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# Studies on the nutrition of two species of catfish, *Silurus meridionalis* Chen and *S. asotus* Linnaeus. I. Effects of dietary protein and lipid on growth performance and feed utilization

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ABSTRACT

A 4 × 3 two-factor experiment was designed to study the effects of dietary protein and lipid on growth performances and feed utilization of two species of juvenile catfish, *Silurus meridionalis* Chen and *S. asotus* Linnaeus, with the initial weight 9.16 ± 0.01 g and 9.10 ± 0.01 g, respectively. Twelve extruded pellet diets were formulated to contain four levels of protein (46%, 43%, 40% and 37%) and three levels of lipid (13%, 10% and 7%). Each diet was fed to a triplicate group of catfish for 8 weeks in a flow-through water system. The results showed that dietary protein had significant effects on the weight gain rate (WGR) of *S. meridionalis* Chen, and the feed intake (FI), feed efficiency ratio (FER) and protein efficiency ratio (PER) of both catfish ($P < 0.05$). The highest WGR of *S. meridionalis* Chen was found as 1193.10 % in the group with 46% of dietary protein and 7% of dietary lipid. And that for *S. asotus* Linnaeu was found as 939.98 % with 43% of dietary protein and 7% of dietary lipid. The FI of both catfish decreased with the increasing of dietary protein level. The FER of both catfish were positively related with dietary protein level (*S. meridionalis* Chen, $r = 0.820$, $p = 0.000$; *S. asotus* Linnaeus, $r = 0.630$, $p = 0.000$), but negatively related with FI (*S. meridionalis* Chen, $r = -0.947$, $p = 0.000$; *S. asotus* Linnaeus, $r = -0.927$, $p = 0.000$). The PER of both catfish were significantly affected by dietary protein ($P < 0.05$), and were relatively lower in 46% of dietary protein groups. There were no significant differences in condition factor and hepatosomatic index among the all treatments in both catfish. Viscerasomatic indices of both catfish were increased with dietary lipid levels. In conclusion, the optimal ratio of dietary protein to lipid for *S. meridionalis* Chen and *S. asotus Linnaeu* was 43: 10 and 43: 7, respectively. Furthermore, *S. meridionalis* Chen got relatively higher growth, feed utilization and better body morphological indices than *S. asotus* Linnaeu under the present experimental conditions.



## 1. Introduction

Protein and lipid are important organic composition and energy materials in the body of animals. They play important roles in metabolism and growth of organism. Meanwhile, protein and lipid are the most expensive components in fish diets (Lee et al., 2000).

Since protein is in a dynamic state, continually being synthesized and degraded, a dietary supply is needed throughout life to provide amino acids and nonspecific nitrogen for maintenance and growth. Furthermore, fish characteristically require much higher protein levels in the diet than necessary for birds and mammals (Cowey and Sargent, 1972). An adequate protein will accelerate the growth of fish. But excessive dietary protein will be used for energy, resulting in higher specific dynamic action (SDA), more ammonia nitrogen (LeGrow and Beamish, 1986), low protein efficiency ratio (PER), low growth, and more cost. So, the proper level of dietary protein is needed to be worked out for each kind of fish. But there is no single level of dietary protein that is optimum for meeting the nitrogen needs of fish. This is because several factors affect the dietary protein requirement, including fish size, water temperature, feed allowance and amount of non-protein energy in the diet (Singh et al., 2009). It has been found that lipid has protein-sparing effects in several fish species, such as red tilapia, southern catfish *Silurus meridionalis* Chen (Fu et al., 2001), red porgy *Pagrus pagrus* (Schuchardt et al., 2008). However, high lipid diets usually lead to elevated lipid levels in the carcass and may also suppress growth. A proper balance of dietary protein and lipid is important for growth, quality and cost of fish.

Southern catfish *S. meridionalis* Chen is a native carnivorous fish. It is the most extensively cultured catfish in China (Fu and Cao, 2006). The silurid catfish *S. asotus* Linnaeus is widely distributed throughout the freshwater of China, Korea and Japan. It is a commercially valuable aquaculture fish in China and Japan (Miwa et al., 2001). Previous studies showed that the optimum dietary protein level for *S. meridionalis* Chen was 47–51% (Zhang et al., 2000). However, interactions between

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dietary protein and lipid on southern catfish are still unknown. Moreover, no published data on the basic nutrients requirements of *S. asotus* Linnaeus are available. The commercial feed used for *S. meridionalis* Chen in China usually contains 40–48% of dietary protein and 5–11% of dietary lipid. The fish meal is about 45–65% in better quality commercial feeds. The commercial feed used for *S. asotus* Linnaeus usually contains 35–46% of dietary protein. The fish meal is about 20–40%. The present study was designed to comparatively analyze the nutrition of the two species of catfish, especially for the effects of dietary protein and lipid on growth performances and feed utilization. In this study, extruded pellet feeds were used.

