acid standards, and multiple analyses were performed to confirm the consistency and reliability of the results.

Data analysis

To ensure the quality and validity of the albumin analysis results obtained using HPLC, strict quality control measures were implemented. HPLC data were analyzed using Chromeleon statistical software to verify results and determine the concentration of each amino acid. These results were then compared with the standard amino acid profile to asses determine the albumin composition of each fish species studied. Data were presented in tabular form and described both qualitatively and quantitatively. To determine if there were significant differences among the amino acid profiles of the different fish species, the data were analyzed using ANOVA with SPSS 25. This statistical test was used to identify any significant variations in amino acid content between the species. Before performing the Analysis of Variance (ANOVA), the data were tested for normality using the Shapiro-Wilk test. This test was selected due to its robustness in determining normality, particularly for small sample sizes. The null hypothesis for the Shapiro-Wilk test is that the data follow a normal distribution. A p-value greater than 0.05 indicates that the null hypothesis cannot be rejected, confirming the data's normality.

RESULTS AND DISCUSSION

Before applying the ANOVA, the normality of the amino acid content data was assessed using the Shapiro-Wilk test. The Shapiro-Wilk test evaluates whether a dataset is normally distributed, with a p-value greater than 0.05 indicating that the data does not significantly deviate from a normal distribution. The results of the test for each amino acid are presented in Table 1.

The table presents the results of the Shapiro-Wilk test for normality, which was applied to the amino acid content data. The W statistic and corresponding p-value are shown for each amino acid. A p-value greater than 0.05 indicates that the data is normally distributed, allowing for the use of parametric tests such as ANOVA. From the results, all p-values are above the 0.05 threshold, confirming that the amino acid content data for each species follows a normal distribution. Given that the normality assumption is satisfied, we can proceed to analyze the amino acid composition, which is critical for determining the quality of protein in a food source. Proteins that contain a complete set of amino acids in the appropriate quantities needed by the body are considered high-quality proteins (Cherry et al. 2019). The amino acid composition of *C. carpio*, *P. pangasius*, *C. striata*, and *T. trichopterus* is presented in Table 2.

The amino acid analysis of albumin extracts from *P. pangasius*, *C. striata*, *C. carpio*, and *T. trichopterus* the presence of 18 amino acids, comprising 9 non-essential amino acids and 9 essential amino acids. The total Non-Essential Amino Acids (∑NEAA) in the albumin were 58.47% for *P. pangasius*, 55.80% for *C. striata*, 58.73% for *C. carpio*, and 58.65% for *T. trichopterus*. Among these, glutamic acid, aspartic acid, and arginine were the most abundant. The total Essential Amino Acids (∑EAA) were 41.51% for *P. pangasius*, 44.20% for *C. striata*, 41.26% for *C. carpio*, and 41.35% for *T. trichopterus*.

Table 1. Results of the shapiro-wilk normality test for amino acid content

Amino acid	W statistic	p-value
Proline	0.976	0.340
Glycine	0.989	0.721
Alanine	0.983	0.587
Glutamic acid	0.978	0.406
Histidine	0.975	0.328
Serine	0.984	0.602
Threonine	0.980	0.452
Arginine	0.977	0.371
Aspartic acid	0.986	0.653
Valine	0.988	0.691
Phenylalanine	0.982	0.562
Methionine	0.975	0.323
Tyrosine	0.987	0.671
Cysteine	0.976	0.342
Tryptophan	0.989	0.719
Leucine	0.983	0.575
Kysine	0.987	0.658
Isoleucine	0.981	0.051

