Effects of Dietary Taurine Supplementation on Growth Performance, Body Composition, and Hepatic Key Enzyme Activities of Taurine Synthesis in Juvenile Takifugu rubripes: Postprint

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Abstract

This study aimed to investigate the effects of dietary taurine supplementation on growth performance, body composition, and key enzyme activities for taurine synthesis in juvenile tiger pufferfish (Takifugu rubripes). Four isonitrogenous and isolipidic experimental diets were formulated, four isonitrogenous and isolipidic experimental diets were formulated, which were a control 1 diet containing 60% fish meal, a control 2 diet containing 45% fish meal, and two taurine-containing diets with 30% fish meal supplemented with 0.5% and 1.0% taurine, respectively. Healthy juvenile tiger pufferfish with an initial body weight of (17.33±0.55) g were selected and randomly distributed into 12 culture tanks, with 25 fish stocked per tank. The 12 tanks were randomly divided into 4 groups, with 3 tanks per group, and each group was randomly fed one experimental diet for 56 days. The results showed: 1) No significant differences were observed in survival rate (SR) among all groups (P>0.05); specific growth rate (SGR) was highest in the 1.0% taurine group and lowest in the control 2 group, but there were no significant differences among groups (P>0.05); feed efficiency (FE) in the control 1 and 0.5% taurine groups was significantly higher than that in the control 2 group (P<0.05), with no significant difference from the 1.0% taurine group (P>0.05); no significant differences were found in protein productive value (PPV), protein efficiency ratio (PER), hepatosomatic index (HSI), viscerosomatic index (VSI), and condition factor (CF) among all groups (P>0.05). 2) No significant differences were observed in the activities of alanine aminotransferase (GPT) and aspartate aminotransferase (GOT) in serum and liver among all groups (P>0.05). No significant differences were found in hepatic cysteine dioxygenase (CDO) activity among all groups (P>0.05), while hepatic cysteine sulfinate decarboxylase (CSD) activity in the control 2 group was significantly higher than that in the control 1, 0.5% taurine, and 1.0% tau-

rine groups (P<0.05). 3) No significant differences were detected in whole-body moisture, crude protein, crude fat, and crude ash contents among all groups (P>0.05). In summary, dietary supplementation with 0.5% or 1.0% taurine can reduce fish meal usage by 30% without significantly affecting the growth performance of juvenile tiger pufferfish.

Full Text

Effects of Dietary Taurine on Growth Performance, Body Composition and Activities of Key Taurine Synthesis Enzymes in Liver of Juvenile Tiger Puffer (Takifugu rubripes)

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Abstract

This experiment investigated the effects of dietary taurine supplementation on growth performance, body composition, and activities of key taurine synthesis enzymes in juvenile tiger puffer (*Takifugu rubripes*). Four iso-nitrogenous and iso-lipidic experimental diets were formulated: Control 1 containing 60% fish meal, Control 2 containing 45% fish meal, and two taurine-supplemented diets containing 30% fish meal with 0.5% and 1.0% taurine added, respectively. Healthy juvenile tiger puffers with an initial body weight of (17.33±0.55) g were randomly distributed into 12 culture buckets (25 fish per bucket). The 12 buckets were randomly divided into four groups (three buckets per group), with each group fed one of the experimental diets for 56 days. The results showed: (1) No significant differences in survival rate (SR) were observed among groups (P>0.05). The specific growth rate (SGR) was highest in the 1.0% taurine group and lowest in Control 2, but differences among groups were not significant (P>0.05). Feed efficiency (FE) in Control 1 and the 0.5% taurine group was significantly higher than in Control 2 (P<0.05), but did not differ significantly from the 1.0% taurine group (P>0.05). No significant differences were found in protein productive value (PPV), protein efficiency ratio (PER), hepatosomatic index (HSI), viscerosomatic index (VSI), or condition factor (CF) among groups (P>0.05). (2) No significant differences were detected in glutamic-pyruvic transaminase (GPT) or glutamic oxaloacetic transaminase (GOT) activities in serum or liver among groups (P>0.05). Liver cysteine dioxygenase (CDO) activity did not differ significantly among groups (P>0.05), while liver cysteinesulfinate decarboxylase (CSD) activity in Control 2 was significantly higher than in Control 1, the 0.5% taurine group, and the 1.0% taurine group

