Research Article

Species Variations in the Proximate Composition, Amino Acid Profile, and Protein Quality of the Muscle Tissue of Grass Carp, Bighead Carp, Siberian Sturgeon, and Wels Catfish

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This study determined the proximate composition, energy value, amino acid profile, and protein quality of the muscle tissue of four food fish species. The fish analyzed contained 78.90–69.89% water, 18.25–15.69% protein, and 2.28–12.57% fat. The energy value of the muscle tissue ranged from 93.50 to 175.83 kcal/100 g. The contents of amino acids in 100 g of protein were 47.64–45.86 g for total essential amino acids (TEAA), 52.36–54.14 g for total neutral amino acids (TNAA), 3.14–2.25 g for total sulphur amino acids (TSAA), and 7.23–7.81 g for total aromatic amino acids (TAraA). The essential amino acid (EAA) composition of the fish was compared with the standard protein, and Chemical Score (CS), Protein Digestibility-Corrected Amino Acid Score (PDCAAS), and Essential Amino Acid Index (EAAI) were calculated. The quality of the muscle tissue proteins of all four fish species was high. These fish can constitute a healthy addition to the human diet.

1. Introduction

The species of fish markedly affects the proximate composition and amino acid profile of their muscle tissue. Depending on the species, fish muscle tissue contains 12.2–21.79% protein [1–6], 0.08–13.1% fat, and 67.3–86.7% water [1, 4, 7, 8]. The energy value of the muscle tissue of different fish species, which depends on the proportion of its basic components, ranged from 210.7 to 797.5 kJ/100 g [4, 9, 10].

Depending on the species, the contents of particular essential amino acids in the muscle tissue (g/100 g protein) freshwater and marine fish varied, respectively, in the ranges of 1.4–5.3 and 0.5–7.9 for histidine, 0.2–6.2 and 0.3–5.2 for isoleucine, 0.4–9.0 and 0.7–10.4 for leucine, 0.3–4.8 and 0.9–16.1 for lysine, 0.1–2.85 and 0.4–4.0 for methionine, 0.1–0.2 and 0.04–0.6 for cysteine, 0.3–6.3 and 0.5–4.3 for phenylalanine, 0.9–1.3 and 0.2–1.5 for tyrosine, 0.3–5.9 and 0.5–7.9 for threonine, 0.2–7.3 and 0.5–8.6 for valine, and 0.1–1.4 and 1.2–2.3 for tryptophan [11].

The quality of protein is determined by its content of amino acids. This quality is evaluated by comparing the essential amino acid profile of the protein tested with a standard protein. At present, the recommended amino acid scoring pattern for evaluating protein quality is the standard protein recommended by the FAO Expert Consultation on Protein Quality Evaluation in Human Nutrition from 2011 (published in FAO Food and Nutrition Paper 92 from 2013 [12]). It takes into account the essential amino acid requirements of different age groups, that is, infants, older children, adolescents, and adults. In addition, protein quality is measured by indices, such as Chemical Score (CS), Protein Digestibility-Corrected Amino Acid Score (PDCAAS), and Essential Amino Acid Index (EAAI) [13, 14]. CS indicates the scarcest amino acid in a given protein, the so-called “limiting amino acid,” which is determined by comparing the contents of particular essential amino acids in the protein tested and in the reference protein. EAAI, like CS, is based on a comparison of the

essential amino acid composition of the protein evaluated and the standard protein, but it also takes into account the presence of all essential amino acids required for protein synthesis. Hence the protein quality, as assessed by EAAI, depends on the contents of all these amino acids, and not only on the level of the limiting amino acid. Similarly to the other two indices, PDCAAS depends on the content of particular essential amino acids in a given protein measured against the standard protein, but it also takes into account protein digestibility.

Fish can play a vital role as an important source of protein in human nutrition. Therefore, there is a need to generate and document nutritional information on the numerous species of food fishes available [11]. Grass carp (*Ctenopharyngodon idella*), bighead carp (*Aristichthys nobilis*), Siberian sturgeon (*Acipenser baerii*), and wels catfish (*Silurus glanis*) are popular food fish of commercial significance in many countries (www.fao.org/fishery/statistics/). Grass carp and bighead carp are herbivorous, whereas Siberian sturgeon and wels catfish are predators. The aforementioned species are freshwater fish.