Table 2. Amino acid composition of freshwater fish albumin

Amino acid	Content (% of total amino acids)*			
	Pangasius pangasius	*Channa striata*	*Cyprinus carpio*	*Trichopodus trichopterus*
Non-essential amino acids				
Proline	2.94±0.2[a]	2.29±0.1[b]	2.52±0.1[ab]	2.68±0.7[ab]
Glycine	7.36±0.1[b]	8.46±0.0[a]	7.04±0.2[c]	7.71±0.0[ab]
Alanine	7.50±0.6[c]	9.09±0.0[a]	8.24±0.2[b]	9.04±1.0[ab]
Glutamic acid	14.70±0.0[c]	14.97±0.1[c]	24.55±0.2[a]	19.08±0.7[b]
Serine	3.58±0.2[ab]	3.58±0.7[ab]	2.29±0.4[b]	3.40±0.9[ab]
Arginine	10.05±0.9[a]	3.88±0.6[c]	3.88±1.0[c]	4.62±0.5[b]
Tyrosine	0.70±0.3[b]	1.20±0.2[a]	0.58±1.3[b]	1.38±0.6[a]
Cysteine	0.44±0.5[c]	0.82±0.0[b]	2.04±0.7[a]	1.40±0.2[b]
Aspartic acid	11.20±0.1[ab]	11.89±0.6[a]	10.05±0.6[b]	9.33±0.2[c]
Total non-essential amino acids (∑NEAA) as a percentage of the total amino acids (% of total amino acids).	58.47	55.80	58.73	58.65
Essential amino acids				
Valine	4.84±0.9[a]	4.80±0.2[a]	4.84±0.5[a]	4.56±0.0[a]
Phenylalanine	2.45±0.0[d]	5.77±0.2[a]	3.32±0.3[c]	5.17±0.2[b]
Methionine	0.04±0.0[d]	1.86±0.4[b]	2.54±0.0[a]	1.86±0.6[b]
Histidine	4.26±0.4[a]	2.86±0.3[b]	2.13±0.0[c]	1.96±0.4[c]
Threonine	3.73±0.0[a]	4.01±0.1[a]	2.78±0.1[b]	3.07±0.3[b]
Tryptophan	0.40±0.1[a]	0.45±0.0[a]	0.45±0.4[a]	0.54±0.1[a]
Leucine	9.16±0.7[ab]	8.90±0.1[b]	9.16±1.0[ab]	9.49±0.0[a]
Lysine	12.01±0.1[a]	10.97±0.7[b]	10.97±0.3[b]	10.02±0.7[c]
Isoleucine	4.61±0.2[a]	4.58±0.2[a]	4.58±0.2[a]	4.68±0.4[a]
Total essential amino acids (∑EAA) as a percentage of the total amino acids (% of total amino acids).	41.51	44.20	41.26	41.35
Total Amino Acids (∑AA) as a percentage of the total amino acids (% of total amino acids)	99.98	100.00	99.99	100.00

Note: *Values are reported as mean ± standard deviation of three replicates. The letters indicate that values sharing the same letter are not significantly different, while values with different letters are significantly different

The amino acids with the highest concentrations in the albumin of each fish species were glutamic acid, aspartic acid, leucine, and lysine. These amino acids are key components of albumin, with lysine being particularly important due to its role in accelerating wound healing. Additionally, the primary components of albumin protein are glutamic acid, aspartic acid, and leucine (Mariotti 2017; Szekeres and Kneipp 2018). Suprayitno (2003) also reported that the highest amino acid content in *C. striata* fish albumin was glutamic acid, leucine, and aspartic acid. The findings of this study are consistent with Prastari et al. (2017), who reported that the highest amino acids in *C. striata* fish were glutamic acid, aspartic acid, lysine, and leucine.

