动物营养学报 2010,22(3):787-796
Chinese Journal of Animal Nutrition

doi: 10.3969/j.issn.1006-267x.2010.03.040

Protein Sparing Effect of Lipid and *L*-carnitine in Diets for Largemouth Bass (*Micropterus salmoides*)

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Abstract: A 3×2 (protein/lipid ratio×*L*-carnitine) factorial experiment was conducted to evaluate the protein sparing effect of lipid and *L*-carnitine in diets for largemouth bass, *Micropterus salmoides*. Two hundred and seventy fingerlings with average body weight of (3.27±0.21) g were randomly divided into six groups with 3 replicates each and fifteen fingerlings per replicate. Six isocaloric experimental diets were formulated with three protein/lipid ratios (39.9%/7.4%, 30.3%/13.9% and 21.5%/19.5%) crossing two *L*-carnitine levels (0 and 1 g/kg), and were fed to the fingerlings for six weeks. The results showed as follows: weight gain rate was 686% when fish were fed the 39.9%/7.4% (protein/lipid) diet but was reduced to 176% when fish were fed the 21.5%/19.5% diet ($P<0.05$). Condition factor of fish fed 21.5%/19.5% (protein/lipid) diet was significantly lower than that of fish fed 39.9%/7.4% (protein/lipid) and 30.3%/13.9% (protein/lipid) diets ($P<0.05$). FCR was increased significantly from 1.15 to 2.33 when the dietary lipid level was increased from 7.4% to 19.5% (protein level was decreased from 39.9% to 21.5%) ($P<0.05$). Body moisture content was lower in the fish fed 21.5%/19.5% than that in the fish fed 39.9%/7.4% diet ($P<0.05$). When the dietary lipid level increased from 7.4% to 19.5% (protein level decreased from 39.9% to 21.5%), the body crude lipid content increased from 5.6% to 11.5% while body crude protein content decreased from 15.6% to 10.4% ($P<0.05$). The liver lipid, muscle lipid and hepatosomatic index reached the highest values when fish were fed 21.5%/19.5% (protein/lipid) diet. The percentage of lymphocytes was significantly increased from 38.30% to 48.41% ($P<0.05$), and the percentage of granulocytes was significantly decreased from 51.75% to 42.14% ($P<0.05$) when dietary lipid level was increased from 7.4% to 19.5% (protein level was decreased from 39.9% to 21.5%). It was concluded that more dietary lipid addition with the aim to spare dietary protein slowed the growth of largemouth bass, and led to a fatty liver and immune suppression. Moreover, though the addition of 1 g/kg *L*-carnitine in diet had no effect on all the parameters tested relevant to fish growth performance, an interactive effect of dietary protein/lipid ratio with *L*-carnitine was observed in the percentages of granulocytes and lymphocytes with the peak values found in the fish fed 21.5%/19.5% (protein/lipid) and 0.1% *L*-carnitine diet.

Key words: Largemouth bass; Protein/lipid ratio; *L*-carnitine; Growth; Body composition

CLC number: S965.2 **Document code**: A **Article ID**: 1006-267X(2010)03-0787-010

Largemouth bass, *Micropterus salmoides*, was introduced to China in 1983 from the USA for aquaculture, and has been one of the most important cultured species in China, with annual production estimated at 100 000 t[1]. Most studies on nutritional requirement of largemouth bass have focused on the macronutrient requirement including protein[2-3], essential amino acid, poly unsaturated fatty acid[4], carbohydrate[5] and protein to energy ratio[6]. But, since the successful and sustainable aquaculture of fish depends upon the provision of nutritionally balanced, environ-

Date received: 2009-12-14

Financial support: *Shanghai* Agriculture Science & Technology Key Grant (NO. 6-4, 2006) and a Grant from the Major State Basic Research Development Program of China (973 Program) (No. 2009CB118702)

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ment friendly and economically viable feed[7], nutritional studies on largemouth bass should also aim to reduce feed cost and minimize the release of pollutants to the environment.

