Postprint of Analysis and Evaluation of Nutritional Components in Spinibarbus hollandi Roe

Authors: Li Cheng, Cheng Xiaofei, Hong Bo, Chen Xiangyi, Wu Yuanan, Li Hong

Date: 2017-10-10T00:00:00+00:00

Abstract

To evaluate the nutritional quality of Spinibarbus hollandi fish eggs, this study employed conventional methods to determine the general nutritional component content, amino acid composition, fatty acid composition, and trace element content of S. hollandi fish eggs. The results showed that S. hollandi fish eggs (fresh sample) contained 27.66% crude protein, 3.18% crude fat, 64.26% moisture, and 3.09% crude ash. A total of 17 amino acids were detected in S. hollandi fish eggs, including 7 essential amino acids (EAA) and 10 non-essential amino acids (NEAA), with total amino acid (TAA) content of 23.21%, EAA content of 9.28%, and NEAA content of 13.93%; the composition ratio of EAA conformed to FAO/WHO standards. Evaluated by amino acid score (AAS) and chemical score (CS), the first limiting amino acid was methionine + cysteine, and the second limiting amino acid was phenylalanine + tyrosine. The essential amino acid index (EAAI) was 59.26%. A total of 11 fatty acids were detected in S. hollandi fish eggs, including 3 saturated fatty acids (SFA), 3 monounsaturated fatty acids (MUFA), and 5 polyunsaturated fatty acids (PUFA), accounting for 22.68%, 48.40%, and 28.93% of total fatty acids, respectively; C20:5n-3 (EPA) + C22:6n-3 (DHA) accounted for 8.53% of total fatty acids. The trace elements copper, zinc, iron, manganese, and selenium were abundant in S. hollandi fish eggs, with zinc and iron contents reaching as high as 90.9865 and 31.3863 mg/kg, respectively. It can be concluded that S. hollandi fish eggs are rich in nutritional value and possess high comprehensive development and utilization value.

Full Text

Nutritional Analysis and Evaluation of *Spinibarbus hollandi* Eggs

Li Cheng[1],[2], Cheng Xiaofei[1], Hong Bo[1], Chen Xiangyi[1], Wu Yuanan[1],[2], Li Hong[1],[3]*

[1]Fisheries Science Institute of Hunan Province, Changsha 410153, China
[2]Collaborative Innovation Center for Efficient and Healthy Production of Fisheries in Hunan Province, Changde 415000, China
[3]Huazhong Agricultural University, Wuhan 430070, China

Abstract

To evaluate the nutritional quality of *Spinibarbus hollandi* eggs, conventional methods were employed to determine the contents of general nutritional components, amino acid composition, fatty acid composition, and trace elements. The results indicated that fresh *S. hollandi* eggs contained 27.66% crude protein, 3.18% crude fat, 64.26% moisture, and 3.09% crude ash. Seventeen amino acids were detected, including 7 essential amino acids (EAA) and 10 non-essential amino acids (NEAA). The total amino acid (TAA) content was 23.21%, with EAA at 9.28% and NEAA at 13.93%. The EAA composition conformed to FAO/WHO standards. Based on amino acid score (AAS) and chemical score (CS), the first limiting amino acid was methionine + cysteine, and the second limiting amino acid was phenylalanine + tyrosine. The essential amino acid index (EAAI) was 59.26%. Eleven fatty acids were identified, comprising 3 saturated fatty acids (SFA), 3 monounsaturated fatty acids (MUFA), and 5 polyunsaturated fatty acids (PUFA), accounting for 22.68%, 48.40%, and 28.93% of total fatty acids, respectively. C20:5n-3 (EPA) + C22:6n-3 (DHA) represented 8.53% of total fatty acids. The eggs were rich in trace elements copper, zinc, iron, manganese, and selenium, with zinc and iron contents reaching 90.9865 mg/kg and 31.3863 mg/kg, respectively. These findings demonstrate that *S. hollandi* eggs possess rich nutritional value and high potential for comprehensive development and utilization.

