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Research Article

Supplementation of Selenium-Yeast Enhances Fishmeal Replacement by Soy Protein Concentrate in Diets for Golden Pompano (*Trachinotus ovatus*)

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An 8-week feeding trial was conducted to investigate the effect of selenium-yeast (Se-yeast) supplementation on replacing fishmeal with soy protein concentrate (SPC) in diets for golden pompano (*Trachinotus ovatus*). The control diet (C) contained 400 g/kg fishmeal, of which 40% and 80% of the fishmeal in diet C were substituted by SPC, with or without 1 g/kg Se-yeast supplementation (four diets, R40, R80, R40 + Se, and R80 + Se, were formulated). The weight gain of the fish-fed diet C showed no obvious difference from that of the fed-diet R40 + Se, although it was higher than that of the fish-fed diets R40, R80, and R80 + Se. Fish-fed diets R40 + Se and R80 + Se exhibited higher weight gain and nitrogen and phosphorus retention efficiencies, whereas they had relatively lower feed intake, feed conversion ratio, and nitrogen and phosphorus waste outputs than fish-fed diets R40 and R80. No statistical differences were found in condition factor and whole-body components either between fish-fed diets R40 and R40 + Se or between fish-fed diets R80 and R80 + Se. Our research suggests that it is feasible to reduce dietary fishmeal for golden pompano to 240 g/kg with SPC and 1 g/kg Se-yeast inclusion.

1. Introduction

Fishmeal is one dominant dietary protein ingredient for fish because of its perfect nutritional profile [1], and the inclusion of fishmeal in carnivorous fish species generally exceeds 30% [2]. However, it is unreachable to sustain the consistently rising consumption of fishmeal with a finite fisheries resource [3]. Therefore, replacing fishmeal with alternative protein ingredients is key to maintaining the sustainability of carnivorous fish culture [4].

Soy protein products, especially soybean meal, are generally utilized as dietary protein sources, benefiting from their superiority, like their relatively high protein content, constant supply, and low cost [5], and have been universally utilized as fishmeal alternatives in diets for carnivorous fish [6–9]. However, the inclusion of antinutritional factors, a deficiency in indispensable amino acids, and the inferiority of protein digestibility limit the utilization potential of soybean meal by carnivorous fish [10, 11]. Different from soybean meal, soy protein concentrate (SPC) is one soy protein product that removes oil and some soluble non-protein components, is characterized by highly digestible protein and low antinutritional factors [12], and has been utilized as a fishmeal alternative in numerous carnivorous fish species such as *red sea bream* (*Pagrus major*) [13], *hybrid grouper* (*Epinephelus fuscoguttatus* × *Epinephelus lanceolatus)* [14], *common sole* (*Solea solea)* [15], and *Japanese flounder* (*Paralichthys olivaceus)* [16]. Nevertheless, some studies have shown that feeding diets high in SPC lead to reduced intake, growth rate, and feed utilization in carnivorous fish [17–19], with some speculating that SPC lacks certain micronutrients present in fishmeal [20].

Selenium (Se) is an essential dietary micronutrient for the regulation of cell growth, immune function, and reaction to stressors [21]. It has been proven that selenium improves the fishmeal replacement potential of soybean meal in some carnivorous fish species like golden pompano (*Trachinotus ovatus)* [22] and *barramundi* (*Lates calcarifer)* [23]. Besides, fishmeal contains more selenium than feed ingredients derived from terrestrial plants, including soybean meal [20]. Therefore, the lack of dietary selenium may be a limiting factor in substituting fishmeal with terrestrial plant ingredients in fish. Studies suggest that supplementation of organic selenium (selenomethionine) rather than its inorganic form (Na_2SeO_3) generates greater absorption and retention rates in fish [24–26]. Selenium yeast (Se-yeast) contains predominantly selenomethionine and a handful of other Se-containing compounds [27] and has been reported to enhance growth performance, feed utilization, and immunocompetence in numerous fish species such as *Wuchang bream* (*Megalobrama amblycephala*) [28], *hybrid striped bass* (*Morone chrysops* × *Morone saxatilis)* [29], *yellowtail kingfish* (*Seriola lalandi)* [30], and *rainbow trout (Oncorhynchus mykiss)* [31]. However, to our best knowledge, the effects of dietary Se-yeast on fishmeal replacement have not been fully investigated [22].