## 2. Materials and methods

### 2.1. Experimental diets

Ingredients and nutrient contents of the experimental diets are presented in Table 1. Fish meal and soybean meal were used as the protein sources. Soybean oil was used as the lipid source. Wheat meal was used as the carbohydrate source. Twelve practical diets were formulated in a 4 × 3 factorial design to contain four levels of protein (46%, 43%, 40% and 37%) and three levels of lipid (13%, 10% and 7%). The experimental diets were processed by the Special Feed Branch of Tongwei Co., Ltd. (Chengdu, China). Briefly, ingredients were ground into fine powder through 180 μm mesh, and then thoroughly mixed with soybean oil. Thereafter, water was added to produce extruded pellet feed (Φ 3.0 mm) with a puffing machine (X620, Sprout-Matador, Denmark).

### 2.2. Experimental fish and feeding trial

Experimental catfish (*S. meridionalis* Chen and *S. asotus* Linnaeus) were obtained from commercial farms. Prior to the initiation of the feeding trial, catfish were acclimated to the system and fed with a commercial diet for 20 days.

The feeding trial was conducted in a flow-through water system. The water was directly pumped from an outdoor pond without a temperature control. The initial average body weight of *S. meridionalis* Chen was 9.16 ± 0.01 g, and that of *S. asotus* Linnaeus was 9.10 ± 0.01 g. There were 3 replicates per treatment. Each tank was used as a replicate, which contained 80 L of water and stocked with 35 fish. Fish were hand fed to satiation twice daily at 6:00 and 18:00, respectively. Feces and uneaten feed were removed to maintain the water quality. During the 56-day feeding trial, water flow rate was 1.8 L/min, water temperature was 20–30 °C, pH 7.2–7.9. Dissolved oxygen was not less than 6 mg $L^{-1}$, and there were negligible levels of free ammonia and nitrite.

### 2.3. Sample collection and analysis

At the termination of the feeding trial, fish were not fed for 24 h. Then, all the fish were removed from the tanks, weighed (each replicate was weighed as a group) and counted. Six livers and six visceral were taken from one tank. Then they were pooled as a replicate of one treatment to calculate the hepatosomatic index (HSI) and viscerasomatic index (VSI), respectively. Proximate composition analysis of feed was performed by the standard methods of AOAC (1995).

### 2.4. Calculations and statistical analysis

Growth performance and feed utilization were calculated as follows:

$$\text{Survival rate (SR; \%)} = 100 \times (\text{final fish number}/\text{initial fish number})$$

$$\text{Weight gain rate (WGR; \%)} = 100 \times [(\text{final body weight} - \text{initial body weight})/\text{initial body weight}]$$

$$\text{Feed intake (FI; g/100 g/day)} = \text{total amount of the feed consumed (g)}/[(\text{initial body weight} + \text{final body weight})(100\text{ g})/2]/\text{days}$$

$$\text{Feed efficiency ratio (FER)} = \text{wet weight gain (g)}/\text{total amount of the feed consumed (g)}$$

$$\text{Protein efficiency ratio (PER)} = \text{wet weight gain (g)}/\text{protein intake (g)}$$

$$\text{Condition factor (CF)} = 100 \times \text{body weight}/(\text{body length})^3$$

$$\text{Hepatosomatic index (HSI; \%)} = 100 \times \text{liver weight}/\text{body weight}$$

$$\text{Viscerasomatic index (VSI; \%)} = 100 \times \text{visceral weight}/\text{body weight}$$

Data from each treatment were submitted to two-way analysis of variance (ANOVA). All the percentage data were transformed to square-root arcsine values before ANOVA. When overall differences were significant ($P < 0.05$), Tukey's test was used to compare the mean values. Statistical analysis was performed using the Statistical Product and Service Solutions (SPSS 16.0) and Microsoft Excel 2007.