Protein is an essential nutrient to build and repair damaged tissues and maintain physiological functions in fish, but it is also an expensive ingredient in aquaculture feed. Finding optimal level of protein in fish feed is important to obtain efficient and economical outcome in aquaculture industry and to reduce nitrogen and organic load in the ecosystem. The inclusion of a non-protein energy source in the diet can spare the use of protein for catabolism in diets with surplus protein[8]. Lipid has long been used in aquaculture feed as a source of energy and essential fatty acid. In the past decade, lipid has been successfully used to spare dietary protein in *Oncorhynchus mykiss*[9], *Dentex dentex*[10], *Cyprinus carpio*[11], *Morone saxatilis*[12], and *Sparus aurata* L.[13]. However, the protein sparing effect in the diet of largemouth bass is not conclusive. Although dietary lipid can be used as a non-protein energy source, excessive dietary lipid can negatively impact body composition[3]. It is therefore important to evaluate the level of non-protein energy through an incremental supplementation of lipid in fish diet[6], and to find the appropriate protein to energy ratio for the fish need.

L-carnitine is a quaternary ammonium compound biosynthesized from lysine and methionine and is required to transport long-chain acyl groups from fatty acid from the cytosol to the mitochondria during lipid metabolism for energy release[14]. In fish feed, *L*-carnitine has significantly improved growth and feed efficiency and reduced lipid deposition in *Dicentrarchus labrax*[15], *Clarias gariepinus*[16] and *Pagrus major*[17]. Since *L*-carnitine can facilitate the entry of long-chain fatty acid into the mitochondria, it has been used to evaluate lipid utilization and the protein sparing effect for lipid[18]. In contrast, Gaylord et al.[19] found that the addition of *L*-carnitine from 1 000 to 3 000 mg/kg to the diet had no effect on growth performance of hybrid striped bass. Therefore, the synergetic effect of *L*-carnitine and lipid levels on fish growth is still worth further investigation in fish.

In this study, we aimed to test the optimal dietary protein to lipid ratio of largemouth bass fingerling and the role of dietary *L*-carnitine in regulating fish performance. The experiment was designed with three levels of dietary protein to lipid ratio cross-classified two levels of *L*-carnitine in the diets. The dependent variable to evaluate the fish response included growth performance, body composition, muscle and liver lipid contents, and leucocytes profile.

1 MATERIALS AND METHODS

1.1 Experimental diets

Six near-isocaloric experimental diets were formulated with fish meal, soybean meal, and wheat starch in pre-determined amounts. The dietary lipid was supplied by fish oil and soybean oil in a 1∶1 ratio, resulting in three levels of dietary lipid: 7.4%, 13.9% and 19.5%, respectively (dietary protein levels were 39.9%, 30.3% and 21.5%, correspondingly). Each protein/lipid ratio diet contained two levels of *L*-carnitine (0 and 1 g/kg). After a thorough mixing, the moist paste was extruded through a 2 mm diameter grinder and was cut into 3 mm long pellets. Moist pellets were air dried for 24 h, then dried at 60～70 ℃ in an oven until moisture＜10%. All diets were analyzed for nutrient levels and they were stored at －20 ℃ until used. Composition and nutrient levels of experimental diets were shown in Table 1.

Table 1　Composition and nutrient levels of experimental diets　(as-fed basis)

Items	Diets					
	1	2	3	4	5	6
Ingredients (g/kg)						
Fish meal	500	500	380	380	270	270
Soybean meal	200	200	152	152	108	108
Corn starch	150	150	150	150	150	150
Fish oil	5	5	45	45	80	80
Soybean oil	5	5	45	45	80	80
Choline chloride	5	5	5	5	5	5
Vitamin C	2	2	2	2	2	2
Vitamin premix[1)]	15	15	15	15	15	15
Mineral premix[2)]	15	15	15	15	15	15
Binding (CMC)	15	15	15	15	15	15
Fiber	88	87	176	175	260	259
L-carnitine	—	1	—	1	—	1
Total	1 000	1 000	1 000	1 000	1 000	1 000
Nutrient levels (%)[3)]						
Crude protein	39.9	39.9	30.3	30.3	21.5	21.5
Crude lipid	7.4	7.4	13.9	13.9	19.5	19.5
Energy (MJ/kg)	15.8	15.8	15.9	15.9	15.8	15.8

[1)] Provided the following per kilogram of diet (mg): *myo*-inositol 400; nicotinic acid 150; calcium pantothenate 44; riboflavin 20; pyridoxine hydrochloride 12; menadione 10; thiamine hydrochloride 10; retinyl acetate 7.3; folic acid 5; biotin 1; cholecalciferol 0.06; cyanocobalamin 0.02; *L*-ascorbic acid 2 000; *DL*-α-tocopherol acetate 800.

