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Nutritional Components, Biochemical Characteristics, Enzyme Activities, and Growth Differences of Five Freshwater Fish Species?

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Abstract: Common carp (*Cyprinus carpio*) is an economically important fish worldwide, with many of its species bred for consumption. However, there are few reports on the comprehensive comparative analysis of the muscle nutritional quality and stress resistance characteristics of different common carp species. In this study, after 15 months of feeding in the same environment, the nutritional components, serum biochemical indices, liver antioxidant and intestinal digestive enzyme activities, and muscle growth-related gene expression were determined in Songpu mirror carp (SPM; *Cyprinus carpio Songpu mirror*), Heilongjiang wild carp (HLJ; *Cyprinus carpio haematopirus*), cold-resistant strain of purse red carp (CPR; *Cyprinus carpio 'Red purse cold-resistant'*), Songhe carp (SH; *Cyprinus carpio 'Songhe'*), and Songpu carp (SP; *Cyprinus carpio Songpu*). Muscle nutrient composition showed that HLJ had a significantly lower crude fat content and higher docosahexaenoic acid (DHA) + eicosapentaenoic acid (EPA) proportion than the other four common carp species ($p < 0.05$). The contents of lysine (Lys) and aspargine (Asp) were significantly higher in the CPR than in other species ($p < 0.05$). Serum biochemical parameters showed that total protein (TP), total cholesterol (T-CHO), triglycerides (TG), and low-density lipoprotein (LDL) were significantly lower in SPM than in the other species ($p < 0.05$). The results of tissue enzyme activity showed that the activities of superoxide dismutase (SOD) and catalase from Micrococcus lysodeikticus (CAT) in the liver were significantly higher, while the activities of lipase (LPS), trypsin (TRS), and α-amylase (α-AMS) in the intestine were significantly the lower in HLJ than in the other species ($p < 0.05$). In addition, the relative expression levels of growth hormone (*GH*), growth hormone receptor (*GHR*), insulin-like growth factor 1 (*IGF1*), insulin-like growth factor receptor (*IGF1R*), and myoblast determination factor (*MyoD*) in SP and SH were significantly higher than those in the other species, while the relative expression of myostatin (*MSTN*) in HLJ was significantly higher ($p < 0.05$). Therefore, there were significant differences in muscle nutritional quality, serum biochemical indices, liver, and intestinal enzyme activities, and muscle growth potential among the five species of common carp. This study could provide a theoretical basis for the germplasm evaluation and variety improvement of common carp.

Keywords: common carp; nutritional components; serum biochemical index; enzyme activity; relative expression

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1. Introduction

Common carp, as the third most farmed freshwater fish, is commercially valuable [1,2]. Common carp is an economically important fish with the characteristics of delicious meat, high nutritional value, strong stress resistance, and environmental adaptability [3–6]. Geographical distribution differences have resulted in long-term natural and artificial selection, so some common carp species with excellent traits have been raised and selectively bred [7]. Heilongjiang wild carp (HLJ; *Cyprinus carpio haematopirus*), cold-resistant strain of purse

red carp (CPR; *Cyprinus carpio 'Red purse cold-resistant'*), Songhe carp (SH; *Cyprinus carpio 'Songhe'*), and Songpu carp (SP; *Cyprinus carpio Songpu*), all of which have passed by the national aquatic stock and improved breeding approval committee from the ministry of agriculture and rural of the people's republic of china. Different indicators in tissues, such as muscle, liver, intestine, and serum, reflect the edibility and breeding value of common carp. Muscle is the tissue that determines the main nutritional components of common carp because it is rich in a variety of essential amino acids and polyunsaturated fatty acids [8,9]. Biochemical indicators in serum could determine metabolic and physiological status and reflect stress resistance and environmental adaptability in common carp [10]. Digestive enzyme activity is an important indicator reflecting the absorption and digestion function, which is crucial to the healthy and rapid growth of common carp [11]. Antioxidant enzyme activity can reflect the antioxidant capacity in common carp [12,13]. The expression of growth-related genes in muscle is critical for growth in common carp [14]. Therefore, it is necessary to determine the quality and expression of growth factors in muscle, antioxidant capacity, digestion and absorption capacity, and serum biochemical indicators in common carp. These indicators play an important role in the comprehensive evaluation of edibility and breeding values and have important effects on the development and utilization of common carp.

SPM, HLJ, CPR, SH, and SP belong to the family Cyprinidae and genus Cyprinus and are common and excellent breeding species for breeding materials. The muscle quality of the Yellow River carp (Cyprinus carpio haematopterus) has been proven to be better than that of the SMP [15]. Muscle nutrients have been analyzed in HLJ, SH, and purse red carp [16–18]. However, a comprehensive comparative evaluation and analysis of the muscle quality, growth, stress resistance, digestion, and absorption capacity of these five common carp species have not yet been reported. In this study, the muscle nutrients, digestive enzyme and lipase activities, serum biochemical indices, and relative expression of growth-related genes of five common carp strains reared in the same rearing environment were analyzed and compared, and we determined the growth, edible nutritional value and antioxidant capacity, digestion and absorption capacity and blood metabolism capacity of these species. This study provides the theoretical basis for further breeding and artificial breeding of fine carp varieties, provides information to help meet the vast consumer demand, and provides the basis for carp production and further processing.

2. Materials and Methods

2.1. Experimental Animals and Animal Care

The experimental fish used in this study were all two-year-old carp of the SPM, HLJ, CPR, SH, and SP species, which were kept under the same feeding conditions, and came from the Hulan Fisheries Experiment Station of Heilongjiang River Fisheries Research Institute, Chinese Academy of Fishery Sciences. The initial weights of five common carp species (150.0 ± 2 g) were consistently selected. A total of 400 fish of each species were raised, and the breeding density was 500 fish/mu. After electronic marking, they were placed in the same breeding area for breeding. The feed formulation was designed according to formula feed for common carp (GB/T 36782-2018, 2019) and National Research Council (NRC) (2011) guidelines, and the proximate composition of the feed ingredient is shown in Table 1. The common carp were fed two times per day (08:00 and 17:00) for 15 months with a pellet diet, according to a 3% body weight for 6 months, then a 2.5% body weight for 6 months, and 2% body weight for the last 3 months. Feed ingredients purchased from Hehe Feed Co., Ltd. (Linyi, China).

Table 1. Formulation and proximate composition of the experimental diets.

Ingredient	Content (Air-Dry Matter, %)
Fish meal [1]	4
Soybean meal [1]	30

Table 1. *Cont.*

Ingredient	Content (Air-Dry Matter, %)
Wheat middling [1]	30
Rapeseed meal [1]	22
Soybean oil	2.5
CMC (carboxymethyl cellulose)	2.2
Vitamin premix [2]	3
Trace mineral premix [2]	3
Dicalcium phosphate	2
Choline chloride	0.6
Lysine	0.7
Total	100
Proximate composition	
Crude protein	28.14
Crude lipid	4.53
Total phosphorus	0.98
Lysine	1.63

Note: [1] Proximate composition: fish meal (crude protein, 67%; crude lipid, 10%), soybean meal (crude protein, 44%; crude lipid, 1.5%), wheat middling (crude protein, 13%; crude lipid, 1.2%), rapeseed meal (crude protein, 38%; crude lipid, 3.8%). [2] Proximate composition: vitamin premix (VA 8000IU, VB1 15 mg, VB2 30 mg, VB6 10 mg, VB12 1 mg, VC100 mg, VD3 3000 IU, VE 100 mg, VK3 5 mg); trace mineral premix (nicotinamide 175 mg, d-biotin 2 mg, inositol 800 mg, folic acid 6 mg, pantothenic acid 50 mg, Cu 3 mg, Fe 30 mg, Mn 13 mg, I 0.8 mg, and Zn 65 mg).

