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Effects of dietary protein and lipid levels on growth performance and body composition of black sea bass *Centropristis striata* (Linnaeus 1758) during grow-out in a pilot-scale marine recirculating system

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Abstract

The influence of four formulated practical diets, with different protein and lipid levels, on the growth and body composition of black sea bass (*Centropristis striata* L.) pre-adults was evaluated in a pilot-scale marine recirculating system. Four test diets were prepared with a combination of two protein levels (44% and 54%) and two lipid levels (10% and 15%). The diets were as follows: low protein and low lipid (LP:LL; 44:10), low protein and high lipid (LP:HL; 44:15), high protein and low lipid (HP:LL; 54:10) and high protein and high lipid (HP:HL; 54:15). Fish (mean weight = 75.5 g) were fed the respective diets for 90 days. For fish fed LP:HL, body weight gain was significantly ($P < 0.05$) higher than fish fed LP:LL. Increasing the protein level from 44% to 54% did not produce a significant effect on weight gain at high lipid level. A significant ($P < 0.01$) interactive effect between dietary protein and lipid levels on the growth and feed utilization was observed. Total lipid content in the whole body, muscle and liver was significantly affected by the dietary lipid levels. The results suggested that a combination of 44% dietary protein and 15% lipid was optimal for the growth of black sea bass.

Keywords: black sea bass, protein, lipid, growth performance, body composition

Introduction

Feed influences the nutritional composition and the marketability of cultured fish (Craig & Gatlin 1995; Hardy 1995). Feed accounts for one of the highest costs in the operation of an aquaculture enterprise, and protein is the most expensive component in balanced feeds and is probably the most important feed element for the growth of cultured species (National Research Council 1993). Dietary lipids play an important role as a source of energy and essential fatty acids. Dietary protein is the most important factor affecting the growth performance of fish and feed cost. It is important to provide adequate levels and ratios of protein, lipid and carbohydrate in diets in order to reduce catabolism of protein for energy (Lee, Jeon & Lee 2002; Kim, Wang, Choi, Park & Bai 2004). The protein-sparing effects by lipid or carbohydrate levels in diets have been reported in some fish species (Miller, Davis & Phelps 2005).

Black sea bass, *Centropristis striata* (Linnaeus 1758), are found in waters along the Atlantic coast from the Gulf of Maine to Northern Florida, and a subspecies inhabits the eastern Gulf of Mexico. Their wide acceptance as an excellent food fish and their high market value has led to over-harvesting of wild stocks in many areas (North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries 2006). An increased awareness of the status of the black sea bass fishery, coupled with high market demand, has led to an interest in the development of culture technologies for commercial production. Several studies have focused on captive spawning (Watanabe, Smith, Berlinsky, Woolridge, Stuart, Copeland & Denson 2003), larviculture (Berlinsky, Watson, Nardi & Bradley 2000), grow-out of juveniles and subadult captive wild black sea bass

(Copeland, Watanabe & Carroll 2002; Copeland, Watanabe, Carroll, Wheatley & Losordo 2003) and economic evaluation of ongrowing of captive wild black sea bass (Copeland, Watanabe & Dumas 2005). The methodology of spawning and larval rearing is well-documented (Watanabe *et al.* 2003; Berlinsky, King & Smith 2005; Copeland & Watanabe 2006), but research is lacking on the growth of hatchery-reared fingerlings to market size. The nutritional requirements of black sea bass have not been studied in detail and in captivity, fish are usually fed with commercial diets developed for other marine species. Basic information on the nutrient requirements of black sea bass is needed to develop a cost-effective commercial feed. However, in order to develop efficient culture strategies for this species, a better understanding of nutritional requirements and the interaction of macronutrients is required.

Given the high interest in the development of culture protocols for black sea bass, this study was designed to initiate the development of practical diets for black sea bass and, more specifically, to determine the effects of varied levels of dietary protein and lipid on the growth performance of subadults.