Non-essential amino acids

The highest non-essential amino acid observed in each fish species was glutamic acid, which comprised 24.55% of the total amino acids in *C. carpio*, 19% in *T. trichopterus*, 14.97% in *C. striata*, and 14.70% in *P. pangasius*. Glutamic acid plays a role in enhancing brain function, particularly memory and intelligence. It also aids in the rapid formation of new tissues in the body, making it beneficial for wound healing (Thangavel et al. 2017). The fish analyzed in this study inhabit environments like swamps, rice fields, and other areas with low dissolved oxygen and dense vegetation. As a result, these fish have high glutamic acid content to support their active lifestyle and mobility, particularly *C. striata* and *P. pangasius*, which are predatory species. Glutamic acid contributes to increasing muscle mass (Cruzat et al. 2018). High-mobility fish such as *C. carpio*, *T. trichopterus*, *P. pangasius*, and *C. striata* require substantial muscle mass, leading to the synthesis of more glutamic acid. The deamination reaction between glutamine and asparagine in fish meat produces glutamic acid (Gauthankar et al. 2021), which accounts for the high glutamic acid content in these fish. The lowest non-essential amino acids observed were proline, which accounted for 2.29 and 2.94% of the total amino acids in *C. striata* and *P. pangasius*, respectively, and cysteine, which represented 0.82% in *C. striata* and 0.44% in *P. pangasius*. The lowest essential amino acid was tryptophan, constituting 0.45% of the total amino acids in *C. carpio*, 0.54% in *T. trichopterus*, and 0.45% in *C. striata*, while methionine was the lowest in *P. pangasius* at 0.04%. The lowest essential amino acid was tryptophan in *C. carpio* (0.45%), *T. trichopterus* (0.54%), and *C. striata* (0.45%), while methionine was the lowest in *P. pangasius* (0.04%).

Essential amino acids

The highest essential amino acid observed in each fish species was lysine, found to represent 10.97% of the total amino acids in *C. carpio*, 10.02% in *T. trichopterus*, 10.97% in *C. striata*, and 12.01% in *P. pangasius*. Lysine plays a crucial role in growth, blood circulation, and antibody formation (Warisan and Yulisman 2019). According to Sundari et al. (2013), lysine is also important for collagen formation in the body and can reduce blood triglyceride levels. The high lysine content in the observed fish is attributed to their diet. Lysine is typically limited in protein synthesis from plant-based protein sources. In fish, lysine is essential for protein synthesis, which is vital for growth and improving the balance of other amino acids (Alissianto et al. 2018). Lysine is also necessary for tissue repair in fish (Mohanty et al. 2014) and collagen formation, which is essential for skin and bone health (Wu et al. 2021). The high lysine content in fish albumin contributes to its reputation for promoting wound healing (Gardner et al. 2019; Mariotti 2017). Lysine is a determining factor in the high-quality protein content of fish albumin compared to plant and other animal proteins, considering that many food products lack this amino acid (BPOM 2019). Amino acids in protein often react with other compounds during food processing, such as with reducing sugars in the Maillard reaction (Hosen et al. 2021). Lysine is one of the most reactive amino acids due to its free amino group, the epsilon-amino group, which can bind to other compounds (Tan et al. 2006). The reaction between lysine and other compounds can render lysine indigestible, unabsorbable, and unusable by the body (Mehta and Deeth 2016). Since lysine is an essential amino acid and often a limiting amino acid in plant-based proteins, particularly cereals, its unavailability affects the protein quality of a food source.

One of the most significant and essential amino acids found in each fish species is arginine. Arginine is classified as a semi-essential or conditionally essential amino acid, depending on the growth stage and health status of the individual (Tapiero et al. 2002). Newborn infants cannot synthesize arginine, making it an essential amino acid for them (Wu et al. 2004). Arginine is crucial for cell division, wound healing, ammonia removal from the body, immunity, and hormone release (Frezza and Mauro 2015). This amino acid is a precursor for Nitric Oxide (NO) synthesis, making it important for blood pressure regulation. Nitric oxide causes blood vessels to dilate, improving blood flow. Arginine is also known for stimulating growth hormone release.

Diet also influences the amino acid content in fish. Species, age, gender, genetics, and harvesting season also play roles (Susilowati et al. 2015). The availability and type of food in a fish's habitat significantly affect carnivorous species (Suprayitno 2014). The better the nutritional content of the fish's diet, the better the nutrition formed in the fish's body. Conversely, fish from habitats with limited food availability and poor nutritional content will have poor nutritional content. Farmed fish generally have better nutritional content than wild fish because farmed fish diets are supplemented with nutrients essential for growth (Novia et al. 2014). Diets with limited amino acid content can lead to growth disorders in fish (Hua et al. 2019), causing other amino acids to be broken down for energy or converted into other compounds.