2.2. Sample Collection

Feeding was stopped for 1 day before the start of the experiment, and the body weight, total length, body length, body height, body width, tail handle length, tail handle height, head length, length of proboscis, and eye interval of 100 carp of each species were measured. Fish Anle (MS-222, 100 mg/L, Beijing Green Hengxing Biological Technology Co., Beijing, China)) was used to anesthetize the experimental fish, 9 of which were selected from each common carp species for tissue collection. Blood was collected from the tail vein and placed in a premade heparin anticoagulant tube, kept at 4 °C for 1–2 h, and centrifuged at 3500 r/min for 10 min. The upper serum was drawn and dispensed into centrifuge tubes and placed at −20 °C for use in the determination of serum biochemical indicators. The liver, intestine, and back muscles (at the same position) were collected from the fish, mixed with samples, and placed in a −80 °C freezer for the determination of corresponding indicators.

2.3. Indicator Determination

The approximate composition of the experimental fish pellet diet and muscle was assessed according to the standard procedure of AOAC (2005). A vacuum freeze dryer (FD-1A-50, Yuming, Zhengzhou, China) was used to determine the muscle moisture content in the experimental fish. The crude protein content in the muscle of the experimental fish was determined using the Kjeldahl method (GB 5009.5-2016). The Soxhlet extraction method (GB5009.6-2016) was used to determine the crude fat of muscle in the experimental fish. Chromatography (1260 and 7890 A, Agilent, Santa Clara, CA, USA) was used to determine the amino acid composition in muscle with tryptophan determined by alkaline hydrolysis (laboratory method) and other amino acids by acid hydrolysis (GB5009.124). Fatty acids were determined by gas chromatography-mass spectrometry (GC-MS). After the intestinal and liver tissues were statically ground and mixed with normal saline (1:9) in a low-temperature environment, the supernatants were assayed for intestinal digestive enzyme activities and liver antioxidant indicators. The crude ash was determined by burning the sample to constant weight at 550 °C. Total protein (TP, A045-2, coomassie brilliant blue method), trypsin (TRS, A080-2, N-benzoyl-L-arginine-ethylester method), α-amylase (α-AMS, C016-1-1, starch-iodine colorimetric method), and lipase (LPS, A054-2-1, methyl halide substrate method) were all detected using enzyme activity detection kits (Jiancheng,

Nanjing, China). Liver antioxidant indices, including total superoxide dismutase (SOD, A001-3, xanthine oxidase method), catalase from Micrococcus lysodeikticus (CAT, A007-1-1, ammonium molybdate method) activity, and malondialdehyde (MDA, A003-1, thiobarbituric acid method) content, were determined by application of enzyme activity detection kits (Jiancheng, China). Serum biochemical indicators were determined by immunoturbidimetry method, including TP (105-000451-00), albumin (ALB, 105-000450-00), alanine aminotransferase (ALT, 105-000442-00), aspartate aminotransferase (AST, 105-000443-00), alkaline phosphatase (ALP, 105-000444-00), total cholesterol (T-CHO, 105-000448-00), triglyceride (TG, 105-000449-00), high-density lipoprotein (HDL, 105-000463-00), low-density lipoprotein (LDL, 105-000464-00), urea (105-000452-00), uric acid (UA, 105-000476-00) and total bile acid (TBA, 105-000456-00) purchased from Mindray of China, and all indicators were measured using a biochemical analyzer (BS350E, Mindray, Shenzhen, China). There were 9 fish in each experimental group in this study.

2.4. Nutritional Value Assessment

According to the FAO/WHO (1973) recommended standard model of nitrogen amino acid score and egg protein model for nutritional value evaluation, the amino acid score (AAS), chemical score (CS), and essential amino acid index (EAAI) were calculated as follows:

AAS = amino acid content of the protein to be evaluated (mg/g N)/FAO scoring model amino acid content (mg/g N);

CS = amino acid content of the protein to be evaluated (mg/g N)/same amino acid content in egg protein (mg/g N);

$$\mathrm{EAAI} = \sqrt[n]{(100\mathrm{aa}_1 \times 100\mathrm{aa}_2 \times \cdots \times 100\mathrm{aa}_n)(\mathrm{AA}_1 \times \mathrm{AA}_2 \times \cdots \times \mathrm{AA}_n)}$$

In the formula, aa_n refers to the percentage of a certain amino acid in the total amount of amino acids, AA_n is the amino acid ratio of this amino acid in the reference protein, and N is the number of amino acid species.

2.5. RNA Extraction and RT-qPCR

RNA extraction was performed on the muscles collected from all experimental fish, which were from the same part of the back muscles. According to the manufacturer's instructions, total RNA was extracted from common carp tissues using the RNeasy Mini Kit (Qiagen, Dusseldorf, Germany). The integrity and quality of the RNA were analyzed using 1.5% agarose gel electrophoresis. The purity of the RNA was determined by UV spectrophotometry. The OD260:280 ratio for all RNA samples was between 1.8 and 2.0. According to the instructions, each cDNA was synthesized from 1 μg of total RNA using the PrimeScript™ RT Reagent Kit with gDNA Eraser (TaKaRa, Beijing, China). Specific primers (Table 2) were obtained using Primer Premier 5.0. RT-qPCR was performed according to the TB Green™ Premix Ex Taq™ II (TaKaRa, China) instructions using an ABI7500 system (Life Technologies, Carlsbad, CA, USA). The primer specificity was confirmed by dissociation curve analysis. Beta-actin (*β-actin*) was used as an internal reference gene. Double-distilled water was used instead of the template as the negative control. The relative expression levels of *MSTN*, *GH*, *GHR*, *IGF1*, *IGF1R*, and *MyoD* were determined using the 2 ($^{-\Delta\Delta Ct}$) method [19]. The primers used in this study are shown in Table 2. At least three replicates per experimental group.

Table 2. Primers used in this experiment.

Gene	Primers	Sequence 5′–3′
GH	F	TCAAGGGATGTCTCGATGGT
	R	CTACAGGGTGCAGTTGGAAT
IGF-1	F	GGGCCTAGTTCAAGACGG
	R	AGTGGCTTTGTCCAGGTAA

Table 2. *Cont.*

Gene	Primers	Sequence 5′–3′
GHR	F	ACAACTGAACAGCTCTCCGG
	R	GAGAAGATACGGCGTCTGGG
IGF-1R	F	GCTTCCTCAAGAGCCTGCGAT
	R	TACGCGCATCATCCTCTTCC
matn	F	GCAGCTGTTACCCAAAGCAC
	R	CCATAGCTGCGCTCTTACGA
MyoD	F	CCACCATGAGGGAGAGGAGA
	R	GATCTCGGACTGGAGGCATC
β-actin	F	GGCAGGTCATCACCATCGG
	R	TTGGCATACAGGTCTTTACGG

2.6. Data Analysis

The calculation formulas of the condition factor (CF) and coefficient of variation (CV) are CF(g/cm^3) = 100 * W/L3 and CV(%) = SD/Mean * 100, where W and L are the weight and body length of the fish, respectively, SD is the standard deviation, and mean is the average value of the morphological traits. Statistical significance was assessed by a one-way analysis of (ANOVA) followed by LSD multiple comparisons in SPSS statistical software version 22.0 (IBM Corp., Armonk, NY, USA). Cluster analysis by using the system clustering method in SPSS statistical software version 22.0. Statistical significance was considered at $p < 0.05$. All data are shown as the mean ± SD of at least three replicates.