Materials and methods

This experiment was conducted at the University of North Carolina Wilmington Center for Marine Science (UNCW-CMS) Aquaculture Facility, Wrightsville Beach, North Carolina, from 30 January 2006 to 30 April 2006. Adult broodstock held in photothermally controlled tanks were induced to spawn using luteinizing hormone releasing hormone analogue (LHRHa) (Watanabe *et al.* 2003). These fish were hatched and reared according to previously published protocols (Copeland & Watanabe 2006). Early juveniles were raised in 150 L rectangular raceways and later in recirculating tanks until approximately 6 months post hatching, when the feeding trial was conducted. Before starting the experiment, the fish were reared using commercial diet [Zeigler Bros. (Gardners, PA, USA) crude protein 50% and lipid 15%].

Experimental system

The experimental units consisted of 12, 1.8 m diameter (volume = 2660 L, depth = 0.91 m) insulated fibreglass tanks. The recirculating system consisted of a bubble wash bead filter (Aquaculture Systems Technology, LLC, New Orleans, LA, USA), cyclobiofilter (MarineBiotech, Beverly, MA, USA) foam fractionator and UV sterilizer. Temperature was controlled using a heat pump, and aeration was supplemented using pure oxygen supplied through diffusers.

Experimental diets

To determine the combined effects of dietary protein and lipid on the growth and feed utilization of black sea bass, four experimental diets were formulated to contain two protein (44% and 54%) and two lipid (10% and 15%) levels (Table 1). The diets were as follows: low protein and low lipid (LP:LL; 44:10), low protein and high lipid (LP:HL; 44:15), high protein and low lipid (HP:LL; 54:10) and high protein and high lipid (HP:HL; 54:15). The protein sources were menhaden meal, squid meal and krill meal. Menhaden meal was increased to increase the protein level in diet. Squid meal and krill meal were constant for all diets. Menhaden oil and soybean lecithin were used as lipid sources. Menhaden oil was increased to provide higher lipid levels in the diets. A high amount of wheat starch was used as a carbohydrate source to increase energy levels in low protein based diets. Energy levels of diets were calculated based on 16.7, 37.7 and 16.7 kJ g^{-1} for protein, lipid and nitrogen-free extracts respectively (Garling & Wilson 1976). All other ingredients were formulated according to the recent studies on nutrient requirements of other marine fish. All ingredients were purchased locally except vitamin and mineral premix (Kohkin Chemical, Kagoshima, Japan, Kagoshima University vitamin and mineral for marine fish). Protein sources were sieved through a 500 μm mesh sieve. Diets were prepared as described previously (Alam, Watanabe & Carroll 2008). To prepare diets, dry ingredients were mixed with a feed mixer (Kitchen Aid, St Joseph, MI, USA), and then, previously mixed menhaden oil and lecithin were added. Approximately 40% distilled water was added to the ingredient mixture to facilitate pelleting using a meat chopper (Model MIN0012; Jacobi-Lewis, Wilmington, NC, USA). After pelleting, diets were dried at 70 °C in a constant temperature oven (DKM 600; Yamato Scientific, Tokyo, Japan). The proximate composition of the diets was analysed (Table 2). The experimental diets were stored at −20 °C until use.

Fish and experimental conditions

Four triplicate groups of fish (initial body weight 75.5 ± 2.2 g) were randomly distributed into each of

Table 1 Composition of diets

	Low protein and low lipid (LP:LL) (g 100 g^{-1} dry diet)	Low protein and high lipid (LP:HL) (g 100 g^{-1} dry diet)	High protein and low lipid (HP:LL) (g 100 g^{-1} dry diet)	High protein and high lipid (HP:HL) (g 100 g^{-1} dry diet)
Protein	44	44	54	54
Lipid	10	15	10	15
Menhaden meal*	30	30	46	46
Squid meal*	20	20	20	20
Krill meal*	10	10	10	10
Menhaden fish oil*	1.5	8.0	0	5.0
Soybean lecithin†	2.5	2.5	2.5	2.5
Wheat gluten (binder)‡	4	4	4	4
Wheat starch§	16.0	12.0	6.5	4.5
Vitamin mix¶	2.5	2.5	2.5	2.5
Mineral mix¶	2.5	2.5	2.5	2.5
Attractants‖	1	1	1	1
Cellulose§	10	7.5	5	2
Total	100	100	100	100
Gross energy (GE) (calculated, kJ g^{-1} diet)	14.0	14.8	13.4	15.5
Protein/energy ratio (mg protein kJ^{-1} GE)	3.2	3.0	4.0	3.5

