Effects of lipid on growth and feed utilization of white seabass (Atractoscion nobilis) fingerlings

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Abstract

A study was carried out to examine the effect of lipid level on growth and feed utilization of white seabass. Fingerling white seabass (27 days old, 0.65±0.05 g, 32±3.2 mm) were fed four formulated diets with four levels of lipid (15.5%, 18%, 19.5% and 21.5% of dry matter) at one level of protein (61% crude protein, dry matter (DM) basis) for six weeks. Survival exceeded 90% for all treatments. Weight gain (g) and specific growth rate (SGR, % day−1) values indicated that fish fed diets with 15.5% and 18% lipid exhibited higher growth performance. Lowest growth was recorded for fish fed diets with 19.5% and 21.5% lipid. Feed intake (FI, g fish−1) was also significantly (P<0.001) affected by dietary lipid levels and tended to decrease with increasing lipid levels. However, the fish that showed the highest FI were those that were fed the 15.5% and 18% lipid diets. Feed conversion ratio (FCR) values indicated that diets containing 19.5% and 21.5% lipid were more efficiently utilized. No significant differences in muscle composition were observed among fish fed the different diets. However, there was a strong linear relationship (P<0.05) between dietary lipid level and liver lipid. Hepatosomatic index (HSI) increased with dietary lipid level. Results indicated that fish performed best with the diets containing 15.5% and 18% lipid when protein concentration was 61.45±0.07%. And, reduced growth and increased body fat were evident when dietary energy increased from 24.2 to 24.9 kJ g−1. More work is needed to determine the precise dietary protein and carbohydrate requirements for this profitable aquaculture species.

Keywords: Dietary lipids; Growth; Feed utilization; White seabass Atractoscion nobilis

1. Introduction

White seabass is an important commercial and sport fish species in Southern California and Baja California, Mexico (Vojkovich and Reed, 1983). Their wide acceptance as an excellent food fish and high market value has led to over-harvesting of wild stocks in many areas (Drawbridge and Kent, 1998). Although, the production of this species for stock enhancement is now a well-controlled process that results in the release of hundreds of thousands of fingerlings annually, nevertheless, the nutritional requirements of this species have not been well defined (Kent et al., 2001). More information of this carnivorous marine species is needed...
to improve growth and feed efficiency and to minimize waste outputs to ensure economical and environmental sustainability of white seabass culture (Drawbridge and Kent, 2001).

Dietary lipid plays a major role in providing a source of concentrated energy and essential fatty acids, especially for carnivorous fish as these species have a limited ability to utilize carbohydrates as an energy source (Oliva-Teles, 2000; Sargent et al., 2002). The increase in digestible energy content of fish diets, by lipid supplementation, has been shown to have a protein sparing effect, therefore reducing nitrogen losses to the environment (Cho and Bureau, 2001). Several studies have shown that providing adequate energy with dietary lipids can minimize the use of more high-priced protein as an energy source (Peres and Oliva-Teles, 1999, 2001; Ai et al., 2004; Hung et al., 2004; Kim and Lee, 2005). So, an adequate lipid level in the diet is important for the growth performance of fish and product quality (Hamre et al., 2004; Tibbetts et al., 2005), and also for the formulation of diets (Pausa et al., 1998). The objective of the present study was to determine the effects of dietary lipid levels on growth, feed efficiency and muscle and liver composition of white seabass fingerlings.

2. Materials and methods

2.1. Diet formulation

Four isonitrogenous diets (61.5% CP) were formulated to contain four lipid levels (15.5%, 18.0%, 19.5% and 21.5% of dry matter). Formulation and proximate analysis of the diets are given in Table 1. Freeze-dried white fish muscle meal and krill meal were the major dietary protein sources. Cod liver oil and corn starch were used as lipid and carbohydrate sources, respectively. All ingredients were blended in a Kitchen Aid mixer (Hobart, Troy, OH, USA), to produce a homogeneous mixture. The wet mixture was pelleted through a 3-mm die in a commercial meat grinder and pellets were dried in a convection oven for 8 h at 65 °C. The dry pellets were placed in covered plastic bags and stored at −20 °C until use. The control diet (CD, Table 1) was a commercially available marine grower feed (Skretting, Vancouver, British Columbia, Canada) currently used in hatchery production of white seabass.