The objective of the study was to determine the proximate composition, energy value, and amino acid profile of the muscle tissue of these four important food fish and to evaluate the quality of their protein in order to compare their nutritional value.

2. Materials and Methods

2.1. Sampling and Morphometrical Measurements. The research material consisted of the muscle tissue of grass carp ($n = 12$), bighead carp ($n = 12$), Siberian sturgeon ($n = 6$), and wels catfish ($n = 12$). The fish came from fish farms located in Eastern Poland and were obtained in the winter. The fish ate natural alimentation which was in the pond (typically for herbivorous fish i.a. grass carp and bighead carp and predatory fish i.a. Siberian sturgeon and wels catfish) and did not receive any industrial feed. After slaughter, the body weight and length of each fish were measured, and the fish were transported to the laboratory within one hour (at $0-4^{\circ}\text{C}$) and eviscerated. The carcasses were weighed to determine the carcass yield. A laboratory sample made by two fillets from each fish was ground twice in a meat mincer with a disc of a 2 mm mesh diameter. After 1 and 2 milling operations, the sample was blended to achieve homogeneity. The size of analytical samples depended on the kind of determination carried out and was consistent with methodological recommendations. The proximate composition and hydroxyproline content were measured on fresh muscle tissue samples, whereas the amino acid profile was determined in samples stored at -36°C .

2.2. Proximate Composition and Content of Hydroxyproline. The proximate composition of the muscle tissue was determined in accordance with international standards (ISO). The moisture content was measured by drying the samples in an oven at $103^{\circ}\text{C} \pm 2^{\circ}\text{C}$ to constant weight [15]. The fat content was determined by the ether extraction method with a Tecator Soxtec System HT 2 1045 Extraction Unit [16]. The

ash content was established by sample incineration in a muffle furnace at $550^{\circ}\text{C} \pm 25^{\circ}\text{C}$ until the resultant ash was light grey in color [17], and the protein content was estimated by the Kjeldahl method ($N \times 6.25$) with a Tecator Kjeltex System 1026 distilling unit after acid digestion [18]. In addition, the hydroxyproline concentration was established [19].

2.3. Amino Acid Composition. The amino acid profile was obtained by ion-exchange chromatography. The amino acid content in the samples (except for cystine, methionine, and tryptophan) was determined after acid hydrolysis with 6 N-HCl at 110°C for 20 h [20]. Cystine and methionine were measured as cysteic acid and methionine sulphone, respectively, by performic acid oxidation before hydrolysis with 6 N-HCl [21]. Tryptophan was quantified using alkaline hydrolysis with $\text{Ba}(\text{OH})_2$ at 110°C for 20 h [22]. Chromatographic analysis was performed in an AAA 400 Ingos automatic amino acid analyzer (Czech Republic, Prague) with an ion-exchange column and UV-VIS detector. The amino acid content in the samples was determined through comparison with the external standard after allowing for recoveries.

All chemical analyses were conducted in duplicate for each sample.

2.4. Carcass Yield, Caloric Value, CS, EAAI, and PDCAAS. Carcass yield, caloric value, CS, EAAI, and PDCAAS were calculated as follows [13, 14, 23]:

Carcass yield % = carcass weight with head/total weight $\times 100\%$.

Energy values = 4 kcal/g or 17 kJ/g for protein and 9 kcal/g or 37 kJ/g for fat.

CS = mg of an amino acid in 1 g of the protein tested/mg of the same amino acid in 1 g of the reference protein. CS is expressed either as a ratio to unity or on a percentage scale.

$$\text{EAAI} = n^{\log \text{EAA}},$$

$$\text{where } \log \text{EAA} = \frac{1}{n} \left(\log \frac{100a_1}{a_{1S}} + \dots + \log \frac{100a_n}{a_{nS}} \right). \quad (1)$$

PDCAAS = mg of limiting amino acid in 1 g of the protein tested/mg of the same amino acid in 1 g of the reference protein $\times$ true protein digestibility. The score is expressed as a decimal, but it may also be expressed in percentage terms.

