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Research Article

Effect of Body Weight on the Nutritional Content of Rice Field Eel, *Monopterus albus*

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The meat yield, nutrient composition, and quality of the skin and muscle of eels with different body weights, 124.10 ± 0.12, 253.42 ± 0.31, and 385.10 ± 0.44 g, was systematically studied, were determined to provide the basic data for the processing and efficient use of rice field eel, *Monopterus albus*. The results showed that muscle and skin accounted for a more significant proportion of eels with body weight of 253.42 ± 0.31 g, compared with other eels ($p < 0.05$ and $p = 0.03$). As increasing offish mass, the collagen protein, essential amino acids, umami amino acids, and total amino acids in muscle and skin increased and then decreased. The eels with body weight of 253.42 ± 0.31 g had the highest contents of these compounds. In the skin and muscle of all test eels, the natrium, magnesium, and kalium were the main essential mineral elements. Similarly, with the increasing of body weight of eel, an increasing and then decreasing trend was observed for all essential mineral elements measured. Our results demonstrated that the nutrient composition of the skin and muscle of *Monopterus albus* could be significantly affected by body weight, and the eels with body weight of 253.42 ± 0.31 g had the most favorable nutrient composition.

1. Introduction

Demand for high-quality aquatic products increased every year by year, and the research on the factors that affected the fish quality draw attentions of fish nutritionist [1–3]. And, the aquaculture producers expect to improve aquatic products and derive more foods. It had been found that the nutrition quality of aquatic species varied with body weight, when the threonine level increased to 1.67%, *Macrobrachium nipponense* showed significant increases in final body weight, specific growth rate, protein efficiency ratio, and weight gain rate ($p < 0.05$) [3–6]. Rice field eel is an important high-quality fish species in China [3, 5]. Current studies mainly focus on the culture technologies of eels [7], but few on the effects of body weight on the nutritional components of this species.

Rice field eel undergoes sex reversal, and fish with body weight ranging from 100 to 450 g are generally male or female [8]. The weight of eels is mainly affected by the industrial farming modes. With 1-year breading cycle, the weight of eels can reach to 100–250 g [9]. In the present study, three different eels with body weight of 124.10 ± 0.12, 253.42 ± 0.31, and 385.10 ± 0.44 g under the same breeding conditions were selected to avoid the influence of sex reversal on the nutritional composition. The muscle and skin were sampled and the nutritional components in the two tissues were measured. Our results are helpful in the developing of eels culture industry.

2. Materials and Methods

2.1. Materials and Samples. Rice field eels were obtained from a eel farming company in Yongnian County, Hebei Province and fed with pellet diet with 41.80% crude protein, 9.50% crude ash, 12.00% crude fat, 18.50kJ/g of total energy, 1.75% phosphorus, 1.85% calcium, and 4.50% fiber (China) compound feed. Nutritional composition: During culture periods, the water qualities were checked every 7 days and controlled as 20–35 cm of water transparency, 23–31°C of the water temperature, 7.1–8.3 of the pH value, more than 4 mg/L of the dissolved oxygen content and less than 0.15 mg/L of the nitrite nitrogen content. Chemical reagents including sodium hydroxide, concentrated sulfuric acid, nitric acid, copper sulfate, potassium sulfate, petroleum ether, and hydrochloric

acid, were obtained by the Handan Branch of Sinopharm Chemical Reagent Co., China.

There were 240 fish divided into three groups (Groups A, B, and C). according to their body weight. The body weight in Groups A, B, and C were 124.10 ± 0.12, 253.42 ± 0.31, and 385.10 ± 0.44 g. During each time of sampling, 20 fish were randomly selected from each group under anesthesia by MS222 and the dorsal skin and muscle of each fish were sampled and stored at −20°C until use.

2.2. Test Methods

2.2.1. Measurement of Morphological Indexes. The ratio between muscle and body weight, the ratio between the fish skin and body weight, fat fitness, and meat yield were measured [10, 11]. In brief, after removing the bones, head, and guts, the skin and muscle were separated to measure their weight and the meat percentage was calculated according to the previous study [12].

2.2.2. Basic Component Determination. The moisture content was determined using a direct drying method by METTLER ME104 Electronic Analytical Balance, purchased from Shanghai Yetuo Technology Co., Ltd. WHL-308 electric heating, constant temperature, radiation drying oven, purchased from Tianjin Tester Test Equipment Co., Ltd. [12]. A Soxhlet extraction method was used to determine the crude fat content by SH220CZF crude fat extractor, obtained from Shandong Haineng Scientific Instrument Co., Ltd. [13], the crude protein content was determined using the Kjeldahl method by K9840 Automatic Kjeldahl Nitrogen Analyzer, obtained from Shandong Haineng Scientific Instrument Co., Ltd. [14], and a high-temperature combustion method was used to determine the total ash content [15].