The golden pompano (*Trachinotus ovatus)* is an established species with expanding production potential for aquaculture in Southeast Asian countries and China [32]. The nutritional studies on golden pompano, especially fishmeal replacement by cost-effective protein ingredients, are well explored; however, factors limiting fishmeal replacement for this fish species are still unclear. Some studies reported that the dietary fishmeal inclusion level could be reduced to 14% with SPC [33] or a blend of soybean meal and poultry by-product meal [22] served as the fishmeal substitute, and on the contrary, our early study suggested that the inclusion of dietary fishmeal for golden pompano must be higher than 32% with SPC used as a fishmeal substitute [34]. By comprising the feed formula composition, it was found that Se-yeast was added to both of the studies by Ren et al. [33] and Wang et al. [22]. Therefore, it was speculated that Se-yeast might be a factor limiting the replacement potential of fishmeal by SPC in golden pompano. To verify our conjecture, two fish meal replacement levels (40% and 80%) and two Se-yeast supplementation levels (0 and 0.1%) were designed in the current study to ascertain the effects of Se-yeast supplementation on fishmeal substitution by SPC in a golden pompano diet based on the evaluation parameters including growth, feed utilization, whole-body composition, and waste output.

2. Materials and Methods

2.1. Feed Ingredients, Experimental Design, and Experimental Diets. The Se-yeast (Fubon brand; Se content: 1600 mg·kg^{-1}) is a mixture of organic Se in selenomethionine and inorganic Se in selenite and was purchased from the Angel Yeast Co., Ltd. (Yichang, China). Steam-dried fishmeal, poultry by-product meal, dehulled soybean meal, SPC, corn gluten meal, rapeseed meal, wheat flour, and fish oil were offered by Zhejiang Hongli Feed Stock Co., Ltd. (Huzhou, China). Table 1 shows the proximate composition of feed ingredients.

A diet containing 400 g·kg^{-1} of fishmeal was formulated as the control (C), and 40% and 80% of the fishmeal in diet C were substituted by SPC to generate diets R40 and R80. In our previous study, we found that dietary supplementation of Se-yeast at 1 g·kg^{-1} could elevate fishmeal replacement level by soybean meal for golden pompano [22]. Therefore, 1 g·kg^{-1} of Se-yeast was added to diets R40 and R80 to generate diets R40 + Se and R80 + Se. The five diets were designed at 480 g·kg^{-1} of crude protein and 65 g·kg^{-1} of crude lipid based on the results determined by Wang et al. [35]. The experimental diets were pelleted using a laboratory extruder (SLP-45, Fishery Machinery and Instrument Research Institute, Chinese Academy of Fishery Sciences) and stored at −20°C after drying. Tables 2 and 3, respectively, show the formula and amino acid composition of diets.

2.2. Fish, Net Pens, and Culture Management. The feeding trial was conducted in Beibu Bay (Qinzhou, China). Fish were offered by a local hatchery. Prior to the feeding trial, fish fingerlings were acclimatized in net pens (1 m × 1 m × 1.5 m). To acclimatize to the experimental condition, all fish were fed with diet C between 8:00 h and 16:00 h for one week.

Prior to the feeding trial, fish were fasted for 24 h and pooled. 375 fish of similar body size were randomly distributed into 15 experimental pens at a density of 25 fish each. Each treatment (C, R40, R80, R40 + Se, and R80 + Se) was triplicated. The initial body weight of the fish was 8.9 ± 0.1 g (mean ± S.D., $n = 15$). Three groups of 15 fish each were randomly collected from the remaining fish and stored at −20°C for analyzing the initial body composition. Fish were fed between 8:00 h and 16:00 h for 8 weeks. Water temperature (26.3–30.2°C) was monitored daily, and salinity (27–33 ppt) was monitored weekly.

At the close of the feeding trial, fish were fasted for 24 h, captured from each net pen, anesthetized with 60 mg·L^{-1} clove oil, and finally group-weighed. Three anesthetized fish were randomly collected from each net pen, dissected and measured the body weight, body length, and liver weight, and then stored at −20°C for the analysis of whole-body components.

2.3. Chemical Analysis. The sampled fish were autoclaved, homogenized, and dried at 105°C. The method recommended in AOAC [36] was used to analyze the contents of moisture, crude protein, crude lipid, ash, and phosphorus in feed ingredients, test diets, and sampled fish. An amino acid analyzer (Sykam-433, Sykam Company with Limited Liability, Munich, Germany) was used to analyze dietary amino acid concentration. The Se contents in fishmeal, SPC, and the test diets were measured by the Guangzhou Puxing Technology Co., Ltd. (Guangzhou, China) using inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7900 series, USA).

Table 1: Proximate composition ($g{\cdot}kg^{-1}$) and selenium content ($mg{\cdot}kg^{-1}$) of the feed ingredients.