2.5. Statistical Analysis. All data are presented as means and standard deviations (SD). The statistical analysis of the data was performed by the Statistica software ver. 6.0 and one-way ANOVA. Differences between the means were tested for statistical significance by the post hoc multiple-comparison test. The chemical composition, morphometrical measurements, and yield were evaluated by Tukey's test (for unequal

TABLE 1: Morphometrical measurements and yield of grass carp, bighead carp, Siberian sturgeon, and wels catfish (mean value $\pm$ SD).

	Species			
	Grass carp ($n = 12$)	Bighead carp ($n = 12$)	Siberian sturgeon ($n = 6$)	Wels catfish ($n = 12$)
Weight (kg)	2.04 ^a $\pm$ 0.55	2.64 ^b $\pm$ 0.30	2.17 ^{ab} $\pm$ 0.82	2.68 ^b $\pm$ 0.38
Length (cm)	54.92 ^a $\pm$ 5.58	50.38 ^a $\pm$ 1.58	79.83 ^b $\pm$ 9.02	74.00 ^b $\pm$ 3.72
Yield (%)	90.40 ^{ac} $\pm$ 1.32	89.79 ^a $\pm$ 0.99	85.94 ^b $\pm$ 2.06	91.50 ^c $\pm$ 1.22

Mean values in rows marked with different letters differ significantly at $p < 0.05$.

TABLE 2: Proximate composition, hydroxyproline level, and energy value of muscles of grass carp, bighead carp, Siberian sturgeon, and wels catfish (mean value $\pm$ SD).

	Species			
	Grass carp ($n = 12$)	Bighead carp ($n = 12$)	Siberian sturgeon ($n = 6$)	Wels catfish ($n = 12$)
Moisture (%)	78.06 ^a $\pm$ 1.40	73.56 ^b $\pm$ 2.01	69.89 ^c $\pm$ 2.11	78.90 ^a $\pm$ 2.44
Protein (%)	18.25 ^a $\pm$ 0.41	15.98 ^b $\pm$ 0.98	15.69 ^b $\pm$ 0.83	16.24 ^b $\pm$ 0.60
Fat (%)	2.28 ^a $\pm$ 1.0	8.93 ^b $\pm$ 2.31	12.57 ^c $\pm$ 2.20	3.78 ^a $\pm$ 2.09
Ash (%)	1.22 ^a $\pm$ 0.04	1.10 ^b $\pm$ 0.05	1.10 ^b $\pm$ 0.08	0.97 ^c $\pm$ 0.02
Hydroxyproline (%)	0.09 ^a $\pm$ 0.01	0.05 ^b $\pm$ 0.01	0.09 ^a $\pm$ 0.02	0.09 ^a $\pm$ 0.01
Energy value (kcal/100 g)	93.50 ^a $\pm$ 8.72	144.27 ^b $\pm$ 20.58	175.83 ^c $\pm$ 17.75	99.14 ^a $\pm$ 19.41

Mean values in rows marked with different letters differ significantly at $p < 0.05$.

sample sizes) and amino acids by Duncan's test. Differences between the groups with $p < 0.05$ were considered statistically significant.

3. Results and Discussion

The mean body weight, length, and carcass yield of the examined fish species are presented in Table 1. Carcass yield ranged from 85.94% for Siberian sturgeon to 91.50% for wels catfish. Carcass yields similar to those obtained in the present study were reported for farmed sturgeon hybrids (89.4%) [24], wild and cultivated pikeperch (88.06% and 83.82%, resp.) [25], and Atlantic salmon (87.5%) [26].