2.2.3. Amino Acid Analysis and Assessment of Nutritional Value. Ten eels were selected from each group, and the skin and muscle were minced and mixed. Accurately weight 100 mg of mixed sample and transfer it into a 20 mL hydrolysis tube. Add 10 mL of hydrochloric acid solution (6 mol/L) and perform hydrolysis at a constant-temperature oven (120°C) for 22 hr. Then, add 4.8 mL of sodium hydroxide solution (10 mol/L) to the hydrolysis flask, adjust the volume to 25 mL, and finally carry out filtration. About 1 mL of supernatant was collected and centrifuged at 11,100 times the force of gravity for 10 min. About 200μL of the supernatant was then subjected to chromatographic analysis using the Biochrom 30+ Amino Acid Automatic Analyzer, which was obtained from British Parkwood Technology Development Co., Ltd. The chromatographic conditions involved the use of a Biochrom 30+ Series amino acid analyzer with a C18 column (4.0 mm × 125 mm) at a column temperature of 40°C and a buffer flow rate of 1.0 mL/min. Mobile Phase A was 20 mmol/L sodium acetate, mobile Phase B was 20 mmol/L sodium acetate : methanol : acetonitrile = 1 : 2 : 2 (volume ratio), and the UV detection wavelength was 338 nm [4, 10].

The amino acid score (AAS), chemical score (CS), and essential amino acid index (EAAI) were calculated using the following formulas [3, 10, 16–18]:

$$\mathrm{AAS} = \frac{\text{Content of certain amino acid in the sample}}{\text{Amino acid content in the WHO/FAO model spectrum}}, \quad (1)$$

$$\mathrm{CS} = \frac{\text{Content of certain amino acid in the sample}}{\text{Content of certain amino acid in egg proteins}}, \quad (2)$$

$$\mathrm{EAAI} = \sqrt[n]{\frac{t1^{*}t2^{*}\ldots^{*}tn}{s1^{*}s2^{*}\ldots^{*}sn}} \times 100, \quad (3)$$

where n represents the number of amino acids for comparison. $t1$, $t2$, …, tn denote the contents of various amino acids in the tested rice field eel protein, measured in mg/g N. Similarly, $s1$, $s2$, …, sn represent the contents of various amino acids in the egg protein, measured in mg/g N [10].

2.2.4. Collagen Content Analysis. The samples were prepared following the procedures outlined in Section 2.2.3. Subsequently, the hydroxyproline content of meat and meat-based products was quantified using the GB/T 9695.23-2008 standard protocol. The concentration of hydroxyproline in the hydrolyzed samples was calculated based on the hydroxyproline standard curve method [12, 16–18].

2.2.5. Determination of Mineral Elements in the Skin and Muscle of Fish. The samples were prepared following the procedure outlined in Section 2.2.3. The mineral elements arsenic (As) and lead (Pb) were analyzed using a graphite furnace atomic absorption spectrometer [15]; calcium, magnesium, iodine, potassium, sodium, iron, zinc, manganese, and copper were determined through the use of the flame atomic absorption method [17, 18].

2.3. Data Analysis. One-way analysis of variance was conducted utilizing Statistical 6.0 software. When significant differences were detected, Duncan's multiple comparison test was used to compare the distinctions between groups. The level of significance was set at $p < 0.05$, and all data are presented as means ± standard deviations [1, 18].

3. Results

3.1. Morphological Parameters of Rice Field Eels. As shown in Table 1, the muscle to body weight ratio and the skin to body weight ratio of eels in Group A were the lowest among the three groups. And, the fertility and meat yield in Group B were highest with values of 3.13% and 69.91%, respectively. The meat yield and fertility in Group A were lower than these of Groups B and C ($p < 0.05$ and $p = 0.03$).

3.2. The Nutrient Composition of Rice Field Eels. As shown in Table 2, no obvious changes were observed for the moisture content in the three groups ($p > 0.05$ and $p = 0.07$). Protein, fat, and ash contents in muscle and skin of eels in Group A were significantly lower than these in Groups B and C ($p < 0.05$, $p = 0.03$). The collagen contents in the muscle and skin of eels in group B were 15.44 and 81.19 mg/g, respectively, which were the highest among three groups.

Table 1: Body characteristics of the three sizes of *Monopterus albus*.

Index	Group		
	A	B	C
Muscle/body weight ratio (%)	28.44 ± 0.12^a	57.41 ± 0.10^b	49.63 ± 0.12^b
Skin/body weight ratio (%)	15.04 ± 0.02^a	24.41 ± 0.06^b	21.22 ± 0.02^b
Fertility (%)	1.75 ± 0.02^a	3.13 ± 0.02^b	2.86 ± 0.03^b
Meat yield (%)	43.11 ± 0.02^a	69.91 ± 0.04^b	62.20 ± 0.01^b

Note: Lowercase letters with upper right index for different groups indicate significant difference ($p < 0.05$).