**Table 1**
Formulation and chemical proximate composition of the experimental diets (% dry matter).

| Ingredients[b] | Diet no. (protein/lipid) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 (46/13) | P2 (43/13) | P3 (40/13) | P4 (37/13) | P5 (46/10) | P6 (43/10) | P7 (40/10) | P8 (37/10) | P9 (46/7) | P10 (43/7) | P11 (40/7) | P12 (37/7) |
| Fish meal[a] | 60.00 | 49.40 | 38.80 | 28.20 | 55.20 | 44.60 | 34.00 | 23.40 | 50.40 | 39.80 | 29.20 | 18.60 |
| Soybean meal[a] | 0.00 | 10.00 | 20.00 | 30.00 | 7.50 | 17.50 | 27.50 | 37.50 | 15.00 | 25.00 | 35.00 | 45.00 |
| Wheat flour[a] | 28.05 | 28.05 | 28.05 | 28.05 | 28.05 | 28.05 | 28.05 | 28.05 | 28.05 | 28.05 | 28.05 | 28.05 |
| Beer yeast[a] | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Soybean oil | 8.10 | 8.70 | 9.30 | 9.90 | 5.40 | 6.00 | 6.60 | 7.20 | 2.70 | 3.30 | 3.90 | 4.50 |
| Vitamin premix | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| Mineral premix | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| *Proximate analysis (n = 3)* | | | | | | | | | | | | |
| Moisture | 8.97 | 9.38 | 9.78 | 10.19 | 9.53 | 9.94 | 10.35 | 10.76 | 10.10 | 10.51 | 10.92 | 11.32 |
| Crude protein | 46.08 | 43.18 | 40.27 | 37.37 | 46.05 | 43.15 | 40.25 | 37.35 | 46.00 | 43.12 | 40.22 | 37.32 |
| Crude lipid | 13.09 | 13.06 | 13.04 | 13.02 | 10.15 | 10.13 | 10.11 | 10.08 | 7.21 | 7.19 | 7.17 | 7.15 |
| Ash | 10.56 | 9.43 | 8.30 | 7.17 | 10.23 | 9.10 | 7.97 | 6.84 | 9.89 | 8.76 | 7.63 | 6.50 |
| Energy (kJ/g) | 14.66 | 14.97 | 15.27 | 15.58 | 14.13 | 14.43 | 14.74 | 15.04 | 13.59 | 13.90 | 14.20 | 14.51 |

[a] Fish meal, crude protein 68.25% dry matter, crude lipid 7.28% dry matter; Soybean meal, crude protein 43.35% dry matter, crude lipid 1.50% dry matter; Wheat flour, crude protein 15.00% dry matter, crude lipid 2.20% dry matter; Beer yeast, crude protein 46.10% dry matter, crude lipid 0.40% dry matter.
[b] All the ingredients were supplied by the Special Feed Branch of Tongwei Co., Ltd.(Chengdu, China).

## 3. Results

### 3.1. Growth and survival

The growth and survival data are presented in Tables 2-1 and 2-2. Neither the survival of *S. meridionalis* Chen (from 74.28% to 97.14%) nor that of *S. asotus* Linnaeu (from 73.33% to 89.52%) was significantly influenced by different levels of dietary proteins and lipids ($P > 0.05$). The survival in some groups of both catfish seemed to be low. The reason could be that carnivorous catfish tend to be aggressive and the big one usually bite, even devour the small one.

The weight gain rate (WGR) of *S. meridionalis* Chen was significantly affected by dietary protein and its interaction with dietary lipid ($P < 0.05$) (Table 2-1). However, effects of dietary lipid on WGR were not significant ($P > 0.05$). When the dietary protein level was 46%, the significant highest WGR of *S. meridionalis* Chen was found as 1193.10 % in the group with 7% of dietary lipid. As the dietary protein level decreased to 43%, the highest WGR was found as 1112.70 % in the group with 10% of dietary lipid, which was not significantly different from that (1193.10 %) presented above. Moreover, when dietary protein level decreased further, the highest WGR that was not significantly different from 1193.10 % only could be found in the treatment with 40% of dietary protein and the highest dietary lipid level (13%).

Dietary protein and lipid had no significant influence on the WGR of *S. asotus* Linnaeu ($P > 0.05$) (Table 2-2). And it was also true for their interaction. The highest value of WGR among all the treatments was found as 939.98 % in the group with 43% of dietary protein and 7% of dietary lipid.

Overall, the results showed that *S. meridionalis* Chen had a relative higher survival and growth than *S. asotus* Linnaeu under the same experimental conditions.

### 3.2. Feed utilization

#### 3.2.1. Feed intake

The feed intake (FI) data are presented in Tables 2-1 and 2-2.

The FI of *S. meridionalis* Chen was significantly affected by dietary protein or lipid ($P < 0.05$), but not their interaction (Table 2-1). When dietary protein level was 37%, the significant highest value of FI was found, regardless of the dietary lipid levels ($P < 0.05$). When dietary protein levels were ranged from 43% to 46%, no significant differences in FI were found, regardless of the dietary lipid levels.

Dietary protein also negatively affected FI of *S. asotus* Linnaeu (Table 2-2). Low dietary protein (37%) significantly increased FI ($P < 0.05$). Neither dietary lipid nor its interaction with dietary protein significantly affected FI of *S. asotus* Linnaeu ($P > 0.05$).

It can be seen from Tables 2-1 and 2-2 that *S. meridionalis* Chen had lower FI than *S. asotus* Linnaeu under the same experimental conditions.

#### 3.2.2. Feed efficiency ratio

The feed efficiency ratio (FER) data are presented in Tables 2-1 and 2-2.

The FER of *S. meridionalis* Chen was significantly affected by dietary protein ($P < 0.05$), and was positively related with dietary protein ($r = 0.820, p = 0.000$) (Table 2-1). Low dietary protein (37%) group had relatively lower FER and showed significant difference in the groups with 13% and 7% of dietary lipid ($P < 0.05$). Moreover, the FER of *S. meridionalis* Chen was negatively related with FI ($r = -0.947$, $p = 0.000$). Neither dietary lipid nor its interaction with dietary protein significantly affected FER of *S. meridionalis* Chen ($P > 0.05$).