Keywords: *Spinibarbus hollandi*; fish eggs; amino acids; fatty acids; trace elements; nutritional evaluation

Introduction

Spinibarbus hollandi, also known as *Spinibarbus caldwelli* or commonly referred to as qingzhun, jianzhong, qingjuan, kenjian, huangjian, and guangyanyu, belongs to the genus *Spinibarbus*, subfamily Barbinae, family Cyprinidae. This omnivorous fish feeds primarily on small fish, shrimp, aquatic insects, blue-green algae, and organic debris, and is distributed across various river systems including the Yangtze, Qiantang, Min, Jiulong, Pearl, and Yuan Rivers, as well as Taiwan and Hainan Islands. As a major economic fish species in the upper reaches of Hunan' s "Xiang, Zi, Yuan, and Li" rivers, *S. hollandi* had annual catch yields of several thousand tons in the 1980s. However, due to hydraulic engineering construction and environmental degradation that destroyed its spawning and feeding grounds, annual catches have dropped to less than 200 tons. Consequently, the species was listed in the IUCN Red Book of Endangered

Species in 2013, making resource conservation and artificial breeding research urgently necessary.

Current research on *S. hollandi* has primarily focused on biological characteristics, artificial propagation, reproductive cell gene cloning and expression, seedling cultivation techniques, aquaculture technology, species identification, and nutritional requirements. Although some studies have examined nutritional components, these have been limited to muscle tissue, with no reports on the nutritional composition and value of *S. hollandi* eggs. Fish egg nutritional components serve as important indicators for evaluating caviar quality and provide reference bases for determining larval nutritional requirements. Therefore, studying *S. hollandi* egg nutrition is significant for artificial propagation. Female *S. hollandi* reach sexual maturity at approximately 3+ years, with absolute fecundity of 14,300–31,000 eggs, relative fecundity of 19.32–21 eggs/g, and egg diameter of 0.8–2.1 mm. These eggs are smaller than those of *Hemitripterus villosus* (4 mm), *Acipenser sinensis* (5–6 mm), and *Huso dauricus* (2.5–3.5 mm). Compared with sturgeon and salmonid eggs typically used for caviar production, *S. hollandi* has both smaller fecundity and egg diameter, and due to relatively limited resources, is not recommended for caviar production.

Currently, researchers both domestically and internationally have determined nutrient content and ratios in larval artificial diets by studying cultured fish egg nutritional components. For example, Yang et al. proposed theoretical requirements for some nutrients in *H. villosus* larvae through egg nutritional analysis. Pousão-Ferreira et al. determined protein requirements for gilthead seabream (*Sparus aurata* L.) larvae based on egg protein content. Sargent et al. suggested that lipid content and composition in marine fish eggs correspond to larval lipid requirements. Mourente et al. determined fatty acid ratios in artificial diets for Senegal sole (*Solea senegalensis* Kaup) by analyzing egg lipid and fatty acid content. This study aims to measure and analyze the general nutritional components, amino acid composition, fatty acid composition, and trace element content of *S. hollandi* eggs to understand their nutritional value and provide fundamental data for comprehensive development and larval feed formulation.

Materials and Methods

Sample Collection

In October 2014, five sexually mature female *S. hollandi* (body weight: 1,319.4 ± 67.2 g; body length: 47.5 ± 2.5 cm) were obtained from a reservoir cage culture base in Zhijiang, Huaihua City, Hunan Province.

Sample Preparation

Eggs were extracted from the five mature females through dissection, homogenized, and mixed thoroughly. Samples were stored at -80 °C for subsequent

determination of general nutritional components, amino acid composition, fatty acid composition, and mineral element content.

Analytical Methods

General Nutritional Components: Moisture content was determined by atmospheric pressure drying at (105 ± 2) °C (GB/T 5009.3-2010). Crude protein was measured by the Kjeldahl method (GB/T 5009.5-2010) using a FOSS Kjeltec 8400 automatic analyzer (Denmark). Crude fat was determined by Soxhlet extraction (GB/T 5009.6-2003) using a FOSS Soxhlet extractor (Denmark). Crude ash content was measured by incineration at 550 °C in a muffle furnace (GB/T 5009.4-2010).

Amino Acid Composition: Determined according to Cheng et al. Fresh samples (0.5 g) were hydrolyzed with 6 mol/L HCl at 110 °C for 22 h, filtered, and diluted to 50 mL. After vacuum drying 0.5 mL of the solution, amino acid composition and content were analyzed using an automatic amino acid analyzer (Beckman® 121 MB, USA).