Table 2: Basic nutrient content of three sizes of *Monopterus albus*.

Index contents	Muscle			Skin		
	A	B	C	A	B	C
Moisture (%)	68.21 ± 0.31^a	66.33 ± 0.42^a	64.44 ± 0.43^a	70.13 ± 0.44^a	68.22 ± 0.51^a	67.11 ± 0.47^a
Protein (%)	17.44 ± 0.67^a	22.53 ± 0.72^b	21.31 ± 0.61^b	17.91 ± 0.65^a	23.87 ± 0.61^b	22.22 ± 0.62^b
Fat (%)	12.11 ± 0.42^a	15.47 ± 0.55^b	15.18 ± 0.53^b	13.41 ± 0.54^a	16.95 ± 0.50^b	16.44 ± 0.44^b
Ash (%)	1.30 ± 0.22^a	1.69 ± 0.26^b	1.60 ± 0.24^b	1.40 ± 0.22^a	1.81 ± 0.24^b	1.75 ± 0.28^b
Collagen (mg/g)	10.12 ± 0.11^a	15.44 ± 0.13^b	14.81 ± 0.01^b	60.22 ± 0.72^a	81.19 ± 0.75^b	76.33 ± 0.71^b

Note: Different uppercase letters with upper right index for different groups in different sampled tissues indicate significant difference ($p < 0.05$).

3.3. Amino Acid Content in the Muscle and Skin of Rice Field Eels. As shown in Table 3, the contents of essential amino acids (EAAs), the umami amino acids (DAAs), and total amino acids (TAAs) in the muscle and skin of eels in Groups B and C were significantly higher than these of Group A ($p < 0.05$ and $p = 0.03$). No significantly difference observed for the amino acid contents of eels in Groups B and C. The ratio between DAA and TAA, and the ratio between EAA/TAA in all three groups were over 0.40.

The AAS and CS were shown in Table 4. The AAS and CS of isoleucine and leucine in the muscle and skin of eels in Groups B and C were higher than A. The AAS and CS of methionine and cysteine, two limiting amino acids (LAAs) of Group C were higher than that of Groups A and B. The AAS of lysine in skin of eels in Groups B and C was higher than that of A. There was no significant difference for the AAS and CS of threonine, phenylalanine, and tryptophan in these tissues of the eels in any of the three groups. The EAAs values of eels in all three group reached over 95%.

3.4. Mineral Element Composition of Rice Field Eels. As shown in Table 5, the content of natrium, magnesium, kalium, and calcium in the muscle and skin of eels in Groups B and C were higher than that of A. For manganese, titanium, and zinc in eels of all three groups, no significant differences were observed. And, the mineral compositions in Groups B and C were similar.

4. Discussion

The rice field eels have high nutritional and medicinal values. It had been confirmed that eating eels over a long period can reduce the stomach problems, lower back pain, and hair loss [18–21]. We found that the fertility and meat yield in Group A were significantly lower these in the other two groups, providing valuable reference for actual production of eels. Choosing the eels with higher body weight might contribute to breeding efficiency.

The moisture, ash, crude fat, and crude protein are the main nutrient indicators of aquatic animals [5, 22]. Our results found that these indicators, except of moisture, in Group A were significantly lower than these in the other two groups. The protein contents in the muscle of group B and group C were 22.53% and 23.87%, respectively, and these in skin of them were 21.31% and 22.22%, which were higher than that of cold-water freshwater sturgeon and other warm-water freshwater fish [23, 24]. The reasons for the differences of protein content might be caused by the varied nutritional conditions, growth environment of different fish species. To some extent, fat content may affect the meat quality and taste. The fat content in muscle of the three-sized rice field eel was 12%–15%, which was significantly higher than that of freshwater fish, such as crucian carp, tilapia, and grass carp [24] but on difference with that of hybrid sturgeon [25]. This might the main reason that rice field eel has delicate taste. The collagen content of eels with medium-body weight eels was 15.44 and 83.19 mg/g, and that in muscle and skin of eels with high-body weight was 14.81 and 76.33 mg/g, respectively. Our results were in line with the results of previous studies [10, 23, 26]. The difference of collagen in muscle and skin might be related to collagen play the different functions in different tissues. Interestingly, high-collagen content present in the skin of eels provide a clue for potential developing collagen-related products, such as fish collagen, gelatin, or collagen peptides.

The composition and content of amino acids determine the freshness of the flesh, which is primarily expressed in three flavors: freshness, sweetness, and bitterness. Due to different amino acid contents, aquatic products present different tastes [10, 23, 27]. As shown in Table 3, the EAAs of Groups B and C were higher than these of Group A, significantly. Among these EAAs in muscle, the lysine had highest

Table 3: *Monopterus albus* amino acid content in three body sizes.