*Integral Fish Foods, Grand Junction, CO, USA. Crude protein for menhaden meal, squid meal and krill meal is 63%, 80% and 60%, respectively; crude lipid for menhaden meal, squid meal and krill meal is 10%.
†ADM, Decatur, IL, USA.
‡Crude protein 80%.
§Sigma-Aldrich, St Louis, MO, USA.
¶Alam, Teshima, Ishikawa and Koshio (2000).
‖Attractants: alanine, betaine, glycine and taurine (0.25% each).

Table 2 Analysed proximate composition of diets

	Low protein and low lipid (LP:LL)	Low protein and high lipid (LP:HL)	High protein and low lipid (HP:LL)	High protein and high lipid (HP:HL)
Protein	44.15	44.8	54.1	54.8
Lipid	10.5	14.3	9.6	15.1
Moisture	11.7	11.3	10.0	10.8
Ash	10.7	11.3	13.5	13.8

Values are means ($N = 3$).

12 tanks (50 fish per tank). Each tank was covered with a lid to minimize disturbance and to prevent fish from jumping out. Fish were fed to apparent satiation twice a day (09:00 and 16:00 hours) as much as they could consume during a 20-min period, and the amount of diet consumed was recorded daily. Water temperature (21.5–23.7 °C, mean ± SD), salinity (33.1–33.9 g L^{-1}), pH (7.0–7.4) and dissolved oxygen (7.54–8.06 mg L^{-1}) were maintained throughout the experimental period. Ambient photoperiod conditions were used. Fish were weighed every month, with feed withdrawn for 24 h before weight measurements. The experiment was conducted for 3 months. At the end of the experiment, five fish from each tank were sacrificed for whole body proximate analysis, and five fish for dissecting dorsal muscle, abdominal muscle and liver. The fish were filleted and portions of dorsal and abdominal muscle (devoid of skin and bone), and liver were frozen until further analysis.

Biochemical and statistical analyses

Crude protein (nitrogen combustion; AOAC 1990) and crude fat content (ether extraction; AOAC 1990) of the diets and fish whole body were determined at New Jersey Feed Laboratory, Trenton, NJ, USA. Ash and moisture contents were analysed using standard methods (AOAC 1990) at UNCW-CMS.

All data were subjected to statistical verification using one-way and two-way analysis of variance (JMP, version 6.0, SAS Institute, Cary, NC, USA). Significant differences between means were evaluated using Tukey–Kramer test (Kramer 1956). Probabilities of $P < 0.05$ were considered significant.

Results

Effects on growth performance

Initial weights of fish averaged 75.5 g with no significant ($P > 0.05$) differences among treatments. On d30 and d60 of the feeding trial, no significant differences in body weight were observed among the test diets (Fig. 1). By d90, a significant ($P<0.01$) interactive effect between dietary protein and lipid levels on body weights was observed (Table 3). On d90, final weight for the LP:HL diet (202.7 g) was not significantly ($P>0.05$) different from both the HP:LL (190.7 g) and HP:HL (198.3 g) diets. However, final weight for the LP:LL diet (157.7 g) was significantly ($P<0.05$) lower than all other diets (Table 3).

On d90, a significant ($P<0.01$) interactive effect between dietary protein and lipid levels on per cent body weight gain (BWG) was observed (Table 3). The BWG showed similar trends in finals weights, with the LP:HL diet (159.3%) not significantly different from both the HP:LL (154.8%) and HP:HL (159.0%) diets. However, BWG for the LP:LL diet (109.9%) was significantly ($P<0.05$) lower than all other diets. Specific growth rate (SGR) on d90 also showed the same trend, with the LP:HL diet (0.45% day^{-1}) not significantly different from both the HP:LL (0.45% day^{-1}) and HP:HL (0.46% day^{-1}) diets. However, SGR for the LP:LL diet (0.35% day^{-1}) was significantly ($P<0.05$) lower than all other diets.