The proximate composition, hydroxyproline content, and energy value of the four fish species are presented in Table 2. The protein level in their muscle tissue ranged from 15.69% to 18.25%. In grass carp, it was higher than in bighead carp, Siberian sturgeon, and wels catfish by 12%, 14%, and 11%, respectively, and protein levels in these three species were similar. The fat content in the muscle tissue of the four species ranged from 2.28% to 12.57%. Siberian sturgeon contained significantly more fat compared to bighead carp, wels catfish, and grass carp, whereas the fat contents in wels catfish and grass carp were similar and significantly lower than in the bighead carp. Among the four fish species analyzed, significant differences in the fat content amounted to 29–82%. The fat content in fish muscle serves as the basis for the classification of fish as lean (containing up to 2% of fat), medium-fat (2–7% of fat), fat (7–15% of fat), and high-fat (above 15% of fat) [27]. According to this classification, the grass carp and wels catfish analyzed in this study belonged to the medium-fat category, whereas the bighead carp and Siberian sturgeon fell into the fat category. The water content in the muscle tissue varied between 69.89% and 78.90%. It was similar for wels catfish and grass carp, both of which had significantly greater water content than bighead carp and Siberian sturgeon. The

lowest water content was found in the Siberian sturgeon's muscle tissue. Significant differences in the water content of these fish were 1–11%. The ash content in the muscle tissue of the four fish species varied from 0.97% to 1.22% (with differences 10%–20%). It was the highest in grass carp, similar in bighead carp and Siberian sturgeon, and the lowest in wels catfish. The hydroxyproline content ranged from 0.05% in bighead carp muscle tissue to 0.09% in the other fish species, which suggests that the collagen content in the muscle tissue of these fish was low. The energy value of their muscle tissue varied between 93.50 kcal/100 g and 175.83 kcal/100 g (394.6–731.8 kJ/100 g). It was highest for the Siberian sturgeon, followed by bighead carp, and lowest for grass carp and wels catfish, two species with similar energy values. The energy value of the muscle tissue of the cultured sturgeon was reported as 105–208 kcal/100 g (444–866 kJ/100 g) [28], and the values obtained for sturgeon in this research were in the same range. The four fish species analyzed in this paper had lower energy values than the Baltic salmon (797.54 kJ/100 g) but higher energy values than the Baltic cod (295.8 kJ/100 g), farmed fish imported from Vietnam and China, such as sutchi catfish and tilapia (267.4 kJ/100 g and 352.8 kJ/100 g, resp.), or oceanic fish imported from China, such as walleye Pollock and sole (210.7 kJ/100 g and 246.3 kJ/100 g, resp.) [4].

Differences in the proximate composition of the muscle tissue of grass carp, bighead carp, Siberian sturgeon, and wels catfish have also been reported by other authors. The muscle tissue of grass carp originating from the Republic of Serbia [6], Iran [29], and Brasil [30] contained, respectively, 14.73%, 17.41%, and 19.31% of protein and 8.02%, 2.35%, and 1.80% of fat. The levels of protein and fat determined in grass carp in the present study differed from the above values (except for the fat level noted in grass carp from Iran). The muscle tissue of bighead carp from Bulgaria contained 15–16.75% of protein and 2.24–4.5% of fat [3], whereas the corresponding values for bighead carp from the Republic of Serbia were 18.03% and

TABLE 3: Amino acid profile of protein of grass carp, bighead carp, Siberian sturgeon, and wels catfish (mean value $\pm$ SD).

