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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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].
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 re-
search 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°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
within one hour (at 0–4°C) and eviscerated. fi+Çhe proximate composition of the muscle tissue was de-
determined in samples stored at −36°C. The

2.2. Proximate Composition and Content of Hydroxyproline.
The proximate composition of the muscle tissue was de-
termined in accordance with international standards (ISO).
The moisture content was measured by drying the samples in
an oven at 103°C ± 2°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°C ± 25°C until the resultant ash was
light grey in color [17], and the protein content was esti-
blished [13, 14, 23]:

\[ \text{PDCAAS} = \frac{\text{mg of an amino acid in 1 g of the protein}}{\text{mg of the same amino acid in 1 g of the reference protein}} \times \text{true protein digestibility} \]

where \( \text{PDCAAS} \) is an index expressed in percentage terms.

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, re-
spectively, by performic acid oxidation before hydrolysis
with 6 N-HCl [21]. Tryptophan was quantified using alkaline
hydrolysis with Ba(OH)\(_2\) at 110°C for 20 h [22]. Chro-
matographic 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]:

\[ \text{Carcass yield } \% = \frac{\text{carcass weight with head}}{\text{total weight}} \times 100\% \]

\[ \text{Energy values} = 4 \text{ kcal/g or 17 kJ/g for protein and} \]
\[ 9 \text{ kcal/g or 37 kJ/g for fat} \]

\[ \text{CS} = \frac{\text{mg of an amino acid in 1 g of the protein tested}}{\text{mg of the same amino acid in 1 g of the reference protein}} \]

\[ \text{PDCAAS} = \text{mg of limiting amino acid in 1 g of the protein tested/mg of the same amino acid in 1 g of the reference protein} \]

\[ \text{EAAI} = n \log \left( \frac{100a_1}{a_1} + \ldots + \frac{100a_n}{a_n} \right) \]

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 measure-
ments, and yield were evaluated by Tukey’s test (for unequal

present study were reported for farmed sturgeon hybrids. Carcass yields similar to those obtained in the ranged from 85.94% for Siberian sturgeon to 91.50% for wels examined fish species are presented in Table 1. Carcass yield fi+Çhe mean body weight, length, and carcass yield of the

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 yield 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 surtchi 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
The amino acid profile of the muscle tissue protein analyzed is presented in Table 3. The muscle tissue of grass carp, bighhead 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 35–46%), 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 0.7–40.8%).

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.
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 cultured sturgeon, and wels catfish. The sum of essential amino acids (without histidine) ranged from 6.69 g) compared with grass carp, bighead carp, Siberian sturgeon, and wels catfish.

### 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.

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

PDCASAS (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 PDCASAS 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 PDCASAS 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 PDCASAS 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
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.

**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.

**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.

References

[1] G. Özyurt and A. Polat, “Amino acid and fatty acid composition of wild sea bass (Dicentrarchus labrax): a seasonal differentiation,” European Food Research and Technology, vol. 222, no. 3-4, pp. 316–320, 2006.

[2] Z. Tzikas, I. Amvrosiadis, N. Soultos, and Sp. Georgakis, “Seasonal variation in the chemical composition and microbiological condition of Mediterranean horse mackerel (Trachurus mediterraneus) muscle from the North Aegean Sea (Greece),” Food Control, vol. 18, no. 3, pp. 251–257, 2007.

[3] L. Hadjinikolova, L. Nikolova, and A. Stoeva, “Comparative investigations on the nutritive value of carp fish meat (Cyprinidae), grown at organic aquaculture conditions,” Bulgarian Journal of Agricultural Science, vol. 14, no. 2, pp. 127–132, 2008.

[4] Z. Usydus, J. Szlinder-Richert, M. Adamczyk, and U. Szatkowska, “Effect of different precooking methods on chemical composition and lipid damage of silver carp (Hypophthalmichthys molitrix (Val.), and rainbow trout, Oncorhyncus mykiss (Walbaum), correlated withbody weight,” Archives of Polish Fisheries, vol. 20, no. 4, pp. 275–280, 2012.

[5] M. R. Gholi, M. Dezhabad, M. S. Dalirie et al., “Nutritional properties of kutum, Rutilius frisi kutum (Kameský), silver carp, Hypophthalmichthys molitrix (Val.), and rainbow trout, Oncorhyncus mykiss (Walbaum), correlated with body weight,” Archives of Polish Fisheries, vol. 20, no. 4, pp. 275–280, 2012.