Fatty Acid Composition: Determined according to Tian et al. Samples were homogenized, and 0.3–0.5 g was weighed into a 10 mL centrifuge tube with 5 mL methanol:chloroform (1:2), shaken for 1 h, filtered, mixed with 4 mL distilled water, and centrifuged at 3,000 r/min for 5 min. The supernatant was removed, and the lower layer was dried under negative pressure at 40 °C. The extracted lipids were dissolved in 1 mL chromatographic-grade n-hexane, methylated with 1 mL 0.4 mol/L KOH-methanol solution for 30 min, then mixed with 2 mL deionized water. After layering, the upper solution was analyzed by gas chromatography (Agilent 7820a, USA) using a 30 m × 0.320 mm × 0.25 μm Agilent 19091J-413 GC column at 210 °C column temperature, 300 °C detector temperature (FID), and 250 °C injector temperature, with high-purity nitrogen as carrier gas (30 mL/min), hydrogen (40 mL/min), and air (450 mL/min). Fatty acid components were calculated by area normalization and expressed as percentages of total fatty acids.

Mineral Element Content: Samples were sent to the Fishery Product Quality Supervision and Testing Center of the Ministry of Agriculture (Changsha) for dry digestion and analysis by atomic absorption spectrophotometry.

Calculation of Theoretical Nutrient Requirements for Larvae

Theoretical dietary nutrient requirements for *S. hollandi* larvae were calculated following Yang et al. Crude protein and fat contents in eggs were converted to a dry matter basis to determine theoretical protein and fat requirements. Amino acid contents were converted to dry matter percentages based on crude protein content. Fatty acid contents were converted to dry matter percentages based on crude fat content. Trace element contents were converted to dry matter percentages based on crude ash content.

Nutritional Quality Evaluation Methods

Based on the FAO/WHO (1973) amino acid scoring pattern and whole egg protein amino acid pattern, amino acid score (AAS), chemical score (CS), and essential amino acid index (EAAI) were calculated using formulas from reference [33]:

$$\mathrm{AAS} = \frac{\mathrm{aa}}{\mathrm{AA(FAO/WHO)}}$$

$$\mathrm{CS} = \frac{\mathrm{aa}}{\mathrm{AA(Egg)}}$$

$$\mathrm{EAAI} = \sqrt[n]{\frac{A}{AE} \times \frac{B}{BE} \times \frac{C}{CE} \times \cdots \times \frac{H}{HE}} \times 100$$

where *aa* is the test sample amino acid content (%), AA(FAO/WHO) is the same amino acid content in the FAO/WHO scoring pattern (%), AA(Egg) is the same amino acid content in whole egg protein (%), n is the number of essential amino acids compared, A, B, C, ···, H are the essential amino acid contents in sample protein (%, dry matter basis), and AE, BE, CE, ···, HE are the corresponding essential amino acid contents in whole egg protein (%, dry matter basis).

All data are expressed as mean ± SD and analyzed using Excel 2003 and SPSS 18.0 statistical software.

Results

General Nutritional Components

As shown in Table 1 , fresh *S. hollandi* eggs contained 64.26% moisture, 27.66% crude protein, 3.18% crude fat, and 3.09% crude ash.

Amino Acid Composition

As shown in Table 2 , 17 amino acids were detected in the eggs (tryptophan was not detected due to acid hydrolysis), including 7 essential amino acids (EAA) and 10 non-essential amino acids (NEAA). Total amino acid (TAA) content reached 23.21%. Glutamic acid was the most abundant (3.50%), followed by proline (2.46%), leucine (2.19%), and lysine (1.73%), while cysteine was the lowest (0.28%). EAA content was 9.28%, NEAA 13.93%, and delicious amino acids (DAA) 7.47%. The ratios of EAA/TAA, EAA/NEAA, and DAA/TAA were 39.98%, 66.62%, and 32.18%, respectively.