Amino acid (g/100 g protein)	Grass carp ($n = 6$)	Bighead carp ($n = 6$)	Siberian sturgeon ($n = 6$)	Wels catfish ($n = 6$)	Standard*
Isoleucine (Ile)	4.28 ^a $\pm$ 0.08	4.24 ^a $\pm$ 0.11	4.33 ^a $\pm$ 0.09	4.35 ^a $\pm$ 0.11	3.0
Leucine (Leu)	7.81 ^a $\pm$ 0.10	7.89 ^{ab} $\pm$ 0.15	7.97 ^b $\pm$ 0.13	7.98 ^b $\pm$ 0.10	6.1
Lysine (Lys)	9.83 ^a $\pm$ 0.11	9.69 ^a $\pm$ 0.17	10.02 ^b $\pm$ 0.17	9.71 ^a $\pm$ 0.07	4.8
Methionine (Met)	2.77 ^a $\pm$ 0.22	2.30 ^{bc} $\pm$ 0.19	2.44 ^b $\pm$ 0.41	2.05 ^c $\pm$ 0.13	2.3 ¹
Cysteine (Cys)	0.37 ^a $\pm$ 0.04	0.24 ^b $\pm$ 0.05	0.23 ^b $\pm$ 0.05	0.20 ^b $\pm$ 0.04	
Phenylalanine (Phe)	3.97 ^a $\pm$ 0.13	4.02 ^{ab} $\pm$ 0.06	4.25 ^c $\pm$ 0.06	4.10 ^b $\pm$ 0.05	4.1 ²
Tyrosine (Tyr)	3.26 ^a $\pm$ 0.12	3.35 ^a $\pm$ 0.09	3.57 ^b $\pm$ 0.06	3.26 ^a $\pm$ 0.08	
Threonine (Thr)	4.75 ^{ab} $\pm$ 0.05	4.71 ^a $\pm$ 0.11	4.86 ^b $\pm$ 0.13	5.15 ^c $\pm$ 0.11	2.5
Tryptophan (Try)	3.02 ^a $\pm$ 0.41	3.04 ^a $\pm$ 0.52	1.80 ^b $\pm$ 0.33	1.98 ^b $\pm$ 0.15	0.66
Valine (Val)	4.91 ^a $\pm$ 0.06	4.93 ^a $\pm$ 0.11	4.85 ^a $\pm$ 0.10	4.74 ^b $\pm$ 0.08	4.0
Histidine (His)	2.69 ^a $\pm$ 0.09	2.67 ^a $\pm$ 0.09	3.29 ^b $\pm$ 0.13	2.34 ^a $\pm$ 0.02	1.6
TEAA	47.64 ^a	47.08 ^a	47.62 ^a	45.86 ^b	29.06
Aspartic acid (Asp)	10.30 $\pm$ 0.10	10.28 $\pm$ 0.17	10.20 $\pm$ 0.18	10.52 $\pm$ 0.17	
Arginine (Arg)	6.59 $\pm$ 0.18	6.63 $\pm$ 0.13	6.66 $\pm$ 0.09	6.63 $\pm$ 0.13	
Serine (Ser)	4.17 $\pm$ 0.03	4.21 $\pm$ 0.07	4.49 $\pm$ 0.06	4.26 $\pm$ 0.07	
Glutamic acid (Glu)	15.06 $\pm$ 0.23	15.11 $\pm$ 0.73	14.91 $\pm$ 0.26	15.98 $\pm$ 0.15	
Proline (Pro)	4.70 $\pm$ 0.21	4.81 $\pm$ 0.26	4.80 $\pm$ 0.26	5.16 $\pm$ 0.22	
Glycine (Gly)	5.45 $\pm$ 0.32	5.67 $\pm$ 0.18	5.21 $\pm$ 0.29	5.43 $\pm$ 0.32	
Alanine (Ala)	6.09 $\pm$ 0.06	6.20 $\pm$ 0.07	6.10 $\pm$ 0.10	6.16 $\pm$ 0.07	
NEAA	52.36 ^a	52.92 ^a	52.38 ^a	54.14 ^b	
TSAA	3.14 ^a	2.53 ^{bc}	2.67 ^b	2.25 ^c	
TArAA	7.23 ^a	7.37 ^a	7.81 ^b	7.36 ^a	

Mean values in rows marked with different letters differ significantly at $p < 0.05$. * Recommended amino acid scoring pattern for adult. ¹Met + Cys. ²Phe + Tyr. TEAA: total essential amino acids; NEAA: nonessential amino acids; TSAA: total sulphur amino acids; TArAA: total aromatic amino acids.