[6] D. Ljubojević, M. Ćirkić, V. Đorđević et al., “Fat quality of marketable fresh water fish species in the Republic of Serbia,” Journal of Food Science, vol. 31, no. 5, pp. 445–450, 2013.

[7] M. Naseri, M. Rezae, S. Moieni, H. Hosseni, and S. Eskandari, “Effect of different precooking methods on chemical composition and lipid damage of silver carp (Hypophthalmichthys molitrix) muscle,” International Journal of Food Science and Technology, vol. 45, no. 10, pp. 1973–1979, 2010.

[8] H. Karl, I. Lehmann, M. Manthey-Karl, C. Meyer, and U. Ostermeyer, “Comparision of nutritional value and microbiological status of new imported fish species on the German market,” International Journal of Food Science and Technology, vol. 49, no. 11, pp. 2481–2490, 2014.

[9] P. Skalecki, M. Florek, A. Litwińczuk, A. Staszkowska, and A. Kaliniak, “The nutritional value and chemical composition of muscle tissue of carp (Cyprinus carpio L.) and rainbow trout (Oncorhyncus mykiss Walb.) obtained from fish farms in the Lublin region,” Scientific Annals of Polish Society of Animal Production, vol. 9, no. 2, pp. 57–62, 2013.

[10] P. Skalecki, M. Florek, A. Litwińczuk, and A. Zaborska, “Utility value and meat quality of rainbow trout (Oncorhyncus mykiss) with regard to the weight of fish,” Scientific Annals of Polish Society of Animal Production, vol. 9, no. 1, pp. 69–73, 2013.

[11] B. Mohanty, A. Mahanty, S. Ganguly et al., “Amino acid compositions of 27 food fishes and their importance in clinical nutrition,” Journal of Amino Acids, vol. 2014, Article ID 269797, 7 pages, 2014.

[12] Report of an FAO Expert Consultation, “Dietary protein quality evaluation in human nutrition,” FAO Food and Nutrition Paper, vol. 92, pp. 1–66, 2013.

[13] B. L. Oser, “Method for integrating essential amino acid content in the nutritional evaluation of protein,” Journal of the American Dietetic Association, vol. 27, no. 5, pp. 396–402, 1951.

[14] Report of Joint FAO/WHO Expert Consultation, “Protein quality evaluation,” FAO Food and Nutrition Paper, vol. 51, pp. 1–66, 1991.

[15] PN-ISO 1442, “Meat and meat products—Determination of moisture content (Reference method),” 2000.

[16] PN-ISO 1444, “Meat and meat products—Determination of free fat content,” 2000.

[17] PN-ISO 936, “Meat and meat products—Determination of total ash,” 2000.

[18] PN-A-04018, “Agricultural foods products. Determination of nitrogen by the Kjeldahl method and expressing as protein,” 1975.

[19] PN-ISO 3496, “Meat and meat products—Determination of hydroxyproline content,” 2000.

[20] M. G. Davies and A. J. Thomas, “An investigation of hydrolytic techniques for the amino acid analysis of foodstuffs,” Journal of the Science of Food and Agriculture, vol. 24, no. 12, pp. 1525–1540, 1973.

[21] E. Schram, S. Moor, and E. J. Bigwood, “Chromatographic determination of cystine as cystic acid,” Biochemical Journal, vol. 57, no. 1, pp. 33–37, 1954.

[22] P. Słaźiński and K. Tyczkowska, “Conditions for the hydrolysis of fodder raw materials and products in determining tryptophan,” Roczniki Technologii i Chemii Żywności, vol. 24, pp. 155–163, 1974.

[23] S. W. Souci, W. Fachmann, and H. Kraut, Food Composition and Nutrition Tables, Medpharm Scientific Publishers, Stuttgart, Germany, 2000.

[24] H. Wedekind, “Chemical composition and processability of farmed sturgeon hybrids with special emphasis on Bester,” International Review of Hydrobiology, vol. 87, no. 5-6, pp. 621–627, 2002.

[25] B. Jankowska, Z. Zakęs, T. Żmijewski, and M. Szczepkowski, “A comparison of selected quality features of the tissue and slaughter yield of wild and cultivated pikeperch Sander lucioperca (L.),” European Food Research and Technology, vol. 217, no. 5, pp. 401–405, 2003.

