

Original Research Articles

Analysis and evaluation of nutritional components in the muscles of three wild species of the genus *Schistura*

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Schistura vinciguerrae, *Schistura polytaenia* and *Schistura albirostris* are important indigenous fish species in the Tengchong region of Yunnan Province and play a significant role in maintaining indigenous fish diversity. Moreover, their unique flavors are favored by the local people. However, no studies on any aspect of these three *Schistura* species have been reported to date. To explore the nutritional components of the muscles of these three wild *Schisturas* and evaluate their nutritional quality, the conventional nutritional components, amino acids, fatty acids, and mineral elements in the muscles of these three *Schistura* species were analyzed. The results showed that the contents of crude protein, crude fat, and ash in the muscles of the three *Schisturas* were 17.47% - 17.73%, 6.67% - 7.23%, and 3.60% - 3.73%, respectively. A total of 17 amino acids were detected in the muscles of these three *Schisturas*, resulting in the same composition. Among them, there were 8 essential amino acids, 9 non-essential amino acids and 4 delicious amino acids. The amino acid with the highest content in the muscles of the three *Schisturas* was glutamic acid. According to the amino acid score and chemical score, the first limiting amino acid in their muscles was methionine, and the second limiting amino acid was tryptophan. A total of 27 fatty acids were detected in the muscles of the three *Schisturas*, with the same composition. Among them, there were 12 saturated fatty acids, 6 monounsaturated fatty acids and 9 polyunsaturated fatty acids. The sum of EPA and DHA contents was (6.05±0.06%, (5.27±0.07%, (10.37±0.06%, respectively. The muscles of the three *Schisturas* were rich in mineral elements such as Ca, Mg, Na, P, K, Zn, Fe, Mn, Cu and Se, and had a balanced structure. The research shows that the three *Schisturas* had high protein and fat content, a complete amino acid profile, excellent fatty acid composition, and a rich mineral profile. This study provided a theoretical reference for the nutritional research and development and utilization of *S. vinciguerrae*, *S. polytaenia* and *S. albirostris*.

1. INTRODUCTION

Fish constitutes a vital source of high-quality animal protein for human consumption, and its nutritional value is fundamentally determined by the composition and quality of nutritional components in the muscle, the chemical composition of fish flesh is regarded as a reliable predictor of the fish's quality and nutritional value.¹ In order to explore the nutritional value of fish, the analysis and evaluation of nutritional components in the muscle have been increasingly applied in the research of different species of fish.²⁻¹⁹ As global demand for aquatic products continues to rise, there is an increasing interest in exploring and

utilizing previously underexploited freshwater fish species, particularly those endemic to biodiversity-rich regions.

Tengchong is located in the western part of Baoshan City, Yunnan Province. Within its territory, three major rivers, the Longchuan River, Daying River, and Binglang River, flow from east to west, all belonging to the Irrawaddy River system. The region is rich in fishery germplasm resources. From April to November 2023, our research team conducted a survey of the current status of fish resources in this area.²⁰ The results revealed that, compared with historical records, the number of endemic indigenous fish species in the region has declined markedly. The stocks of *Schistura*, a key local economic species, have also plum-

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meted, while market prices have continued to soar. In recent years, the price of wild *Schistura* has skyrocketed to 400 yuan per kilogram.

Schistura, belonging to the family Nemacheilidae within the order Cypriniformes, it is a small fish species widely distributed in Southeast Asia, South Asia, West Asia and southern China.^{21,22} *Schistura vinciguerrae*, *Schistura polytaenia*, and *Schistura albirostris* are three species within this genus. *S. vinciguerrae* is distributed in the Longchuan River, Daying River, and the Irrawaddy and Salween River basins in Myanmar, while *S. polytaenia* and *S. albirostris* are mainly found in the Longchuan River basin.²² In the Tengchong area of Yunnan Province, these three species are collectively known as “Xiao Hua Yu”. Due to their small size, tender flesh, and delicious taste, they are highly favored by local people and possess good potential for development and utilization.

Currently, research on these three *Schistura* species is scarce both domestically and internationally, with no reports on the analysis of their muscle nutritional composition, significantly limiting the in-depth development and rational utilization of this resource. To fill this research gap, this study systematically determined, for the first time, the muscle nutritional components of *S. vinciguerrae*, *S. polytaenia*, and *S. albirostris*. Comprehensively analyzing and evaluating their nutritional value not only provides essential data for assessing the nutritional value of these three *Schistura* species but also serves as a critical foundation for guiding artificial propagation, feed formulation, and value-added processing.

2. MATERIALS AND METHODS

TEST MATERIALS

Ten specimens each of *S. vinciguerrae*, *S. polytaenia*, and *S. albirostris* were captured in April 2024 from the same waters of the Binlang River in Houqiao Town (25°33'29.46"N, 98°12'28.59"E→25°13'46.12"N, 98°11'17.07"E), Tengchong City. The body weight and length of *S. vinciguerrae* were (2.83±0.58 g and (6.17±0.56 cm; *S. polytaenia* were (4.07±0.85 g and (6.29±0.42 cm; *S. albirostris* were (1.69±0.20 g and (5.38±0.26 cm. All individuals were healthy, robust, and free from disease. Whole fish were frozen in liquid nitrogen and stored for later use. The sampling site is the white muscle on the back.