2.2. Animals and husbandry

A total of 750 white seabass, Atractoscion nobilis, fingerlings (27 days old, 0.65±0.05 g, 32±3.2 mm) were randomly distributed among 15 square plastic tanks at a stocking density of 50 fish per tank. Each tank of 60 l was supplied with recirculated seawater with a sand filter and a biofilter at a flow rate of 1.46 l min⁻¹. The photoperiod, temperature and salinity of the seawater in the tanks were maintained at 14:10 h (fluorescent light), 23±0.5 °C and 33 ‰, respectively.

Fish were acclimated in the system for one week before beginning the feeding trial. During this period, the fingerlings were fed the 15.5% lipid diet. Each dietary treatment was assigned to three tanks in a completely randomized design. Fish were fed to apparent satiation, four meals per day (0700, 1200, 1700 and 2200 h), 7 days per week for 6 weeks.

### Table 1

<table>
<thead>
<tr>
<th>Ingredients (g/100 g)</th>
<th>Dietary treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle fish mealᵃ</td>
<td>15.5L 18L 19.5L 21.5L CD</td>
</tr>
<tr>
<td>Krill mealᵇ</td>
<td></td>
</tr>
<tr>
<td>Cod liver oilᶜ</td>
<td></td>
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<tr>
<td>Lecithin</td>
<td></td>
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<tr>
<td>Gelatin</td>
<td></td>
</tr>
<tr>
<td>Corn starch</td>
<td></td>
</tr>
<tr>
<td>Mineral premixᵈ</td>
<td></td>
</tr>
<tr>
<td>Vitamin premixᵉ</td>
<td></td>
</tr>
<tr>
<td>Na benzoate</td>
<td></td>
</tr>
<tr>
<td>Antioxidant premixᶠ</td>
<td></td>
</tr>
</tbody>
</table>

### Proximate composition: (g/100 g dry weight)

<table>
<thead>
<tr>
<th>Component</th>
<th>15.5L</th>
<th>18L</th>
<th>19.5L</th>
<th>21.5L</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein (N × 6.25)</td>
<td>61.5</td>
<td>61.4</td>
<td>61.2</td>
<td>61.8</td>
<td>50.0</td>
</tr>
<tr>
<td>Crude lipid</td>
<td>15.5</td>
<td>18.0</td>
<td>19.5</td>
<td>21.5</td>
<td>15.1</td>
</tr>
<tr>
<td>Ash</td>
<td>7.5</td>
<td>7.4</td>
<td>6.4</td>
<td>6.1</td>
<td>10.8</td>
</tr>
<tr>
<td>NFE+crude fiber</td>
<td>15.5</td>
<td>13.3</td>
<td>12.9</td>
<td>10.6</td>
<td>24.1</td>
</tr>
<tr>
<td>Gross energy (kJ g⁻¹)</td>
<td>23.4</td>
<td>24.1</td>
<td>24.6</td>
<td>24.9</td>
<td>21.8</td>
</tr>
</tbody>
</table>

² Made from white fish muscle (81.3% protein, 10.8% lipid, 6.4% ash).
³ Krill meal (65.8% protein, 10.8% lipid, 7% ash), from Skretting, Vancouver, British Columbia, Canada.
⁴ Cod liver oil.
⁵ g/kg mineral premix: K₂HPO₄ 320; NaH₂PO₄, 250; Ca(H₂PO₄)₂, 200; MgSO₄·7H₂O, 150; calcium lactate, 35; ferric citrate, 25; NaCl, 10, ZnSO₄·7H₂O, 3.53; MnSO₄·H₂O·6H₂O, 0.31; CrCl₃·6H₂O, 0.01; crystalline silica, 17.0.
⁶ g/kg vitamin premix: inositol, 256.39; choline chloride, 149.78; niacin, 51.28; riboflavin; p-amino benzoic acid, 25.53; pantothenic acid, 17.92; β-carotene, 9.39; menadione, 6.11; thiamin-HCl, 3.85; pyridoxine, 3.06; folic acid, 0.96; biotin, 0.39; cholecalciferol, 25973 IU, α-tocopherol, 25643 IU; vitamin B₁₂, 5.59 mg.
⁷ Butylatedhydroxytoluene.
⁸ Nitrogen free extract (NFE)+crude fiber=100−(% crude protein +% total lipid +% ash).
⁹ Digestible protein:digestible energy (DP:DE).
determined from observation of acceptance and refusal of feed. During the third and sixth week of the experiment, daily feed intake (DFI) was calculated from the mean daily averages of feed consumed on a dry weight basis. During these same two weeks, remaining feeds were siphoned out; filtered and drained from each tank daily (for 7 days).