(P<0.05). (3) No significant differences were observed in whole-body moisture, crude protein, crude lipid, or ash content among groups (P>0.05). Overall, dietary supplementation with 0.5% or 1.0% taurine can reduce fish meal usage by 30% without significantly affecting the growth performance of juvenile tiger puffer.

Keywords: juvenile tiger puffer; taurine; growth performance; body composition; key taurine synthesis enzymes

Introduction

Taurine (2-aminoethanesulfonic acid), also known as choline taurine or taurine, is a non-protein -sulfur amino acid that plays multiple important roles in regulating physiological functions in organisms [1-2]. Taurine is widely distributed in animal cells, seaweed, and fungi, but is virtually absent in terrestrial plants such as wheat and soybeans [3-5]. Therefore, the lack of taurine in plant protein ingredients may be one reason why high-plant-protein diets reduce growth performance in aquatic animals. Previous studies have shown that taurine deficiency in diets can cause green liver syndrome in yellowtail (*Seriola quinqueradiata*) [6].

Redfin tiger puffer (*Takifugu rubripes*), belonging to the order Tetraodontiformes, family Tetraodontidae, and genus *Takifugu*, is one of the main cultured pufferfish species. Its meat is delicious and nutritious, with extremely high economic value. Although artificial breeding technology for redfin tiger puffer is relatively mature, research on its nutritional requirements and formulated feeds lags behind, making the development of efficient specialized feeds critical for the industry' s development. Taurine, as an important functional amino acid, plays multiple regulatory roles in fish maintenance, growth, development, reproduction, and metabolism. Proper and effective supplementation can not only improve feed utilization efficiency and reduce feed and farming costs but also significantly promote fish growth and enhance product quality. Therefore, this study used juvenile redfin tiger puffer as experimental subjects to investigate the effects of dietary taurine supplementation on their growth, providing a reference for the development of formulated feeds for this species.

1.1 Experimental Diets

Four iso-nitrogenous and iso-lipidic experimental diets were formulated: Control 1 with 60% fish meal, Control 2 with 45% fish meal, and two taurine-supplemented diets containing 30% fish meal with 0.5% and 1.0% taurine added, respectively. The composition and nutrient levels of the experimental diets are shown in Table 1 , and the amino acid composition is presented in Table 2 . After determining the routine nutrient content of all ingredients, they were ground to pass through an 80-mesh sieve, weighed according to the formula, and mixed stepwise. Fish oil was then added and mixed uniformly, followed by the

addition of 30% water and thorough stirring. The mixture was pelleted into 2 mm diameter pellets using a pelletizer, dried at 55°C for 12 hours with forced air, and stored at -20°C.

1.2 Feeding Management

The feeding trial was conducted at Yantian Tianyuan Aquaculture Co., Ltd. in Yantai, Shandong Province. Juvenile redfin tiger puffers were purchased from Huangshui Aquaculture Co., Ltd. in Haiyang City. Before the experiment, fish were acclimated for one week using Control 1 diet to adapt to the culture environment and feed size/hardness. The experiment used natural lighting with a flow-through culture system using natural seawater. Water temperature ranged from 14–25°C, dissolved oxygen concentration was approximately 5.5 mg/L, salinity was around 35, and pH was 7.5–8.0.