DETERMINATION OF MUSCLE NUTRITIONAL COMPONENTS

Moisture content was determined as per the “National Food Safety Standard Determination of Moisture in Foods” (GB 5009.3-2016) and “Determination of moisture in feedstuffs” (GB/T 6435-2014) (drying at 105°C to constant mass). Ash content was determined according to the “National Food Safety Standard Determination of Ash in Foods” (GB 5009.4-2016) and “Determination of crude ash in feedstuffs” (GB/T 6438-2007) (550°C ashing method).

Crude protein content was determined by the method of the “National Food Safety Standard Determination of Protein in Foods” (GB 5009.5-2016) and “Determination of crude protein in feedstuffs - Kjeldahl method” (GB/T 6432-2018) (Kjeldahl nitrogen determination).

Crude fat content was assayed by the acid hydrolysis method referenced in the “National Food Safety Standard Determination of Fat in Foods” (GB 5009.6-2016) (Acid hydrolysis method).

Hydrolyzed amino acids and tryptophan content were quantified using high-performance liquid chromatography (HPLC). For hydrolyzed amino acids, separation was performed on an amino acid analysis column (4.6 mm × 100 mm, 2.7 µm), with detection wavelengths set at 338 nm and 262 nm. The mobile phase consisted of (A) 10 mM Na₂HPO₄ and 10 mM Na₂B₄O₇ (pH 8.2, adjusted with HCl) and (B) a mixture of methanol (MeOH), acetonitrile (ACN), and water (H₂O) in a ratio of 45:45:10. Tryptophan analysis was conducted using a SHISEIDO C18 column (4.6 mm × 150 mm, 5 µm), with a mobile phase composed of (A) 0.1% formic acid in aqueous solution and (B) acetonitrile (ACN).

Fatty acid content was determined as per the “National Food Safety Standard Determination of Fatty Acids in Foods” (GB 5009.168-2016) (GC : Agilent 7890A , Column: HP-88,100 mm×0.25 mm×0.20µm)..

Mineral element content analysis: Elements K, Ca, Na, Mg, P were determined by reference to the OES test method in the “National Food Safety Standard Determination of Multi-elements in Foods” (GB 5009.268-2016) [ICP-OES, optima 8000, Perkin Elmer (USA)]. Elements Mn, Fe, Cu, Zn, Se were determined by reference to the MS test method in the “National Food Safety Standard Determination of Multi-elements in Foods” (GB 5009.268-2016) [ICP-MS, iCAPRQ, Thermo (USA)].

NUTRITIONAL VALUE EVALUATION

Nutritional value was evaluated according to the amino acid scoring standard pattern suggested by FAO/WHO (1973).² Amino acid score (AAS), chemical score (CS), and essential amino acid index (EAAI) were calculated using the following formulas:

$$\text{AAS} = [\text{Amino acid content in test protein (mg/g N)}] / [\text{Amino acid content in FAO scoring pattern (mg/g N)}]$$

$$\text{CS} = [\text{Amino acid content in test protein (mg/g N)}] / [\text{Same amino acid content in whole egg protein (mg/g N)}]$$

$$\text{EAAI} = \sqrt[n]{(100A/aE)(100B/bE)(100C/cE) \cdots (100H/hE)}$$

Where: n is the number of essential amino acids compared; A, B, C,...H are the essential amino acid contents of the fish muscle protein; aE, bE, cE,...hE are the essential amino acid contents of whole egg protein.

DATA ANALYSIS

Experimental data were processed using Excel. One-way analysis of variance (ANOVA) was performed using SPSS 27.0 software.

Table 1. Nutritional components in muscle of three *Schistura* species ($\bar{X} \pm s$, %)

Organisms	Crude fat	Crude protein	Crude ash	Moisture
<i>S. vinciguerrae</i>	7.23 $\pm$ 0.20 ^a	17.52 $\pm$ 0.16	3.71 $\pm$ 0.20	70.23 $\pm$ 0.55
<i>S. Polytaenia</i>	6.67 $\pm$ 0.21 ^b	17.74 $\pm$ 0.22	3.74 $\pm$ 0.16	70.63 $\pm$ 0.42
<i>S. albirostris</i>	6.76 $\pm$ 0.37 ^b	17.47 $\pm$ 0.12	3.62 $\pm$ 0.12	70.50 $\pm$ 0.46

Note: Values in the same column with different superscript letters indicate significant differences ($P < 0.05$), while those with the same letter or no letter indicate no significant difference ($P > 0.05$).