Fish were weighed in bulk to the nearest 0.001 g and measured individually for total length (TL) to the nearest 0.1 mm at the start, middle and end of the experiment. Before each weighing, the fish were deprived of feed for one day. At the start and end of the trial, sub-samples of 10 fish from each tank were euthanized and the liver and white muscle were excised, weighed and frozen at −20 °C for future analysis.

2.3. Analytical methods

The dry weights of muscle and liver samples were measured from triplicate samples per dietary treatment after freeze-drying for 48 h. Mean total N content was determined by the micro-Kjeldhal method (AOAC, 1995), and crude protein was then calculated as % N × 6.25. Total lipid was determined by extraction using chloroform–methanol (2:1 v/v) following the method of Folch et al. (1957). Ash content was determined by weight after heating the sample at 500 °C for 8 h. The carbohydrate percentage in diets, consisting of nitrogen-free extractives (NFE) and crude fiber, was calculated by summing the crude protein, total lipid and ash fractions and taking the difference from 100 (Jobling, 2001). Gross energy content was determined by an adiabatic bomb calorimeter (PARR 1281, Moline, IL, USA).

2.4. Statistical analysis

Data from each treatment were subjected to one-way analyses of variance (ANOVA), using Minitab 13.2 for Windows (Minitab Inc TM 2000, State College, PA, USA). Means were compared after analysis of variances by Tukey’s test (P = 0.05). The level of significance was chosen at P ≤ 0.05, and the results are presented as mean ± standard error of the mean (S.E.M.).

3. Results

Survival was similar (P > 0.05) among dietary treatments and ranged from 97±3.2% to 91±6.8%

Table 2

<table>
<thead>
<tr>
<th>Diets</th>
<th>15.5L</th>
<th>18L</th>
<th>19.5L</th>
<th>21.5L</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survival (%)</td>
<td>97.3±3.29</td>
<td>97.6±3.22</td>
<td>94.1±3.71</td>
<td>91.7±6.84</td>
<td>94.4±3.72</td>
</tr>
<tr>
<td>Initial BW (g)</td>
<td>0.7±0.02</td>
<td>0.6±0.04</td>
<td>0.6±0.01</td>
<td>0.7±0.03</td>
<td>0.7±0.03</td>
</tr>
<tr>
<td>Final BW (g)</td>
<td>22.2±0.43a</td>
<td>22.2±0.92a</td>
<td>19.2±0.40b</td>
<td>15.4±0.50c</td>
<td>18.6±0.38ab</td>
</tr>
<tr>
<td>Weight gain (g)</td>
<td>21.5±0.42a</td>
<td>21.6±0.88a</td>
<td>18.6±0.40b</td>
<td>14.7±0.53c</td>
<td>17.9±0.39b</td>
</tr>
<tr>
<td>SGR</td>
<td>9.1±0.05a</td>
<td>9.1±0.09a</td>
<td>8.7±0.05b</td>
<td>8.1±0.14c</td>
<td>8.6±0.09b</td>
</tr>
<tr>
<td>FI</td>
<td>21.1±0.49a</td>
<td>20.9±0.43b</td>
<td>12.8±0.73b</td>
<td>10.2±0.32c</td>
<td>14.2±0.47d</td>
</tr>
<tr>
<td>FCR</td>
<td>1.0±0.04a</td>
<td>1.0±0.03a</td>
<td>0.7±0.03c</td>
<td>0.7±0.04c</td>
<td>0.8±0.01b</td>
</tr>
<tr>
<td>PER</td>
<td>1.7±0.06a</td>
<td>1.7±0.05a</td>
<td>2.4±0.11b</td>
<td>2.4±0.12b</td>
<td>2.5±0.03b</td>
</tr>
</tbody>
</table>

Body weight (BW).
Specific growth rate (SGR).
Feed intake (FI): total feed consumed (g) during 42 days.
Feed conversion ratio (FCR).
Protein efficiency ratio (PER).