Amino Acid Nutritional Quality Evaluation

Based on FAO/WHO and whole egg protein amino acid patterns, AAS, CS, and EAAI values were calculated (Table 3). According to AAS, the lowest score was for methionine + cysteine (0.54), followed by phenylalanine + tyrosine (0.76), with the highest for isoleucine (0.93). According to CS, methionine + cysteine also scored lowest (0.31), followed by phenylalanine + tyrosine (0.51), with leucine highest (0.72). Thus, both AAS and CS identified methionine + cysteine as the first limiting amino acid and phenylalanine + tyrosine as the second limiting amino acid. The EAAI was 59.26%.

Fatty Acid Composition

As shown in Table 4 , *S. hollandi* eggs contained 11 fatty acids: 3 saturated fatty acids (SFA) comprising 22.68% of total fatty acids, 3 monounsaturated fatty acids (MUFA) comprising 48.40%, and 5 polyunsaturated fatty acids (PUFA) comprising 28.93%. The dominant fatty acids were C16:0, C18:1n-9, C18:2n-6, C20:4n-6, and C22:6n-3 (DHA), accounting for 90.11% of total fatty acids. EPA and DHA contents were relatively high at 1.80% and 6.73% of total fatty acids, respectively, with EPA + DHA totaling 8.53%. The n-3 PUFA content was 8.96%, n-6 PUFA 19.97%, and the n-3/n-6 ratio was 0.45.

Trace Element Content

As shown in Table 5 , five trace elements were detected: copper, zinc, iron, manganese, and selenium. Zinc was the most abundant (90.9865 mg/kg), followed by iron (31.3863 mg/kg), with lower levels of copper (1.4220 mg/kg) and manganese (0.4559 mg/kg), and selenium being the lowest (0.1115 mg/kg).

Theoretical Nutrient Requirements for Larvae

As shown in Table 6 , the theoretical dietary protein and fat requirements for *S. hollandi* larvae were 77.39% and 8.90% (dry matter basis), respectively. Due to high C16:0 and C18:1n-9 contents in eggs, larval diets should contain similar levels of palmitic and oleic acids (1.89% and 3.75%, respectively). EPA and DHA contents were relatively low in eggs, suggesting larval diet levels of 0.16% and 0.60%, respectively. Theoretical amino acid requirements are presented in Table 7 , with methionine, cysteine, phenylalanine, and tyrosine being the main limiting amino acids. Dietary levels should not be lower than those in eggs: 1.12%, 0.78%, 2.49%, and 2.15%, respectively. Theoretical trace element requirements are shown in Table 8 , with recommended dietary levels of 6.2402 mg/kg copper, 399.2806 mg/kg zinc, 137.7341 mg/kg iron, 2.0006 mg/kg manganese, and 0.4893 mg/kg selenium.

Discussion

Protein and fat are the most costly nutrients among the six major nutrient categories and primary factors for evaluating animal product nutritional value. Protein promotes growth, repairs damaged cells, and provides energy, making it essential for animal development and survival. *S. hollandi* eggs contain 27.66% crude protein, which is lower than eggs of *Hucho taimen* (33.45%), *Thymallus arcticus grubei* (31.57%), and *Oncorhynchus mykiss* (32.02%), but significantly higher than *Hemitripterus villosus* (17.26%), *Acipenser schrenckii* (20.70%), *Acipenser baerii* (22.60% or 20.38%), *Acipenser ruthenus* (18.40%), *Acipenser gueldenstaedti* (20.77%), golden trout (25.94%), *Coregonus peled* (24.16%), and *Coregonus autumnalis* (24.48%). Fat is crucial for energy storage and cellular structure. *S. hollandi* eggs contain 3.18% crude fat, substantially lower than *A. schrenckii* (16.40%), *A. baerii* (17.90% or 13.58%), *A. ruthenus* (12.40%), *A. gueldenstaedti* (10.41%), golden trout (7.37%), *C. peled* (10.90%), *C. autumnalis* (9.20%), *O. mykiss* (5.19%), and *H. taimen* (6.43%), but similar to *H. villosus* (2.83%) and *T. arcticus grubei* (4.93%). These comparisons demonstrate that *S. hollandi* eggs are a typical high-protein, low-fat natural food material.