Amino acid profile of albumin in *Pangasius pangasius*

Pangasius pangasius, a popular freshwater fish in Indonesia, displays a diverse albumin amino acid profile. The albumin in *P. pangasius* contains non-essential amino acids in varying amounts, with glutamic acid comprising the largest portion at 14.70% of the total amino acids. Glutamic acid plays a crucial role in metabolism (Walker and van der Donk 2016) and contributes a distinctive umami flavor (Yamamoto and Inui-Yamamoto 2023). It also has anti-cancer properties (Moldovan et al. 2023). Other significant amino acids in *P. pangasius* include alanine at 7.50%, which is involved in glucose metabolism and energy production (Li et al. 2024), and arginine at 10.05%, known for its benefits in immune function and wound healing (Martí I Líndez and Reith 2021).

Proline, glycine, and aspartic acid are also present in significant amounts, with respective concentrations of 2.94, 7.36, and 11.20%. Proline is important for protein structure (Wu et al. 2011), while glycine functions as an inhibitory neurotransmitter and supports collagen synthesis (Salceda 2022). Aspartic acid, essential for energy production (Holeček 2023), highlights *P. pangasius*'s potential as a protein source that supports metabolism. On the other hand, *P. pangasius* also contains histidine and serine, which contribute to tissue repair and general health (Brosnan and Brosnan 2020; Holeček 2022), although they are present in lower amounts compared to other amino acids.

Regarding essential amino acids, *P. pangasius* excels in lysine content at 12.01%, vital for protein, enzyme, and hormone synthesis in the human body. Leucine and valine are also present in significant amounts, with concentrations of 9.16 and 4.84%, respectively. Leucine plays a key role in muscle protein synthesis and blood sugar regulation (Castro et al. 2016), while valine supports muscle metabolism and tissue repair (Mann et al. 2021). Although methionine and cysteine are present in lower amounts (0.04 and 0.44%, respectively), they remain essential for metabolic functions like protein synthesis and glutathione antioxidant formation (Elango 2020).

The use of albumin from *P. pangasius* plays a crucial role in nutrition and health, particularly in integrating proteins and amino acids into the human diet. Due to its rich content of essential amino acids, *P. pangasius* can serve as an excellent protein source for health foods and dietary supplements. These amino acids are vital for protein synthesis, energy metabolism, and other key physiological processes. Previous studies highlight *P. pangasius* as a significant high-quality protein source, including albumin, which supports muscle repair and growth in humans (Nguyen et al. 2022; Chakma et al. 2022). For instance, Anugrahati et al. (2012) used *P. pangasius* in producing high-protein biscuits. Additionally, consuming albumin-rich foods like *P. pangasius* can boost immune function and may improve infection resistance (Mohanty et al. 2014). *Pangasius pangasius* offers high-quality protein with a well-balanced amino acid profile, contributing to human health, while omega-3 fatty acids in wild pangasius provide cardiovascular and cognitive benefits (Chakma et al. 2022).

Amino acid profile of albumin in *Channa striata*

Channa striata is widely recognized for its high nutritional value, especially its albumin content, which is often used for traditional medicinal purposes (Mat 2007; Sahid et al. 2018). The amino acid profile of *C. striata* albumin reveals a unique composition, with glutamic acid dominating at 14.97%. This indicates that *C. striata* can also provide a strong umami flavor and support cognitive function through glutamic acid's role in nerve signal transmission (Zhou and Danbolt 2014). Alanine, at 9.09%, is one of the major amino acids, highlighting the potential of *C. striata* in supporting energy metabolism through the glucose-alanine cycle (Petersen et al. 2019).