3. Results

3.1. Morphological Difference Analysis of Five Common Carp Species

In order to evaluate the degree of morphological differences between the five freshwater fish species, the eight different morphological traits were divided by the body length to eliminate the effect of size on the parameter values. Morphological differences were significant among the five species of common carp ($p < 0.05$) (Table 3). The results of mean values of cluster analysis on the mean values of eight proportional traits showed that SH and CPR were divided into one branch, and HLJ, SP, and SPM were divided into another branch in the five common carp (Figure 1).

Table 3. Average statistics of the proportional traits of the five varieties of common carp.

Items	SPM	HLJ	CPR	SH	SP
Total length/Body length	1.227 ± 0.033 ^{b}	1.224 ± 0.018 ^{b}	1.239 ± 0.021 ^{a}	1.200 ± 0.047 ^{c}	1.238 ± 0.016 ^{a}
Body height/Body length	0.412 ± 0.026 ^{b}	0.312 ± 0.017 ^{e}	0.442 ± 0.028 ^{a}	0.360 ± 0.018 ^{d}	0.402 ± 0.019 ^{c}
Body width/Body length	0.208 ± 0.018 ^{b}	0.161 ± 0.010 ^{d}	0.251 ± 0.017 ^{a}	0.201 ± 0.014 ^{c}	0.204 ± 0.013 ^{bc}
Tail handle length/Body length	0.153 ± 0.017 ^{d}	0.175 ± 0.010 ^{b}	0.167 ± 0.010 ^{c}	0.188 ± 0.011 ^{a}	0.167 ± 0.011 ^{c}
Tail handle height/Body length	0.139 ± 0.008 ^{c}	0.117 ± 0.007 ^{e}	0.160 ± 0.010 ^{a}	0.135 ± 0.007 ^{d}	0.143 ± 0.007 ^{b}
Head length/Body length	0.282 ± 0.033 ^{b}	0.268 ± 0.017 ^{b}	0.304 ± 0.019 ^{a}	0.258 ± 0.014 ^{c}	0.309 ± 0.014 ^{a}
Length of proboscis/Body length	0.108 ± 0.008 ^{c}	0.090 ± 0.011 ^{d}	0.119 ± 0.010 ^{a}	0.093 ± 0.008 ^{d}	0.116 ± 0.008 ^{a}
Eye interval/Body length	0.116 ± 0.007 ^{c}	0.095 ± 0.006 ^{e}	0.124 ± 0.008 ^{b}	0.102 ± 0.005 ^{d}	0.128 ± 0.008 ^{a}

Note: Data are presented as mean ± SD (n = 100). The same row with different letters indicates significant differences between groups based on one-way analysis of variance (ANOVA) ($p < 0.05$).

3.2. Morphological Index and Muscle Texture Analysis of Five Common Carp

To determine the morphological differences, muscle hardness, and shear force of the five common carp species, we analyzed their morphological differences and muscle texture (Table 4). Among the five common carp, HLJ showed a significantly lower body mass than that of the other four common carp ($p < 0.05$), but there were no significant differences among CPR, SP, SPM, and SH. HLJ had the highest CV of body mass, and SP had the lowest. The results also showed that SP and CPR had significantly higher CF than the other common carp ($p < 0.05$). In addition, the muscle texture results showed that the hardness

of HLJ was the highest and was significantly higher than that of SP ($p < 0.05$). In addition, the muscle shear force of SPM was the highest, followed by those of HLJ and SH, which were significantly higher than those of CPR and SP ($p < 0.05$).

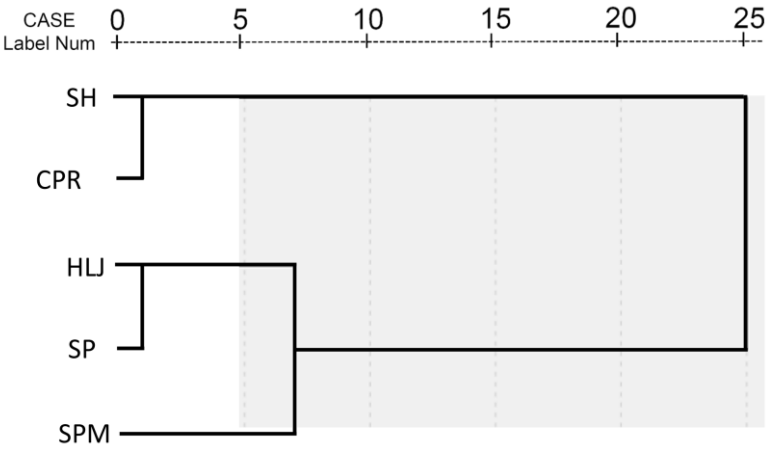

Figure 1. The clustering relationship among the five species of common carp. The cluster analysis was performed on the average of the ratios of eight traits and body lengths using the SPSS software.

Table 4. Morphological index and muscle texture characteristics in five species of common carp.

	SPM	HW	SH	CPR	SP
Body mass/g	1268.19 ± 223.26 ^{a}	495.71 ± 142.71 ^{c}	1205.93 ± 220.92 ^{a}	952.82 ± 170.96 ^{b}	1265.51 ± 125.12 ^{a}
CV/%	17.60	28.79	18.32	17.94	9.89
CF/%	3.43 ^{b}	3.01 ^{b}	3.30 ^{b}	5.84 ^{a}	5.86 ^{a}
Hardness/N	4.29 ± 1.62 ^{a}	6.61 ± 1.90 ^{a}	4.34 ± 0.56 ^{a}	1.34 ± 0.21 ^{b}	1.19 ± 0.63 ^{b}
Shear force/N	9.59 ± 1.24 ^{a}	4.93 ± 0.36 ^{b}	2.78 ± 0.12 ^{c}	1.84 ± 0.16 ^{d}	1.70 ± 0.40 ^{d}

Note: Data are presented as mean ± SD (n = 100). The same row with different letters indicates significant differences between groups based on one-way analysis of variance (ANOVA) ($p < 0.05$).

3.3. Basic Nutrients of the Five Common Carp Species

To analyze the differences in muscle quality among the five common carp, basic nutritional components were measured (Table 5). The proportions of moisture, ash, crude protein, and crude fat in the muscles of the five common carp were 73.50–77.99%, 1.03–1.27%, 17.64–16.72%, and 3.68–7.35%, respectively. The muscle moisture proportion of HLJ was significantly higher than that of the other four common carp ($p < 0.05$). The proportion of crude protein in the muscle of CPR tended to be higher than that in the other species, but there were no significant differences among the five common carp. However, the proportion of crude ash in the muscle of HLJ was significantly lower than that of the other four common carp species ($p < 0.05$), and this trait was highest in SH. The proportion of crude fat in the muscle of CPR was significantly higher than that of the other four common carp ($p < 0.05$), and this trait was the lowest in HLJ ($p < 0.05$). Among the five varieties of common carp, CPR is a high-protein source material, and HLJ is a low-fat source material.

Table 5. The muscular proximate chemical composition in five species of common carp (fresh flesh weight, %).

	SPM	HW	SH	CPR	SP
Crude fat	4.70 ± 0.42 ^{b}	3.68 ± 0.39 ^{c}	5.09 ± 0.07 ^{b}	7.35 ± 0.28 ^{a}	5.16 ± 0.37 ^{b}
Crude protein	17.27 ± 0.23	17.32 ± 0.55	17.42 ± 0.55	17.82 ± 0.90	17.42 ± 0.55
Ash	1.18 ± 0.43 ^{c}	1.03 ± 0.59 ^{d}	1.27 ± 0.59 ^{a}	1.12 ± 0.08 ^{c}	1.23 ± 0.79 ^{b}
Moisture	77.11 ± 0.97 ^{b}	77.99 ± 0.73 ^{a}	76.53 ± 0.42 ^{b}	73.50 ± 1.29 ^{c}	77.49 ± 0.83 ^{ab}

Note: Data are presented as mean ± SD of three replicates (n = 9). The same row with different letters indicates significant differences between groups based on one-way analysis of variance (ANOVA) ($p < 0.05$).