Amino acids in protein (mg/g)	Muscle			Skin		
	A	B	C	A	B	C
*Threonine	0.62 ± 0.01^{a}	0.88 ± 0.01^{b}	0.80 ± 0.02^{b}	0.63 ± 0.02^{a}	0.91 ± 0.01^{b}	0.85 ± 0.01^{b}
*Valine	1.11 ± 0.02^{a}	1.42 ± 0.03^{b}	1.39 ± 0.03^{b}	1.20 ± 0.02^{a}	1.52 ± 0.02^{b}	1.49 ± 0.01^{b}
*Histidine	0.63 ± 0.04^{a}	0.84 ± 0.01^{b}	0.80 ± 0.03^{b}	0.69 ± 0.02^{a}	0.89 ± 0.01^{b}	0.86 ± 0.02^{b}
*Isoleucine	0.77 ± 0.01^{a}	1.11 ± 0.02^{b}	1.04 ± 0.03^{b}	0.83 ± 0.01^{a}	1.24 ± 0.02^{b}	1.19 ± 0.03^{b}
*Leucine	1.38 ± 0.01^{a}	1.79 ± 0.03^{b}	1.71 ± 0.02^{b}	1.43 ± 0.02^{a}	1.82 ± 0.02^{b}	1.77 ± 0.02^{b}
*Methionine	0.60 ± 0.02^{a}	0.80 ± 0.01^{b}	0.77 ± 0.02^{b}	0.61 ± 0.02^{a}	0.83 ± 0.01^{b}	0.79 ± 0.02^{b}
*Phenylalanine	0.73 ± 0.02^{a}	0.94 ± 0.02^{b}	0.91 ± 0.01^{b}	0.76 ± 0.02^{a}	0.98 ± 0.01^{b}	0.95 ± 0.01^{b}
*Lysine	1.52 ± 0.02^{a}	1.91 ± 0.01^{b}	1.87 ± 0.02^{b}	1.55 ± 0.01^{a}	1.99 ± 0.01^{b}	1.89 ± 0.02^{b}
Essential amino acids (EAA)	7.36 ± 0.03^{a}	9.69 ± 0.04^{b}	9.29 ± 0.02^{b}	7.70 ± 0.01^{a}	10.18 ± 0.04^{b}	9.79 ± 0.02^{b}
[A]Aspartic acid	1.66 ± 0.01^{a}	2.11 ± 0.02^{b}	2.04 ± 0.03^{b}	1.73 ± 0.01^{a}	2.19 ± 0.02^{b}	2.10 ± 0.03^{b}
[A]Glutamic acid	3.32 ± 0.02^{a}	4.22 ± 0.03^{b}	4.11 ± 0.03^{b}	3.41 ± 0.02^{a}	4.38 ± 0.02^{b}	4.28 ± 0.01^{b}
[A]Glycine	1.22 ± 0.02^{a}	1.55 ± 0.03^{b}	1.48 ± 0.03^{b}	1.25 ± 0.03^{a}	1.59 ± 0.02^{b}	1.50 ± 0.04^{b}
[A]Tyrosine	1.11 ± 0.02^{a}	1.30 ± 0.04^{b}	1.26 ± 0.05^{b}	1.15 ± 0.01^{a}	1.39 ± 0.02^{b}	1.32 ± 0.03^{b}
[A]Alanine	0.83 ± 0.01^{a}	1.14 ± 0.01^{b}	1.02 ± 0.03^{b}	0.87 ± 0.02^{a}	1.25 ± 0.02^{b}	1.23 ± 0.02^{b}
Umami amino acids (DAA)	8.14 ± 0.03^{a}	10.32 ± 0.03^{b}	9.91 ± 0.03^{b}	8.41 ± 0.02^{a}	10.80 ± 0.02^{b}	10.43 ± 0.02^{b}
serine	0.71 ± 0.02^{a}	0.85 ± 0.02^{b}	0.77 ± 0.01^{ab}	0.72 ± 0.01^{a}	0.87 ± 0.02^{b}	0.79 ± 0.02^{ab}
arginine	1.11 ± 0.02^{a}	1.17 ± 0.01^{a}	1.15 ± 0.02^{a}	1.13 ± 0.01^{a}	1.19 ± 0.02^{a}	1.17 ± 0.01^{a}
proline	0.70 ± 0.01^{a}	0.95 ± 0.02^{b}	0.89 ± 0.02^{b}	0.71 ± 0.02^{a}	0.99 ± 0.02^{b}	0.94 ± 0.03^{b}
Total amino acids (TAA)	18.02 ± 0.05^{a}	22.98 ± 0.06^{b}	22.01 ± 0.05^{b}	18.67 ± 0.03^{a}	24.03 ± 0.02^{b}	23.12 ± 0.02^{b}
DAA/TAA	0.45	0.45	0.45	0.45	0.45	0.45
EAA/TAA	0.41	0.42	0.42	0.41	0.42	0.42

Notes: *indicates an EAA and [A]indicates a DAA. In the same sampled tissue, a significant difference is indicated by the right superscript letter associated with the detection value for the same detection index of different groups ($p < 0.05$).