3. RESULTS

GENERAL NUTRITIONAL COMPONENTS

The general nutritional components of the muscles of the three *Schistura* species were mainly moisture, ash, protein, and fat (Table 1). The moisture content in *S. vinciguerrae* muscle ranged from 69.60%-70.60%, with an average of 70.23 $\pm$ 0.55%; crude protein content ranged from 17.33%-17.62%, average 17.50 $\pm$ 0.17%; crude fat content ranged from 7.00%-7.38%, average 7.23 $\pm$ 0.21%; ash content ranged from 3.50%-3.90%, average 3.70 $\pm$ 0.20%. For *S. polytaenia*, moisture ranged from 70.30%-71.10%, average 70.63 $\pm$ 0.42%; crude protein ranged from 17.49%-17.92%, average 17.73 $\pm$ 0.21%; crude fat ranged from 6.53%-6.92%, average 6.67 $\pm$ 0.21%; ash ranged from 3.60%-3.90%, average 3.73 $\pm$ 0.15%. For *S. albirostris*, moisture ranged from 70.10%-71.00%, average 70.50 $\pm$ 0.46%; crude protein ranged from 17.34%-17.60%, average 17.47 $\pm$ 0.15%; crude fat ranged from 6.34%-7.00%, average 6.73 $\pm$ 0.38%; ash ranged from 3.52%-3.75%, average 3.60 $\pm$ 0.10%.

AMINO ACID COMPOSITION AND NUTRITIONAL VALUE EVALUATION

AMINO ACID COMPOSITION

Seventeen amino acids were detected in the muscle of *S. vinciguerrae*, with a total amino acid (TAA) content of 15.82 $\pm$ 0.22%. This included all 8 essential amino acids (EAA) required by the human body, accounting for 6.35 $\pm$ 0.26%. Regarding amino acid composition, glutamic acid had the highest proportion at 2.39 $\pm$ 0.03%, followed by lysine, leucine, and aspartic acid. The ratios of EAA/TAA and EAA/NEAA (non-essential amino acids) were 40.14 and 67.12, respectively. The delicious amino acid (DAA) content was 5.83 $\pm$ 0.05%, with a DAA/TAA value of 36.85. The proportions of branched-chain amino acids (BCAA) and aromatic amino acids (AAA) were 3.08 $\pm$ 0.17% and 1.42 $\pm$ 0.07%, respectively, with a BCAA/AAA value of 216.90 (see Table 2).

Seventeen amino acids were detected in the muscle of *S. polytaenia*, with a TAA content of 15.52 $\pm$ 0.13%. This included all 8 essential amino acids, accounting for 6.04 $\pm$ 0.26%. Glutamic acid had the highest proportion at 2.44 $\pm$ 0.05%, followed by lysine, aspartic acid, and leucine. The EAA/TAA and EAA/NEAA values were 38.92 and 63.71, respectively. DAA content was 5.89 $\pm$ 0.08%, with a DAA/TAA value of 37.95. The proportions of BCAA and AAA were

2.88 $\pm$ 0.17% and 1.39 $\pm$ 0.03%, respectively, with a BCAA/AAA value of 207.19 (see Table 2).

Seventeen amino acids were detected in the muscle of *S. albirostris*, with a TAA content of 14.82 $\pm$ 0.06%. This included all 8 essential amino acids, accounting for 6.07 $\pm$ 0.08%. Glutamic acid had the highest proportion at 2.16 $\pm$ 0.06%, followed by leucine, lysine, and aspartic acid. The EAA/TAA and EAA/NEAA values were 40.96 and 69.37, respectively. DAA content was 5.30 $\pm$ 0.11%, with a DAA/TAA value of 35.76. The proportions of BCAA and AAA were 3.11 $\pm$ 0.07% and 1.33 $\pm$ 0.02%, respectively, with a BCAA/AAA value of 233.83 (see Table 2).

MUSCLE NUTRITIONAL VALUE EVALUATION

The essential amino acid composition and scores for the three *Schistura* species are shown in Table 3. AAS results showed that lysine had the highest AAS among the three species, with values of 1.56, 1.54, and 1.42, respectively. Except for methionine and tryptophan, the AAS for all other essential amino acids in the three species were greater than 0.9. CS results showed that lysine also had the highest CS among the three species, with values of 1.20, 1.18, and 1.10, respectively. Except for methionine and tryptophan, the CS for all other essential amino acids were greater than 0.7. Based on the AAS and CS results, methionine was the first limiting amino acid and tryptophan was the second limiting amino acid in the muscle protein of *S. vinciguerrae*, *S. polytaenia*, and *S. albirostris*. The essential amino acid indices (EAAI) for *S. vinciguerrae*, *S. polytaenia*, and *S. albirostris* were 68.09, 59.78, and 61.88, respectively.