Ingredients	Dry matter	Crude protein	Crude lipid	Ash	Se content
Fishmeal, steam-dried	928	656	87	154	2.1
Poultry by-product meal	930	632	88	163	
Soy protein concentrate	942	674	7	60	0.1
Soybean meal	895	447	14	61	
Rapeseed meal	882	384	36	65	
Corn gluten meal	937	796	5	8	
Wheat flour	865	154	12	8	

Crude protein, crude lipid, ash, and Se content are expressed as the feed ingredients stored in air.

Table 2: Formulation ($g{\cdot}kg^{-1}$), proximate composition ($g{\cdot}kg^{-1}$), and selenium content ($mg{\cdot}kg^{-1}$) of the test diets.

Ingredients	C[1]	R40[1]	R80[1]	R40 + Se[1]	R80 + Se[1]
Fishmeal	400	240	80	240	80
Soy protein concentrate	0	160	321	160	321
Poultry by-product meal	100	100	100	100	100
Soybean meal	130	130	130	130	130
Rapeseed meal	80	80	80	80	80
Corn gluten meal	40	40	40	40	43
Choline chloride	2	2	2	2	2
Starch, gel	10	10	10	10	10
Wheat flour	168	166	152	165	152
Celite	10	1	0	1	0
$CaHPO_4$	10	10	10	10	10
Rovimix premix[2]	30	30	30	30	30
Se-yeast	0	0	0	1	1
Fish oil	20	31	42	31	42
Proximate composition					
Dry matter	903	908	914	909	915
Crude protein	497	484	476	475	487
Crude lipid	62	59	54	58	58
Ash	105	92	78	87	80
Phosphorus	16	13	10	13	10
Se content	2.9	2.5	2.2	5.6	5.4

[1]C: the control diet; R40 and R80: 40% and 80% of the fishmeal in diet C were replaced by soy protein concentrate (SPC), respectively. R40 + Se and R80 + Se: 40% and 80% of the fishmeal in diet C were replaced by SPC with supplementation of 1 g kg^{-1}Se-yeast, respectively. [2]Rovimix premix provides per kg of feed: vitamin A, 8000 IU; vitamin D3, 2000 IU; vitamin E, 100 mg; vitamin K3, 7.5 mg; vitamin B1, 15 mg; vitamin B2, 15 mg; vitamin B6, 12.5 mg; vitamin B12, 0.05 mg; D-biotin, 0.25 mg; D-calcium pantothenate, 40 mg; folic acid, 5 mg; niacinamide, 50 mg; vitamin C, 140 mg; inositol, 120 mg; $FeSO_4$, 40 mg; $CuSO_4.5H_2O$, 25 mg; $MnSO_4.4H_2O$, 10 mg; $ZnSO_4$, 100 mg; $MgSO_4.7H_2O$, 200 mg; $CoCO_3$, 0.35 mg; KI, 0.05 mg; Na_2SeO_3, 0.3 mg; $C_{14}H_{19}NO$, 5 mg.

Table 3: Amino acid content ($g{\cdot}kg^{-1}$) of the test diets.

Diet	Asp	Glu	Ser	His	Gly	Thr	Arg	Ala	Tyr	Cys	Val	Met	Phe	Ile	Leu	Lys	Pro
C[1]	31.71	69.33	18.54	11.60	23.46	19.18	27.84	26.47	15.52	2.88	18.24	9.30	18.38	17.68	32.66	29.63	24.56
R40[1]	36.51	77.09	20.75	12.29	25.34	16.31	30.29	24.62	16.13	2.74	21.07	8.80	20.32	19.26	33.91	29.51	25.66
R80[1]	37.34	81.79	21.80	8.68	23.36	15.42	31.60	21.82	16.50	2.00	20.76	6.95	21.43	19.84	34.05	26.94	25.91
R40 + Se[1]	29.92	75.30	21.97	2.27	22.95	15.34	27.15	22.87	15.95	2.12	18.75	7.89	19.62	18.03	32.07	24.87	22.67
R80 + Se[1]	38.25	88.38	23.48	4.03	24.13	16.49	32.18	22.95	17.62	2.65	21.73	7.55	22.71	20.53	35.76	27.09	26.37

Amino acid content is expressed on the basis of the diets stored in air ($n = 2$). [1]C: the control diet; R40 and R80: 40% and 80% of the fish meal in diet C were replaced by soy protein concentrate (SPC), respectively. R40 + Se and R80 + Se: 40% and 80% of the fish meal in diet C were replaced by SPC with supplementation of 1 g kg^{-1}Se-yeast, respectively.