On d90, a highly significant ($P<0.01$) interactive effect between dietary protein and lipid levels on feed conversion ratio (FCR), feed intake (FI) and protein efficiency ratio (PER) was observed (Table 3). The FCR and FI showed similar trends in final weights and weight gain with the LP:HL diet (1.42 and 1.55) not significantly different from both HP:LL (1.51 and 1.63) and HP:HL diets (1.36 and 1.50). However, FCR and FI for the LP:LL diet (2.39 and 2.00) were significantly ($P<0.05$) higher than all other diets. The lowest PER (0.96) was found in the LP:LL diet, whereas the highest PER (1.61) was found in the LP:HL diet. Protein efficiency ratio in the high protein diets was not significantly different at both lipid levels. However, PER was significantly ($P<0.05$) lower for the HP:LL and HP:HL diets (1.20–1.33) than the LP:HL diet (1.61). No mortalities were observed during the study, with more than 98% survival in all treatments through d90.

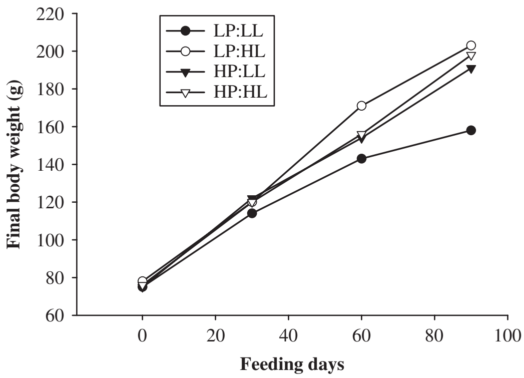

Figure 1 Effects of dietary protein [low protein (LP) = 44%; high protein (HP) = 54%] and lipid [low lipid (LL) = 10%; high lipid (HL) = 15%] on final body weight (g) of juvenile black sea bass after 30, 60 and 90 days feeding. Plotted point represent means (N = 3).

Table 3 Final body weight (FBW), per cent body weight gain (BWG), specific growth rate (SGR), apparent total feed intake (FI), apparent feed conversion ratio (FCR), apparent protein efficiency ratio (PER) of black sea bass fed different dietary protein and lipid diets for 3 months [LP (low protein) = 44% protein, HP (high protein) = 54% protein, LL (low lipid) = 10% lipid, HL (high lipid) = 15% lipid)

	FBW*	BWG†	SGR‡	FI§	FCR¶	PER‖
LP:LL	157.7 ± 5.2^{a}	109.9 ± 3.78^{a}	0.35 ± 0.01^{a}	2.00 ± 0.04^{a}	2.39 ± 0.11^{a}	0.96 ± 0.04^{a}
LP:HL	202.7 ± 3.9^{b}	159.3 ± 10.4^{b}	0.45 ± 0.27^{b}	1.55 ± 0.03^{b}	1.42 ± 0.05^{b}	1.61 ± 0.06^{c}
HP:LL	190.7 ± 7.5^{b}	154.8 ± 4.6^{b}	0.45 ± 0.01^{b}	1.63 ± 0.04^{b}	1.51 ± 0.09^{b}	1.20 ± 0.05^{b}
HP:HL	198.3 ± 3.7^{b}	159.0 ± 4.8^{b}	0.46 ± 0.02^{b}	1.50 ± 0.02^{b}	1.36 ± 0.04^{b}	1.33 ± 0.04^{b}
Two-way ANOVA (P-value)						
Protein (A)	0.1061	0.0470	0.0231	0.0083	0.0083	0.8739
Lipid (B)	0.0092	0.0221	0.0231	0.0011	0.0011	0.0032
A × B	0.0078	0.0080	0.0448	0.0017	0.0017	0.0007

Initial body weight, 75.5 ± 2.2 g. Values are means ± SEM (N = 3). Means with different letters in the same column differ significantly ($P<0.05$).

*FBW, final body weight (g).

†BWG (%) = [(final wet weight − initial wet weight)/initial wet weight] × 100.

‡SGR = [ln (mean final weight) − ln (mean initial weight)/56 d] × 100.

§FI = g 100 g^{-1} BWday^{-1}.

¶FCR = total feed intake (g)/wet weight gain (g).