6.29% [6]. In the present study, this fish species showed a higher fat content, whereas the protein level was within the range reported by Hadjinikolova et al. [3]. The muscle tissue of sturgeon from Northern Italy [28] and sturgeon hybrid from Germany [24] contained more protein (19.23% and 18.3%, resp.) and less fat (7.63% and 6.3%, resp.) than the Siberian sturgeon tissue examined in this study. In the muscle tissue of sturgeon from Poland analyzed by other authors [31], the protein content reached 14.3–16.5% and the fat content 6.4–9.5%. The protein level determined for this species in the present study remained within the above range, but the fat content was higher. Wels catfish from the Republic of Serbia [6] and Greece [32] contained, respectively, 17.34% and 18% of protein and 3.96% and 3.2–3.8% of fat. The present study of this species showed lower protein content and a fat level within the above range of values. The protein content determined here for wels catfish muscle tissue was also consistent with the range of values provided in nutrition tables (13.4–16.5%) [23]. Differences in the levels of basic components in the muscle tissue of fish have been confirmed by a number of authors. The proximate composition of muscle tissue depends on the species, age, diet, season, source, and geographical origin [6, 33–36].

The amino acid profile of the muscle tissue protein analyzed is presented in Table 3. The muscle tissue of grass carp, bighead carp, Siberian sturgeon, and wels catfish contained the following amounts of particular essential amino acids per 100 g protein: 4.24–4.35 g isoleucine (with differences 0.5–2.6%), 7.81–7.98 g leucine (with differences 0.2–2.2%), 9.69–10.02 g lysine (with differences 1.9–3.3%), 2.05–2.77 g methionine (with differences 12–26%), 0.20–0.37 g cysteine (with differences 35.2–46%), 3.97–4.25 g phenylalanine (with differences 3.6–6.6%), 3.26–3.57 g

tyrosine (with differences 6.2–8.7%), 4.71–5.15 g threonine (with differences 5.7–8.6%), 1.80–3.04 g tryptophan (with differences 0.7–40.8%), 4.74–4.93 g valine (with differences 0.5–3.9%), and 2.34–3.29 g histidine (with differences 18.3–28.9%). The sums of essential amino acids in the muscle tissue of grass carp, bighead carp, and Siberian sturgeon were similar (47.64–47.08 g per 100 g of protein) but significantly higher than TEAA in the muscle tissue of wels catfish (45.86 g). In all fish, lysine was the most abundant essential amino acid (9.69–10.02 g), and cysteine was the least abundant (0.20–0.37 g). Isoleucine was the only essential amino acid whose content was comparable in all four species. The sulphur amino acid content in muscle tissue was highest for grass carp (3.14 g), followed by Siberian sturgeon and bighead carp (2.76 g and 2.53 g, resp.), and lowest for wels catfish (2.25 g). The level of aromatic amino acids was significantly higher in Siberian sturgeon muscle tissue (7.81 g) than in the muscle tissue of the other fish species (7.23–7.37 g). The muscle tissue of herbivorous species, that is, grass carp and bighead carp, differed in the content of methionine and cysteine, but the levels of the other amino acids were comparable. The muscle tissue of predatory fish, namely, Siberian sturgeon and wels catfish, contained similar amounts of leucine, cysteine, and tryptophan, whereas the contents of lysine, methionine, phenylalanine, tyrosine, threonine, valine, and histidine varied significantly. The sum of nonessential amino acids was higher in wels catfish muscle tissue (54.14 g/100 g of protein) than in the other three fish species, in which these values were comparable. Among the nonessential amino acids, the levels of glutamic acid were the highest (14.91–15.98 g), and those of serine the lowest (4.17–4.49 g). The sum of

TABLE 4: CS (Chemical Score) and EAAI (Essential Amino Acid Index) for protein of grass carp, bighead carp, Siberian sturgeon, and wels catfish (%).

Amino acid	Grass carp	Bighead carp	Siberian sturgeon	Wels catfish	Standard*
Ile	143	141	144	145	3.0
Leu	128	129	131	131	6.1
Lys	205	202	209	202	4.8
Met + Cys	137	110	116	98	2.3
Phe + Tyr	176	180	191	180	4.1
Thr	190	188	194	206	2.5
Try	458	461	273	300	0.66
Val	123	123	121	119	4.0
His	168	167	206	146	1.6
EAAI	139	136	134	128	

* Recommended amino acid scoring pattern for adult.