Data are based on triplicate dietary groups; means (± S.E.) in the same row not sharing a common superscript letter are significantly different (P < 0.05).
over the six-week trial. The fish adapted well to the experimental system, and no disease or water quality problems were observed during the study. The effects of dietary lipid levels on specific growth rate, feed intake, feed conversion ratio and protein efficiency ratio of white seabass fingerlings fed the experimental diets are presented in Table 2.

Weight gain, SGR and FI values indicated that the fish fed diets containing 15.5 or 18.0 g/100 g lipid (diets 15.5L and 18L) were significantly higher than those observed in other treatments \((P<0.05)\). Fish fed the 21.5L diet had the lowest growth \((P<0.05)\). The total FI (g) and FCR were also significantly \((P<0.001)\) affected by dietary lipid levels and tended to decrease with increasing lipid levels. The fish that showed the maximum FI were those feed with the 15.5L and 18L diets (Table 2). The FCR values indicate that the 19.5L and 21.5L diets were the most efficiently utilized. The highest PER generally increased with increasing dietary lipid level in 19.5L and 21.5L treatments.

The effect of dietary lipid levels on muscle and liver composition is presented in Table 3. Dietary lipid level had no significant effect \((P>0.05)\) on lipid, protein, energy and dry matter contents of muscle. Lipid content of liver increased in direct proportion to dietary lipid levels and achieved the highest levels when the fish fed the 19.5L \((73.9\pm0.68\%)\) and 21.5L \((74.3\pm0.72\%)\) diets \((P<0.05)\). Protein content of liver showed a declining trend with increasing dietary lipid level \((P<0.05)\). The fingerlings fed the CD showed the highest protein content. The fingerlings fed the CD had livers that were twice as large as the livers from fish fed the 15.5L diet. The concentration of protein in the liver varied significantly \((P<0.005)\) in relation to the dietary treatment, with the greatest value corresponding to the white seabass fed the CD \((23.1\pm0.15\%)\), and followed by the 15.5L \((20.1\pm0.04\%)\) diet. The lowest protein in the liver was observed among fish feed on 18L, 19.5L and 21.5L diets.

4. Discussion

Increasing lipid level of fish feeds has been shown to be an effective approach to improving feed efficiency and protein utilization, and decreasing N waste outputs and feed costs, especially in carnivorous fish species. Moreover, the nutritional strategy for protein sparing effect is to increase adequate amount of lipid in fish diet to reduce protein inclusion without compromising growth \((Sargent et al., 2002; Ai et al., 2004)\).

In this study, effects of increasing dietary lipid level were observed on growth, SGR, FCR and PER of white seabass fingerlings. The growth response data indicated that the maximum growth was obtained at 15.5% and 18% L and DP:DE 26.8 and 25.9 g/MJ, respectively. These findings are similar to results reported for other marine fish species, like red drum, black rockfish, red sea bream and Asian seabass, which have shown that lipid level around 17% improved growth of fish fed feeds containing 30% to 50% protein \((Takeuchi et al., 1991; Craig et al., 1999; Lee et al., 2002; Williams et al., 2003)\). However, increased dietary lipid to more than 18% in 61% protein diet did not improve weight gain, SGR and PER of white seabass fingerlings. Some authors have reported that high dietary lipid level might depress