2.4. Calculations and Statistics. The parameters were calculated as described in Wu et al. [37].

$$\text{Feed intake}\left(\% d^{-1}\right) = 100 \times \frac{I}{[(W_0 + W_t)/2 \times t]},$$

$$\text{Weight gain}\,(g) = \frac{W_t}{N_t} - \frac{\%\mathrm{W}_0}{\%\mathrm{N}_0},$$

$$\text{Feed conversion ratio (FCR, in dry feed)} = \frac{I}{(W_t - \%\mathrm{W}_0)},$$

$$\text{Nitrogen retention efficiency (NRE, \%)} = 100 \times \frac{(W_t \times C_{\mathrm{Nt}} - \%\mathrm{W}_0 \times \%\mathrm{C}_{\mathrm{N0}})}{(I \times C_{\mathrm{Nf}})},$$

$$\text{Phosphorus retention efficiency (PRE, \%)} = 100 \times \frac{(W_t \times C_{\mathrm{Pt}} - \%\mathrm{W}_0 \times \%\mathrm{C}_{\mathrm{P0}})}{(I \times C_{\mathrm{Pf}})}, \quad (1)$$

$$\text{Condition factor}\left(\mathrm{g\,cm}^{-3}\right) = 100 \times \frac{W_B}{L^3},$$

$$\text{Hepatosomatic index (HSI, \%)} = 100 \times \frac{W_L}{W_B},$$

$$\text{Nitrogen wastes}\left[g\,N\ (\text{kg fish gain})^{-1}\right] = 1000 \times (I \times C_{\mathrm{Nf}}) \times \frac{(1 - \mathrm{NRE})}{(W_t - \mathrm{W}_0)},$$

$$\text{Phosphorus wastes}\left[g\,P\ (\text{kg fish gain})^{-1}\right] = 1000 \times (I \times C_{\mathrm{Pf}}) \times \frac{(1 - \mathrm{PRE})}{(W_t - \mathrm{W}_0)},$$

$$\text{The ratio of fishmeal consumption to fish production}\left(\mathrm{RCP}, g\,g^{-1}\right) = \mathrm{WG} \times \mathrm{FCR} \times \frac{\mathrm{FL}}{(W_t/N_t \times \mathrm{DMF}_t - W_0/N_0 \times \mathrm{DMF}_0)},$$

where $I\,(g)$ is the total amount of the dry feed consumed by fish; $W_0\,(g)$ is the total initial body weight and $W_t\,(g)$ is the total final body weight; t (*d*) is the duration of the trial; N_t is the number of fish at the end of the trial, and N_0 is at the start; C_{Nt} (%) is the nitrogen content of fish body at the end of the trial, and C_{N0} (%) is at the start; C_{Nf} (%) is the nitrogen content of test diets; C_{Pt} (%) is the the phosphorus content of the fish body at the end of the trial, and C_{P0} (%) is at the start; C_{Pf} (%) is the phosphorus content of test diets; $W_B\,(g)$ is the body weight of the sampled fish, and L (cm) is the body length; $W_L\,(g)$ is the liver weight of the sampled fish; FL ($\mathrm{g{\cdot}kg^{-1}}$) is the fish meal content of the test diets; DMF_t ($\mathrm{g{\cdot}kg^{-1}}$) is the dry matter content of the fish sampled at the end of the trial, and $\mathrm{DMF}_0{\cdot}(\mathrm{g{\cdot}kg^{-1}})$ is at the start.

The statistical analysis was conducted according to Ilham et al. [23]. Briefly, all data were checked for normal distribution by the One-Sample Kolmogorov–Smirnov test and homogeneity of variances by Levene's test, and a two-way ANOVA was performed to examine the effect of fishmeal replacement level, Se-yeast, and their interaction on the test parameters among fish-fed diets R40, R80, R40 + Se, and R80 + Se. To determine the least dietary fishmeal level that can satisfy the production performance of golden pompano, the differences in the test parameters among fish-fed diets C, R40, R80, R40 + Se, and R80 + Se were determined with a one-way ANOVA followed by Duncan's test. The significant level was set at $P < 0.05$. Moreover, hierarchical cluster analysis (HCA) was performed to evaluate production performance in golden pompano based on weight gain, NRE, nitrogen waste, and RCP, according to Ren et al. [38]. The ANOVA and Duncan's tests were performed using the software IBM SPSS (version 21.0, IBM Corp., Armonk, New York). The HCA was performed with the Vegan package in R 3.3.2 (New Jersey, USA).

3. Results

3.1. Growth and Feed Utilization. Results of the two-way ANOVA in Table 4 show that the FBW, weight gain, NRE, and PRE were affected by fishmeal level and Se-yeast, the FCR was affected by Se-yeast, and the feed intake was not affected by fishmeal level, Se-yeast, or their interaction.