[26] T. Larsson, E. O. Koppang, M. Espe et al., “Filet quality and health of Atlantic salmon (Salmo salar L.) fed a diet supplemented with glutamate,” Aquaculture, vol. 426–427, pp. 288–295, 2014.

[27] PN-A-86770, “Fish and fishery products—Terminology,” 1999.

[28] A. Badiani, P. Anfossi, L. Fiorentini et al., “Nutritional composition of cultured sturgeon (Acipenser spp.),” Journal of Food Composition and Analysis, vol. 9, no. 2, pp. 171–190, 1996.

[29] M. Afkhami, A. Mokhlesi, K. D. Bastami, R. Khoshrood, N. Eshaghi, and M. Ehsanpour, “Survey of some chemical compositions and fatty acids in cultured common carp (Cyprinus carpio) and grass carp (Ctenopharyngodon idella),” Noshahr, Iran, World Journal of Fish and Marine Sciences, vol. 3, no. 6, pp. 533–538, 2011.

[30] R. Scherer, P. R. Augusti, V. C. Bochi et al., “Chemical and microbiological quality of grass carp (Ctenopharyngodon idella) slaughtered by different methods,” Food Chemistry, vol. 99, no. 1, pp. 136–142, 2006.

[31] B. Jankowska, R. Kolman, M. Szczepkowski, and T. Żmijewski, “Production value, chemical composition and colour of fillets of the reciprocal hybrid of Siberian sturgeon with green sturgeon (Acipenser baeri Br x (Acipenser baeri x Acipenser medirostris Ayres),” Czech Journal of Animal Science, vol. 50, no. 5, pp. 220–225, 2005.
[32] E. S. Lazos, G. Aggelousis, and A. Alexakis, “Metal and proximate composition of the edible portion of 11 freshwater fish species,” Journal of Food Composition and Analysis, vol. 2, no. 4, pp. 371–381, 1989.

[33] A. Öksüz, A. Küçükgülmez, A. Diler, M. Çelik, and E. Koyuncu, “Research note: A comparison of the chemical composition of zander (Sander lucioperca) living in different lakes of Turkey,” Journal of Muscle Foods, vol. 20, no. 4, pp. 420–427, 2009.

[34] M. Ćirković, D. Trbović, D. Ljubojević, and V. Dordević, “Meat quality of fish farmed in polyculture in carp ponds in Republic of Serbia,” Tehnologija Mesa, vol. 52, no. 1, pp. 106–121, 2011.

[35] S. Yeganeh, B. Shabanpour, H. Hosseini, M. R. Imanpour, and A. Shabani, “Comparison of farmed and wild common carp (Cyprinus carpio): Seasonal variations in chemical composition and fatty acid profile,” Czech Journal of Food Sciences, vol. 30, no. 6, pp. 503–511, 2012.

[36] F. Wang, X. Ma, W. Wang, and J. Liu, “Comparison of proximate composition, amino acid and fatty acid profiles in wild, pond- and cage-cultured longsnout catfish (Leiocassis longirostris),” International Journal of Food Science and Technology, vol. 47, no. 8, pp. 1772–1776, 2012.

[37] L. Polak-Justczak and M. Adamczyk, “Quality and amino acid composition of protein of fish from the Vistula Lagoon,” Żywność Nauka Technologia Jakość, vol. 64, no. 3, pp. 75–83, 2009.

[38] O.O. Oluwaniyi, O. O. Dosumu, and G. V. Awolola, “Effect of local processing methods (boiling, frying and roasting) on the amino acid composition of four marine fishes commonly consumed in Nigeria,” Food Chemistry, vol. 123, no. 4, pp. 1000–1006, 2010.

[39] G. S. El oudiani and N. Moujahed, “Atlantic mackerel amino acids and mineral contents from the Tunisian middle eastern coast,” International Journal of Agricultural Policy and Research, vol. 3, no. 2, pp. 77–83, 2015.

[40] E. I. Adeyeye, “Amino acid composition of three species of Nigerian fish: Clarias anguillaris, Oreochromis niloticus and Cynoglossus senegalensis,” Food Chemistry, vol. 113, no. 1, pp. 43–46, 2009.

[41] G. Schaafsma, “The protein digestibility-corrected amino acid score,” Journal of Nutrition, vol. 130, no. 7, pp. 1865–1867, 2000.

[42] J. Gawęcki, Białka w żywności i żywieniu, WAR Publisher, Poznań, Poland, 2003.