Glutamic acid is a major delicious amino acid and plays important roles in brain tissue metabolism and synthesis of various physiologically active substances. Among the 17 amino acids in *S. hollandi* eggs, glutamic acid was the most abundant (3.50%), consistent with findings for sturgeon, *H. taimen*, golden trout, *H. villosus*, *T. arcticus grubei*, perch, mandarin fish, and crucian carp eggs, though Jiang et al. reported aspartic acid as the highest in rainbow trout eggs. The type, quantity, and proportion of essential amino acids primarily determine protein nutritional value. The EAAI of *S. hollandi* eggs was 59.26%, higher than Russian sturgeon (50.66%), Siberian sturgeon (44.43%), and golden trout (58.83%). The EAA/TAA ratio was 39.98% and EAA/NEAA 66.62%, meeting FAO/WHO ideal protein standards (EAA/TAA 40%, EAA/NEAA > 60%), indicating excellent amino acid balance and high-quality protein.

Fatty acids are major energy sources, classified as SFA, MUFA, and PUFA based on saturation. *S. hollandi* eggs contained 22.68% SFA, similar to Siberian sturgeon (25.81%), Russian sturgeon (26.39%), golden trout (16.89%), *H. villosus* (24.73%), and *H. taimen* (22.50%). PUFA, primarily from deep-sea fish, exhibit biological activity in reducing cardiovascular disease risk and promoting growth. *S. hollandi* eggs contained 28.93% PUFA, lower than Siberian sturgeon (39.30%), Russian sturgeon (37.82%), *H. villosus* (50.29%), golden trout (58.51%), *H. taimen* (36.28%), perch (36.68%), and mandarin fish (45.82%), but higher than crucian carp (22.90%). This indicates lower PUFA content compared to most sturgeon and salmonid eggs. Ji et al. discussed HUFA requirements in freshwater fish for growth, health, and reproduction. EPA and DHA are core HUFA components with demonstrated benefits for brain cell development and memory enhancement. *S. hollandi* eggs contained 8.53% EPA + DHA, lower than Siberian sturgeon (16.83%), Russian sturgeon (19.47%), *H. villosus* (40.59%), golden trout (16.53%), *H. taimen* (16.62%), perch (16.08%),

and mandarin fish (33.84%), but higher than crucian carp (8.45%). These interspecies differences likely relate to evolutionary classification, culture environment, feeding habits, and diet. Notably, EPA + DHA content was substantially higher than in *S. hollandi* muscle (3.72%), consistent with findings that fish eggs contain higher EPA and DHA than muscle, possibly because some fish, like tuna, preferentially store specific fatty acids in ovaries during spawning for physiological functions. Recent studies indicate MUFA also regulates lipid metabolism, protects vascular endothelium, and reduces hypercoagulation. *S. hollandi* eggs contained 48.40% MUFA, higher than Siberian sturgeon (34.89%), Russian sturgeon (35.82%), golden trout (24.60%), *H. villosus* (23.86%), and *H. taimen* (41.226%). The n-3/n-6 ratio is an important nutritional indicator, with higher values indicating greater health benefits. *S. hollandi* eggs had an n-3/n-6 ratio of 0.45, exceeding the FAO/WHO recommendation (0.1–0.2). These analyses confirm that *S. hollandi* eggs contain abundant fatty acids with significant nutritional and health benefits.

S. hollandi eggs are rich in trace elements, particularly zinc (90.9865 mg/kg) and iron (31.3863 mg/kg), which are 19.2-fold and 5.3-fold higher than in *S. hollandi* muscle, respectively, and 5-fold and 1.4-fold higher than in *Acipenser schrenckii* eggs. Trace elements are vital for normal physiological functions and metabolism. Zinc and copper induce metallothionein synthesis to bind and detoxify heavy metals like lead, cadmium, and mercury. Zinc and selenium exhibit anti-aging effects, and zinc clinically treats tissue trauma and promotes ulcer healing. Iron is essential for hematopoiesis, participating in hemoglobin, cytochrome, and enzyme synthesis while promoting growth. Thus, *S. hollandi* eggs can provide abundant trace elements, especially zinc and iron, for special populations.

When larval nutritional requirements are unknown, egg nutrient contents can serve as theoretical references. This study predicted larval dietary protein and fat requirements of 77.39% and 8.90%, respectively, similar to Yang et al.' s estimates for *H. villosus* larvae (75.33% protein, 12.42% fat). However, these theoretical requirements based on egg nutrient profiles should only serve as references for larval feed formulation, with actual requirements determined through feeding trials.