Results of the one-way ANOVA and Duncan's test in Table 4 show that weight gain in the fish-fed diet C showed no significant difference from the fish-fed diet R40 + Se, whereas it was higher than the fish-fed diets R40, R80, and R80 + Se. Feed intake and FCR in the fish-fed diets R40 showed no significant difference from those in the fish-fed diets C, R80, and R40 + Se, but were higher than those in the

Table 4: Initial body weight (IBW, g fish^{-1}), final body weight (FBW, g fish^{-1}), weight gain (g fish^{-1}), feed intake (% d^{-1}), feed conversion ratio (FCR), nitrogen retention efficiency (NRE, %), and phosphorus retention efficiency (PRE, %) of golden pompano fed the test diets for 8 weeks.

Treatments	IBW	FBW	Weight gain	Feed intake	FCR	NRE	PRE
C[1]	8.90 ± 0.13	63.58 ± 3.25^{d}	54.68 ± 3.12^{c}	4.81 ± 0.06^{ab}	1.54 ± 0.03^{ab}	18.44 ± 0.47^{bc}	18.62 ± 0.62^{a}
R40[1]	8.87 ± 0.10	54.35 ± 1.48^{bc}	45.48 ± 1.38^{b}	4.96 ± 0.18^{b}	1.62 ± 0.04^{b}	18.25 ± 0.29^{ab}	21.75 ± 0.20^{b}
R80[1]	8.95 ± 0.10	47.55 ± 0.81^{a}	38.61 ± 0.67^{a}	4.70 ± 0.20^{ab}	1.57 ± 0.06^{ab}	17.31 ± 0.42^{a}	26.96 ± 0.44^{d}
R40 + Se[1]	8.84 ± 0.27	59.27 ± 3.68^{cd}	50.43 ± 3.41^{c}	4.70 ± 0.03^{ab}	1.52 ± 0.02^{ab}	19.47 ± 0.40^{c}	25.14 ± 0.51^{c}
R80 + Se[1]	9.02 ± 0.19	50.61 ± 0.86^{ab}	41.59 ± 0.67^{ab}	4.52 ± 0.09^{a}	1.50 ± 0.05^{a}	18.80 ± 0.39^{bc}	28.69 ± 0.53^{e}
Two-way ANOVA							
Fishmeal level	NS	0.002	0.001	0.073	0.286	0.048	0.000
Selenium-yeast	NS	0.029	0.023	0.072	0.042	0.007	0.004
Interaction	NS	0.509	0.458	0.776	0.610	0.677	0.159

Feed intake and feed conversion ratios are expressed on a dry-feed basis. [1]C: the control diet; R40 and R80: 40% and 80% of the fishmeal in diet C were replaced by soy protein concentrate (SPC), respectively. R40 + Se and R80 + Se: 40% and 80% of the fishmeal in diet C were replaced by SPC with supplementation of 1 g·kg^{-1}Se-yeast, respectively. The superscripts represent the results of Duncan's test among fish-fed diets C, R40, R80, R40 + Se, and R80 + Se. The data with different superscripts in the same column means a significant difference at $P < 0.05$.

fish-fed diet R80 + Se. Compared with the fish-fed diet C, the NRE was lower than in the fish-fed diet R80; the NRE in fish-fed diets R40, R40 + Se, and R80 + Se showed no significant difference; and the PRE was higher in fish-fed diets R40, R80, R40 + Se, and R80 + Se.

3.2. Morphology and Body Composition. Results of the two-way ANOVA in Table 5 show that the condition factor and whole-body components were not affected by the fishmeal replacement level, Se-yeast, or their interaction. The HSI was affected by the interaction between fishmeal level and Se-yeast.

Results of the one-way ANOVA and Duncan's test in Table 5 show that no significant differences were found in condition factor and whole-body contents of moisture, crude lipid, ash, and phosphorus among fish fed different test diets. A higher HSI was found in the fish-fed diet R80 + Se than in the fish-fed diets C and R80. Higher whole-body crude protein was found in the fish-fed diet R40 than in the fish-fed diet R80.

3.3. Wastes Output, Wild Fish Resource, and Production Performance. Results of the two-way ANOVA in Table 6 show that the nitrogen waste was affected by Se-yeast, the phosphorous waste was affected by fishmeal level and Se-yeast and their interaction, and the RCP was affected by fishmeal level.

Results of the one-way ANOVA and Duncan's test in Table 6 show that, compared with fish-fed diet C, the nitrogen waste in fish-fed other four diets showed no significant difference, but the phosphorous waste and RCP in fish-fed other four diets were lower. Results of HCA in Figure 1 show that fish-fed diet R40 + Se displayed the closest production performance to fish-fed diet C.