[2)] Provided the following per kilogram of diet: KH_2PO_4 22 g; $FeSO_4 \cdot 7H_2O$ 1.0 g; $ZnSO_4 \cdot 7H_2O$ 0.13 g; $MnSO_4 \cdot 4H_2O$ 52.8 mg; $CuSO_4 \cdot 5H_2O$ 12 mg; $CoSO_4 \cdot 7H_2O$ 2 mg; KI 2 mg.

[3)] Analyzed values.

1.2　Experimental design

Pellet-trained fish were obtained from a commercial producer (*Jiangsu*, China). Before the experiment, all fish with the average body weight of (3.27±0.21) g were acclimatized for one week in the aquaria at 15 fish per tank (200 L) and fed a commercial diet in triplicate (18 tanks in total). During the 6 weeks feeding trial, fish were fed twice daily (08:00 and 16:00) to apparent satiation with the experimental diets and the daily feed application to each tank was recorded. The photoperiod was 12 h light and 12 h dark. The water quality parameters across the experiments were temperature 23.8 ~ 26.5 ℃, dissolved oxygen 5.53~6.74 mg/L, pH 7.8~8.0 and total ammonia-nitrogen<0.01 mg/L. At the end of the trial, fish from each aquarium were harvested, counted, weighed (bulk and individually), and measured (total length). Ten fish from each tank were randomly collected for analysis. Five fish were used for the whole body composition analysis and five fish were used for the analysis of blood smear and chemical composition in the white muscle (from fillet) and liver. The growth performance and morphometry indices were calculated as follows:

survival rate (%) = 100 × final fish number/initial fish number;

weight gain rate (%) = 100 × (W_t − W_0)/W_0, where W_0 is the initial weight and W_t is the final weight;

condition factor (%) = 100 × W/L^3, where W is weight (g) and L is length (cm);

hepatosomatic index (HSI, %) = 100 × (liver weight/body weight);

feed conversion ratio (FCR) = dry feed weight/wet weight gain.

1.3　Biochemical composition analysis

The analysis of ash, crude protein, crude lipid and moisture in fish were conducted in five replicates, and those in the diets were carried out in triplicate following the standard methods[20].

Moisture was determined by oven dry at 105 ℃ to a constant weight. Crude protein was analyzed by the Kjeldahl method after acid digestion. Crude lipid was determined by the ether extraction method by a Soxtec system. Ash was determined after combustion at 550 ℃ to constant weight.

1.4 Blood sampling and smear

At the end of the trial, after fish were fasted for 24 h, the caudal peduncle was cut with a scalpel and the blood was taken with a heparinized microhematocrit capillary tube. Blood smears were stained using the Hema 3 stain (Biochemical Sciences, St. Louis, MO). Leucocytes were differentiated into lymphocytes, thrombocytes and granulocytes. Each leucocytes type was expressed in a percentage of the total leucocytes.

1.5 Statistical analysis

Data were expressed as mean ± standard error, and were subjected to Two-way ANOVA (SPSS 14.0). If a significant difference was identified, differences between means were compared by Duncan's multiple range test. The level of significant difference was set at $P<0.05$.