Glycine content in *C. striata* reaches 8.46%, which is important not only for collagen synthesis but also for functioning as a neurotransmitter that inhibits excessive activity in the central nervous system (Marques et al. 2020), providing a calming effect that can benefit mental health (Soh et al. 2024). Aspartic acid is also significant in *C. striata*, with a concentration of 10.30% which helps maintain the energy levels in the body.

The essential amino acid profile in *C. striata* is led by lysine at 10.97%, similar to *C. carpio*. Lysine is vital for tissue growth and repair, particularly in the context of muscle and bone health (Matthews 2020). Additionally, leucine and valine, with concentrations of 8.70 and 5.15%, respectively, support muscle protein synthesis and energy production during exercise (Akram et al. 2020). The methionine content, though low at 0.38%, is still crucial as it supports antioxidant production and is involved in methylation processes that affect DNA and protein function (Ji et al. 2019).

Channa striata albumin's distinctive amino acid profile, which includes a well-balanced mix of non-essential and essential amino acids, makes it ideal for use in functional foods and dietary supplements designed to support muscle health, wound healing, and overall nutrition. Its high levels of glutamic acid and lysine enhance its effectiveness in promoting physical recovery, positioning *C. striata* as a valuable nutritional resource for individuals recovering from illness or surgery. Numerous studies have highlighted the benefits of *C. striata* albumin. One such study demonstrated that a gel formulated with 6% *C. striata* albumin significantly promoted wound healing in rats, resulting in an 80% closure rate by the seventh day (Puspitasari and Suprayitno 2020). Additionally, the high protein content and amino acid profile of *C. striata* albumin play a vital role in tissue regeneration, making it an economical substitute for human serum albumin (Mardiyah et al. 2022). Another study found that in patients suffering from hypoalbuminemia, the administration of *C. striata* extract led to a significant increase in albumin levels from 2.95 to 3.17 g/dL, thereby enhancing overall protein intake (Fauzan et al. 2020).

Amino acid profile of albumin in *Cyprinus carpio*

Cyprinus carpio, one of the freshwater fish widely cultivated in Indonesia, shows an intriguing amino acid profile in its albumin. One of the most prominent aspects is the high glutamic acid content, which reaches 24.55%, significantly higher than that in *P. pangasius* and *C. striata*. This indicates that *C. carpio* has exceptional potential in providing a rich umami flavor, which can be a valuable addition in developing fish-based food products. The high glutamic acid content also plays a role in brain function and mental health (Umeda et al. 2022), making *C. carpio* a highly useful source of albumin for supporting cognition and brain health.

Alanine in *C. carpio* is also relatively high, at 8.24%, reflecting the potential of this fish in supporting energy metabolism and overall health. Proline and glycine, with levels of 2.52 and 7.04% respectively, are important for protein structure and function, as well as collagen synthesis, which supports skin and connective tissue health (de Paz-Lugo et al. 2018; de Paz-Lugo et al. 2023). The aspartic acid level in *C. carpio* reaches 10.05%, indicating that this fish can contribute to energy production and the metabolism of other amino acids, which is crucial for optimal body function.

In terms of essential amino acids, *C. carpio* stands out with the highest methionine content among the four analyzed fish, at 2.54%. Methionine is an essential amino acid critical for protein synthesis and methionine metabolism, playing a role in detoxification (Yang et al. 2020) and DNA and RNA formation (Bauerle et al. 2015). Leucine and lysine are present at 9.16 and 10.97% respectively. Cysteine in *C. carpio* is also relatively high, at 2.04%, supporting the formation of glutathione (Kimball and Jefferson 2006), an antioxidant that protects cells from oxidative damage.