3.4. Assessment of Amino Acid Composition and Nutritional Value in the Muscle of Five Common Carp Species

The proportions of 17 amino acids in fresh muscle samples were determined to evaluate the nutritional value of the five common carp, including 7 kinds of EAAs (6.96–7.76%), 4 kinds of FAAs (6.42–7.56%), 2 kinds of HEAAs (1.49–1.73%), and 4 kinds of NEAAs (8.32–9.79%) (Table 6). Glu was the most abundant amino acid in the fresh muscle of the five common carp species, followed by Asp, Lys, and Leu. These amino acids accounted for the largest proportions in CPR and HLJ. The proportions of TAA, FAA, and EAA in CPR were significantly higher than those in the other four carp species ($p < 0.05$). However, SPM and HLJ had significantly lower contents of TAAs, FAAs, and EAAs contents than the other common carp ($p < 0.05$). Similarly, the F/T ratios of CPR were the highest, and those of HLJ were the lowest. The E/T ratios of HLJ were the highest, and those of CPR were the lowest.

Table 6. Amino acid content in five species of common carp (fresh flesh weight, g/100 g).

	SPM	HW	SH	CPR	SP
Asp *•	2.02 ± 0.05 ^{c}	1.94 ± 0.01 ^{d}	2.07 ± 0.00 ^{c}	2.31 ± 0.01 ^{a}	2.15 ± 0.03 ^{b}
Thr #	0.77 ± 0.25	0.82 ± 0.05	0.86 ± 0.05	0.88 ± 0.02	0.88 ± 0.02
Ser •	0.85 ± 0.18	0.82 ± 0.05	0.85 ± 0.04	0.86 ± 0.05	0.86 ± 0.06
Glu *•	2.79 ± 0.00 ^{c}	2.70 ± 0.02 ^{d}	2.88 ± 0.02 ^{b}	3.18 ± 0.04 ^{a}	2.98 ± 0.02 ^{ab}
Gly *•	0.72 ± 0.03 ^{cd}	0.72 ± 0.02 ^{d}	0.76 ± 0.03 ^{bc}	0.86 ± 0.02 ^{a}	0.79 ± 0.01 ^{b}
Ala *•	1.00 ± 0.12	1.06 ± 0.07	1.17 ± 0.07	1.21 ± 0.12	1.15 ± 0.09
Cys •	0.16 ± 0.03 ^{c}	0.17 ± 0.02 ^{bc}	0.20 ± 0.00 ^{ab}	0.22 ± 0.07 ^{a}	0.21 ± 0.02 ^{a}
Val #	0.86 ± 0.08	0.86 ± 0.05	0.89 ± 0.06	0.90 ± 0.02	0.86 ± 0.08
Met #	0.52 ± 0.03	0.51 ± 0.03	0.47 ± 0.13	0.54 ± 0.04	0.48 ± 0.07
Ile #	0.77 ± 0.03 ^{b}	0.81 ± 0.04 ^{ab}	0.84 ± 0.02 ^{a}	0.87 ± 0.02 ^{a}	0.85 ± 0.04 ^{a}
Leu #	1.62 ± 0.05	1.64 ± 0.13	1.69 ± 0.06	1.72 ± 0.13	1.70 ± 0.20
Tyr •	0.35 ± 0.05 ^{b}	0.31 ± 0.05 ^{b}	0.46 ± 0.07 ^{a}	0.45 ± 0.16 ^{a}	0.52 ± 0.11 ^{a}
Phe #	0.68 ± 0.06 ^{b}	0.69 ± 0.05 ^{b}	0.74 ± 0.06 ^{ab}	0.83 ± 0.05 ^{a}	0.77 ± 0.05 ^{ab}
Lys #	1.74 ± 0.06 ^{cd}	1.70 ± 0.01 ^{d}	1.81 ± 0.01 ^{c}	2.02 ± 0.00 ^{a}	1.88 ± 0.01 ^{b}
His ※	0.46 ± 0.02 ^{c}	0.46 ± 0.02 ^{bc}	0.49 ± 0.02 ^{bc}	0.56 ± 0.02 ^{a}	0.52 ± 0.02 ^{b}
Arg ※	1.03 ± 0.02 ^{b}	1.09 ± 0.08 ^{ab}	1.13 ± 0.11 ^{a}	1.17 ± 0.05 ^{a}	1.12 ± 0.02 ^{a}
Pro •	0.56 ± 0.08	0.60 ± 0.07	0.64 ± 0.08	0.70 ± 0.09	0.66 ± 0.09
Trp #	—	—	—	—	—
TAA	16.90 ± 0.44 ^{c}	16.90 ± 0.58 ^{c}	17.95 ± 0.42 ^{b}	19.28 ± 0.30 ^{a}	18.38 ± 0.28 ^{b}
Flavor amino acid (FAA)	6.53 ± 0.13 ^{d}	6.42 ± 0.10 ^{d}	6.88 ± 0.10 ^{c}	7.56 ± 0.09 ^{a}	7.07 ± 0.08 ^{b}
Essential amino acid (EAA)	6.96 ± 0.19 ^{d}	7.03 ± 0.22 ^{d}	7.30 ± 0.24 ^{c}	7.76 ± 0.15 ^{a}	7.42 ± 0.26 ^{b}
Half essential amino acids (HEAA)	1.49 ± 0.02 ^{d}	1.55 ± 0.06 ^{cd}	1.62 ± 0.09 ^{bc}	1.73 ± 0.03 ^{a}	1.64 ± 0.02 ^{b}
Non-essential amino acids (NEAA)	8.45 ± 0.33 ^{d}	8.32 ± 0.32 ^{d}	9.03 ± 0.11 ^{c}	9.79 ± 0.23 ^{a}	9.32 ± 0.08 ^{b}
FAA/TAA (F/T)%	38.64	37.99	38.33	39.21	38.47
EAA/TAA (E/T)%	41.18	41.60	40.67	40.25	40.37
HEAA/TAA%	8.82	9.17	9.03	8.97	8.92
EAA/NEAA%	82.37	84.50	80.84	79.51	79.61

Note: * is flavor amino acid, # is essential amino acid, ※ is half essential amino acids, • is non-essential amino acid (n = 9). The same row with different letters indicates significant differences between groups based on one-way analysis of variance (ANOVA) ($p < 0.05$).

Using the AAS and CS methods, we determined the nutritional value of EAAs in the muscle of the five common carp varieties (Table 7). The AAS values of EAAs in the muscles of the five common carp were all greater than or close to 1.00, with lysine showing the highest values (2.81–2.50%). The CS values of EAAs in the muscles of the five common carp were all greater than 0.8, with lysine showing the highest values (2.39–2.13%). According to the amino acid scores, the AAS and CS were the lowest for Met + Cys and Ile, indicating that these EAAs were the first and second limiting amino acids for the AAS and CS values of the five common carp, respectively.

Table 7. Evaluation of essential amino acid composition in five species of common carp (mg/g).