essential amino acids in the muscle tissue of cultured sturgeon (47.15 g/100 g of protein) reported by Badiani et al. [28] was comparable to that found in this fish species in the present study. The greatest difference relative to their findings was a considerably higher tryptophan content determined in the present study. In the muscle tissue protein of fish caught in the Vistula Lagoon [37], such as herring, perch, pikeperch, and eel, the sum of essential amino acids (without histidine) ranged from 39.93 g (per 100 g of protein) for eel to 45.36 g for pikeperch. As in the present study, the content of lysine was the highest. The fish from the Vistula Lagoon had a higher content of sulphur amino acids (3.93–4.20 g) and, with the exception of pikeperch, a lower content of aromatic amino acids (6.42–6.69 g) compared with grass carp, bighead carp, Siberian sturgeon, and wels catfish. The sum of essential amino acids (except tryptophan, which was not determined) in the muscle tissue protein of marine fish, such as *Clupea harengus*, *Scomber scombrus*, and *Urophycis tenuis*, varied from 40.73 g to 44.04 g per 100 g of protein [38]. As in the present study, the quantity of lysine was the highest and that of cysteine the lowest. The contents of sulphur amino acids (3.44–3.69 g) and aromatic amino acids (10.24–11.24 g) in these fish species were higher than in grass carp, bighead carp, Siberian sturgeon, and wels catfish. EL oudiani and Moujahed [39] reported the sum of essential amino acids (with histidine, tryptophan not determined) in *Scomber scombrus* as 38.55 g/100 g of protein and the contents of sulphur amino acids and aromatic amino acids as 3.34 g and 9.62 g, respectively. According to these results, the muscle tissue of grass carp, bighead carp, Siberian sturgeon, and wels catfish contained less sulphur amino acids and aromatic amino acids compared with *Scomber scombrus*. In *Clarias anguillaris*, *Oreochromis niloticus*, and *Cynoglossus senegalensis*, the sum of essential amino acids (without tryptophan) amounted to 30.0–31.7 g/100 g of protein [40]. This suggests that, although tryptophan was not determined, TEAA values in those fish species were lower than the values found in the present study in the muscle tissue of grass carp, bighead carp, Siberian sturgeon, and wels catfish.

The quality of protein was evaluated against the standard protein with the use of CS, PDCAAS, and EAAI. Compared with the standard protein recommended by FAO Expert Consultation on Protein Quality Evaluation in Human Nutrition from 2011, the levels of all essential amino acids in the

grass carp, bighead carp, Siberian sturgeon, and wels catfish were higher, with the exception of the methionine + cysteine level in wels catfish (2.25 g/100 g of protein, which was similar) (Table 3). The muscle tissue protein of grass carp, bighead carp, Siberian sturgeon, and wels catfish fully measured up to the standard protein. The limiting amino acid (CS) was methionine + cysteine in the protein of wels catfish, bighead carp, and Siberian sturgeon (CS: 98%, 110%, and 116%, resp.) and valine in the protein of grass carp (CS: 123%). The level of the limiting amino acid was lower than in the standard protein only for wels catfish, whereas for bighead carp, Siberian sturgeon, and grass carp, the limiting amino acid was more abundant compared to the standard (Table 4).

PDCAAS (Protein Digestibility-Corrected Amino Acid Score) values for essential amino acids ranged from 92% for methionine + cysteine in the muscle tissue protein of wels catfish to over 100% for all amino acids in the muscle tissue protein of the other species (Table 5).

Table 5 contains data regarding the limiting amino acids, as well as the 11 essential amino acids. In order to provide more detailed information, the values of particular essential amino acids exceeding 100 have not been rounded. Protein digestibility-corrected amino acid scores above 100% would be considered as 100% [14]. The truncation of PDCAAS values to 100% is acceptable only if the protein is used as the sole protein source in the diet. Truncated values should not be used in evaluating the nutritional significance of proteins in mixed diets [41]. Both PDCAAS and CS indicated a lower methionine + cysteine content in the protein of wels catfish compared with the standard protein. EAAI ranged between 128 in wels catfish and 139 in grass carp, which shows that the sum of essential amino acids in the protein of grass carp, bighead carp, Siberian sturgeon, and wels catfish was higher than it was in the reference standard protein (Table 4). Thus, EAAI did not confirm the lower methionine + cysteine content in the protein of wels catfish. In the available literature, the values of CS, EAAI, and PDCAAS for fish muscle tissue proteins do not refer to the standard assumed in this research and therefore cannot be compared with the results obtained for the fish species analyzed.