2 RESULTS

2.1 Growth performance

After a feeding trial of 6 weeks, all fish survived, and the fish growth related indices under different diets were presented in Table 2. Weight gain rate was decreased significantly from 686% in fish fed 39.9%/7.4% (protein/lipid) diet to 176% in fish fed 21.5%/19.5% (protein/lipid) diet ($P<0.05$). Condition factor of fish fed 21.5%/19.5% (protein/lipid) diet was significantly lower than that of fish fed 39.9%/7.4% (protein/lipid) and 30.3%/13.9% (protein/lipid) diets ($P<0.05$), while the difference between the latter two groups was not significant ($P>0.05$). The HSI of fish fed 21.5%/19.5% (protein/lipid) diet was significantly higher than that of fish fed 39.9%/7.4% (protein/lipid) and 30.3%/13.9% (protein/lipid) diets ($P<0.05$), while no significant difference on HSI was detected between fish fed the 39.9%/7.4% (protein/lipid) and 30.3%/14.9% (protein/lipid) diets. FCR was increased significantly from 1.15 to 2.33 when the dietary lipid level was increased from 7.4% to 19.5% (protein level decreased from 39.9% to 21.5%) ($P<0.05$). Supplementation with 1 g/kg *L*-carnitine had no effect on weight gain rate, condition factor, HSI and FCR ($P>0.05$). There was no interactive effect between dietary protein/lipid ratio and *L*-carnitine on any growth related parameters ($P>0.05$).

Table 2 Growth performance of largemouth bass fed different diets

Items		Weight gain rate (%)	Condition factor (%)	HSI (%)	FCR
Protein/Lipid	*L*-carnitine (g/kg)				
39.9%/7.4%	0	686±65^{c}	1.28±0.03^{b}	2.20±0.14^{a}	1.15±0.03^{c}
	1	661±86^{c}	1.35±0.04^{b}	1.90±0.08^{a}	1.16±0.02^{c}
30.3%/13.9%	0	549±73^{bc}	1.32±0.03^{b}	2.60±0.22^{a}	1.33±0.01^{b}
	1	450±43^{b}	1.27±0.02^{b}	2.60±0.21^{a}	1.35±0.02^{b}
21.5%/19.5%	0	231±37^{a}	1.18±0.02^{a}	4.20±0.37^{b}	2.08±0.02^{a}
	1	176±43^{a}	1.18±0.02^{a}	3.80±0.43^{b}	2.33±0.01^{a}
P-value of Two-way ANOVA					
Protein/Lipid		0.00	0.00	0.00	0.00
L-carnitine		0.28	0.65	0.36	0.18
(Protein/Lipid)×*L*-carnitine		0.85	0.10	0.83	0.63

Values in the same row with different small letter superscripts mean significant difference ($P<0.05$). The same as below.

2.2 Body composition and liver and muscle lipid contents

Table 3 presented the whole body composition of the fish fed various experimental diets. Dietary protein/lipid ratio significantly affected the body moisture, crude protein and crude lipid

contents ($P<0.05$), while no significant difference was detected in body ash content ($P>0.05$). Fish fed 19.5% lipid (21.5% protein) diet had lower body moisture content than fish fed 7.4% lipid (39.9% protein) diet ($P<0.05$). The body crude lipid content was significantly increased from 5.6% to 11.5% ($P<0.05$) when the dietary lipid level was increased from 7.4% to 19.5% (protein level was decreased from 39.9% to 21.5%). Interestingly, such an increase of dietary lipid level significantly reduced whole body crude protein content from 15.6% to 10.4% ($P<0.05$).

Table 4 showed the lipid contents in liver and muscle of fish fed different diets. When the dietary lipid level was increased from 7.4% to 19.5% (protein level was decreased from 39.9% to 21.5%), the liver lipid content was significantly increased from 1.59% to 4.65% ($P<0.05$), and the muscle lipid content was significantly increased from 1.33% to 3.67% ($P<0.05$).

Supplementation of *L*-carnitine had no significant effect on the body composition and liver and muscle lipid contents ($P>0.05$), and no interactive effect between dietary protein/lipid ratio and *L*-carnitine on the all parameters tested above ($P>0.05$).