The FER of *S. asotus* Linnaeu had the same changing trend with that of *S. meridionalis* Chen (Table 2-2). It was positively related with dietary protein ($r = 0.630$, $p = 0.000$) and negatively related with FI ($r = -0.980$,

**Table 2-1**
Effects of dietary protein and lipid on growth, survival and feed utilization of southern catfish *Silurus meridionalis* Chen.

| Dietary lipid level (%) | Dietary protein level (%) | Initial weight (g) | Final weight (g) | Weight gain rate (%) | Feed intake (g/100 g/day) | Feed efficiency ratio (g/g) | Protein efficiency ratio (g/g) | Survival (%) |
|---|---|---|---|---|---|---|---|---|
| *Individual treatment means* [1] | | | | | | | | |
| 13 | 46 | 9.16 | $90.97^{ab}$ | $892.88^{ab}$ | 1.87 | 1.53 | 3.32 | 93.33 |
| 13 | 43 | 9.15 | $94.90^{ab}$ | $936.91^{ab}$ | 1.85 | 1.56 | 3.62 | 92.38 |
| 13 | 40 | 9.13 | $108.48^{cde}$ | $1087.60^{cde}$ | 1.89 | 1.52 | 3.78 | 79.05 |
| 13 | 37 | 9.19 | $96.58^{abc}$ | $951.01^{abc}$ | 2.12 | 1.37 | 3.65 | 87.62 |
| 10 | 46 | 9.16 | $96.04^{abc}$ | $948.45^{abc}$ | 1.79 | 1.63 | 3.54 | 97.14 |
| 10 | 43 | 9.19 | $111.47^{de}$ | $1112.70^{de}$ | 1.83 | 1.57 | 3.65 | 79.05 |
| 10 | 40 | 9.20 | $103.48^{bcd}$ | $1024.70^{bcd}$ | 1.90 | 1.51 | 3.75 | 83.81 |
| 10 | 37 | 9.17 | $93.15^{ab}$ | $915.72^{ab}$ | 2.03 | 1.39 | 3.72 | 85.71 |
| 7 | 46 | 9.14 | $118.22^{e}$ | $1193.10^{e}$ | 1.81 | 1.59 | 3.45 | 80.00 |
| 7 | 43 | 9.13 | $101.52^{bcd}$ | $1011.50^{bcd}$ | 1.81 | 1.58 | 3.67 | 85.72 |
| 7 | 40 | 9.14 | $92.35^{ab}$ | $910.24^{ab}$ | 1.86 | 1.49 | 3.70 | 84.76 |
| 7 | 37 | 9.16 | $85.05^{a}$ | $828.55^{a}$ | 2.05 | 1.35 | 3.62 | 87.94 |
| Pooled S.E.M. | | 0.01 | 1.71 | 18.87 | 0.02 | 1.53 | 0.03 | 1.58 |
| *Means of main effect* [2] | | | | | | | | |
| 13 | | 9.16 | 97.73 | 967.11 | $1.93^{q}$ | 1.49 | 3.59 | 88.09 |
| 10 | | 9.18 | 101.03 | 100.40 | $1.89^{p}$ | 1.53 | 3.67 | 86.43 |
| 7 | | 9.14 | 99.28 | 985.85 | $1.88^{p}$ | 1.50 | 3.61 | 84.60 |
| | 46 | 9.16 | 101.74 | 1011.50 | $1.83^{x}$ | $1.58^{z}$ | $3.44^{x}$ | 90.16 |
| | 43 | 9.16 | 102.63 | 1020.40 | $1.83^{x}$ | $1.57^{z}$ | $3.65^{y}$ | 85.71 |
| | 40 | 9.16 | 101.44 | 1007.50 | $1.88^{y}$ | $1.51^{y}$ | $3.74^{y}$ | 82.54 |
| | 37 | 9.17 | 91.59 | 898.42 | $2.06^{z}$ | $1.37^{x}$ | $3.67^{y}$ | 87.09 |
| *ANOVA*: ***P*-values** | | | | | | | | |
| Protein | | 0.932 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.392 |
| Lipid | | 0.403 | 0.234 | 0.295 | 0.010 | 0.214 | 0.234 | 0.659 |
| Protein × Lipid | | 0.953 | 0.000 | 0.000 | 0.365 | 0.366 | 0.447 | 0.241 |

[1] Treatment means represent the average values for three tanks per treatment. Tukey's test was conducted for individual means only if there was a significant interaction (ANOVA: $P < 0.05$). Means followed by the same letter are not significantly different.
[2] Main effect means followed by the different letter are significantly different ($P < 0.05$) as determined by Tukey's test.