EAA	FAO/WHO Scoring Pattern	Whole Egg Protein Scoring Pattern	AAS					CS				
			SPM	HW	SH	CPR	SP	SPM	HW	SH	CPR	SP
Thr	40	47	1.14 ± 0.37	1.21 ± 0.09	1.24 ± 0.11	1.22 ± 0.08	1.26 ± 0.05	0.97 ± 0.31	1.03 ± 0.08	1.05 ± 0.10	1.04 ± 0.07	1.08 ± 0.04
Val	50	50	1.27 ± 0.10	1.26 ± 0.09	1.28 ± 0.12	1.25 ± 0.03	1.24 ± 0.13	1.08 ± 0.09	1.08 ± 0.08	1.09 ± 0.10	1.06 ± 0.03	1.06 ± 0.11
Met + Cys	35	57	1.01 ± 0.06 ▲	1.01 ± 0.09 ▲	0.97 ± 0.19 ▲	1.05 ± 0.06 ▲	1.00 ± 0.09 ▲	0.86 ± 0.05 ▲	0.86 ± 0.07 ▲	0.83 ± 0.16 ▲	0.89 ± 0.05 ▲	0.85 ± 0.07 ▲
Ile	40	54	1.14 ± 0.04 ▲▲	1.19 ± 0.08 ▲▲	1.20 ± 0.06 ▲▲	1.20 ± 0.03 ▲▲	1.22 ± 0.08 ▲▲	0.97 ± 0.04 ▲▲	1.01 ± 0.07 ▲▲	1.02 ± 0.05 ▲▲	1.02 ± 0.02 ▲▲	1.04 ± 0.07 ▲▲
Leu	70	86	2.40 ± 0.07	2.41 ± 0.20	2.42 ± 0.01	2.39 ± 0.11	2.44 ± 0.32	2.04 ± 0.06	2.05 ± 0.17	2.06 ± 0.01	2.03 ± 0.09	2.08 ± 0.28
Phe + Tyr	60	93	1.53 ± 0.08	1.47 ± 0.43	1.72 ± 0.23	1.79 ± 0.36	1.84 ± 0.23	1.30 ± 0.07	1.25 ± 0.37	1.46 ± 0.19	1.52 ± 0.30	1.57 ± 0.19
Lys	55	70	2.57 ± 0.10	2.50 ± 0.05	2.60 ± 0.10	2.81 ± 0.14	2.70 ± 0.09	2.19 ± 0.09	2.13 ± 0.04	2.21 ± 0.09	2.39 ± 0.12	2.30 ± 0.08
EAAI			34.31	29.55	30.44	31.26	31.28					

Note: ▲ is the first limiting amino acid, ▲▲ is the second limiting amino acid.

3.5. Comparative Analysis of the Fatty Acid Composition of Five Common Carp Species

The fatty acid composition was determined by the content of 22 kinds of fatty acids in fresh muscle in 5 common carp species; there were 8 kinds of SFAs (0.663–1.085%), 5 kinds of MUFAs (1.151–1.862%), and 9 kinds of PUFAs (0.794–1.144%) (Table 8). The contents of TFA and EFA were the highest in CPR and were significantly lower in HLJ than in the other four common carp ($p < 0.05$). Among the five common carp species, C16:0 was the most abundant SFA (0.498–0.801%), C18:1n9c was the most abundant MUFA (0.946–1.568%), C18:2n6c was the most abundant PUFA was the highest (0.609–0.948%), and HLJ had a significantly lower proportion of these fatty acids than the other four common carp species ($p < 0.05$). However, interestingly, the total proportion of DHA + EPA in fresh muscle was significantly higher in HLJ (0.057%) than in the other four common carp species ($p < 0.05$).

Table 8. Fatty acid content in five species of common carp (fresh flesh weight, g/100 g).

Fatty Acid	SPM	HW	SH	CPR	SP
C14:0	0.022 ± 0.000^{c}	0.019 ± 0.002^{d}	0.022 ± 0.001^{cd}	0.032 ± 0.001^{a}	0.025 ± 0.002^{b}
C15:0	0.005 ± 0.000^{b}	0.005 ± 0.000^{b}	0.005 ± 0.000^{b}	0.006 ± 0.000^{a}	0.005 ± 0.000^{b}
C16:0	0.603 ± 0.035^{b}	0.498 ± 0.038^{c}	0.588 ± 0.044^{b}	0.801 ± 0.024^{a}	0.639 ± 0.024^{b}
C17:0	0.007 ± 0.00^{b}	0.007 ± 0.00^{b}	0.007 ± 0.001^{b}	0.008 ± 0.001^{a}	0.007 ± 0.000^{b}
C18:0	0.177 ± 0.003^{b}	0.126 ± 0.006^{c}	0.186 ± 0.015^{b}	0.224 ± 0.024^{a}	0.186 ± 0.009^{b}
C20:0	0.006 ± 0.001^{b}	0.005 ± 0.00^{c}	0.006 ± 0.001^{b}	0.008 ± 0.001^{a}	0.007 ± 0.000^{b}
C22:0	0.002 ± 0.000^{ab}	0.001 ± 0.001^{b}	0.002 ± 0.000^{b}	0.003 ± 0.000^{a}	0.003 ± 0.000^{a}
C24:0	0.002 ± 0.000	0.002 ± 0.000	0.002 ± 0.000	0.003 ± 0.000	0.003 ± 0.000
Saturated fatty acid (SFA)	0.824 ± 0.039^{b}	0.663 ± 0.036^{c}	0.818 ± 0.061^{b}	1.085 ± 0.048^{a}	0.875 ± 0.017^{b}
C16:1	0.105 ± 0.008^{b}	0.094 ± 0.015^{b}	0.096 ± 0.006^{b}	0.152 ± 0.023^{a}	0.116 ± 0.013^{b}
C18:1n9c	1.369 ± 0.038^{a}	0.946 ± 0.047^{b}	1.278 ± 0.021^{a}	1.568 ± 0.139^{a}	1.329 ± 0.030^{a}
C20:1	0.060 ± 0.009^{ab}	0.056 ± 0.002^{b}	0.071 ± 0.008^{a}	0.070 ± 0.007^{a}	0.072 ± 0.006^{a}
C22:1n9	0.059 ± 0.006^{bc}	0.052 ± 0.002^{c}	0.057 ± 0.008^{bc}	0.069 ± 0.005^{a}	0.064 ± 0.008^{ab}
C24:1	0.004 ± 0.001	0.003 ± 0.000	0.003 ± 0.001	0.003 ± 0.001	0.004 ± 0.000
Monosaturated fatty acids (MUFA)	1.597 ± 0.062^{b}	1.151 ± 0.056^{d}	1.505 ± 0.042^{c}	1.862 ± 0.140^{a}	1.585 ± 0.023^{b}
C18:2n6c *	0.778 ± 0.054^{bc}	0.609 ± 0.026^{d}	0.730 ± 0.027^{c}	0.948 ± 0.062^{a}	0.841 ± 0.025^{b}
C18:3n3 *	0.058 ± 0.004^{b}	0.056 ± 0.004^{b}	0.056 ± 0.002^{b}	0.066 ± 0.004^{a}	0.058 ± 0.002^{b}
C18:3n6	0.019 ± 0.003^{a}	0.011 ± 0.002^{c}	0.014 ± 0.001^{bc}	0.017 ± 0.001^{a}	0.016 ± 0.003^{ab}
C20:2	0.018 ± 0.002^{b}	0.019 ± 0.001^{b}	0.021 ± 0.002^{ab}	0.023 ± 0.004^{ab}	0.023 ± 0.002^{a}