‖PER = weight gain (g)/total protein intake in dry basis (g).

Effects on body compositions, dorsal and abdominal muscle and liver

Proximate composition of whole fish at the end of the feeding trial is presented in Table 4. Whole body moisture content was significantly ($P<0.05$) affected by dietary protein and lipid level, with no interactive effects ($P>0.05$). Moisture content (%) was significantly lower for fish fed high lipid diets (63.2–63.7) than those fed low lipid diets (64.6–65.9). Protein content of fish (16.7–17.5%) was not significantly affected by dietary protein or lipid levels ($P>0.05$). Body lipid content was significantly ($P<0.05$) affected by dietary protein and lipid level with significant interactive effects. Lipid (percentage wet basis) content of fish fed the high lipid diet (15.6–15.9) was significantly ($P<0.05$) higher than for the low lipid diet (11.9–13.9) regardless of dietary protein level ($P<0.05$). Neither dietary protein nor lipid level had a significant effect on ash content (4.10–4.54% wet basis) of fish ($P>0.05$).

Most of the lipid (percentage dry basis) was found in the abdominal muscle (43.0–55.9) and liver (42.3–57.4) compared with the dorsal muscle (12.3–25.1). Lipid levels of dorsal muscle, abdominal muscle and liver were significantly ($P<0.05$) affected by dietary lipid level (Table 5). At both dietary protein levels, total lipid increased with dietary lipid level in the dorsal muscle and abdominal muscles while total lipid decreased with increasing dietary lipid in the liver. Lipid levels of dorsal muscle were also significantly ($P<0.001$) affected by dietary protein, with higher muscle lipid at the higher dietary protein level (Table 5). Significant ($P<0.05$) interactive effects between dietary protein and lipid on abdominal muscle and liver lipid levels were observed.

Crude protein levels (percentage dry basis) were much higher in dorsal muscle (64.7–77.0) than in abdominal muscle (43.1–50.5) or in liver (16.4–23.6). Crude protein content in the dorsal muscle was significantly ($P<0.05$) lower in fish fed the HP:HL diets (64.7) than in the other diets (71.3–77.0). Crude protein content in the abdominal muscle was significantly lower in fish fed the HP diets (43.1–46.2) than in the LP:LL diet (50.5). In the liver, crude protein content was significantly higher in fish fed the HP:HL

Table 4 Effects of different dietary proteins and lipid levels on whole body proximate composition [LP (low protein) = 44% protein, HP (high protein) = 54% protein, LL (low lipid) = 10% lipid, HL (high lipid) = 15% lipid)

	Moisture	Protein	Lipid	Ash
LP:LL	65.9 ± 0.51^{b}	17.5 ± 0.35^{a}	11.9 ± 0.01^{a}	4.5 ± 0.18^{a}
LP:HL	63.7 ± 0.27^{a}	17.3 ± 0.50^{a}	15.6 ± 0.27^{c}	4.10 ± 0.11^{a}
HP:LL	64.6 ± 0.09^{b}	17.5 ± 0.50^{a}	13.9 ± 0.01^{b}	4.54 ± 0.27^{a}
HP:HL	63.2 ± 0.01^{a}	16.6 ± 0.55^{a}	15.9 ± 0.16^{c}	4.33 ± 0.19^{a}
Two-way ANOVA (*P*-value)				
Protein (A)	0.0394	0.4221	0.0362	0.9879
Lipid (B)	0.0026	0.2469	0.0007	0.1521
A × B	0.2907	0.5070	0.0062	0.5933

Values are means ± SEM ($N=3$). Means with different letters in the same column differ significantly ($P<0.05$).