**Table 2-2**
Effects of dietary protein and lipid on growth, survival and feed utilization of catfish *Silurus asotus* Linnaeu.

| Dietary lipid level (%) | Dietary protein level (%) | Initial weight (g) | Final weight (g) | Weight gain rate (%) | Feed intake (g/100 g/day) | Feed efficiency ratio (g/g) | Protein efficiency ratio (g/g) | Survival (%) |
|---|---|---|---|---|---|---|---|---|
| *Individual treatment means* [1] | | | | | | | | |
| 13 | 46 | 9.10 | 88.08 | 867.36 | 2.12 | 1.48 | 3.22 | 81.90 |
| 13 | 43 | 9.02 | 92.94 | 929.82 | 2.13 | 1.51 | 3.49 | 89.52 |
| 13 | 40 | 9.10 | 92.91 | 920.22 | 2.26 | 1.41 | 3.51 | 84.76 |
| 13 | 37 | 9.01 | 85.67 | 849.63 | 2.42 | 1.29 | 3.45 | 73.33 |
| 10 | 46 | 9.05 | 88.43 | 877.74 | 2.22 | 1.43 | 3.11 | 80.00 |
| 10 | 43 | 9.10 | 84.97 | 833.04 | 2.16 | 1.46 | 3.40 | 86.66 |
| 10 | 40 | 9.11 | 85.15 | 833.94 | 2.17 | 1.45 | 3.61 | 80.95 |
| 10 | 37 | 9.17 | 78.04 | 751.07 | 2.26 | 1.37 | 3.67 | 77.14 |
| 7 | 46 | 9.13 | 83.51 | 814.36 | 1.98 | 1.59 | 3.46 | 84.76 |
| 7 | 43 | 9.08 | 94.48 | 939.98 | 2.08 | 1.54 | 3.57 | 84.76 |
| 7 | 40 | 9.17 | 81.24 | 785.61 | 2.09 | 1.50 | 3.73 | 78.10 |
| 7 | 37 | 9.13 | 84.03 | 820.22 | 2.41 | 1.30 | 3.49 | 80.00 |
| Pooled S.E.M. | | 0.01 | 1.41 | 15.79 | 0.02 | 0.02 | 0.04 | 1.36 |
| *Means of main effect* [2] | | | | | | | | |
| 13 | | 9.06 | 89.90 | 891.76 | 2.23 | 1.42 | 3.42 | 81.19 |
| 10 | | 9.11 | 84.15 | 823.95 | 2.20 | 1.43 | 3.45 | 81.91 |
| 7 | | 9.13 | 85.82 | 840.04 | 2.14 | 1.48 | 3.56 | 82.38 |
| | 46 | 9.09 | 86.67 | 853.15 | $2.11^x$ | $1.50^y$ | $3.26^x$ | 82.22 |
| | 43 | 9.07 | 90.80 | 900.95 | $2.12^x$ | $1.50^y$ | $3.49^y$ | 86.98 |
| | 40 | 9.13 | 86.43 | 846.59 | $2.17^x$ | $1.45^y$ | $3.62^y$ | 81.27 |
| | 37 | 9.11 | 82.58 | 806.97 | $2.37^y$ | $1.33^x$ | $3.54^y$ | 76.83 |
| *ANOVA: P-values* | | | | | | | | |
| Protein | | 0.488 | 0.260 | 0.220 | 0.000 | 0.000 | 0.001 | 0.108 |
| Lipid | | 0.115 | 0.248 | 0.190 | 0.075 | 0.095 | 0.113 | 0.940 |
| Protein × Lipid | | 0.399 | 0.651 | 0.574 | 0.055 | 0.217 | 0.243 | 0.826 |

[1] Treatment means represent the average values for three tanks per treatment. Tukey's test was conducted for individual means only if there was a significant interaction (ANOVA: P < 0.05). Means followed by the same letter are not significantly different.
[2] Main effect means followed by the different letter are significantly different (P < 0.05) as determined by Tukey's test.

$p = 0.000$). Neither dietary lipid nor its interaction with dietary protein significantly affected the FER of *S. asotus* Linnaeu ($P > 0.05$).

Overall, the results showed that *S. meridionalis* Chen had relative higher FER than *S. asotus* Linnaeu under the same experimental conditions.

*3.2.3. PER*

The PER are presented in Tables 2-1 and 2-2.

The PER of *S. meridionalis* Chen was significantly affected by dietary protein ($P < 0.05$) (Table 2-1). Among all the dietary lipid groups, the PER increased with the decreasing of dietary protein level except that in the group with 37% of dietary protein. In the treatments with 13% of dietary lipid, the PER of *S. meridionalis* Chen fed with 46% dietary protein was significantly lower than those fed 40% or 37% dietary protein ($P < 0.05$). However, in the groups with dietary lipid less than 13% (7% and 10%), the PER of *S. meridionalis* Chen showed no significant differences among all the dietary protein levels. Neither dietary lipid nor its interaction with dietary protein significantly affected PER of *S. meridionalis* Chen ($P > 0.05$).