The contents of particular essential amino acids in 100 g of the muscle tissue for the four fish species and the

TABLE 5: PDCAAS (Protein Digestibility-Corrected Amino Acid Score) for protein of grass carp, bighead carp, Siberian sturgeon, and wels catfish (%).

Amino acid	Grass carp	Bighead carp	Siberian sturgeon	Wels catfish	Standard*
Ile	134	133	136	136	3.0
Leu	120	122	123	123	6.1
Lys	193	190	196	190	4.8
Met + Cys	128	104	109	92	2.3
Phe + Tyr	166	169	179	169	4.1
Thr	179	177	183	194	2.5
Try	430	433	256	282	0.66
Val	115	116	114	111	4.0
His	158	157	193	137	1.6

*Recommended amino acid scoring pattern for adult.

TABLE 6: Essential amino acid content in muscle (g/100 g muscle) of grass carp, bighead carp, Siberian sturgeon, and wels catfish and the recommended daily intake for an adult man weighing 70 kg.

Amino acid	Recommended daily intake*		Grass carp	Bighead carp	Siberian sturgeon	Wels catfish
	(mg/kg body weight)	(g/70 kg body weight)				
Thr	6.5	0.46	0.88	0.79	0.80	0.80
Val	11.4	0.80	0.91	0.83	0.80	0.74
Ile	15.7	1.10	0.79	0.71	0.71	0.68
Leu	9.5	0.67	1.44	1.33	1.31	1.25
Tyr + Phe	12.1	0.85	1.33	1.24	1.29	1.15
Cys + Met	12.1	0.85	0.58	0.43	0.44	0.35
Try	2.9	0.20	0.56	0.51	0.30	0.31
Lys	9.4	0.66	1.82	1.63	1.65	1.52
ΣEAA	79.6	5.59	8.31	7.47	7.3	6.8

*According to Gawęcki [42].

recommended daily intake for an adult man weighing 70 kg are presented in Table 6. The sum of essential amino acids in 100 g of the muscle tissue of grass carp, bighead carp, Siberian sturgeon, and wels catfish was higher than the recommended daily intake. However, one has to point out the lower content of sulphur amino acids and isoleucine in all fish species analyzed as well as the lower valine content in wels catfish. Therefore, the recommended daily intake of all essential amino acids for an adult weighing 70 kg would require the consumption of 200 g of the muscle tissue of grass carp, bighead carp or Siberian sturgeon, or 250 g of wels catfish muscle tissue.

4. Conclusion

The four fish species examined in this study are characterized by high nutritional value and offer health benefits to consumers. However, the chemical composition of their muscle tissue is species-dependent. The muscle tissue of grass carp and wels catfish examined in this study had a lower caloric value than that of bighead carp and Siberian sturgeon, which may be useful in formulating a restricted calorie diet. Grass carp and wels catfish were classified as medium-fat fish, whereas bighead carp and Siberian sturgeon were categorized as fatty fish. The muscle tissue protein level was the highest in grass carp, but the quality of proteins was high in all species. All of them can serve as valuable sources of essential amino acids in terms of both quantity and quality.

The essential amino acid content in the protein of these fish was similar (for methionine + cysteine in wels catfish muscle) or even higher than that in the standard protein. Compared with the standard protein, the content of the limiting amino acid in muscle tissue was greater for grass carp, bighead carp, and Siberian sturgeon and similar for wels catfish. CS and PDCAAS confirmed the slightly lower value of protein in wels catfish muscle due to its lower content of methionine + cysteine. All four species, however, were particularly rich in lysine and tryptophan. These fish can constitute a healthy addition to the human diet, and the results obtained in this study can serve as a reference for nutritionists and dieticians.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Additional Points

This study has documented the effect of fish species on the proximate composition, energy value, amino acid profile, and protein quality of the muscle tissue of grass carp, bighead carp, Siberian sturgeon, and wels catfish. The research results can serve as a reference for nutritionists and dieticians.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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