4. Discussions

The SPC is one commonly used feed ingredient in marine carnivorous fish species including golden pompano. In the current study, the weight gain of fish decreased as the SPC inclusion level increased, while the weight gain between fish-fed diet C and diet R40 + Se showed no statistical difference. And our results indicated that when the SPC was served as a fishmeal alternative with supplementation of Se-yeast at 1 g·kg^{-1}, dietary fishmeal for golden pompano could be reduced to 240 g·kg^{-1}, which was lower than that (320 g·kg^{-1}) determined by Wu et al. [34]. Besides, based on the results of hierarchical cluster analysis in our study, golden pompano fed diet R40 + Se showed the closest production performance to fish-fed diet C; in other words, the addition of Se-yeast could enhance fishmeal replacement potential by SPC in the golden pompano diet. In comparison, with SPC served as a fishmeal substitute, the fishmeal content (240 g·kg^{-1}) maintained in the diet for golden pompano was much lower than that in the diets for *common sole* (*Solea solea)* (325 g·kg^{-1}) [15]; *starry flounder* (*Platichthys stellatus)* (408 g·kg^{-1}) [39]; *totoaba* (*Totoaba macdonaldi)* (430 g·kg^{-1}) [40]; and *pearl gentian grouper* (*Epinephelus lanceolatus*♂ × *Epinephelus fuscoguttatus*♀*)* (455 g·kg^{-1}) [41].

Se, as an essential trace element, has important physiologic functions in human and animal nutrition [42], although both its supplemental form and dose are still being disputed [43]. Generally, Se deficiency results in mortality, growth depression, and tissue pathologies, while excessive dietary selenium causes toxicity in fish [44]. However, the requirement of Se varies among different marine fishes; for example, 0.20 mg·kg^{-1} organic or inorganic Se for *hybrid striped bass* (*Morone chrysops* × *Morone saxatilis)* [29], 3.98 mg·kg^{-1}Se-yeast for *meagre* (*Argyrosomus regius)* [45], 5.56 mg·kg^{-1}Se-yeast for *yellowtail kingfish* [46], 9.20 mg/kg selenomethionine for *cutthroat trout (Oncorhynchus clarki bouvieri)* [47], and 12.34 mg·kg^{-1}Se-yeast for *triangular bream (Megalobrama terminalis)* [48]. In the current study, the concentration of Se declined from 2.9 to 2.2 mg·kg^{-1} with dietary fishmeal reduced from 400 g·kg^{-1} to 80 g·kg^{-1}, suggesting that fishmeal replacement by SPC may lead to a deficiency of dietary selenium. Weight gain of fish improved with Se-yeast addition when fed at the same SPC level (R40 + Se vs. R40, R80 + Se vs. R80), which implied that Se addition is

Table 5: Condition factor (g·cm^{-3}), hepatosomatic index (HSI, %), and proximate composition (%) of the whole body of golden pompano fed the test diets for 8 weeks.

Treatments	Condition factor	HSI	Moisture	Crude protein	Crude lipid	Ash	Phosphorus
C[1]	4.04 ± 0.25	0.96 ± 0.17^{a}	69.57 ± 1.43	16.34 ± 0.04^{ab}	10.88 ± 0.61	3.19 ± 0.03	0.55 ± 0.03
R40[1]	3.97 ± 0.31	1.06 ± 0.20^{ab}	69.88 ± 2.10	17.09 ± 0.06^{b}	9.79 ± 2.07	3.38 ± 0.02	0.58 ± 0.00
R80[1]	3.63 ± 0.38	0.85 ± 0.23^{a}	71.36 ± 1.23	16.00 ± 0.50^{a}	9.50 ± 0.74	3.39 ± 0.09	0.57 ± 0.01
R40+Se[1]	4.21 ± 0.34	1.00 ± 0.07^{ab}	70.49 ± 1.89	16.57 ± 0.53^{ab}	9.53 ± 0.72	3.38 ± 0.19	0.58 ± 0.02
R80+Se[1]	3.95 ± 0.14	1.30 ± 0.12^{b}	69.56 ± 1.46	16.73 ± 0.32^{ab}	10.43 ± 0.95	3.39 ± 0.10	0.59 ± 0.03
ANOVA							
Fishmeal level	0.130	0.644	0.812	0.160	0.713	0.944	0.841
Se-yeast	0.149	0.078	0.611	0.731	0.694	0.983	0.746
Interaction	0.821	0.027	0.321	0.078	0.485	0.971	0.479

Crude protein, crude lipid, ash, and phosphorus are expressed on a wet-weight basis. [1]C: the control diet; R40 and R80: 40% and 80% of the fishmeal in diet C were replaced by soy protein concentrate (SPC), respectively. R40 + Se and R80 + Se: 40% and 80% of the fishmeal in diet C were replaced by SPC with supplementation of 1 g kg^{-1}Se-yeast, respectively. The superscripts represent the results of Duncan's test among fish-fed diets C, R40, R80, R40 + Se, and R80 + Se. The data with different superscripts in the same column means a significant difference at $P < 0.05$.