Table 4: The amino acid score and chemical score of three sizes of *Monopterus albus* (mg/g).

Essential amino acids	Muscle						Skin					
	A		B		C		A		B		C	
	Amino acid score	Chemical score	Amino acid score	Chemical score	Amino acid score	Chemical score	Amino acid score	Chemical score	Amino acid score	Chemical score	Amino acid score	Chemical score
Isoleucine	1.22 ± 0.03^{a}	0.73 ± 0.01^{a}	1.45 ± 0.04^{b}	1.02 ± 0.03^{b}	1.41 ± 0.02^{b}	0.98 ± 0.01^{b}	1.25 ± 0.02^{a}	0.75 ± 0.03^{a}	1.49 ± 0.03^{b}	1.11 ± 0.03^{b}	1.44 ± 0.03^{b}	1.04 ± 0.03^{b}
Leucine	1.11 ± 0.02^{a}	0.74 ± 0.02^{a}	1.39 ± 0.02^{b}	1.06 ± 0.03^{b}	1.30 ± 0.03^{b}	0.98 ± 0.01^{b}	1.13 ± 0.01^{a}	0.76 ± 0.02^{a}	1.48 ± 0.02^{b}	1.10 ± 0.02^{b}	1.40 ± 0.02^{b}	1.05 ± 0.03^{b}
Threonine	1.00 ± 0.01	0.72 ± 0.01	1.05 ± 0.02	0.77 ± 0.03	1.07 ± 0.02	0.74 ± 0.02	1.04 ± 0.01	0.75 ± 0.02	1.11 ± 0.02	0.80 ± 0.03	1.10 ± 0.03	0.78 ± 0.03
Valine	1.04 ± 0.01	0.69 ± 0.02	1.15 ± 0.02	0.76 ± 0.03	1.10 ± 0.02	0.73 ± 0.02	1.05 ± 0.02^{a}	0.71 ± 0.01	1.18 ± 0.02^{b}	0.79 ± 0.02	1.12 ± 0.02	0.76 ± 0.02
Methionine + cysteine	0.83 ± 0.02^{a}	0.82 ± 0.02^{a}	1.18 ± 0.03^{a}	1.15 ± 0.02^{a}	1.10 ± 0.02^{b}	1.11 ± 0.03^{b}	0.85 ± 0.03^{a}	0.85 ± 0.02^{a}	1.22 ± 0.04^{a}	1.19 ± 0.02^{a}	1.19 ± 0.02^{b}	1.16 ± 0.03^{b}
Phenylalanine + tryptophan	1.34 ± 0.01	0.82 ± 0.02	1.47 ± 0.01	0.91 ± 0.02	1.43 ± 0.03	0.86 ± 0.02	1.38 ± 0.02	0.83 ± 0.02	1.55 ± 0.02	0.97 ± 0.02	1.47 ± 0.02	0.90 ± 0.02
Lysine	1.80 ± 0.03^{a}	1.01 ± 0.01	2.35 ± 0.03^{b}	1.11 ± 0.02	2.28 ± 0.03^{b}	1.08 ± 0.03	1.89 ± 0.03^{a}	1.04 ± 0.01	2.44 ± 0.03^{b}	1.18 ± 0.02	2.38 ± 0.02^{b}	1.13 ± 0.02
Total	1.15 ± 0.01	0.85 ± 0.02	1.25 ± 0.01	0.94 ± 0.02	1.20 ± 0.02	0.90 ± 0.02	1.17 ± 0.02	0.85 ± 0.02	1.29 ± 0.02	0.98 ± 0.02	1.25 ± 0.02	0.93 ± 0.02
Essential amino acid index	96.77 ± 0.56	96.32 ± 0.50	98.14 ± 0.51	97.22 ± 0.52	97.99 ± 0.49	96.86 ± 0.44	96.88 ± 0.45	96.55 ± 0.44	98.66 ± 0.50	97.84 ± 0.47	97.78 ± 0.44	96.92 ± 0.51

Note: In the same sampled tissue, the right superscript letter associated with the detection value for the same detection index of different groups indicates a significant difference ($p < 0.05$).

Table 5: The essential mineral contents of the three sizes of *Monopterus albus* (based on wet weight, mg/kg).