Table 8. *Cont.*

Fatty Acid	SPM	HW	SH	CPR	SP
C20:3n3	0.003 ± 0.001	0.003 ± 0.001	0.004 ± 0.000	0.003 ± 0.001	0.003 ± 0.000
C20:3n6	0.035 ± 0.004	0.035 ± 0.002	0.037 ± 0.003	0.043 ± 0.005	0.036 ± 0.003
C20:4n6	0.004 ± 0.001 ^{ab}	0.004 ± 0.000 ^{b}	0.004 ± 0.000 ^{b}	0.005 ± 0.001 ^{a}	0.005 ± 0.001 ^{a}
C20:5n3 (EPA)	0.007 ± 0.000 ^{b}	0.015 ± 0.001 ^{a}	0.007 ± 0.001 ^{b}	0.006 ± 0.001 ^{c}	0.006 ± 0.000 ^{bc}
C22:6n3 (DHA)	0.032 ± 0.002 ^{b}	0.042 ± 0.002 ^{a}	0.034 ± 0.006 ^{b}	0.033 ± 0.006 ^{b}	0.033 ± 0.005 ^{b}
Polysaturated fatty acids (PUFA)	0.954 ± 0.069 ^{b}	0.794 ± 0.036 ^{c}	0.907 ± 0.038 ^{b}	1.144 ± 0.007 ^{a}	1.021 ± 0.007 ^{b}
DHA + EPA	0.039 ± 0.002 ^{b}	0.057 ± 0.002 ^{a}	0.041 ± 0.007 ^{b}	0.039 ± 0.007 ^{b}	0.039 ± 0.007 ^{b}
Essential fatty acids (EFA)	0.836 ± 0.057 ^{b}	0.665 ± 0.031 ^{c}	0.786 ± 0.029 ^{b}	1.014 ± 0.065 ^{a}	0.899 ± 0.027 ^{b}
Total fatty acids (TFA)	3.375 ± 0.166 ^{b}	2.608 ± 0.122 ^{c}	3.230 ± 0.138 ^{b}	4.091 ± 0.251 ^{a}	3.481 ± 0.012 ^{b}

Note: * is the essential fatty acids. The same row with different letters indicates significant differences between groups based on one-way analysis of variance (ANOVA) ($p < 0.05$) (n = 9).

3.6. Comparative Analysis of Serum Biochemical Parameters of Five Common Carp Species

Twelve main biochemical indices in serum were determined to analyze the differences in blood physiology and biochemistry of the five common carp species (Table 9). The contents of TP, T-CHO, TG, and LDL were significantly higher in CPR than in the other four common carp ($p < 0.05$). The contents of AST and AST/ALT in HLJ were the highest ($p < 0.05$). The UA content in SH was significantly higher than those in the other four common carp ($p < 0.05$). TP, T-CHO, TG, and LDL were significantly lower in SPM, which were significantly lower than those in the other common carp species ($p < 0.05$).

Table 9. Serum biochemical parameters in five species of common carp.

Parameters	SPM	HW	SH	CPR	SP
TP (g/L)	29.73 ± 2.84 ^{d}	32.74 ± 4.46 ^{b}	26.89 ± 2.41 ^{c}	38.28 ± 1.93 ^{a}	33.61 ± 1.23 ^{b}
ALB (g/L)	10.63 ± 1.35 ^{c}	12.31 ± 1.53 ^{a}	10.76 ± 0.69 ^{bc}	12.76 ± 0.68 ^{a}	13.66 ± 1.53 ^{a}
ALT (U/L)	4.42 ± 1.07 ^{ab}	5.13 ± 0.64 ^{ab}	4.53 ± 1.03 ^{ab}	4.07 ± 1.00 ^{b}	5.60 ± 0.60 ^{a}
AST (U/L)	46.08 ± 6.10 ^{b}	128.67 ± 44.90 ^{a}	47.63 ± 10.12 ^{b}	11.25 ± 3.06 ^{c}	31.23 ± 1.63 ^{b}
AST/ALT	12.05 ± 2.06 ^{b}	22.80 ± 5.07 ^{a}	10.57 ± 0.78 ^{b}	2.80 ± 0.58 ^{d}	5.63 ± 1.44 ^{c}
ALP (U/L)	33.86 ± 5.19 ^{ab}	22.53 ± 6.08 ^{c}	43.47 ± 10.48 ^{a}	27.80 ± 1.06 ^{bc}	31.96 ± 8.07 ^{abc}
T-CHO (mmol/L)	2.79 ± 0.41 ^{d}	4.08 ± 0.47 ^{b}	3.27 ± 0.52 ^{c}	5.14 ± 0.63 ^{a}	3.84 ± 0.32 ^{b}
TG (mmol/L)	1.09 ± 0.13 ^{d}	1.38 ± 0.41 ^{c}	1.38 ± 0.44 ^{c}	2.16 ± 0.27 ^{a}	1.78 ± 0.29 ^{b}
HDL (mmol/L)	1.64 ± 0.34 ^{c}	2.00 ± 0.32 ^{b}	1.84 ± 0.23 ^{bc}	2.66 ± 0.28 ^{a}	2.55 ± 0.55 ^{a}
LDL (mmol/L)	0.96 ± 0.15 ^{d}	2.56 ± 0.21 ^{b}	2.09 ± 0.20 ^{c}	3.47 ± 0.67 ^{a}	2.50 ± 0.48 ^{b}
UREA (mmol/L)	2.81 ± 0.50 ^{b}	3.45 ± 0.56 ^{a}	2.96 ± 0.47 ^{ab}	3.57 ± 0.79 ^{a}	3.25 ± 0.60 ^{ab}
UA (μmol/L)	296.18 ± 8.79 ^{b}	278.25 ± 54.41 ^{b}	381.48 ± 58.07 ^{a}	99.83 ± 13.8 ^{d}	147.90 ± 20.37 ^{c}
TBA (μmol/L)	1.05 ± 0.27 ^{b}	1.56 ± 0.29 ^{a}	1.71 ± 0.70 ^{a}	0.48 ± 0.08 ^{c}	0.49 ± 0.16 ^{c}

Note: The same row with different letters indicates significant differences between groups based on one-way analysis of variance (ANOVA) ($p < 0.05$) (n = 9).

3.7. Antioxidant Capacity of Five Common Carp Species

We determined the contents of SOD, MDA, and CAT in the liver to analyze the antioxidant capacity of five common carp species (Figure 2). The contents of SOD and CAT were significantly higher in HLJ than in the other four kinds of carp ($p < 0.05$), and these contents were the lowest in SH. The MDA content was the highest in CPR, while it was the lowest in HLJ. In contrast to the SOD and CAT contents, the MDA content in HLJ was significantly lower than that in CPR and SPM ($p < 0.05$).

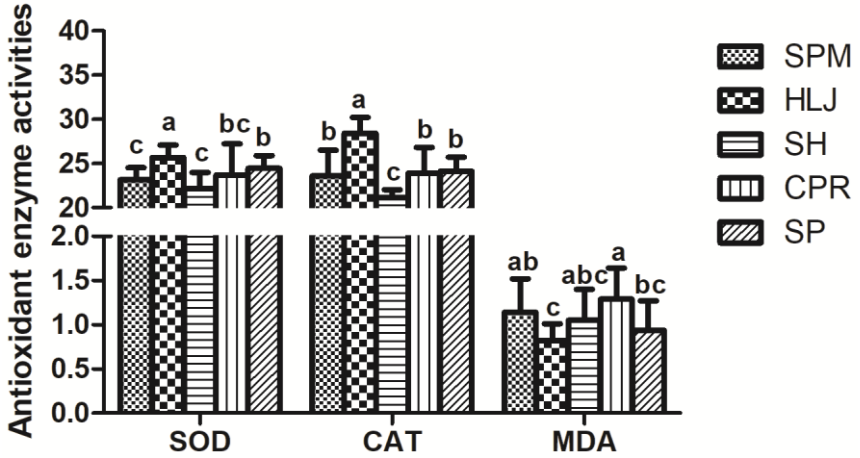

Figure 2. Antioxidant capacity in five species of common carp. Antioxidant enzymes were assayed, including superoxide dismutase (SOD, U/mg), catalase (CAT, U/mg), and malonic dialdehyde (MDA, nmol/mg) in the liver. The same row with different letters indicates significant differences between groups based on one-way ANOVA ($p < 0.05$).