FATTY ACID COMPOSITION

The relative contents of major fatty acids in the muscles of the three *Schistura* species are shown in Table 4. Twenty-seven fatty acids were detected in the muscles of all three species, including 12 saturated fatty acids (SFA), 6 monounsaturated fatty acids (MUFA), and 9 polyunsaturated fatty acids (PUFA). In *S. vinciguerrae* muscle, the proportions were: SFA 43.00 $\pm$ 0.06%; MUFA 40.81 $\pm$ 0.04%; PUFA 16.19 $\pm$ 0.07%; EPA+DHA 6.05 $\pm$ 0.06%; total essential fatty acids (Σ EFA) 4.74 $\pm$ 0.02%; total non-essential fatty acids (Σ NEFA) 95.26 $\pm$ 0.02%. In *S. polytaenia* muscle: SFA 38.41 $\pm$ 0.11%; MUFA 37.94 $\pm$ 0.10%; PUFA 23.65 $\pm$ 0.21%; EPA+DHA 5.27 $\pm$ 0.07%; Σ EFA 7.36 $\pm$ 0.03%; Σ NEFA 92.64 $\pm$ 0.03%. In *S. albirostris* muscle: SFA 43.44 $\pm$ 0.07%; MUFA 36.53 $\pm$ 0.16%; PUFA 20.03 $\pm$ 0.19%; EPA+DHA 10.37 $\pm$ 0.06%; Σ EFA 3.47 $\pm$ 0.01%; Σ NEFA 96.53 $\pm$ 0.01%.

Table 2. Content and composition of amino acids in muscle of three *Schistura* species ($\bar{X} \pm s$, %)

Amino acid	<i>S. vinciguerrae</i>	<i>S. Polytaenia</i>	<i>S. albirostris</i>
Asp(Aspartic acid)#	1.24 ± 0.05	1.35 ± 0.08	1.27 ± 0.07
Glu(Glutamic acid)#	2.39 ± 0.03 ^a	2.44 ± 0.05 ^a	2.16 ± 0.06 ^b
Ser(Serine)	0.65 ± 0.01 ^{ab}	0.66 ± 0.03 ^a	0.62 ± 0.01 ^b
Gly(Glycine)#	1.03 ± 0.02 ^a	0.96 ± 0.01 ^b	0.72 ± 0.02 ^c
His(Histidine)	0.40 ± 0.00 ^b	0.43 ± 0.01 ^a	0.41 ± 0.01 ^b
Arg(Arginine)	1.24 ± 0.02 ^a	1.21 ± 0.03 ^{ab}	1.17 ± 0.01 ^b
Thr(Threonine)*	0.69 ± 0.03	0.69 ± 0.04	0.66 ± 0.01
Ala(Alanine)#	1.17 ± 0.03	1.15 ± 0.03	1.16 ± 0.02
Pro(Proline)	0.82 ± 0.03 ^a	0.78 ± 0.02 ^{ab}	0.75 ± 0.02 ^b
Tyr(Tyrosine)	0.53 ± 0.04	0.51 ± 0.03	0.51 ± 0.02
Val(Valine)*	0.91 ± 0.07	0.85 ± 0.05	0.92 ± 0.05
Met(Methionine)*	0.21 ± 0.01 ^a	0.11 ± 0.01 ^b	0.12 ± 0.01 ^b
Ile(Isoleucine)*	0.78 ± 0.04	0.73 ± 0.05	0.81 ± 0.02
Leu(Leucine)*	1.39 ± 0.07	1.30 ± 0.08	1.38 ± 0.02
Phe(Phenylalanine)*	0.76 ± 0.03	0.76 ± 0.05	0.71 ± 0.01
Lys(Lysine)*	1.48 ± 0.06 ^a	1.48 ± 0.06 ^a	1.35 ± 0.02 ^b
Trp(Tryptophan)*	0.13 ± 0.00 ^a	0.12 ± 0.00 ^b	0.12 ± 0.01 ^b
TAA(Total Amino Acid)	15.82 ± 0.22 ^a	15.52 ± 0.13 ^b	14.82 ± 0.06 ^c
EAA(Essential Amino Acid)	6.35 ± 0.26	6.04 ± 0.26	6.07 ± 0.08
NEAA(Non-Essential Amino Acid)	9.46 ± 0.05 ^a	9.48 ± 0.14 ^a	8.75 ± 0.12 ^b
DAA(Delicious Amino Acid)	5.83 ± 0.05 ^a	5.89 ± 0.08 ^a	5.30 ± 0.11 ^b
BCAA(Branched-Chain Amino Acid)	3.08 ± 0.17	2.88 ± 0.17	3.11 ± 0.07
AAA(Aromatic Amino Acids)	1.42 ± 0.07	1.39 ± 0.03	1.33 ± 0.02
DAA/TAA	36.85	37.95	35.76
BCAA/AAA	216.90	207.19	233.83
EAA/TAA	40.14	38.92	40.96
EAA/NEAA	67.12	63.71	69.37

Note: *means essential amino acids; #means delicious amino acids; Values in the same row with different superscript letters indicate significant differences ($P < 0.05$), while those with the same letter or no letter indicate no significant difference ($P > 0.05$); the same applies to Tables 4 and 5.