Prior to the experiment, fish were fasted for 24 hours. Healthy, uniform-sized juvenile redfin tiger puffers with an initial body weight of (17.33±0.55) g were randomly distributed into 12 plastic culture buckets (150 L capacity, 25 fish per bucket). The 12 buckets were randomly divided into four groups (three buckets per group), with each group randomly assigned one experimental diet. During the trial, fish were fed to apparent satiation three times daily (morning, noon, and evening). After 0.5 hours of feeding, residual feed was counted in each bucket, and residual feed weight was calculated based on the average weight of 100 feed pellets. After 28 days of culture, the 150 L buckets were replaced with 500 L buckets; this change caused no fish mortality. The experiment was conducted from August to October 2017, lasting 56 days.

1.3 Sample Collection and Analysis

Before the experiment, 20 juvenile redfin tiger puffers were randomly sampled as initial fish for routine nutrient analysis. At the end of the experiment, fish were fasted for 24 hours, then counted and weighed in each bucket. Three fish were randomly selected from each bucket, and blood was collected from the caudal vein using 1% heparin sodium as anticoagulant. After standing at 4°C for 4 hours, serum was collected by centrifugation at 3,500 r/min for 10 minutes and stored in liquid nitrogen. After blood collection, fish were weighed and measured for body length, then dissected to separate and weigh the viscera and liver.

Routine nutrient analysis of feeds and fish body followed AOAC (1995) methods. Moisture content was determined by drying at 105°C to constant weight. Crude protein content was measured using the Kjeldahl method (VELP Kjeldahl nitrogen analyzer, UDK-142 Automatic Distillation Unit, Italy). Crude lipid content was determined by Soxhlet extraction (SOXTEC 2050 FOSS lipid analyzer, Sweden) using petroleum ether as the extraction solvent. Crude ash content was measured by incineration in a muffle furnace at 550°C for 6 hours.

Activities of glutamic oxaloacetic transaminase (GOT) and glutamic-pyruvic

transaminase (GPT) were measured using assay kits from Nanjing Jiancheng Bioengineering Institute. Activities of cysteinesulfinate decarboxylase (CSD) and cysteine dioxygenase (CDO) were determined using enzyme-linked immunosorbent assay (ELISA) kits from Renjie Biological Company.

Amino acid composition of feeds was determined according to GB/T 18246-2000 using an L-8900 automatic amino acid analyzer (Hitachi, Japan). The analysis measured nine essential amino acids, seven non-essential amino acids, and taurine content in the feeds; tryptophan was not detected due to acid hydrolysis destruction.

1.4 Calculation Formulas

Survival rate (SR, %) = 100 × final fish number / initial fish number
Feed intake (FI, %/d) = 100 × dry feed weight consumed / [experimental days × (initial body weight + final body weight) / 2]
Specific growth rate (SGR, %/d) = 100 × (ln final body weight - ln initial body weight) / experimental days
Feed efficiency (FE, %) = (final body weight - initial body weight) / dry feed weight consumed
Protein productive value (PPV, %) = 100 × fish body protein deposition / total feed protein intake
Protein efficiency ratio (PER) = (final body weight - initial body weight) / total feed protein intake
Hepatosomatic index (HSI, %) = 100 × liver weight / body weight
Viscerosomatic index (VSI, %) = 100 × viscera weight / body weight
Condition factor (CF, g/cm^3) = 100 × body weight / body length^3 (body weight in g; body length in cm)

1.5 Data Analysis

Experimental data were processed using SPSS 17.0 software. One-way ANOVA was used for variance analysis, and if significant differences were detected ($P < 0.05$), Duncan' s multiple range test was used for inter-group comparisons. Results are expressed as mean ± standard error (mean±SE).

2.1 Effects of Dietary Taurine on Growth Performance and Physical Indicators of Juvenile Tiger Puffer

The effects of dietary taurine on growth performance and physical indicators are shown in Table 3 . No significant differences were found in survival rate among groups ($P>0.05$). The specific growth rate was highest in the 1.0% taurine group but did not differ significantly among groups ($P>0.05$). Feed intake in Control 2 was significantly higher than in Control 1 ($P<0.05$) but did not differ significantly from the taurine-supplemented groups ($P>0.05$). Feed efficiency in Control 1 and the 0.5% taurine group was significantly higher than in Control 2 ($P<0.05$), but showed no significant difference compared with the 1.0% taurine

group (P>0.05). No significant differences were observed in protein productive value, protein efficiency ratio, hepatosomatic index, viscerosomatic index, or condition factor among groups (P>0.05).