Table 3　Body composition of largemouth bass fed different diets　(%)

Items		Moisture	Crude lipid	Crude protein	Ash
Protein/Lipid	*L*-carnitine (g/kg)				
39.9%/7.4%	0	74.60 ± 0.37^{b}	5.60 ± 0.29^{a}	15.60 ± 0.29^{e}	3.30 ± 0.12^{a}
	1	74.20 ± 0.41^{b}	6.10 ± 0.54^{a}	14.40 ± 0.93^{de}	3.40 ± 0.42^{a}
30.3%/13.9%	0	72.60 ± 1.06^{ab}	8.60 ± 0.56^{b}	13.00 ± 0.37^{cd}	3.30 ± 0.28^{a}
	1	72.30 ± 0.84^{ab}	8.60 ± 0.80^{b}	12.20 ± 0.64^{bc}	3.90 ± 0.20^{a}
21.5%/19.5%	0	71.10 ± 0.55^{a}	11.50 ± 0.48^{c}	10.40 ± 0.23^{a}	3.70 ± 0.23^{a}
	1	72.30 ± 0.98^{ab}	10.80 ± 0.44^{c}	11.00 ± 0.17^{ab}	3.50 ± 0.24^{a}
P-value of Two-way ANOVA					
Protein/Lipid		0.01	0.00	0.00	0.61
L-carnitine		0.69	0.87	0.29	0.52
Protein/Lipid × *L*-carnitine		0.52	0.57	0.24	0.31

Table 4　Liver and muscle lipid contents of largemouth bass fed different diets　(%)

Items		Liver lipid	Muscle lipid
Protein/Lipid	*L*-carnitine (g/kg)		
39.9%/7.4%	0	1.59 ± 0.37^{a}	1.36 ± 0.09^{a}
	1	1.60 ± 0.15^{a}	1.33 ± 0.02^{a}
30.3%/13.9%	0	2.11 ± 0.25^{a}	2.81 ± 0.36^{b}
	1	2.23 ± 0.14^{a}	2.70 ± 0.06^{b}
21.5%/19.5%	0	3.62 ± 0.22^{b}	3.41 ± 0.20^{bc}
	1	4.65 ± 0.25^{b}	3.67 ± 0.37^{c}
P-value of Two-way ANOVA			
Protein/Lipid		0.00	0.00
L-carnitine		0.07	0.83
(Protein/Lipid) × *L*-carnitine		0.11	0.70

2.3　Leucocytes profile

Table 5 presented the percentages of lymphocytes, thrombocytes and granulocytes in leucocytes of fish fed different diets. The percentage of lymphocytes was significantly increased from 38.30% to 48.41% ($P<0.05$), and the percentage of granulocytes was significantly decreased from 51.75% to 42.14% ($P<0.05$) when dietary

lipid level was increased from 7.4% to 19.5% (protein level was decreased from 39.9% to 21.5%). Dietary lipid level had no significant effect on the percentage of thrombocytes ($P > 0.05$). Supplementation of *L*-carnitine had no significant effect on leucocytes profile ($P > 0.05$), but there was significant synergistic effect on granulocytes ($P < 0.05$) and lymphocytes ($P < 0.05$) with the highest values found in fish fed the 19.5% lipid (21.5% protein) and 1 g/kg *L*-carnitine diet.

Table 5 Blood cell percentage of largemouth bass fed different diets (%)

Items		Lymphocytes	Thrombocytes[1)]	Granulocytes[2)]
Protein/Lipid	*L*-carnitine (g/kg)			
39.9%/7.4%	0	38.30±1.01[a]	9.96±1.28	51.75±1.76[b]
	1	39.42±2.68[a]	8.69±1.51	51.90±3.43[b]
30.3%/13.9%	0	47.66±3.20[b]	8.02±0.51	44.33±3.20[a]
	1	48.07±1.42[b]	10.78±1.23	41.15±0.66[a]
21.5%/19.5%	0	48.41±2.42[b]	9.45±2.11	42.14±1.40[a]
	1	38.43±1.56[a]	9.76±1.75	51.81±0.68[b]
P-value of Two-way ANOVA				
Protein/Lipid		0.01	0.98	0.01
L-carnitine		0.13	0.62	0.22
(Protein/Lipid)×*L*-carnitine		0.03	0.41	0.02

1) Include both spiked and spindle shaped cells.

2) Include neutrophils, monocytes, basophils and eosinophils.