The PER of *S. asotus* Linnaeu had the same changing trend with that of *S. meridionalis* Chen and was also significantly affected by dietary protein (Table 2-2). The PER of *S. asotus* Linnaeu fed diet with 46% of protein and 10% of lipid was significantly lower than those in the treatments with 7% of dietary lipid and 40% or 43% of dietary protein ($P < 0.05$). Neither dietary lipid nor its interaction with dietary protein significantly affected PER of *S. asotus* Linnaeu ($P > 0.05$).

It can be seen from Tables 2-1 and 2-2 that *S. meridionalis* Chen had higher PER than *S. asotus* Linnaeu under the same experimental conditions.

*3.3. Body morphological index*

The condition factor (CF), HSI, and VSI data are presented in Tables 3-1 and 3-2. There were no significant differences in CF and HSI of both catfish among all the treatments with different dietary protein and lipid levels ($P > 0.05$).

Dietary lipid, not dietary protein, significantly affected the VSI of *S. meridionalis* Chen (Table 3-1). Interaction between dietary protein and lipid on the VSI was also significant ($P < 0.05$). When dietary protein level was 46%, the values of VSI significantly increased with the increasing of dietary lipid levels. However, there were no significant differences in VSI among all the treatments with dietary protein level less than 46%, regardless of the dietary lipid levels. The VSI in the treatment with 46% dietary protein and 7% dietary lipid was found as 5.96 %, which was significantly lower than that (6.91 %) in the treatment with 43% dietary protein and 10% dietary lipid.

The VSI of *S. asotus* Linnaeu were significantly affected by dietary lipid ($P < 0.05$), not by dietary protein or its interaction with dietary lipid (Table 3-2). The highest VSI was found as 9.29 % in the group with the lowest dietary protein (37%) and the highest dietary lipid (13%). It was significantly higher than that (7.78 %) in the group with 46% dietary protein and 7% dietary lipid.

Under the same experimental conditions, CF, HSI and VSI of *S. meridionalis* Chen were relatively lower than those of *S. asotus* Linnaeu.

## 4. Discussion

In the present study, dietary lipid had no significant effects on WGR of *S. meridionalis* Chen. However, dietary protein and its interaction with dietary lipid significantly influenced WGR. When the ratio of dietary protein to lipid was P46/L13 or P37/L7, the values of WGR were significantly lower than those in the treatments with the ratio of P40/L13, P43/L10, or P46/L7. It is suggested that an optimal ratio of dietary protein to dietary lipid is very important to the growth of *S. meridionalis* Chen. In previous studies on other fish species, the optimal ratios of dietary protein to lipid had been determined, such as red porgy *Pagrus pagrus* P50/L15 (Schuchardt et al., 2008), channel

**Table 3-1**
Effects of dietary protein and lipid on body morphological indices of southern catfish *Silurus meridionalis* Chen.

| Dietary lipid level (%) | Dietary protein level (%) | Condition factor | Hepatosomatic index | Viscerasomatic index |
|---|---|---|---|---|
| *Individual treatment means* [1] | | | | |
| 13 | 46 | 0.79 | 1.17 | 7.33[c] |
| 13 | 43 | 0.87 | 1.19 | 6.18[ab] |
| 13 | 40 | 0.81 | 1.30 | 6.82[abc] |
| 13 | 37 | 0.82 | 1.30 | 6.59[abc] |
| 10 | 46 | 0.80 | 1.24 | 6.47[abc] |
| 10 | 43 | 0.79 | 1.24 | 6.91[bc] |
| 10 | 40 | 0.79 | 1.26 | 6.64[abc] |
| 10 | 37 | 0.78 | 1.34 | 6.51[abc] |
| 7 | 46 | 0.84 | 1.17 | 5.96[a] |
| 7 | 43 | 0.77 | 1.11 | 6.43[abc] |
| 7 | 40 | 0.80 | 1.09 | 6.12[ab] |
| 7 | 37 | 0.79 | 1.23 | 6.92[bc] |
| Pooled S.E.M. | | 0.01 | 0.02 | 0.08 |
| *Means of main effect* | | | | |
| 13 | | 0.82 | 1.24 | 6.73 |
| 10 | | 0.79 | 1.27 | 6.63 |
| 7 | | 0.80 | 1.15 | 6.36 |
| | 46 | 0.81 | 1.19 | 6.59 |
| | 43 | 0.81 | 1.18 | 6.51 |
| | 40 | 0.80 | 1.22 | 6.53 |
| | 37 | 0.80 | 1.29 | 6.67 |
| *ANOVA: P*-values | | | | |
| Protein | | 0.796 | 0.252 | 0.672 |
| Lipid | | 0.086 | 0.059 | 0.021 |
| Protein × Lipid | | 0.148 | 0.893 | 0.000 |

[1] Treatment means represent the average values for three tanks per treatment. Tukey's test was conducted for individual means only if there was a significant interaction (ANOVA: P < 0.05). Means followed by the same letter are not significantly different.
[2] Main effect means followed by the different letter are significantly different (P < 0.05) as determined by Tukey's test.