Table 3. Composition and scores of essential amino acids in the muscle of three *Schistura* species (mg/g N)

EAA	FAO/WHO	Egg	<i>S. vinciguerrae</i>			<i>S. Polytaenia</i>			<i>S. albirostris</i>		
			Content	AAS	CS	Content	AAS	CS	Content	AAS	CS
Thr	2.50	2.92	2.46	0.98	0.84	2.43	0.97	0.83	2.36	0.94	0.81
Val	3.10	4.10	3.25	1.05	0.79	3.00	0.97	0.73	3.29	1.06	0.80
Ile	2.50	3.31	2.79	1.12	0.84	2.57	1.03	0.78	2.90	1.16	0.88
Leu	4.40	5.34	4.96	1.13	0.93	4.58	1.04	0.86	4.94	1.12	0.93
Lys	3.40	4.41	5.29	1.56	1.20	5.22	1.54	1.18	4.83	1.42	1.10
Met+Cys	2.20	3.86	0.75	0.34	0.19	0.39	0.18	0.10	0.43	0.20	0.11
Phe+Tyr	3.80	5.65	4.61	1.21	0.82	4.48	1.18	0.79	4.36	1.15	0.77
Trp	0.60	0.99	0.46	0.77	0.46	0.42	0.70	0.42	0.43	0.72	0.43
EAA(Essential Amino Acid Indices)			68.09			59.78			61.88		

MACRO AND TRACE ELEMENTS

The contents of macro and trace elements in the muscles of the three *Schistura* species are shown in Table 5. The results indicated that the muscles of all three species were rich in minerals and trace elements. For *S. vinciguerrae*, the most

abundant macro element was Ca, at $9.47 \times 10^3 \pm 0.04$ mg/Kg; the most abundant trace element was Zn, at 63.99 ± 0.37 mg/Kg. For *S. polytaenia*, the most abundant macro element was Ca, at $7.53 \times 10^3 \pm 0.05$ mg/Kg; the most abundant trace element was Fe, at 29.46 ± 0.12 mg/Kg. For *S. albirostris*, the most abundant macro element was Ca, at $6.85 \times 10^3 \pm 0.02$

Table 4. Primary fatty acids relative content in the muscle of three *Schistura* species ($\bar{X} \pm s$, %)

Fatty acid	<i>S. vinciguerrae</i>	<i>S. polytaenia</i>	<i>S. albirostris</i>
C12:0	0.40±0.01 ^a	0.25±0.01 ^c	0.32±0.00 ^b
C13:0	0.06±0.01 ^a	0.03±0.00 ^b	0.05±0.01 ^a
C14:0	3.44±0.01 ^a	1.92±0.02 ^c	2.61±0.02 ^b
C15:0	0.48±0.00 ^b	0.48±0.00 ^b	0.56±0.01 ^a
C16:0	25.36±0.02 ^b	24.13±0.14 ^c	26.56±0.12 ^a
C17:0	1.03±0.03 ^b	1.20±0.03 ^a	1.07±0.00 ^b
C18:0	10.96±0.02 ^b	9.46±0.02 ^c	11.38±0.02 ^a
C20:0	0.64±0.01 ^a	0.45±0.00 ^b	0.35±0.01 ^c
C21:0	0.07±0.01	0.04±0.03	0.06±0.04 ³
C22:0	0.26±0.01 ^a	0.20±0.01 ^b	0.26±0.02 ^a
C23:0	0.07±0.01	0.06±0.02	0.04±0.03
C24:0	0.23±0.00	0.20±0.03	0.17±0.03
ΣSFA (Saturated Fatty Acids)	43.00±0.06 ^b	38.41±0.11 ^c	43.44±0.07 ^a
C14:1	0.07±0.00 ^a	0.05±0.00 ^b	0.08±0.00 ^a
C16:1	15.13±0.02 ^a	8.89±0.16 ^c	13.53±0.12 ^b
C18:1n9c	24.25±0.05 ^b	27.73±0.05 ^a	21.71±0.08 ^c
C20:1	1.12±0.00 ^a	1.06±0.04 ^b	0.99±0.01 ^c
C22:1n9	0.03±0.01	0.06±0.03	0.04±0.02
C24:1	0.20±0.00 ^a	0.14±0.01 ^c	0.18±0.01 ^b
ΣMUFA (Monounsaturated Fatty Acids)	40.81±0.04 ^a	37.94±0.10 ^b	36.53±0.16 ^c
C18:2n6c	4.38±0.01 ^b	6.92±0.01 ^a	3.26±0.01 ^c
C18:3n3	3.40±0.01 ^c	7.52±0.01 ^a	3.81±0.08 ^b
C18:3n6	0.36±0.02 ^b	0.44±0.03 ^a	0.22±0.01 ^c
C20:2	0.38±0.04 ^b	0.78±0.09 ^a	0.22±0.04 ^c
C20:3n3	0.33±0.00 ^c	0.77±0.02 ^a	0.69±0.01 ^b
C20:3n6	0.24±0.00 ^b	0.35±0.02 ^a	0.26±0.01 ^b
C20:4n6	1.04±0.01 ^c	1.61±0.03 ^a	1.20±0.02 ^b
C20:5n3 (EPA)	3.45±0.02 ^b	2.00±0.09 ^c	5.30±0.09 ^a
C22:6n3 (DHA)	2.60±0.07 ^c	3.27±0.02 ^b	5.07±0.03 ^a
ΣPUFA (Polyunsaturated Fatty Acids)	16.19±0.07 ^c	23.65±0.21 ^a	20.04±0.19 ^b
EPA + DHA	6.05±0.06 ^b	5.27±0.07 ^c	10.37±0.06 ^a
ΣEFA (Essential Fatty Acids)	4.74±0.02 ^b	7.36±0.03 ^a	3.47±0.01 ^c
ΣNEFA (Non-Essential Fatty Acids)	95.26±0.02 ^b	92.64±0.03 ^c	96.52±0.01 ^a