Table 5 Effects of different dietary protein and lipid levels on dorsal muscle, abdominal muscle and liver protein and lipid content (percentage dry basis) in fish fed after 3 months [LP (low protein) = 44% protein, HP (high protein) = 54% protein, LL (low lipid) = 10% lipid, HL (high lipid) = 15% lipid]

	Dorsal muscle		Abdominal muscle		Liver	
	Protein	Lipid	Protein	Lipid	Protein	Lipid
LP:LL	77.0 ± 0.20^{c}	12.3 ± 0.45^{a}	50.5 ± 0.25^{c}	46.2 ± 0.4^{ab}	16.4 ± 0.40^{a}	51.0 ± 0.7^{b}
LP:HL	76.2 ± 0.45^{c}	17.7 ± 0.80^{b}	$48.8 \pm 0.60b^{c}$	48.8 ± 1.3^{b}	18.5 ± 0.45^{b}	46.3 ± 0.45^{a}
HP:LL	71.3 ± 0.85^{b}	18.7 ± 1.3^{b}	46.2 ± 0.50^{ab}	43.0 ± 0.30^{a}	17.7 ± 0.05^{ab}	57.4 ± 1.05^{c}
HP:HL	64.7 ± 0.30^{a}	25.1 ± 0.15^{c}	43.1 ± 0.85^{a}	55.9 ± 0.95^{c}	23.6 ± 0.30^{c}	42.3 ± 0.50^{a}
Two-way ANOVA (*P*-value)						
Protein (A)	0.0016	0.0003	0.4585	0.4585	0.0150	0.6428
Lipid (B)	0.0455	0.0006	0.0237	0.0237	0.0062	0.0096
A × B	0.0046	0.5508	0.0040	0.0040	0.0054	0.0018

Values are mean ± SEM ($N=3$). Means with different letters in the same column differ significantly ($P<0.05$).

diets (23.6) compared with the other diets (16.4–18.5). Significant interactive ($P < 0.01$) effects between dietary protein and lipid on tissue protein levels were observed.

Discussion

The SGRs in the present study (0.35–0.46% day^{-1}) (Table 3) were lower than those observed in a previous study for the same species (0.47–0.53% day^{-1}) (Copeland *et al*. 2002). As specific growth rates decrease with increasing fish size, these differences in SGR are probably due to a higher initial weight of the fish used in the present study. However, the overall growth rate of the black sea bass fed the fishmeal-based experimental diets observed in this study was better than observed in pilot-scale production studies using commercial generic diet and similar size of fish in our laboratory (W. O. Watanabe, unpubl. data).

In the present study, BWG for fish fed 44% protein was significantly higher in fish fed 15% lipid compared with 10% lipid. This is consistent with the observation that increasing dietary energy by lipid supplementation usually has a protein-sparing effect, allowing more efficient use of protein, while reducing N excretion to the environment (Bureau, Kaushik & Cho 2002). Protein-sparing has been demonstrated in salmon *Salmo salor* L. (Johnsen, Hillestad & Austreng 1991), trout *Oncorhynchus mykiss* (Walbaum) (Beamish & Medland 1986), carp *Cyprinus carpio* L. (Watanabe, Takeuchi, Satoh, Ida & Yaguchi 1987), hybrid striped bass *Morone chrysops* × *M. saxatilis* (Walbaum) (Nematipour, Brown & Gatlin III 1992), yellowtail *Seriola quinqueradiata* (Temmnich & Schlegel) (Shimeno, Hosokawa, Takeda & Kajiyama 1980), red sea bream *Pagrus major* (Temmnich & Schlegel) (Takeuchi, Shiina & Watanabe 1991) and in gilthead sea bream *Sparus aurata* L. (Vergara, Robaina, Izquierdo & Higuera 1996).

In the present study, fish fed HP:HL (54:15) did not have significantly higher BWG compared with fish fed LP:HL (44:15). When fish are fed a diet containing excess lipid with an appropriate protein level, growth may be reduced or constant due to an imbalance of digestible energy/crude protein ratio and excessive fat deposition in the visceral cavity and tissue (Lovell 1989). In our previous study (Alam *et al*. 2008) with juvenile black sea bass (5 g initial weight), we found that a diet containing 45% crude protein with 13.3% lipid produced optimum growth performance. Berlinsky *et al*. (2000) found that subadult black sea bass fed a diet containing 52% protein and 18% lipid were significantly larger than fish fed a diet containing 38% protein and 12% lipid. Copeland *et al*. (2002) reported higher growth rates in subadult black sea bass fed commercial diets containing between 50% and 56% protein compared with diets containing 41% and 45% protein. All these studies were conducted using different commercial diets where protein and lipid sources were unknown. Results of the present study suggested that the fishmeal-based diet containing 44% crude protein and 15% lipid was an appropriate combination for the growth of black sea bass under the present conditions.