3.8. Comparative Analysis of Digestive Enzyme Activities of Five Common Carp Species

The activities of three digestive enzymes, α-AMS, LPS, and TRS, in the intestine, were determined to identify differences in digestion among the five common carp species (Figure 3). The activity of α-AMS and LPS showed the highest activities in CPR, followed by SH, SPM, SP, and HLJ. TRS activity was the highest in CPR, the lowest in HLJ, and intermediate in SP, SPM, and SH. The significantly lower α-AMS, LPS, and TRS activities in HLJ than in the other four common carp species ($p < 0.05$).

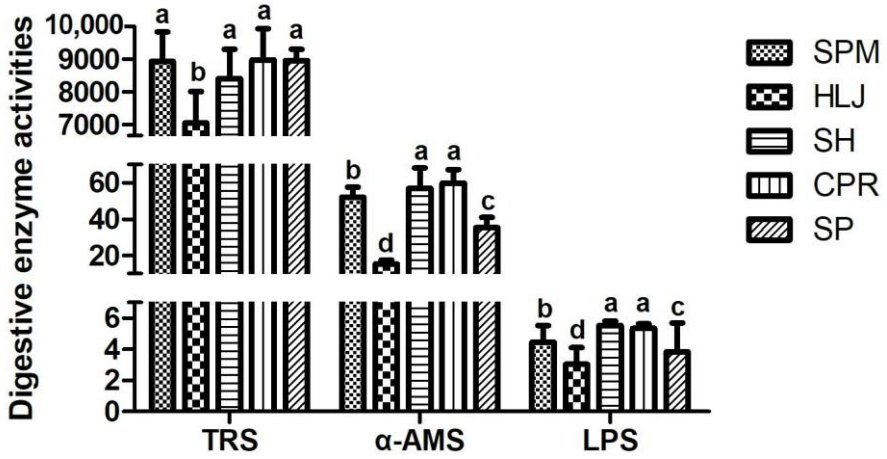

Figure 3. Digestive enzyme activities in five species of common carp. Digestive enzymes were defined, including α-Amylase (AMS, U/mg prot), lipase (LPS, U/g prot), and trypsin (TRS, U/mg prot) in intestinal tissue. The same row with different letters indicates significant differences between groups based on one-way ANOVA ($p < 0.05$).

3.9. Comparative Analysis of Growth-Related Factors of Five Common Carp Species

Using RT-qPCR technology, we determined the relative expression of five growth-related factors in the muscles of five common carp species (Figure 4). The relative expression levels of *GH*, *GHR*, *IGF1R*, and *MyoD* in the muscle of SP were significantly higher than those in the other four common carp ($p < 0.05$). The relative expression of *IGF1* in the muscle was significantly higher in SH than in the other four common carp species ($p < 0.05$). Among the common carp species, HLJ had the highest relative expression of *MSTN* in the muscles ($p < 0.05$). In addition, the results showed that the relative expression levels of *GH*,

GHR, *IGF1*, *IGF1R*, and *MyoD* in the muscle of HLJ were significantly lower than those in the other four common carp ($p < 0.05$).

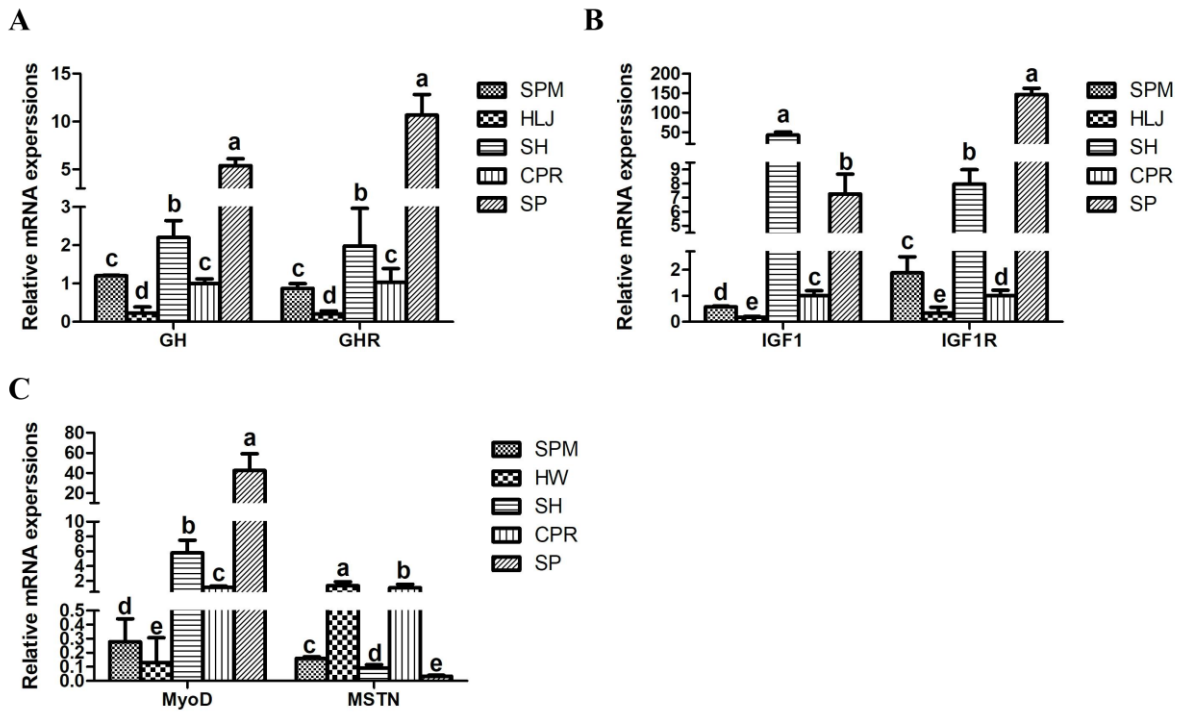

Figure 4. Relative genes expression of growth-related genes in the muscles in five species of common carp. The mRNA expression of growth-related genes produced a relative fold value compared to that of CPR. Lowercase letters indicate significant effects on the relative gene expression of growth-related genes ($p < 0.05$). Note: (**A**) *GH* and *GHR*, (**B**) *IGF1* and *IGF1R*, (**C**) *MyoD* and *MSTN*.

4. Discussion

Currently, common carp accounts for 11.5% of China's freshwater aquaculture fish [20]. Furthermore, because of its strong environmental adaptability, common carp has become a potential candidate species for aquaculture in Asia and some European countries [21–23]. In this study, five species of common carp were used as experimental materials, and their differences in nutritional value, blood metabolism, antioxidant capacity, digestion and absorption capacity, and growth in the same feeding environment were determined. The new species of the five common carp have been approved by the national aquatic stock and improved breeding approval committee from the ministry of agriculture and rural of the people's republic of china. The results of this study showed that they had significant differences in morphological traits and had distant relationships. The CV of body mass was highest in the HLJ species. The CV was used as an index of the dispersion degree of population growth, indicating that HLJ could have a high selection potential for body mass, which could provide possibilities for breeding and germplasm protection among different populations. The CF of SP and CPR was the highest; CF is an index reflecting the degree of fatness and growth of fish [24]. Because SP and CPR are both short-bodied, it is speculated that the high CF might be related to their morphological characteristics [25,26]. In addition, muscle nutrition and texture characteristics are important indicators reflecting the quality of fish, in which hardness and shear force are positively correlated with taste [27], and nutritional composition is an important factor affecting the nutritional value of fish [28]. The results of this study showed no significant difference in crude protein content among the five types of common carp species. The muscle of HLJ not only had greater hardness and shear force values but also the lowest crude fat content ($p < 0.05$). However, the high fat content in fish muscle is easily affected by oxidation, which would greatly reduce the sensory quality and taste [29], suggesting that HLJ is the better protein source. Greater

hardness and shear force can also overcome the problems of difficult segmentation and molding of fish muscle in a later stage. Therefore, the meat quality of HLJ is greater than that of the other common carp species in terms of nutritional value, production, and processing.