Table 6: Waste outputs of nitrogen (g N (kg fish gain)$^{-1}$) and phosphorus (g P (kg fish gain)$^{-1}$) and the ratio of fish meal consumption to fish production (RCP, g·g^{-1}) of golden pompano fed the test diets for 8 weeks.

Treatments	Nitrogen waste	Phosphorous waste	RCP
C[1]	115.93 ± 3.31^{ab}	22.96 ± 0.35^{d}	1.98 ± 0.14^{c}
R40[1]	123.90 ± 1.82^{b}	20.37 ± 0.28^{c}	1.27 ± 0.14^{b}
R80[1]	122.04 ± 3.07^{b}	14.87 ± 0.36^{a}	0.43 ± 0.01^{a}
R40 + Se[1]	110.16 ± 1.36^{a}	16.72 ± 0.17^{b}	1.21 ± 0.08^{b}
R80 + Se[1]	116.60 ± 5.78^{ab}	14.06 ± 0.53^{a}	0.38 ± 0.01^{a}
ANOVA			
Fishmeal level	0.468	0.000	0.000
Se-yeast	0.022	0.002	0.353
Interaction	0.214	0.012	0.967

[1]C: the control diet; R40 and R80: 40% and 80% of the fishmeal in diet C were replaced by soy protein concentrate (SPC), respectively. R40 + Se and R80 + Se: 40% and 80% of the fishmeal in diet C were replaced by SPC with supplementation of 1 g kg^{-1}Se-yeast, respectively. The superscripts represent the results of Duncan's test among fish-fed diets C, R40, R80, R40 + Se, and R80 + Se. The data with different superscripts in the same column means a significant difference at $P < 0.05$.

necessary with fish fed high SPC diets. Nonetheless, the weight gain was lower in fish-fed diet R80 + Se (5.4 mg·kg^{-1} selenium) than fish-fed diet C (2.9 mg·kg^{-1} selenium), which indicates that some factors except Se deficiency may be responsible for the growth arrest in fish fed high SPC-based diet. Thus, Se deficiency may be an important factor affecting the utilization of SPC by golden pompano. Wu et al. [49] reported that the presence of some undesirable proteins (e.g., protease inhibitors, lectins, and allergens) has been recognized as the main factor limiting soy-derived protein ingredients as a fish meal substitute in fish diets. Besides, the level of methionine requirement for golden pompano is 10.6 g·kg^{-1} [50], and the methionine content was 9.3 g·kg^{-1} in diet C and was 7.55 g·kg^{-1} in diet R80 + Se, suggesting methionine deficiency may occur in fish-fed diet R80 + Se. Thus, exploration of the synergetic effect of the removal of undesirable proteins in SPC and supplementation of methionine and selenium is recommended in the future.

In the current study, compared with fish-fed diet C, no statistical difference was found in the feed intake of fish fed the other four test diets, regardless of whether Se-yeast supplementation was used or not, indicating that replacing dietary fishmeal with SPC has no negative effects on the palatability of feed, and meanwhile Se-yeast has a limited promoting effect on palatability. Moreover, at the same fishmeal level, higher NRE and PRE, whereas lower FCR, were found in fish fed-diets R40 + Se and R80 + Se than in fish-fed diets R40 and R80, suggesting that Se may be a growth-promoting factor that plays its role by improving feed utilization efficiency. The abovementioned outcomes were consistent with early studies on African catfish (*Clarias gariepinus)* [51] and Nile tilapia (*Oreochromis niloticus)* [52], in which dietary Se concentration improved feed utilization. In contrast, dietary Se did not influence FCR and protein efficiency ratio in rainbow trout [53] and crucian carp (*Carassius auratus gibelio)* [54]. The effects of Se on fishmeal replacement by SPC remain to be explored in various fish species.