In conclusion, *S. hollandi* eggs represent a typical high-protein, low-fat natural food with complete amino acid profiles, balanced proportions, high unsaturated fatty acid content, and abundant zinc and iron trace elements, offering extremely high nutritional value and broad development potential.

References

[1] Editorial Committee of *Fujian Fish Fauna*. *Fujian Fish Fauna* (Volume 1) [M]. Fuzhou: Fujian Science and Technology Press, 1984: 330–331.
[2] Chen Zhenyu. *Spinibarbus hollandi* in the Li River [J]. *Guangxi Fisheries Science and Technology*, 1984(3): 1–7.

[3] Tang Q Y, Liu H Z, Yang X P, et al. Molecular and morphological data suggest that *Spinibarbus caldwelli* (Nichols) (Teleostei: Cyprinidae) is a valid species [J]. *Ichthyological Research*, 2005, 52(1): 77–82.
[4] Luo Kaijun. Biological characteristics and germplasm resource evaluation of *Spinibarbus hollandi* [D]. Master' s thesis. Guiyang: Guizhou University, 2008.
[5] Wen Caiyan, Xu Jian, Zou Peizhen, et al. Study on testis development of cultured *Spinibarbus hollandi* [J]. *Freshwater Fisheries*, 2005, 35(3): 41–43.
[6] Li Zhen, Zhang Yinjiang, Zhang Leting, et al. Feeding selectivity of *Spinibarbus hollandi* on *Spirogyra*, *Hydrilla verticillata*, and *Ceratophyllum demersum* and its impact on water quality [J]. *Acta Hydrobiologica Sinica*, 2013, 37(4): 735–743.
[7] Zhang Sheng, Lü Yejian. Large-scale breeding technology of *Spinibarbus hollandi* [J]. *Scientific Fish Farming*, 2009(11): 10–11.
[8] Zheng Minquan. Artificial breeding technology of *Spinibarbus caldwelli* [J]. *Fisheries Science*, 2002, 21(5): 8–10.
[9] Tang Lianghua, Su Min, Lü Boyan, et al. Cloning and expression analysis of vasa homologous gene in *Spinibarbus caldwelli* [J]. *Journal of Fisheries of China*, 2012, 36(6): 868–878.
[10] Su Min, Lü Boyan, Tang Lianghua, et al. Cloning and expression of scp3 gene in *Spinibarbus caldwelli* [J]. *Journal of Fujian Normal University: Natural Science Edition*, 2011, 27(6): 71–76.
[11] Liu Boren. Large-size fingerling cultivation technology of *Spinibarbus caldwelli* [J]. *Scientific Fish Farming*, 2005(7): 8–9.
[12] Lu Youlong. Discussion on key techniques for pond cultivation of *Spinibarbus caldwelli* fingerlings [J]. *China Fisheries*, 2008(10): 41–42.
[13] Luo Qinhong, Zhong Liangming, Wu Yuxuan, et al. Key technical points for pond monoculture of *Spinibarbus hollandi* [J]. *Freshwater Fisheries*, 2002, 32(1): 25–26.
[14] Zhu Enhua. Study on pond and cage culture technology of *Spinibarbus caldwelli* [D]. Master' s thesis. Wuhan: Huazhong Agricultural University, 2008.
[15] Zhang Liangsong. Pond culture technology of *Spinibarbus caldwelli* [J]. *Freshwater Fisheries*, 2004, 34(5): 51–53.
[16] Cheng Jinming. Study on reservoir cage culture technology of *Spinibarbus hollandi* [J]. *China Fisheries*, 2011(1): 37.
[17] Yang Junxing, Chen Yinrui. Study on species differentiation of genus *Spinibarbus* [J]. *Journal of Zhanjiang Fisheries College*, 1995, 15(1): 1–5.
[18] Lü Yaoping, Chen Jianming, Ye Jinyun, et al. Effects of dietary protein levels on growth, carcass composition, and digestive enzyme activities of juvenile *Spinibarbus caldwelli* [J]. *Journal of Agricultural Biotechnology*, 2009, 17(2): 276–281.
[19] Lü Yaoping, Huang Xuxiong, Yang Yanbo, et al. Analysis and evaluation of muscle nutritional components of *Spinibarbus caldwelli* from the Oujiang River [J]. *Journal of Huazhong Agricultural University*, 2008, 27(1): 86–90.
[20] Bing Xuwen. Comparison of muscle nutritional quality between *Spinibarbus sinensis* and *Spinibarbus hollandi* [J]. *Journal of Dalian Fisheries University*, 2005, 20(3): 233–237.