Mineral elements	Muscle			Skin		
	A	B	C	A	B	C
Natrium	443.66 ± 4.21^{a}	567.88 ± 4.81^{b}	546.51 ± 4.72^{b}	457.35 ± 5.01^{a}	584.43 ± 5.46^{b}	561.44 ± 4.71^{b}
Magnesium	510.12 ± 4.31^{a}	637.25 ± 5.42^{b}	608.11 ± 4.81^{b}	523.20 ± 4.21^{a}	666.33 ± 5.27^{b}	644.11 ± 5.05^{b}
Kalium	304.22 ± 3.12^{a}	419.11 ± 3.26^{b}	381.12 ± 3.11^{b}	312.46 ± 3.31^{a}	421.87 ± 3.03^{b}	405.43 ± 3.75^{b}
Calcium	85.34 ± 1.07^{a}	158.11 ± 1.14^{b}	144.56 ± 1.11^{b}	90.25 ± 1.02^{a}	169.33 ± 0.99^{b}	152.34 ± 1.00^{b}
Manganese	1.12 ± 0.02	1.26 ± 0.02	1.18 ± 0.02	1.16 ± 0.02	1.31 ± 0.03	1.22 ± 0.01
Ferrum	11.45 ± 0.14	12.44 ± 0.10	12.06 ± 0.15	37.44 ± 0.20	43.31 ± 0.14	40.62 ± 0.20
Zinc	20.31 ± 0.45	28.11 ± 0.44	25.39 ± 0.41	42.55 ± 0.54	49.94 ± 0.58	47.72 ± 0.52

Note: In the same sampled tissue, the right superscript letter associated with the detection value for the same detection index of different groups indicates a significant difference ($p < 0.05$).

content and the methionine had lowest content. Lysine plays an important role in essential amino acid nutrients and participates in human metabolism [28]. high-lysine content can regulate the ratio of EAAs improve and intake the protein utilization [26, 29]. Our results demonstrated the eels could provide stable lysine and other nutrition for human diets. Similarly, the DAAs and TAAs of Groups B and C were also significantly higher than these of Group A.

Further, the DAA/TAA ratio of eels in all three groups were lower than cold-water fish, such as sturgeon [17, 23, 25], but higher than marine fish, such as puffer fish [30] and salmon [31]. It had been found that the protein with EAA/TAA ratio over 0.4 could be rated as high-quality protein [10, 21, 22, 32–34]. We found that the EAA/TAA ratio in the muscle and skin of eels of all three groups were higher than 0.4, indicating the protein produced by eels reached the highest quality protein standard.

Further, AAS and CS analysis also confirmed that eels could provide high-quality protein. First, the AAS was over 0.80 and the CS was over 0.52 in all groups. Second, two LAAs, methionine and cysteine, had high content in muscle and skin of eels with high-body weight (Group C), which was consistent with that of sturgeon [23], salmon [31], and grass carp [11]. Third, the EAAs values of eels among all the three groups reached over 95%. The EAAs value is an important indicator for evaluating the nutritional value of protein and its value over 95% indicates a highest quality protein source [10, 35].

Mineral elements are important for the fish metabolism, growth and development, diseases prevention and flavor [4, 36]. We found that the Na^{+}, Mg^{2+}, K^{+}, and Ca^{2+} of eels in two groups (Group B and C) were higher than these of Group A (Table 5). The Mg activates a variety of enzymes in organisms. For example, important for bone growth and development are alkaline phosphatase and pyrophosphatase, but require Mg^{2+} [37, 38]. It had been found that the mineral contents varied in different fish growth stage. For example, the contents of Zn^{2+}, Fe^{2+}, and Mn^{2+} in the muscles of 1-year-old salmon were higher than these of other stages [11]. We found that the contents of Zn^{2+}, Fe^{2+}, and Mn^{2+} in muscle and skin of eels in all three groups had no significantly changes, indicating that the requirement of these minerals might varied in the different fish species. In conclusion, our study demonstrated that the body weight could affect the nutritional contents of rice field eel, *M. albus*. Importantly, we found that the effects of medium-body weight (253.42 ± 0.31 g) and high-body weight (385.10 ± 0.44 g) on these nutritional parameters had no significance. Thus, we recommend using eels with medium-body weight (253.42 ± 0.31 g) for further breeding application, considering cost saving.

Data Availability

The data supporting this study are from previously reported studies and datasets, which have been cited. The processed data are available from the corresponding author, upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] L. Cong, W. Zheng, F. Liu et al., "Effects of dietary phosphorus content on growth and phosphorus metabolism of yellow catfish (*Pelteobagrus fulvidraco*)," *Journal of Northwest Sci-Tech University of Agriculture and Forestry*, no. 11, pp. 15–22, 2016.

[2] J. Shao, J. Yuan, Y. Shen, R. Hu, and Z. Gu, "First isolation and characterization of *Edwardsiella tarda* from diseased Asian swampeel, *Monopterus albus* (Zuiew)," *Aquaculture Research*, vol. 47, no. 11, pp. 3684–3688, 2016.