The composition and content of amino acids in protein, especially the composition and content of essential amino acids, are important indicators for evaluating the quality and nutritional value of fish meat [30,31]. Amino acids in fish currently play a key role in maintaining human health. Lys and Leu have antioxidant and anticancer effects [32]. Asp and Glu both promote wound healing and antitumor cell proliferation in humans and affect the taste of fish [33–36]. In this study, the Lys, Glu, and Asp contents of CPR muscle were significantly higher than those in the other common carp ($p < 0.05$), suggesting that CPR plays an important role in human health. Furthermore, the trends in E/T and F/T were the opposite in HLJ, revealing that the nutritional value of muscle components in HLJ was higher, but its meat flavor may be poor. Currently, the FAO/WHO defines high-quality proteins as having an EAA/NEAA greater than 60% in the amino acid composition [37]. The AAS (>1.0) and CS (>0.6) values can be used to assess the nutritional value of proteins [38]. The results of this study showed that the EAA/NEAA values were all greater than 0.6, and the AAS and CS scores were greater than 1.0 and 0.8 (both were the highest in Lys) in the five species of common carp, respectively. The five species of common carp all produced high-quality proteins, a suitable amino acid balance, and a uniform composition. These fish could compensate for the lack of Lys in cereal foods, thereby improving the utilization rate of protein by the human body, which is of great significance for people who have a grain-based diet. The first limiting amino acid in the five common carp was Met + Cys, and the results of this study are similar to those of previous studies [15,17]. The SFA C16:0, a key metabolite in fish, was abundant in the five species of common carp in this study, and its level was not affected by diet [39]. This finding was consistent with the fatty acid content in the muscle of other freshwater fishes, such as crucian carp (*Carassius carassius*), Chinese perch (*Siniperca chuatsi*), snakehead (*Channa argus*), grass carp (*Ctenopharyngodon idella*), common carp, black carp (*Mylopharyngodon piceus*), silver carp (*Hypophthalmichthys molitrix*), swamp eel (*Monopterus albus*), and oriental weatherfish (*Misgurnus anguillicaudatus*) [40]. Fish meat is the main source of unsaturated fatty acids for humans. The EPA and DHA in PUFAs have antioxidative and antiaging effects, which can prevent the occurrence of cardiovascular and other diseases and promote brain development in mammals [41–44]. In this study, it was found that the content of DHA + EPA in HLJ muscle was the highest, and the contents of SFA and TFA were the lowest ($p < 0.05$), indicating that the nutritional value of HLJ muscle might be higher and that it has a positive effect on the health of mammals.

Analysis of blood indicators can provide valuable information on the physiology and health of fish [45]. Analysis of blood indicators can provide valuable information on the physiology and health of fish [45]. The concentrations of TG and T-CHO in the serum rise sharply in response to environmental stress or viral infection [45,46]. Elevated serum LDL levels are more harmful to the heart in common carp [47]. The results showed that the TP, TC, TG, and LDL levels were significantly lower in SPW than in the other four carp species ($p < 0.05$), suggesting that SPW had stronger environmental adaptability than the other common carp. The liver is the main organ involved in the stress response and can reflect the antioxidant capacity of fish [12]. The intestine is the organ of digestion and absorption in fish, and the activity of digestive enzymes in the intestine is the key indicator reflecting the absorption and digestion function in these animals [48]. The effects of reactive oxygen species (ROS) on cellular function involved in lipid peroxidation and cellular dysfunction can be mitigated by the secretion of SOD and CAT in the liver [49]. The level of MDA was positively correlated with the accumulation of ROS in vivo [50]. On the other hand, LPS plays an important role in breaking down dietary fat [51]. α-AMS is clearly involved in the breakdown of dietary carbohydrates, and its activity depends on the diet of the fish [52]. TRS has important effects on growth in the juvenile/preadult stages [53,54]. The activities of SOD and CAT were significantly higher in HLJ than those in the other four common carp ($p < 0.05$), and MDA was relatively low, so it is speculated

that the liver's antioxidant capacity was strongest in HLJ. In contrast, the activities of the LPS, TRS, and α-AMS intestinal digestive enzymes in HLJ were significantly lower than those in the other common carp species ($p < 0.05$), which might be one of the reasons for the lower body mass of HLJ.

The growth of fish mainly depends on the growth of muscle. Muscle is the main edible part for consumers, and its growth is regulated by a variety of genes [14]. *GH* plays a vital role in the regulation of growth hormones in vertebrates and is located at a key position along the *GH-IGF1* axis [55]. The *GH* secreted by the pituitary binds to *GHR* on the surface of hepatocytes to stimulate the synthesis and release of *IGF*, and *IGF* and insulin-like growth factor-binding proteins (*IGFBPs*) then act on *IGFR* on the surface of target cells to further promote cell proliferation and growth [56,57]. *MyoD* has a crucial effect on the initiation and maintenance of skeletal muscle differentiation and development during myogenesis [58]. The relative expression levels of *GH*, *GHR*, *IGF1*, *IRF1R*, and *MyoD* were significantly higher in SP and SH than in the other species, while the expression level in HLJ was significantly lower ($p < 0.05$). SP and SH might have more growth potential than the other three common carp. Moreover, previous studies have shown that *MSTN* is a negative regulator of skeletal muscle growth [59]. Interestingly, the relative expression of the *MSTN* was the highest in Heilongjiang wild carp ($p < 0.05$), indicating that muscle growth might be negatively regulated by MSTN in HLJ, resulting in its lower body mass.

5. Conclusions

Our study revealed the nutritional components, serum biochemical indices, liver antioxidant enzyme activities, intestinal digestive enzymes, and muscle growth-related gene expression of five common carp species under the same feeding conditions. HLJ was better in terms of nutritional value and antioxidant capacity but weaker in terms of environmental adaptability, digestive capacity, and muscle growth potential. In contrast, SPM had strong environmental adaptability, CPR had a strong antioxidant capacity and digestion ability, and SP and SH had higher growth potential. The above findings all provide an important theoretical basis for the further breeding and improvement of excellent varieties of common carp.

Author Contributions: Z.J. and X.J. conceived the project and designed the experiments. X.J. wrote the manuscript. Y.L. and J.T. carried out the determination of enzyme activity and other tests. C.L. and X.H. performed the experiments. Y.G., L.C. and X.S. analyzed the data. The manuscript was revised and improved by L.S. and Z.J. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: All animal procedures in this study were conducted according to the guidelines for the care and use of laboratory animals of the Heilongjiang River Fisheries Research Institute, Chinese Academy of Fishery Sciences (CAFS). The studies in animals were reviewed and approved by the Committee for the Welfare and Ethics of Laboratory Animals of the Heilongjiang River Fisheries Research Institute, CAFS (approval code: 2019-03-15).

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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