With its rich amino acid profile, particularly the high content of glutamic acid, *C. carpio* albumin offers considerable potential for creating fish-based food products that emphasize umami flavor and health benefits. It serves as an excellent source of high-quality protein for daily diets. Applications include the development of protein supplements or functional food items which can support brain health and metabolic function. Nurfaidah et al. (2024) created a nutrient-dense complementary food by adding *C. carpio* meat flour and albumin, both of which are rich in essential amino acids and fatty acids needed for growth and development. This supports previous findings by Elmadfa et al. (2017), which emphasized that *C. carpio* meat is a valuable protein source vital for tissue growth and repair due to its enhanced amino acid profile compared to other protein sources. The nutritional richness of *C. carpio* also makes it suitable for health supplements and traditional medicines. Moreover, extracts from *C. carpio*, such as collagen, are used in cosmetics and skincare products for their benefits in improving skin health and providing anti-aging effects (Xu et al. 2021).

Amino acid profile of albumin in *Trichopodus trichopterus*

Trichopodus trichopterus, though less popular compared to other freshwater fish, shows a significant amino acid profile. Glutamic acid in *T. trichopterus* reaches 19.08%. The alanine content in this fish is also relatively high, at 9.04%, indicating the potential of *T. trichopterus* in supporting energy metabolism and overall health. Glycine in *T. trichopterus* reaches 7.71%. Histidine in *T. trichopterus* is the lowest among the four fish, at 1.96%, but still plays an important role in growth and tissue repair. Serine and threonine are present at relatively uniform levels compared to other fish, with serine at 3.40% and threonine at 3.07%. The aspartic acid level reaching 9.33% indicates that *T. trichopterus* also holds potential for supporting energy production and amino acid metabolism.

In terms of essential amino acids, the *T. trichopterus* stands out with the highest leucine content among fish species, at 9.49%. This makes it an excellent source for promoting muscle protein synthesis and regulating blood sugar. The lysine content in this fish is 10.02%, vital for protein, enzyme, and hormone synthesis (Xiao et al. 2023) and plays a key role in supporting immune function. Phenylalanine and methionine levels are at 5.17 and 1.86%, respectively, important for neurotransmitter production and hormone regulation. The tryptophan content, at 0.54%, is slightly higher than in other fish, which is significant as tryptophan is a precursor to serotonin, a neurotransmitter that helps regulate mood, sleep, and behavior. This makes *T. trichopterus* albumin valuable for mental health and sleep support (Lindseth et al. 2015; Correia and Vale 2022; Davidson et al. 2022). Additionally, its cysteine content is 1.40%.

These amino acid profiles suggest that *T. trichopterus* albumin has potential for use in nutrition and health, particularly in the development of functional foods and dietary supplements. For example, it can serve as a raw material for protein supplements for athletes or specialized foods aimed at improving mental health and sleep quality (Médale and Kaushik 2009; Mora and Hayes 2015), thanks to its tryptophan content's role in serotonin regulation. Moreover, this fish is also rich in vitamins and minerals that contribute to immune function and overall well-being.

In conclusion, this study presents the amino acid profile of albumin from freshwater fish species: *C. carpio*, *P. pangasius*, *C. striata*, and *T. trichopterus*. The results show that all species exhibit a rich composition of both essential and non-essential amino acids, with glutamic acid, aspartic acid, lysine, and leucine being the most abundant across all samples. Notably, *P. pangasius* and *C. striata* displayed the highest lysine content among the species studied, with values of 12.01 and 10.97%, respectively, which is significant for muscle repair and protein synthesis. *Cyprinus carpio* and *T. trichopterus* stood out with its high glutamic acid content (24.55 and 19.08%), which supports tissue regeneration and cognitive functions.

These findings confirm that albumin from these fish species is a valuable source of high-quality protein, suitable for use in nutraceuticals, functional foods, and dietary supplements aimed at supporting metabolic processes, muscle health, and wound healing. Additionally, the study highlights the sustainability of using these fish species as alternative protein sources, contributing to food security. Given the potential benefits of these proteins, further research should focus on optimizing extraction methods and investigating the practical applications of fish albumin in health-related products, particularly for populations with higher protein needs, such as athletes and the elderly.

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