[3] L. Xia, P. Han, X. Cheng et al., "*Aeromonas veronii* caused disease and pathological changes in Asian swamp eel *Monopterus albus*," *Aquaculture Research*, vol. 50, no. 10, pp. 2978–2985, 2019.

[4] H.-K. Xie, D.-Y. Zhou, Z.-Y. Liu et al., "Effects of natural phenolics on shelf life and lipid stability of freeze-dried scallop adductor muscle," *Food Chemistry*, vol. 295, pp. 423–431, 2019.

[5] A. T. Nguyen, E. L. Damsteegt, J. H. Z. Chia, Y. Kazeto, and P. M. Lokman, "Effects of gonadotropins, 11-ketotestosterone, and insulin-like growth factor-1 on target gene expression and growth of previtellogenic oocytes from shortfinned eels, *Anguilla australis*, in vitro," *Fish Physiology and Biochemistry*, vol. 48, pp. 853–867, 2022.

[6] W.-H. Jiang, X. Yang, Q.-B. Zhou et al., "Requirement level of dietary protein for *Monopterus albus*," *Acta Hydrobiologica Sinica*, vol. 46, no. 8, pp. 1205–1214, 2022.

[7] H. G. Worlanyo, S. Jiang, Y. Yu et al., "Effects of dietary threonine on growth and immune response of oriental river prawn (*Macrobrachium nipponense*)," *Fish & Shellfish Immunology*, vol. 128, pp. 288–299, 2022.

[8] H. Zhao, Q. He, C. Zhang et al., "A review of studies on sex differentiation and sex change in hermaphroditic fishes," *Journal of Fisheries of China*, vol. 46, no. 4, pp. 644–656, 2022.

[9] E. V. Todd, H. Liu, S. Muncaster, and N. J. Gemmell, "Bending genders: the biology of natural sex change in fish," *Sexual Development*, vol. 10, no. 5-6, pp. 223–241, 2016.

[10] Q. Xie and Y. Liu, "Effect of body weight on the nutrient composition of the muscle and skin tissues of Oncorhynchus mykiss," *Journal of Food Composition and Analysis*, vol. 124, Article ID 105684, 2023.

[11] Z. Li, H. Ding, L. Zhang, and Z. Tu, "Comparative analysis on the nutritional quality of grass carp muscle from different habitats," *Food and Fermentation Industries*, vol. 47, no. 17, pp. 133–139, 2021.

[12] Q. Xie and Y. Liu, "Comparative analysis of the nutrient components in the muscle and skin tissues of hybrid sturgeon (*Acipenser baerii* ♀ × *Acipenser schrenckii* ♂) of different sizes," *Aquaculture Research*, vol. 53, no. 17, pp. 6124–6134, 2022.

[13] National Health and Family Planning Commission, *GB 5009.5-2016 National Food Safety Standard Determination of Protein in Food*, China Standards Press, Beijing, 2016.

[14] National Health and Family Planning Commission, *GB 5009.6-2016 National Food Safety Standard Determination of Fat in Food*, China Standards Press, Beijing, 2016.

[15] National Health and Family Planning Commission, *GB 5009.4-2016 National Food Safety Standard Determination of Ash in Food*, China Standards Press, Beijing, 2016.

[16] P. Huang, W.-Q. Wang, C. Gong, R.-H. Wang, F. Bai, and Y.-H. Zhao, "Chemical compositions of different muscle zones in giant hybrid sturgeon," *Food Research and Development*, no. 18, pp. 162–168, 2020.

[17] M. Zhang, S. Zeng, X. Yang, Y. Wang, F. Zhao, and X. Yang, "Comparative study on nutrient components in muscle of hybrid sturgeon at different growth stages," *Chinese Journal of Animal Nutrition*, vol. 31, no. 9, pp. 4378–4386, 2019.

[18] F. Guo, Q. Zhou, J. Zhong et al., "The influence of particle size of raw feed material on production performance and nitrogen emission of rice field eel, *Monopterus albus*," *Acta Agriculturae Universitatis Jiangxiensis*, vol. 40, no. 6, pp. 1286–1292, 2018.

[19] K. Feng, H. Luo, Y. Li et al., "High efficient gene targeting in rice field eel *Monopterus albus* by transcription activator-like effector nucleases," *Science Bulletin*, vol. 62, no. 3, pp. 162–164, 2017.

[20] F. Boughattas, D. Vilkova, E. Kondratenko, and R. Karoui, "Targeted and untargeted techniques coupled with chemometric tools for the evaluation of sturgeon (*Acipenser gueldenstaedtii*) freshness during storage at 4°C," *Food Chemistry*, vol. 312, Article ID 126000, 2020.

[21] D. Tang, S. Wu, K. Luo et al., "Sequence characterization and expression pattern analysis of six kinds of IL-17 family genes in the Asian swamp eel(*Monopterus albus*)," *Fish & Shellfish Immunology*, vol. 89, pp. 257–270, 2019.