mg/Kg; the most abundant trace element was Zn, at 38.25±0.17 mg/Kg.

4. DISCUSSION

GENERAL NUTRITIONAL COMPONENTS

The quality of fish can be reflected by its body composition and content. As the main edible part, the moisture, ash, fat, and protein content in muscle are not only key parameters for evaluating fish meat quality and nutritional value,^{3, 4} but also fundamental nutritional elements for maintaining growth, development, and physiological metabolism.⁵ Studies have shown that the nutritional value of fish meat primarily depends on muscle protein and fat content. “High protein, low fat” is an important characteristic of high-

quality edible fish,^{6-8,23} aligning with modern healthy dietary concepts and representing a core advantage for the development and utilization of fish resources.

The results of this study showed that the crude protein content in the muscles of the three wild *Schistura* species ranged from 17.47% to 17.73%, and crude fat ranged from 6.67% to 7.23%. All exhibited a “high protein” characteristic, with fat content within a moderate range, forming a “high protein, moderate fat” nutritional profile. One-way ANOVA indicated no significant overall difference in crude fat content among the three species. However, LSD post-hoc multiple comparisons showed that the crude fat content of *S. vinciguerrae* was significantly higher than that of *S. polytaenia*, with *S. albirostris* falling in between. This subtle difference suggests that while the three species belong to the same genus and have overlapping distribution

Table 5. Macro and trace elements in the muscle of three *Schistura* species (mg/kg)

Mineral element	<i>S. vinciguerrae</i>	<i>S. polytaenia</i>	<i>S. albirostris</i>
Ca	9.47×10 ³ ± 0.04 ^a	7.53×10 ³ ± 0.05 ^b	6.85×10 ³ ± 0.02 ^c
P	6.15×10 ³ ± 0.06 ^a	5.37×10 ³ ± 0.01 ^b	3.85×10 ³ ± 0.03 ^c
K	3.03×10 ³ ± 0.03 ^b	3.53×10 ³ ± 0.02 ^a	2.55×10 ³ ± 0.01 ^c
Na	759.30 ± 3.16 ^a	633.48 ± 0.82 ^b	534.95 ± 1.49 ^c
Mg	402.54 ± 4.10 ^a	359.72 ± 0.69 ^b	322.50 ± 1.64 ^c
Zn	63.99 ± 0.37 ^a	26.57 ± 0.17 ^c	38.25 ± 0.17 ^b
Fe	15.39 ± 0.39 ^b	29.46 ± 0.12 ^a	14.45 ± 0.18 ^c
Mn	4.58 ± 0.34 ^b	9.27 ± 0.16 ^a	4.23 ± 0.20 ^b
Cu	2.86 ± 0.07 ^a	0.84 ± 0.03 ^c	1.04 ± 0.02 ^b
Se	0.12 ± 0.01 ^b	0.14 ± 0.00 ^a	0.10 ± 0.01 ^c

Table 6. Comparison of the General Nutritional Composition in muscle among three *Schistura* Species and Other Species within the Family Cobitidae (%)

Item	Wild <i>S.</i> <i>vinciguerrae</i>	Wild <i>S.</i> <i>polytaenia</i>	Wild <i>S. albirostris</i>	Wild <i>Mastacembelus</i> <i>armatus</i> ⁴	Wild <i>Sinibotia</i> <i>pulchra</i> ⁹	Wild <i>Cobitis</i> <i>taenis</i> ¹⁰
Moisture	70.23±0.55	70.63±0.42	70.50±0.46	76.49±0.26	77.05±1.24	76.94±0.87
Crude Protein	17.50±0.17	17.73±0.21	17.47±0.15	20.45±0.18	16.53±0.13	16.81±0.74
Crude Fat	7.23±0.21	6.67±0.21	6.73±0.38	1.72±0.46	1.10±0.02	1.61±0.05
Crude Ash	3.70±0.20	3.73±0.15	3.60±0.10	0.92±0.03	1.47±0.04	2.80±0.15

areas, showing regularity in overall fat storage strategies, there may be biologically significant metabolic differentiation between specific species. This is hypothesized to be related to differences in their natural feeding preferences (e.g., prey types, feeding frequency) and energy allocation strategies (e.g., proportions allocated to growth, development, and environmental adaptation), reflecting their adaptive differentiation across heterogeneous microhabitats within the same river basin.