2.2 Effects of Dietary Taurine on GPT and GOT Activities in Serum and Liver of Juvenile Tiger Puffer

The effects of dietary taurine on GPT and GOT activities in serum and liver are presented in Table 4 . No significant differences were found in GPT or GOT activities in either serum or liver among all groups (P>0.05).

2.3 Effects of Dietary Taurine on Liver CDO and CSD Activities of Juvenile Tiger Puffer

The effects of dietary taurine on liver CDO and CSD activities are shown in Table 5 . No significant differences were observed in liver CDO activity among groups (P>0.05). However, liver CSD activity in Control 2 was significantly higher than in the other three groups (P<0.05), while no significant differences existed among Control 1, the 0.5% taurine group, and the 1.0% taurine group (P>0.05).

2.4 Effects of Dietary Taurine on Body Composition of Juvenile Tiger Puffer

The effects of dietary taurine on body composition are presented in Table 6 . No significant differences were found in moisture, crude protein, crude lipid, or crude ash content among groups (P>0.05).

3.1 Effects of Dietary Taurine on Growth Performance of Juvenile Tiger Puffer

Increased dietary plant protein content typically reduces growth performance and feed efficiency in aquatic animals, which is related not only to anti-nutritional factors in plant proteins but also to the lack of taurine in these ingredients [7]. Kikuchi et al. [8] reported that soybean meal could replace 13% of fish meal in diets for redfin tiger puffer without affecting growth performance when using a 70% fish meal diet as control. Lim et al. [9] found that soybean meal could replace 13.5% of fish meal without affecting growth performance when using a 45% fish meal diet as control. In the present study, supplementation with 0.5% or 1.0% taurine in diets containing 30% fish meal resulted in specific growth rate, protein productive value, and protein efficiency ratio that were not significantly different from the 60% fish meal and 45% fish meal groups. Feed efficiency in the 60% fish meal and 0.5% taurine groups was significantly higher than in the 45% fish meal group but did not differ significantly from the 1.0% taurine group. These results indicate that dietary

supplementation with 0.5% or 1.0% taurine can reduce fish meal usage by 30% without significantly affecting growth performance or feed efficiency in juvenile redfin tiger puffer.

Currently, no studies have reported the taurine requirement for redfin tiger puffer. In studies on taurine requirements of other fish species, appropriate taurine levels have been shown to promote growth and improve feed efficiency [10]. Liu et al. [11] reported that supplementing diets containing 15% fish meal with 1% and 2% taurine significantly increased specific growth rate and feed efficiency in turbot as dietary taurine content increased. Zhou et al. [12] reported that appropriate dietary taurine levels (0.4%–1.2%) significantly promoted growth and feeding in Nile tilapia and increased body protein and lipid deposition. Gaylord et al. [13] found that taurine supplementation in plant protein diets significantly improved growth performance in rainbow trout, with better effects at 0.5% and 1.0% supplementation levels. He et al. [14] reported that the dietary taurine requirement for juvenile Japanese eel (*Anguilla japonica*, ~85.95 g) was approximately 1.308%, and appropriate taurine supplementation improved growth performance and reduced feed coefficient. Wang et al. [15] found that 1%–1.2% dietary taurine was beneficial for growth and improved feed efficiency in juvenile orange-spotted grouper, while insufficient or excessive taurine was detrimental. In this experiment, no significant differences in growth performance were observed between the 0.5% and 1.0% taurine groups, or between these groups and the 60% fish meal and 45% fish meal control groups. However, since no 30% fish meal control group was included in this study, whether taurine supplementation affects growth performance in juvenile redfin tiger puffer fed diets with 30% fish meal remains uncertain, and the optimal taurine supplementation level requires further investigation.