**Table 3-2**
Effects of dietary protein and lipid on body morphological indices of catfish *Silurus asotus* Linnaeu.

| Dietary lipid level (%) | Dietary protein level (%) | Condition factor | Hepatosomatic index | Viscerasomatic index |
|---|---|---|---|---|
| *Individual treatment means* [1] | | | | |
| 13 | 46 | 0.92 | 2.19 | 8.19 |
| 13 | 43 | 0.88 | 2.06 | 8.06 |
| 13 | 40 | 0.93 | 2.18 | 8.65 |
| 13 | 37 | 0.90 | 2.24 | 9.29 |
| 10 | 46 | 0.88 | 2.29 | 8.25 |
| 10 | 43 | 0.93 | 2.02 | 8.00 |
| 10 | 40 | 0.88 | 2.02 | 8.50 |
| 10 | 37 | 0.85 | 1.97 | 8.83 |
| 7 | 46 | 0.85 | 2.26 | 7.78 |
| 7 | 43 | 0.88 | 1.88 | 7.81 |
| 7 | 40 | 0.87 | 2.23 | 7.98 |
| 7 | 37 | 0.87 | 2.28 | 8.56 |
| Pooled S.E.M. | | 0.01 | 0.03 | 0.10 |
| *Means of main effect* [2] | | | | |
| 13 | | 0.91[q] | 2.17 | 8.547[q] |
| 10 | | 0.89[pq] | 2.08 | 8.397[pq] |
| 7 | | 0.87[p] | 2.16 | 8.034[p] |
| | 46 | 0.89 | 2.25[y] | 8.08[x] |
| | 43 | 0.90 | 1.98[x] | 7.96[x] |
| | 40 | 0.89 | 2.14[xy] | 8.38[xy] |
| | 37 | 0.88 | 2.16[xy] | 8.89[y] |
| *ANOVA: P*-values | | | | |
| Protein | | 0.576 | 0.032 | 0.002 |
| Lipid | | 0.047 | 0.383 | 0.038 |
| Protein × Lipid | | 0.221 | 0.273 | 0.942 |

[1] Treatment means represent the average values for three tanks per treatment. Tukey's test was conducted for individual means only if there was a significant interaction (ANOVA: P < 0.05). Means followed by the same letter are not significantly different.
[2] Main effect means followed by the different letter are significantly different (P < 0.05) as determined by Tukey's test.

catfish *Ictalurus punctatus* P32/L7.5 (Jiang et al., 2010), African catfish *Clarias gariepinus* P43/L8 (Ali and Jauncey, 2005). In the present study, the three significant highest WGRs were observed under the condition of the following profiles of dietary protein and lipid. The ratios of dietary protein to lipid for *S. meridionalis* Chen were P46/L7, P43/L10 and P40/L13, respectively. There was no significant difference in WGR among these three treatments. In consideration of the prices of fish meal, soybean meal and soybean oil used in the present study, diet P43/L10 costs less than diet P46/7. The difference is about RMB 225/ton feed. In consideration of the feed processing, due to the relative high level of dietary lipid, it is technically difficult to produce extruded feeds in a large scale following the formulation of diet P40/L13. So based on the growth data, the optimal ratio of dietary protein to lipid for *S. meridionalis* could be P43/L10.

Meanwhile, in the present study, dietary protein and lipid had no significant effect on the WGR of catfish *S. asotus* Linnaeu. Nevertheless, the highest value of WGR was found as 939.98% in the group with 43% of dietary protein and 7% of dietary lipid. This is similar to 43% (dietary protein)/8% (dietary lipid) for African catfish *C. gariepinus* Burchell (Ali and Jauncey, 2005). The higher dietary lipid (>7%) is unnecessary for better growth when the dietary protein contents are ranged from 37% to 46% for *S. asotus* Linnaeu. It is important for the formulation of practical diets for this species of catfish.