[21] Chen Yiming, Huang Jun, Cai Zide, et al. Analysis of meat yield and muscle nutritional components of *Spinibarbus hollandi* [J]. *Reservoir Fisheries*, 2001, 21(2): 22-24.
[22] Xue Xiwen, Yu Huahong, Ye Fandi, et al. Analysis of muscle nutritional components of *Spinibarbus caldwelli* [J]. *Jiangxi Fishery Science and Technology*, 2002(4): 21-23.
[23] Peng Ling, Liu Zhu, Zhu Bifeng, et al. Determination of amino acid composition and trace elements in *Spinibarbus hollandi*, *Spinibarbus sinensis*, and *Spinibarbus denticulatus* [J]. *Amino Acids and Biotic Resources*, 2005, 27(4): 6-7.
[24] Yang Jingjing, Jiang Zhiqiang, Zuo Rantao, et al. Analysis and evaluation of nutritional components of *Hemitripterus villosus* eggs [J]. *Acta Zoonutrimenta Sinica*, 2014, 26(4): 1103-1110.
[25] Cao Shuangjun, Zhang Zhenqi, Yang Sihua, et al. Sturgeon biology and nutritional requirements [J]. *Guangdong Feed*, 2000, 9(1): 40-41.
[26] Pousão-Ferreira P, Morais S, Dores E, et al. Eggs of gilthead seabream *Sparus aurata* L. as a potential enrichment product of *Brachionus* sp. in the larval rearing of gilthead seabream *Sparus aurata* L. [J]. *Aquaculture Research*, 2001, 30(10): 751-758.
[27] Sargent J, McEvoy L, Estevez A, et al. Lipid nutrition of marine fish during early development: current status and future directions [J]. *Aquaculture*, 1999, 179(1/2/3/4): 217-229.
[28] Mourente G, Vázquez R. Changes in the content of total lipid, lipid classes and their fatty acids of developing eggs and unfed larvae of the Senegal sole, *Solea senegalensis* Kaup [J]. *Fish Physiology and Biochemistry*, 1996, 15(3): 221-235.
[29] Cheng Xiaofei, Tian Jingjing, Ji Hong, et al. Effects of different lipid sources in silkworm pupa-based diets on growth, body composition, and health status of mirror carp (*Cyprinus carpio* var. specularis) [J]. *Acta Hydrobiologica Sinica*, 2013, 37(4): 656-668.
[30] Tian J J, Ji H, Oku H, et al. Effects of dietary arachidonic acid (ARA) on lipid metabolism and health status of juvenile grass carp, *Ctenopharyngodon idellus* [J]. *Aquaculture*, 2014, 430: 57-65.
[31] FAO/WHO. Energy and protein requirements [M]. Rome: Food and Agriculture Organization of the United Nations, 1973: 63.
[32] Institute of Nutrition and Food Safety, Chinese Academy of Preventive Medicine. Food composition tables (national representative values) [M]. Beijing: People' s Medical Publishing House, 1991: 30-82.
[33] Fan Wenxun, Li Zeying, Zhao Xuhe. Nutritional evaluation of protein foods [M]. Beijing: People' s Medical Publishing House, 1984: 42-44.
[34] Zhang Yongquan, Yin Jiasheng, Du Jia, et al. Comparative analysis of muscle nutritional components between male and female *Phoxinus lagowskii* [J]. *Food Science*, 2013, 34(17): 259-262.
[35] Han Xiaoli, Du Jinsong, Liu Lizhi, et al. Analysis of meat yield and nutritional value of *Esox lucius* [J]. *Chinese Journal of Zoology*, 2009, 44(3): 70-75.
[36] Zhang Yongquan, Yin Jiasheng, Guo Wenxue, et al. Analysis and evalua-