The level of dietary lipid that is acceptable in terms of product quality and reducing nitrogen load into the environment varies with fish species depending on their relative ability to use dietary lipid as an energy source and on the main sites of lipid storage (Regost, Arzel, Cardinal, Robin, Laroche & Kaushik 2001). This study indicated that, given optimum dietary protein, the ability to utilize lipid by black sea bass is high. Further study using higher dietary lipid is necessary to determine the maximum lipid utilization by black sea bass.

In this study, the highest FI and FCR (Table 3) was found for the group fed the LP:LL diet. This is probably because fish eat to satisfy their energy requirement (Lee & Kim 2001). With the exception of the LP:LL diet (FCR = 2.39), FCRs in this study (1.36–1.42) were very similar to those reported for wild-caught subadult black sea bass grown in a recirculating system using a 50% crude protein and 12% crude lipid commercially prepared diet (FCR = 1.52) (Copeland *et al*. 2002, 2003).

In accordance with the protein-sparing action of higher dietary lipid, the highest PER in this study was obtained in fish fed the LP:HL diet (44% protein and 15% lipid). Dietary lipid supplementation improved feed efficiency and PER in a number of finfish species (Weatherup, McCracken, Foy, Rice, Mckendry, Mairs & Hoey 1997; McGoogan & Gatlin 1999; Thoman, Davis & Arnold 1999). At a dietary lipid level of 15%, increasing protein from 44% to 54% caused PER to decrease significantly, consistent with our previous study using juvenile black sea bass (Alam *et al*. 2008). This is also consistent with other studies showing a decrease in PER with increasing dietary protein beyond the optimum level (Lee & Kim 2001).

A high level of carbohydrate (12%) was used in the LP:HL diets compared with the high protein diets (HP:LL and HP:HL, 6.5% and 4.5% carbohydrate respectively) and provided better growth performance, suggesting that black sea bass were able to utilize carbohydrate as an energy source. However, fish fed LP:LL diet, containing 16% carbohydrate and 10% cellulose, showed lowest growth performance. This indicated that in addition to protein and lipid, it is important to determine the proper levels of carbohydrates in diets, because an imbalance in non-protein energy sources or levels and non-nutritive substances such as cellulose in the diets might have adverse influences on growth, nutrient utilization, digestibility and body lipid deposition (Garling & Wilson 1976; Hillestad, Johnsen & Asgard 2001).

Increasing dietary lipid may increase growth, but also affect carcass quality, mainly because of an increase in lipid deposition. In the present study, whole body lipid content was positively related with dietary lipid level ($P<0.05$) (Table 4). This is in agreement with other studies which showed that an increase in dietary lipid content was usually associated with an increase in body lipid (Peres & Oliva-Teles 1999; Alam, Teshima, Koshio, Uyan & Ishikawa 2003). In the present study, black sea bass deposited lipid in abdominal muscle (43–56%, dry weight) and liver (42–57%), and to a lesser extent in dorsal muscle (12–25%) (Table 5). So, increased dietary lipid had little effect on dorsal muscle lipid compared with abdominal muscle and liver. Similar results were reported for turbot *Psetta maxima* L. (Regost *et al.* 2001), rockfish *Sebastes schlegeli* (Hilgendorf) (Lee *et al.* 2002) and red drum *Sciaenops ocellatus* L. (McGoogan & Gatlin 1999). This suggests that the diets containing high lipid were not efficiently utilized for muscle accretion of black sea bass, but rather increased body fat deposition.

In conclusion, the results suggested that a combination of 44% dietary protein and 15% lipid was optimal for the growth performance of black sea bass grow-out fed with a fishmeal-based diet. This study also indicates that black sea bass are able to utilize a high level of dietary lipid with low protein based diets. A high level of lipid deposition in the body, however, was observed for the black sea bass fed high dietary lipid and may affect product quality and marketability. These findings will help to formulate cost-effective, nutritionally balanced artificial formulated diets for black sea bass culture that can be tailored to meet specific consumer preferences for flesh quality.

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