In the present study, the FI of both catfish decreased with the increasing of dietary protein levels (*S. meridionalis* Chen, $r = -0.811$, $p = 0.000$; *S. asotus* Linnaeu, $r = -0.622$, $p = 0.000$), regardless of the dietary lipid contents. The same results had been found in previous studies on grass carp *Ctenopharyngodon idella* (Du et al., 2005) and tilapia *Oreochromis niloticus* (De Silva and Gunasekera, 1989). However, the FER increased with the increasing of dietary protein levels. When dietary protein decreased to the lowest level (37%), the FER had the significant lowest values. In other word, the FER was negatively related with the FI in the present study (*S. meridionalis* Chen, $r = -0.947$, $p = 0.000$; *S. asotus* Linnaeu, $r = -0.927$, $p = 0.000$). It was implied that catfish could decrease the FI as dietary protein levels increasing to get higher FER, and then could gain adequate energy and nutrition. The reason is that higher FI consumed more energy for FI and digestion (Page and Andrews, 1973). Compared to those with 37% of dietary protein, in the present study, PER decreased in the group with 46% of dietary protein. Furthermore, this decrease was significant when dietary lipid level was 13%. It demonstrated that if dietary lipid level was adequate for energy, 46% of dietary protein seemed to be a little excessive. Furthermore, excessive dietary protein will be used for energy. This could result in higher SDA and more excreted ammonia nitrogen (LeGrow and Beamish, 1986). That could be the reason why the WGR of *S. meridionalis* Chen in the group with 46% of dietary protein and 13% of dietary lipid (P46/L13) was significantly lower than that in the P40/L13 group.

Based on the WGR, FER and PER in the present study, it is recommended that the optimal dietary protein content for *S. meridionalis* Chen could be 43%, corresponding with 10% of the optimal dietary lipid (P43/L10). Several previous studies had reported the optimal dietary protein level for *S. meridionalis* Chen, but the results were not consistent. Zhang et al. (2000) revealed that 47–51% of dietary protein level (dietary lipid: 10.1–12.8%) is optimal for *S. meridionalis* Chen based on the data on the specific growth rate, feed conversion rate and PER. Those results were consistent with that from Wang et al. (1998). In the present study, however, when dietary protein levels were 43% and dietary lipid contents were 10%, *S. meridionalis* Chen had relatively higher WGR and better feed utilization. The result was similar to that (the optimal dietary protein level: 41.1–45.1%) reported by Wu and Zhang (1996). However, it is difficult to compare these results above directly because of the differences in experimental conditions, including the size of the experimental fish, the culture system condition, diet formulation and feed processing. For example, Zhang et al. (2000) and Wang et al. (1998) used white fish meal as the main dietary protein source (37.5–74.9% and 44.6–64.3%, respectively). However, both of fish meal (18.6–60.0%) and soybean meal (0.0–45.0%) were used as the main dietary protein source in the present study. In addition, extruded pellet feed was used in the present study. Meanwhile, moist feed was used in the previous studies (Wang et al., 1998; Zhang et al., 2000).

In regard to the FER, in the present study, the values for *S. meridionalis* Chen ranged from 1.35 to 1.63, and those for *S. asotus* Linnaeu were 1.29 to 1.59. In the previous study, when the optimal dietary protein level (51%) was provided, the FER for *S. meridionalis* Chen was increased to 1.27 (Zhang et al., 2000). Meanwhile, in a previous study on the ratio of protein to lipid in diet for *S. meridionalis* Chen, the values of FER ranged from 1.29 to 1.45 (Fu et al., 2001). It was suggested that the values of FER in the present study (1.29–1.63) were a little bit higher than the others in the previous studies (1.27–1.45). After comparing the experimental diets used in the present study with those in the previous studies, an obvious difference was found as the style of the diets. Extruded pellet feed was used in the present study. Meanwhile, moist feed was used in the previous studies. It was suggested that *S. meridionalis* Chen could use extruded pellet feed better than moist feed. Further study is needed.

VSI percentage is an important trait directly affecting the yield in fish production. It was reported that high dietary lipid level could increase VSI of fish, such as juvenile cobia *Rachycentron canadum* (Wang et al., 2005), surubim *Pseudoplatystoma coruscans* (Martino et al., 2002), and rainbow trout *Oncorhynchus mykiss* (Chaiyapechara et al., 2003). In the present study, dietary lipid and its interaction with dietary protein significantly influenced the VSI of *S. meridionalis* Chen. Under the condition of 46% dietary protein, the VSI significantly increased with the increasing of dietary lipid. Meanwhile, dietary lipid increased the VSI of *S. asotus* Linnaeu, regardless of dietary protein levels. Moreover, the lowest VSI of both catfish was found in the group with the highest dietary protein (46%) and the lowest dietary lipid (7%). And the highest VSI of *S. meridionalis* Chen and *S. asotus* Linnaeu was found in the P46/L13 group and P37/L13 group, respectively. Higher values of VSI mean the lower portion of fillet in catfish. It was suggested that the optimal ratio of dietary protein to lipid is important to the body morphology of the both catfish.

## 5. Conclusion

In the present study, the optimal ratio of dietary protein to lipid for *S. meridionalis* Chen and *S. asotus* Linnaeu were estimated to be 43: 10 and 43: 7, respectively, although there were no significant differences in WGR of *S. asotus* Linnaeu. Furthermore, *S. meridionalis* Chen got relatively higher growth, feed utilization and better body morphological indices than *S. asotus* Linnaeu under the same experimental conditions. Further studies are needed to compare the difference in nutrition between the two catfish.

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