tion of nutritional components of mature eggs of *Hucho taimen* [J]. *Food Science*, 2015, 36(4): 97-100.
[37] Suo Li, Zhao Jiwei, Zhang Ying, et al. Analysis of nutritional components of *Thymallus arcticus grubei* eggs [J]. *Chinese Journal of Fisheries*, 2010, 23(2): 34-36.
[38] Jiang Zuofa, Liu Yong, Lu Tongyan, et al. Comparison of amino acid and fatty acid contents in two color variants of rainbow trout eggs [J]. *Journal of Dalian Fisheries University*, 2004, 19(4): 306-308.
[39] Liu Xiaoyong, Suo Li, Zhang Ying, et al. Comparative analysis of nutritional components in eggs of three cultured sturgeon species [J]. *Freshwater Fisheries*, 2014, 44(5): 82-86.
[40] Gao Lujiao, Xia Yongtao, Huang Yanqing, et al. Comparison of nutritional components between Russian sturgeon eggs and Siberian sturgeon eggs [J]. *Marine Fisheries*, 2012, 34(1): 57-63.
[41] Jiang Zuoyu, Li Jian, Yao Junjie, et al. Determination and analysis of nutritional components in eggs and skin of golden trout cultured in mountain spring water [J]. *Food Science*, 2015, 36(1): 234-239.
[42] Guo Yan, Ma Yanwu, Cai Lingang, et al. Nutritional analysis and evaluation of muscle and eggs of *Coregonus peled* and *Coregonus autumnalis* from Sayram Lake [J]. *Chinese Journal of Fisheries*, 2004, 17(1): 62-67.
[43] Zhang Changying. Biochemistry [M]. 2nd ed. Beijing: People' s Medical Publishing House, 1985: 305, 561.
[44] Rao Qiuhua, Luo Tuyan, Su Desen, et al. Analysis and evaluation of nutritional components of *Acipenser schrenckii* roe [J]. *Journal of Agriculture*, 2011, 1(5): 28-31.
[45] Dai Zhongbo, Ding Zhuoping, Liu Chengchu, et al. Evaluation of nutritional value of eggs from three freshwater cultured fish species [J]. *Acta Nutrimenta Sinica*, 2007, 29(1): 103-104.
[46] Liang Yinquan, Cui Xiqun, Liu Youliang. Biochemical composition analysis and nutritional quality evaluation of mandarin fish muscle [J]. *Acta Hydrobiologica Sinica*, 1998, 22(4): 386-388.
[47] Hang Xiaomin, Tang Yonglian, Liu Xianglong. Research progress on polyunsaturated fatty acids [J]. *Progress in Biotechnology*, 2001, 21(4): 18-21.
[48] Ji Hong, Tian Jingjing. Research progress on nutritional roles of highly unsaturated fatty acids (HUFAs) in freshwater fish [J]. *Journal of Fisheries of China*, 2014, 38(9): 1650-1665.
[49] Zhang Qiang, Wang Yongli. Extraction and analysis of lipids from *Syngnathus acus* and *Hippocampus japonicus* [J]. *Chinese Journal of Analytical Chemistry*, 1996, 24(2): 139-143.
[50] Wiegand M D. Composition, accumulation and utilization of yolk lipids in teleost fish [J]. *Reviews in Fish Biology and Fisheries*, 1996, 6(3): 259-286.
[51] Gao Lujiao, Shi Zhaohong, Ma Chunyan, et al. Research progress on broodstock lipid nutrition and reproductive performance [J]. *Marine Fisheries*, 2006, 28(2): 163-166.
[52] Liu Gensheng, Xu Guifa. Protective effects of monounsaturated fatty acids on cardiovascular health [J]. *Journal of Hygiene Research*, 2006, 35(3): 357-359.

[53] Yu Chaoyun, Yang Hui. Relationship between trace elements and human physiological functions [J]. *Shandong Medical Journal*, 2009, 49(9): 113-114.
[54] Kong Xiangrui. Nutritional, physiological, and clinical significance of essential trace elements [M]. Hefei: Anhui Science and Technology Press, 1982: 42.

Note: Figure translations are in progress. See original paper for figures.