Comparing the general nutritional components of these three wild *Schistura* species with other wild Cobitidae species (Table 6), it can be seen that the moisture content of the three *Schistura* species was maintained at around 70%, lower than that of wild *Mastacembelus armatus*, *Sinibotia pulchra*, and *Cobitis taenis*. The lower moisture content may indirectly enhance muscle firmness and eating quality. The crude protein content was stable at around 17.50%, lower than wild *M. armatus* but higher than wild *S. pulchra* and *C. taenis*, further confirming their “high protein” nutritional advantage. Notably, the crude fat and ash contents of the three wild *Schistura* species were higher than those of the other three wild Cobitidae species. The moderate crude fat compensates for the flavor deficiency of low-fat fish, enhancing muscle tenderness and flavor complexity, while the higher ash content reflects a richer reserve of mineral elements, further demonstrating the unique nutritional value of these fish.

AMINO ACID COMPOSITION AND NUTRITIONAL QUALITY EVALUATION

Amino acids, as the fundamental structural units of proteins, their types, content, and composition ratios are core indicators for evaluating protein nutritional value,⁶ and are also key factors determining the nutritional efficacy and flavor of fish meat. This study found that 17 amino acids were detected in the muscles of all three wild *Schistura* species, with identical compositions, all of which contain the 8 essential amino acids required by the human body. Glutamic acid had the highest content of all three. Glutamic acid is a key amino acid in the biochemical metabolism of brain tissue, participating in the synthesis of various physiologically active substances.²⁴ It can be converted into glutamine in the blood. Glutamine, a commonly used nutritional supplement and an important substrate for hepatic gluconeogenesis, has multiple physiological functions, including promoting protein synthesis, protecting the gastrointestinal tract, enhancing immunity, regulating acid-base balance, and accelerating wound healing.²⁵ This indicates that consuming these three *Schistura* species can help supplement the body's amino acid requirements, offering both nutritional and health benefits. Furthermore, glutamic acid, aspartic acid, glycine, and alanine, as core delicious amino acids (DAA), directly determine the umami characteristics of food proteins. Glutamic acid and aspartic acid contribute to umami taste, while glycine and alanine contribute to sweetness.¹¹ In this study, the DAA/TAA ratios for the three species were 36.83%, 37.95%, and 35.76%,

respectively, slightly lower than that of *Sinibotia pulchra* 38.76%),⁹ higher than that of *Triplophysa venusta* 31%),² and the ratios for *S. vinciguerrae* and *S. polytaenia* were higher than that of wild *Cobitis taenis* 36.29%),¹⁰ indicating that all three *Schistura* species are delicious edible fish.

Besides glutamic acid, lysine content was the highest in the muscles of *S. vinciguerrae* and *S. polytaenia*, and ranked third in *S. albirostris*. Amino acid score (AAS) and chemical score (CS) showed that lysine had the highest score among the three species (AAS and CS > 1), indicating that lysine is the most advantageous essential amino acid in these three *Schistura*. Lysine, an animal-based amino acid, is low in cereal foods and easily lost, making it the first limiting amino acid in cereals.²⁶ It is also a “growth amino acid” essential for animal growth and development, crucially involved in protein synthesis in the body.²⁷ Therefore, consuming these three *Schistura* species can compensate for lysine deficiency in cereal-based diets, effectively improving the body's utilization of dietary protein.

According to the FAO/WHO ideal amino acid pattern for high-quality protein, the essential amino acid to non-essential amino acid ratio (EAA/NEAA) should be ≥60%, and the essential amino acid to total amino acid ratio (EAA/TAA) should be around 40%.²⁸ The ratios for the three *Schistura* species all met these standards, confirming that they are high-quality proteins. Additionally, the branched-chain amino acid-to-aromatic amino acid ratio (BCAA/AAA) is closely associated with liver health. Studies have shown that this ratio is 3.0-3.5 in normal individuals but can decrease to 1.0-1.5 when the liver is damaged.¹² The BCAA/AAA ratios measured in this study for the three species were 2.17, 2.07, and 2.34, respectively, all higher than the ratio in individuals with liver damage. This suggests that consuming these three *Schistura* species offers significant dietary health benefits for patients with liver disease, consistent with findings from studies on other *Cobitidae* species,^{2,9,13} while also filling a research gap regarding the liver health benefits of *Schistura* fishes. The essential amino acid index (EAAI) is an important indicator for evaluating the composition and quality of protein in food. A higher index indicates a more balanced amino acid composition, better protein quality, and a higher utilization rate.¹³ The EAAI values for *S. vinciguerrae*, *S. polytaenia*, and *S. albirostris* in this study were 68.09, 59.78, and 61.88, respectively, all significantly higher than those for *Triplophysa venusta*,² further confirming that these three *Schistura* species are high-quality proteins with a balanced amino acid composition.