3 DISCUSSIONS

In this study, the highest weight gain occurred in fish fed a diet containing 39.9% protein and 7.4% lipid. Bright et al.[6] reported that a diet containing 6%～7% lipid and 40% protein obtained the best growth in juvenile largemouth bass, which was in accordance with our results in a 6-week feeding trial at the fingerling stage. Also in our study, although the increase of dietary lipid level from 7.4% to 13.9% (protein level from 39.9% to 30.3%) did not significantly affect the fish condition factor and hepatosomatic index, it significantly reduced weight gain and increased feed conversion ratio. When the dietary lipid level reached 19.5% (protein level was 21.5%), the bass showed the lowest weight gain rate and the body became slim as indicated by the low condition factor. The difference between this study and other studies was that we used near-isocolaric diets to keep the same energy content among diets rather than only adjusting protein to energy ratio. Therefore, these findings could be explained partially by protein deficient in lipid rich diets of this study since Brian et al.[21] found that the specific growth rate of largemouth bass was the greatest at a protein level of 37%.

It seemed that largemouth bass had limited ability to utilize high dietary lipid because increased dietary lipid led to lipid deposition in the whole body, liver and white muscle tissues. The lowest body lipid deposition occurred in fish fed 39.9%/7.4% (protein/lipid) diet, indicating that low lipid diet could minimize lipid deposition, which was in agreement with a previous study by Bright et al.[6] on largemouth bass fingerlings. It was worthwhile noticing that the dietary lipid of 19.5% (21.5% protein) significantly increased the liver lipid and the HSI value (4.2%) of largemouth bass, which could be an early sign of the fatty liver or liver tumefaction. In another study, Gaylord et al.[12] found that body lipid deposition in white bass Morone chrysops was increased significantly when the dietary lipid level was above 10%. Our data suggested that largemouth bass and other species in the Perciformes fish may not

be able to effectively metabolize lipid energy when dietary lipid level was over 13.9%.

The susceptibility of pathogens and environmental stress could be tested by the response of fish to immune parameters. Veterinary studies have demonstrated that animal fed diet containing a high concentration of unsaturated fatty acid showed a reduced resistance to pathogen infections and low immune response to stress[22-24]. In our study, fish fed 30.3%/13.9% or 21.5%/19.5% (protein/lipid) dietary showed a significant reduction of granulocytes, an important agent for phagocytosis. Virella et al.[25] demonstrated that lipid peroxidation of fatty acid may inhibit cellular proliferation due to the toxicity of oxidized fatty acid. Previous studies reported that excessive lipid reserves in tissues may ultimately reduce growth due to loss of appetite[26-27]. The accumulation of lipid in the liver and the body of largemouth bass at high dietary lipid level suggested that the potential to quickly metabolize lipid was low and the protein sparing effect was not obvious in this fish. Together with other results in this study, though previous studies have found protein was spared when the lipid level was 15%～17% in the diet in rainbow trout[9], common dentex[10] and gilthead sea bream[13], our results could suggest that largemouth bass could not use lipid as an energy substrate to effectively spare body protein when the dietary lipid was over 13.9%.

L-carnitine was isolated from meat and could improve energy production in mitochondria through β-oxidation of fatty acid[28]. This has led to the belief that exogenous administration of *L*-carnitine could enhance the performance of fish by improving energy utilization efficiency and reducing lipid oxidation[16-17]. Previous studies on fish have showed that *L*-carnitine supplementation could lower body lipid content[16,29-31] and improve growth and FCR[16-17,32-33]. But in our study, no effect was found when 1 g/kg *L*-carnitine was supplied into the diet, and the result was in consistent with the finding of Birkenfeld et al.[34] who demonstrated that supplementation of *L*-carnitine to the sow diet did not influence body composition and lipid metabolism. Gaylord et al.[12] explained the controversial conclusion of strong the effect of *L*-carnitine on lipid metabolism in fish by the fact of dietary lysine and methionine being precursors for the synthesis of *L*-carnitine. The strong effect could only be found when these amino acids were not enough or under limited supply in the diet[18]. In this study, an interactive effect between dietary protein/lipid and *L*-carnitine was observed in the granulocytes with the peak value was found in the fish fed 21.5%/19.5% (protein/lipid) and 1 g/kg *L*-carnitine diet. Though, there were many aspects which could pose effect on *L*-carnitine, including quantity, duration and route of delivery, and it seemed clear that the ambiguity among many studies testing *L*-carnitine could be a result of different concentrations of carnitine administered to animals and/or the different strategies in supplying *L*-carnitine. This result could be an indicative of the important role of *L*-carnitine in fish nutrition, but further research should be undertaken to explore the dose dependent effect of *L*-carnitine on fish growth.