Somatic indices like condition factor and HSI are crude measures of both the nutritional and healthy status of fish [55]. In the current study, no statistical differences were found in condition factor, HSI, and body components among fish-fed diets C, R40, and R80, suggesting that the morphology and whole-body components of golden pompano were not changed with SPC as a fishmeal alternative. Similar results were also observed in early researches. For instance, partially replacing dietary fishmeal with SPC has no effect on the condition factor, HSI, and viscerosomatic index of juvenile hybrid grouper [14]. No significant change

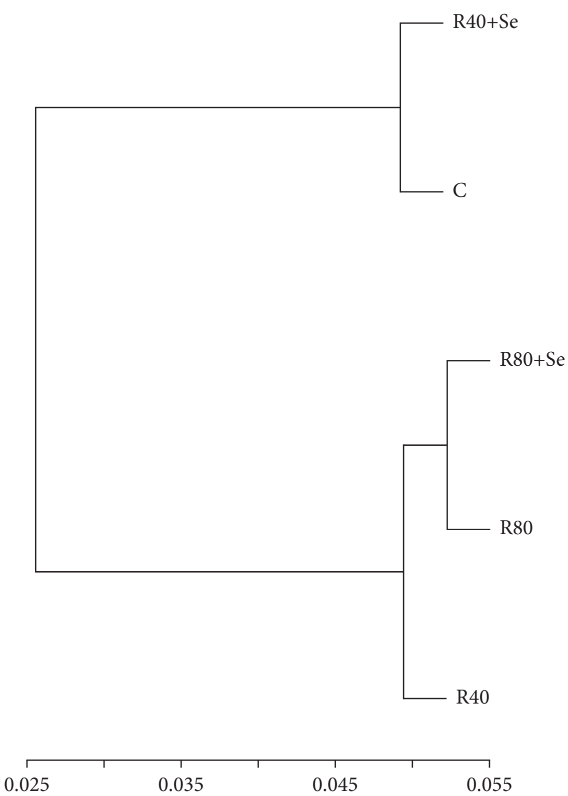

Figure 1: Hierarchical cluster analysis (HCA) of golden pompano fed different test diets based on the variables weight gain, NRE, NWO, and RCP. C: the control diet; R40 and R80: 40% and 80% of the fishmeal in diet C were replaced by soy protein concentrate (SPC), respectively. R40 + Se and R80 + Se: 40% and 80% of the fishmeal in diet C were replaced by SPC with supplementation of 1 g·kg^{-1}Se-yeast, respectively.

was found in the carcass and muscle composition of totoaba fed SPC-based diet [40]. Therefore, the reduced weight gain and unchanged morphological parameters and body components suggested that a change in dietary Se concentration might be a cause of limiting SPC served as a fishmeal substitute.

The impacts of fish farming practices on the water environment can be reflected in the waste outputs of nitrogen and phosphorus produced via feeding [34]. In the present study, nitrogen and phosphorous wastes were significantly influenced by Se supplementation (R40 + Se vs. R40), and our results revealed that Se supplementation decreased nitrogen and phosphorus emissions from the aquaculture of golden pompano, with dietary fishmeal substituted by SPC at high levels. In our study, for each kilogram of fish weight gain, the nitrogen and phosphorous wastes derived from golden pompano respectively increased by 110.16–123.90 g and 11.8–17.1 g, which were higher than those from the farming of *Japanese sea bass*, *Lateolabrax japonicus* (60–95 g N per kg fish gain, 7–12 g P per kg fish gain) [56], and *largemouth bass*, *Micropterus salmoides* (39–50 g N per kg fish gain, 5–11 g P per kg fish gain) [38]. The difference among the abovementioned studies may result from the diversity of metabolism capacity or even fish species.

The RCP was first raised by Wang et al. [57] to evaluate the impact of fish aquaculture on wild fishery resources. In our study, the RCP declined from 1.98 to 1.21 when 40% of the fishmeal in diet C was substituted by SPC with Se-yeast addition (diet R40 + Se). This result indicates that fishmeal consumption in golden pompano farming can be reduced to 1.21 by feeding a 240 g·kg^{-1}fishmeal-based diet with 1 g·kg^{-1}Se-yeast supplementation. The devaluation of RCP in golden pompano fed R40 + Se was higher than that in *giant croaker* (0.92) [37] and *largemouth bass* (0.66) [38], suggesting that the dependence of golden pompano aquaculture on wild fishery resource is much higher than that of *giant croaker* and *largemouth bass* aquaculture.

To conclude, the dietary fishmeal inclusion level for golden pompano could be declined to 240 g·kg^{-1} with the SPC as a fishmeal alternative and 1 g·kg^{-1} of Se-yeast supplementation. The decline in growth in golden pompano a fed high SPC-based diet might result from Se deficiency rather than low feed intake and feed utilization. By supplementation of 1 g·kg^{-1}Se-yeast in the diet containing 240 g·kg^{-1} of fishmeal, the pollution emission of nitrogen and phosphorous derived from golden pompano aquaculture was reduced, as well as the dependence on fishmeal.

Data Availability

The data supporting the findings of our study are included in the manuscript.

Ethical Approval

All the sampled fish were treated following the guidelines of the Administration of Laboratory Animals published by the State Science and Technology Commission of China.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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