FATTY ACID COMPOSITION

The types and composition of fatty acids are important indicators for evaluating the nutritional value and health benefits of fish meat.²⁹ Their composition is influenced by both the inherent genetic characteristics of the fish species and environmental factors, such as feed and diet, and shows high plasticity. It has been suggested that “the fatty acid composition of fish roughly reflects the fatty acid composition of their diet”.^{30,31} Lipids are the most variable general nutritional component in fish, with ranges from

0.2% to 64% among species,¹⁴ with differences potentially exceeding a hundredfold. Even within the same genus, significant variation can occur due to factors such as age, physiological state, and nutritional supply.^{15,16}

In this study, 27 fatty acids were detected in the muscles of all three wild *Schistura* species, with identical compositions. In-depth analysis revealed that among saturated fatty acids (SFA), palmitic acid (C16:0) had the highest content in all three, consistent with the general rule that palmitic acid content is commonly high in both freshwater and marine fish.¹⁷ Among monounsaturated fatty acids (MUFA), oleic acid (C18:1n9c) had the highest content. Oleic acid can reduce blood cholesterol and low-density lipoprotein levels, thereby decreasing the incidence of coronary heart disease,¹⁸ indicating that these three *Schistura* species offer significant cardiovascular health benefits. The three species showed differences in the predominant polyunsaturated fatty acids (PUFA): the highest content in *S. vinciguerrae* muscle was linoleic acid (C18:2n6c); in *S. polytaenia*, it was α-linolenic acid (C18:3n3); and in *S. albirostris*, it was EPA (C20:5n3). EPA and DHA are important derivatives of α-linolenic acid, while arachidonic acid is an important derivative of linoleic acid. Arachidonic acid plays a role in regulating various physiological functions in the human body, and EPA and DHA are essential fatty acids for human and animal growth and development. The contents of these three fatty acids also reflect, to some extent, the nutritional value of fish meat.^{6,32} *S. albirostris*, rich in EPA, has a more significant advantage in supplementing essential fatty acids and exerting cardiovascular protective effects. *S. polytaenia*, with α-linolenic acid as its main PUFA, can serve as an important precursor source for the human body to synthesize EPA and DHA. *S. vinciguerrae*, through its higher linoleic acid content, provides an ample precursor for arachidonic acid synthesis in the body. Therefore, all three *Schistura* species can serve as high-quality food sources for humans to obtain long-chain polyunsaturated fatty acids, such as EPA and DHA, with good health benefits.

MINERAL ELEMENTS

Mineral elements are important substances that constitute body tissues and maintain normal physiological functions. They are divided into essential macro elements (e.g., Ca, Mg) and trace elements (e.g., Fe, Zn, Se) required by the human body. Trace elements are widely involved in human metabolism, enzymatic reactions, and various life activities, making them essential nutrients.¹⁹ Furthermore, mineral elements not only affect the nutritional value of fish meat but also regulate the shelf life and flavor of fish products.³³ This study detected 5 macro elements and 5 trace elements with identical compositions in the muscles of all three wild *Schistura* species. Calcium (Ca) was the most abundant macro element in all species. Ca is a key component for the formation of bones and teeth and is also involved in physiological processes such as nerve conduction and muscle contraction. This indicates that these three *Schistura* species are high-quality dietary sources of calcium for human supplementation, especially suitable for

individuals seeking to strengthen bone health. Among trace elements, Zn was the most abundant in *S. vinciguerrae* and *S. albirostris*, while Fe was the most abundant in *S. polytaenia*. Fe is an important component of hemoglobin and myoglobin, and it participates in hematopoiesis and helps prevent iron-deficiency anemia. Zn is a constituent or activator of various enzymes, involved in metabolism and immune regulation.^{34,35} Therefore, the three *Schistura* species possess a complete range of essential minerals, with abundant levels, effectively meeting the human body's requirements.

This study was limited to the analysis of wild-caught specimens of the three *Schistura* species, and did not include a comparison with cultured populations. In future research, our team will undertake the domestication and artificial propagation of these three wild *Schistura* species, aiming to contribute actively to the restoration of their natural resources and their subsequent development and utilization.

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AUTHORS' CONTRIBUTION-CREDIT TAXONOMY

Methodology: XiaoMin Bi (Equal), Lili Cui (Equal). Data curation: XiaoMin Bi (Lead). Investigation: XiaoMin Bi

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No competing interests were disclosed.

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The animal experiment was approved by the Yunnan Academy of Fishery Science.

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The data used is confidential.

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