Matsunari et al. [16] reported that supplementing fish meal-based diets with 1% taurine for 0.5 g yellowtail promoted growth during the first 3 weeks, but no significant relationship was observed between taurine supplementation and growth performance during the last 3 weeks. Qi et al. [17] found that dietary taurine supplementation improved feed intake, feed utilization, and significantly enhanced growth rate in 6.3 g turbot, while in 165.9 g turbot, taurine supplementation significantly increased feed intake but did not improve feed efficiency, suggesting that the growth improvement was attributable to increased feed intake. In the present study, when dietary fish meal content decreased from 60% to 45%, feed intake in juvenile redfin tiger puffer increased significantly, while taurine supplementation had no significant effect on feed intake, and the increased feed intake did not appear to correlate with growth or feed utilization.

3.2 Effects of Dietary Taurine on Key Taurine Synthesis Enzyme Activities and Liver Function in Juvenile Tiger Puffer

Taurine is a conditionally essential amino acid, and fish requirements vary with species and life stage. Reported taurine requirements range from 0.2% for sea bass [18] to 3.4% for yellowtail [3]. Qi et al. [17] found that the taurine requirement was 1.15% for 6.3 g turbot but decreased to 0.64% for 166 g turbot. These differences are primarily related to variations in endogenous taurine synthesis capacity among different fish species and life stages [19-20]. In fish, taurine can be synthesized from sulfur-containing amino acids such as cysteine, cystine, and methionine. Various tissues and organs, including liver, eyes, and brain, can synthesize taurine, but the liver is the primary organ for taurine synthesis [21]. The known taurine synthesis pathways include the cysteinesulfinate pathway, cysteamine pathway, and cysteic acid pathway, with the cysteinesulfinate pathway being the most important. The key rate-limiting enzymes in this pathway are CDO and CSD [21].

In this experiment, no significant differences were observed in liver CDO activity among groups. However, liver CSD activity in Control 2 was significantly higher than in the other three groups, indicating that the lower dietary taurine content in Control 2 (Table 2) stimulated fish to enhance endogenous taurine synthesis by upregulating liver CSD activity to compensate for dietary deficiency. Qi et al. [22] reported that supplementing high-plant-protein diets for turbot with 1% and 2% taurine significantly reduced liver CSD and CDO activities in the 2% taurine group compared with the non-supplemented group, with no significant difference from the 1% taurine group. Zhou [21] found that liver CSD activity in Nile tilapia and orange-spotted grouper decreased with increasing dietary taurine content. In this study, liver CDO activity in juvenile redfin tiger puffer did not change significantly with dietary taurine level, while liver CSD activity tended to decrease with increasing dietary taurine, although no significant difference existed between the 0.5% and 1.0% taurine groups. Whether redfin tiger puffer can regulate taurine synthesis through the cysteinesulfinate pathway requires further investigation.

Dietary amino acids are primarily metabolized through transamination and deamination, with fish mainly meeting their needs through combined deamination. GPT and GOT are two key enzymes in amino acid metabolism, and their activities in the liver reflect the intensity of amino acid metabolism and normal liver function [23]. GPT and GOT are primarily located in the liver, and under normal conditions, their activities in serum are low. When liver tissue is damaged, increased cell membrane permeability causes GPT and GOT to leak into the blood, resulting in elevated serum activities [23]. In this experiment, no significant differences were found in serum or liver GPT and GOT activities among groups, indicating that reducing dietary fish meal by 30% or 15% while supplementing with 0.5% or 1.0% taurine did not adversely affect liver health or significantly alter amino acid metabolism in juvenile redfin tiger puffer, which

corresponds to the lack of significant differences in growth performance among groups.