4 CONCLUSIONS

① More dietary lipid addition with the aim to spare dietary protein slowed the growth of largemouth bass, and led to a fatty liver and immune suppression.

② Largemouth bass and other Perciformes fish may not be able to effectively metabolize lipid energy when dietary lipid level was over 13.9% (dietary protein level was lower than 30.3%).

③ The only interactive effect of *L*-carnitine with dietary protein/lipid ratio was observed in the granulocytes and lymphocytes with the peak values found in the fish fed 21.5%/19.5% (protein/lipid) and 0.1% *L*-carnitine diet.

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脂肪和 *L*－肉碱对大口黑鲈饲料中蛋白质的节约作用

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摘 要: 本试验旨在探讨脂肪和 *L* －肉碱对大口黑鲈饲料中蛋白质的节约作用。采用 3×2(蛋白质脂肪比×*L* －肉碱)完全随机设计,配制了不同蛋白质脂肪比(39.9%/7.4%、30.3%/13.9%和 21.5%/19.5%)和 *L* －肉碱水平(0 和 1 g/kg 饲料)的 6 种等能饲料。选取平均初重为(3.27±0.21)g 的大口黑鲈幼鱼 270 尾,随机分为 6 组(每组 3 个重复,每个重复 15 尾),随机饲喂 1 种饲料,试验期 6 周。结果表明:随着饲料中脂肪水平从 7.4%升高到 19.5%(蛋白质水平从 39.9%下降到 21.5%),鲈鱼的增重率从 685%显著降低到 176%($P<0.05$),饲料效率从 1.15 增加到 2.33($P<0.05$),且投喂蛋白质脂肪比为 21.5%/19.5%饲料的鲈鱼的肥满度显著低于投喂蛋白质脂肪比为 39.9%/7.4%和 30.3%/13.9%饲料的鲈鱼($P<0.05$)。投喂蛋白质脂肪比为 21.5%/19.5%饲料的鲈鱼体水分含量显著低于投喂蛋白质脂肪比为 39.9%/7.4%的饲料($P<0.05$),且随着饲料中脂肪水平从 7.4%升高到 19.5%(蛋白质水平从 39.9%下降到 21.5%),全鱼脂肪含量从 5.6%显著升高到 11.5%($P<0.05$),全鱼粗蛋白质含量从 15.6%显著下降到 10.4%($P<0.05$)。鱼体肝脏和肌肉中脂肪含量以及肝体指数在投喂蛋白质脂肪比为 21.5%/19.5%饲料时达到最高值。此外,随着饲料中脂肪水平从 7.4%升高到 19.5%(蛋白质水平从 39.9%下降到 21.5%),淋巴细胞百分比由 38.30%升高到 48.41%($P<0.05$),粒细胞百分比由 51.75%下降到 42.14%($P<0.05$)。由此得出,以节约蛋白质为目的的过量添加脂肪会导致鱼体生长速度降低,甚至引起脂肪肝的发生和机体免疫系统的应激反应。此外,饲料中添加 1 g/kg 的 *L* －肉碱并不能提高大口黑鲈的生长性能,但蛋白质脂肪比和 *L* －肉碱对淋巴细胞百分比和粒细胞百分比存在互作作用,并在饲喂添加 1 g/kg *L* －肉碱的蛋白质脂肪比为 21.5%/19.5%的饲料时达到峰值。[**动物营养学报,2010,22(3):787-796**][**中文全文见《动物营养学报》网站(www.ChinaJAN.com)中文版 2010 年 22 卷 3 期**]

关键词: 大口黑鲈;蛋白质脂肪比;*L* －肉碱;生长;体成分

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(编辑 管景颖)