[22] H. Ren, Z. Lan, H. Sun, and Y. Li, "Nutritional value of sturgeon and market of its intensive processing products," *Jiangxi Fishery Science and Technology*, no. 1, pp. 36–39, 2015.

[23] H. Huang, Y. Wei, L. Li et al., "Effects of seasonal variation on nutrient composition of hybrid sturgeon (*Huso dauricus* ♀ × *Acipenser schrenckii* ♂)," *Science and Technology of Food Industry*, vol. 42, no. 7, pp. 360–365, 2021.

[24] Y.-L. Wang, W.-L. Lin, L.-H. Li et al., "Basic nutrient composition analysis of freshwater fish muscles based on four orders and thirteen species," *Science and Technology of Food Industry*, vol. 40, no. 11, pp. 277–283, 2019.

[25] D. Zhang, L. Wu, X. Zhang et al., "Nutrient components and texture profiles in the flesh of *Atlantic salmon*, triploid rainbow trout, and golden trout," *Journal of Fishery Sciences of China*, vol. 27, no. 2, pp. 186–194, 2020.

[26] K. Mielcarek, A. Puścion-Jakubik, K. J. Gromkowska-Kępka et al., "Proximal composition and nutritive value of raw, smoked and pickled freshwater fish," *Foods*, vol. 9, no. 12, Article ID 1879, 2020.

[27] Z. Chen, T. Liu, G. Han et al., "Nutritional evaluation and histological analysis of six species of sturgeon skin," *Fisheries Science*, vol. 41, no. 6, pp. 938–948, 2022.

[28] C. Katopodis, L. Cai, and D. Johnson, "Sturgeon survival: the role of swimming performance and fish passage research," *Fisheries Research*, vol. 212, pp. 162–171, 2019.

[29] W. M. Furuya, T. P. da Cruz, and D. M. Gatlin III, "Amino acid requirements for Nile Tilapia: an update," *Animals*, vol. 13, no. 5, Article ID 900, 2023.

[30] X.-T. Chen, J.-N. Wu, M. Xu et al., "Analysis and evaluation of nutritional component in fish skin and fish meat of four species of puffer fish," *Modern Food Science and Technology*, vol. 36, no. 1, pp. 69–77, 2020.

[31] H. Su, Y.-X. Li, X.-L. Qian, X.-Y. Fan, J. Zhang, and N.-P. Tao, "Nutrition analysis and quality evaluation of *Aristichthys nobilis*, *Thunnus obesus* and *Salmon salar* head," *Science and Technology of Food Industry*, vol. 40, no. 17, pp. 212–217, 224, 2019.

[32] D. Xu, M. Xie, and L. Yang, "Molecular characterization and expression analysis of IL-10 and IL-20L genes in swamp eel (*Monopterus albus*) against *Aeromonas veronii* infection," *Aquaculture Reports*, vol. 24, Article ID 101164, 2022.

[33] J. Li, Q. Liu, J. Wang, Q. Liu, and Z. Peng, "Effect of red pepper (*Zanthoxylum bungeanum* Maxim.) leaf extract on volatile flavor compounds of salted silver carp," *Food Science & Nutrition*, vol. 8, no. 3, pp. 1355–1364, 2020.

[34] S. Liu, M. Wu, and X. Yao, "Effects of reactive oxygen species scavengers on thermophilic micro-aerobic digestion for sludge stabilization," *Environmental Research*, vol. 185, no. 1, Article ID 109453, 2020.

[35] Y. Su, M.-X. Lu, L.-Q. Jing et al., "Nutritional properties of larval epidermis and meat of the edible insect *Clanis bilineata tsingtauica* (*Lepidoptera: Sphingidae*)," *Foods*, vol. 10, no. 12, Article ID 2895, 2021.

[36] Y. Gao, D. Jia, Q. Hu, and D. Li, "Foxl3, a Target of miR-9, stimulates spermatogenesis in spermatogonia during natural sex change in *Monopterus albus*," *Endocrinology*, vol. 157, no. 11, pp. 4388–4399, 2016.

[37] Q. L. Zhou, L. Y. Wang, X. L. Zhao, Y. S. Yang, Q. Ma, and G. Chen, "Effects of salinity acclimation on histological characteristics and miRNA expression profiles of scales in juvenile rainbow trout (*Oncorhynchus mykiss*)," *BMC Genomics*, vol. 23, Article ID 300, 2022.

[38] W. B. Zhou, Z. H. P. Chu, L. X. Li et al., "Studies on dietary available phosphorus requirement of juvenile hybrid sturgeon (*Acipenser baerii* ♀ × *A. schrenckii* ♂)," *Freshwater Fisheries*, vol. 51, no. 2, pp. 63–71, 2021.