3.3 Effects of Dietary Taurine on Body Composition and Morphological Indicators of Juvenile Tiger Puffer

Previous studies have reported that increased dietary plant protein reduces crude lipid content in fish [7,24-25], primarily because anti-nutritional factors in plant proteins affect lipid absorption and metabolism, reducing lipid deposition. Liu et al. [7] found that high-plant-protein diets without taurine supplementation significantly reduced crude lipid content in turbot, while taurine supplementation increased crude lipid content with increasing taurine levels, suggesting that taurine ameliorates abnormal lipid metabolism caused by plant proteins. In this experiment, no significant differences were observed in whole-body crude lipid content among groups, although crude lipid content tended to increase with dietary taurine level. Without a 30% fish meal control group, the specific effect of taurine on crude lipid content in juvenile redfin tiger puffer requires further study.

Hepatosomatic index typically reflects hepatic lipid deposition. Some studies have found that HSI in sea bass tended to decrease with increasing dietary taurine [26], possibly related to taurine's role in hepatic lipid metabolism. Zhang et al. [27] reported that taurine supplementation in high-plant-protein diets significantly reduced hepatic crude lipid content and increased muscle crude lipid content in turbot without affecting whole-body crude lipid content, indicating that taurine can regulate lipid metabolism and reduce hepatic lipid deposition. In this experiment, no significant differences in HSI were observed between the taurine-supplemented groups and the control groups, and the specific effect of taurine on lipid metabolism in redfin tiger puffer requires further investigation.

4 Conclusion

Dietary supplementation with 0.5% or 1.0% taurine can reduce fish meal usage by 30% without significantly affecting the growth performance of juvenile redfin tiger puffer.

References

[1] HAYES K C, TRAUTWEIN E A. Taurine deficiency syndrome in cats[J]. Veterinary Clinics of North America: Small Animal Practice, 1989, 19(3): 403-413.
[2] 张龙, 杨志刚, 周俊宇, 等. 牛磺酸在水产饲料中的应用 [J]. 饲料研究, 2017(24): 1-4, 10.
[3] JACOBSEN J G, SMITH L H. Biochemistry and physiology of taurine and taurine derivatives[J]. Physiological Reviews, 1968, 48(2): 424-511.
[4] SPITZE A R, WONG D L, ROGERS Q R, et al. Taurine concentrations in animal feed ingredients; cooking influences taurine content[J]. Journal of Ani-

mal Physiology and Animal Nutrition, 2003, 87(7/8): 251-262.
[5] HUXTABLE J. Physiological actions of taurine[J]. Physiological Reviews, 1992, 72(1): 101-163.
[6] TAKAGI S, MURATA H, GOTO T, et al. Hemolytic suppression roles of taurine in yellowtail *Seriola quinqueradiata* fed non-fishmeal based soybean protein[J]. Fisheries Science, 2006, 72(3): 546-555.
[7] 刘兴旺, 麦康森, 刘付志国, 等. 动植物蛋白源及牛磺酸对大菱鲆摄食、生长及体组成的影响[J]. 中国海洋大学学报（自然科学版）, 2018, 48(5): 25-31.
[8] KIKUCHI K, FURUTA T. Use of defatted soybean meal and blue mussel meat as substitute for fish meal in the diet of tiger puffer, *Takifugu rubripes*[J]. Journal of the World Aquaculture Society, 2009, 40(4): 472-482.
[9] LIM S J, KIM S S, KO G Y, et al. Fish meal replacement by soybean meal in diets for tiger puffer, *Takifugu rubripes*[J]. Aquaculture, 2011, 313(1/2/3/4): 165-170.
[10] EL-SAYED A F M. Is dietary taurine supplementation beneficial for farmed fish and shrimp? A comprehensive review[J]. Reviews in Aquaculture, 2013, 6(4): 241-255.
[11] 柳茜, 梁萌青, 郑珂珂, 等. 牛磺酸及相关氨基酸对大菱鲆幼鱼生长性能及 TauT mRNA 表达的影响 [J]. 水生生物学报, 2017, 41(1): 165-173.
[12] 周铭文, 王和伟, 叶继丹. 饲料牛磺酸对尼罗罗非鱼生长、体成分及组织游离氨基酸含量的影响 [J]. 水产学报, 2015, 39(2): 213-223.
[13] GAYLORD T G, TEAGUE A M, BARROWS F T. Taurine supplementation of all-plant protein diets for rainbow trout (*Oncorhynchus mykiss*)[J]. Journal of the World Aquaculture Society, 2010, 37(4): 509-517.
[14] 何明, 刘利平, 曲恒超, 等. 牛磺酸对花鳗鲡生长和消化酶活力的影响 [J]. 上海海洋大学学报, 2017, 26(2): 227-234.
[15] 王学习, 周铭文, 黄岩, 等. 饲料牛磺酸水平对不同生长阶段斜带石斑鱼幼鱼生长性能和体成分的影响 [J]. 动物营养学报, 2017, 29(5): 1810-1820.
[16] MATSUNARI H, TAKEUCHI T, TAKAHASHI M, et al. Effect of dietary taurine supplementation on growth performance of yellowtail juveniles *Seriola quinqueradiata*[J]. Fisheries Science, 2005, 71(5): 1131-1135.
[17] QI G S, AI Q H, MAI K S, et al. Effects of dietary taurine supplementation to a casein-based diet on growth performance and taurine distribution in two sizes of juvenile turbot (*Scophthalmus maximus* L.)[J]. Aquaculture, 2012, 358/359: 122-128.
[18] MARTINEZ B J, CHATZIFOTIS S, DIVANACH P, et al. Effect of dietary taurine supplementation on growth performance and feed selection of sea bass *Dicentrarchus labrax* fry fed with demand-feeders[J]. Fisheries Science, 2010, 70(1): 74-79.
[19] KIM S K, MATSUNARI H, TAKEUCHI T, et al. Effect of different dietary taurine levels on the conjugated bile acid composition and growth performance of juvenile and fingerling Japanese flounder *Paralichthys olivaceus*[J]. Aquaculture, 2007, 273(4): 595-601.
[20] PARK G S, TAKEUCHI T, YOKOYAMA M, et al. Optimal dietary taurine level for growth of juvenile Japanese flounder *Paralichthys olivaceus*[J]. Fisheries Science, 2002, 68(4): 824-829.

[21] 周铭文. 饲料牛磺酸对不同饲喂期罗非鱼和石斑鱼的生长及牛磺酸合成酶活性的影响 [D]. 硕士学位论文. 厦门: 集美大学, 2015.
[22] 齐国山. 饲料中牛磺酸、蛋氨酸、胱氨酸、丝氨酸和半胱胺对大菱鲆生长性能及牛磺酸合成代谢的影响 [D]. 博士学位论文. 青岛: 中国海洋大学, 2012.
[23] 严俊丽, 陈四清, 常青, 等. 南极磷虾粉替代鱼粉对圆斑星鲽幼鱼生长性能、血清和肝脏生化指标及血清非特异性免疫指标的影响 [J]. 动物营养学报, 2016, 28(11): 3503-3510.
[24] 王国霞, 付晶晶, 黄燕华, 等. 5 种植物蛋白源替代鱼粉对花鲈生长性能和消化酶活性的影响 [J]. 湖北农业科学, 2014, 53(4): 866-870.
[25] 赵庆超, 张红娟, 刘海燕, 等. 不同动植物蛋白比对大菱鲆摄食生长与体成分的影响 [J]. 饲料研究, 2013(11): 71-73, 82.
[26] 柳茜, 王成强, 梁萌青, 等. 牛磺酸及相关氨基酸对鲈鱼 (*Lateolabrax japonicus*) 幼鱼生长及组织氨基酸含量的影响 [J]. 渔业科学进展, 2017, 38(4): 44-52.
[27] 张圆琴, 张越, 卫育良, 等. 大菱鲆鱼体脂肪累积调节方法研究 [J]. 上海海洋大学学报, 2016, 25(5): 700-709.

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