| Table 3  
Muscle and liver composition (dry weight) and hepatosomatic index (HSI) of white seabass fingerlings fed experimental diets for six weeks \((n=3)\)  
<table>
<thead>
<tr>
<th>Diets</th>
<th>15.5L</th>
<th>18L</th>
<th>19.5L</th>
<th>21.5L</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muscle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total lipid (g/100 g)</td>
<td>7.0±0.08</td>
<td>7.0±0.20</td>
<td>7.0±0.22</td>
<td>7.1±0.06</td>
<td>7.5±0.10</td>
</tr>
<tr>
<td>Crude protein (g/100 g)</td>
<td>87.0±0.15</td>
<td>86.4±0.63</td>
<td>85.7±0.84</td>
<td>85.9±0.67</td>
<td>86.9±0.70</td>
</tr>
<tr>
<td>Ash (g/100 g)</td>
<td>7.2±0.08</td>
<td>7.4±0.20</td>
<td>7.3±0.22</td>
<td>7.6±0.16</td>
<td>7.4±0.13</td>
</tr>
<tr>
<td>Dry matter (g/100 g)</td>
<td>20.0±0.20</td>
<td>19.6±0.23</td>
<td>19.8±0.12</td>
<td>18.9±0.24</td>
<td>20.4±0.18</td>
</tr>
<tr>
<td>Gross energy (kJ g(^{-1}))</td>
<td>22.1±0.04</td>
<td>22.0±0.10</td>
<td>22.2±0.04</td>
<td>22.2±0.15</td>
<td>23.0±0.36</td>
</tr>
<tr>
<td><strong>Liver</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSI *</td>
<td>2.2±0.09(^c)</td>
<td>2.7±0.13(^c)</td>
<td>2.8±0.05(^c)</td>
<td>3.1±0.10(^b)</td>
<td>4.3±0.12(^*)</td>
</tr>
<tr>
<td>Total lipid (g/100 g)</td>
<td>66.5±0.46(^b)</td>
<td>68.7±0.29(^b)</td>
<td>73.9±0.68(^a)</td>
<td>74.3±0.72(^c)</td>
<td>42.3±0.49(^d)</td>
</tr>
<tr>
<td>Crude protein (g/100 g)</td>
<td>20.1±0.04(^c)</td>
<td>17.2±0.32(^b)</td>
<td>16.1±0.62(^a)</td>
<td>16.9±0.10(^b)</td>
<td>23.1±0.15(^c)</td>
</tr>
<tr>
<td>Dry matter (g/100 g)</td>
<td>50.3±1.20(^a)</td>
<td>52.7±2.60(^a)</td>
<td>50.3±1.45(^b)</td>
<td>51.3±0.88(^a)</td>
<td>47.7±0.67(^b)</td>
</tr>
<tr>
<td>Gross energy (kJ g(^{-1}))</td>
<td>31.6±0.42(^c)</td>
<td>33.9±0.29(^b)</td>
<td>33.9±0.31(^b)</td>
<td>34.9±0.36(^a)</td>
<td>27.1±0.11(^d)</td>
</tr>
</tbody>
</table>

Data are based on triplicate dietary groups; means (±S.E.M.) in the same row not sharing a common superscript letter are significantly different \((P<0.05)\).

* HSI: hepatosomatic index=(liver weight (g)/whole body weight (g))×100.
growth in some species (Espinós et al., 2003; Pei et al., 2004; Du et al., 2005). The growth reduction at high lipid levels could be due to the limited ability to digest and absorb high amounts of lipid, a reduction in feed intake, excess lipid accumulation in liver and other visceral organs, or creation of dietary or metabolic imbalances (Luo et al., 2005).

At the end of the trial, FCR was significantly lower ($P<0.001$) for fish fed the two diets with the highest lipid levels (19.5% and 21.5%) than fish fed the other diets. Dietary lipids had a significant effect on FCR, from 1.0 for fish fed the lowest lipid (15.5% and 18%) diets to 0.7 through fish that were fed the 19.5L and 21.5L diets. The FCR values we observed compared favorably to FCR observed in other studies with marine carnivorous fish. Williams et al. (2003) reported an FCR of 0.78 for juvenile Asian seabass (growing from 80 to 210 g) fed a diet containing 60.3% of protein and 18% lipid. Although, the higher performance among juvenile white seabass, in terms of growth was observed at diets 15.5L and 18L, the best FCR values were achieved with the two diets containing the greatest lipid levels (19.5 and 21.5 g/100 g).

In this study, FI of white seabass was regulated by the diet lipid level supplied by the diets ($P<0.001$). Other studies have reported that the amount of digestible energy (DE) regulated the amount of feed ingested by the fish (Lupatsch et al., 2001; Peres and Oliva-Teles, 2001) and that growth decreased with increasing dietary energy content (Ellis and Reigh, 1991). However, Encarnacao et al. (2004) presented evidence that feed intake is regulated by target protein growth of fish. Body protein deposition was not affected by dietary energy content; it appears that fish regulate their feed consumption to achieve a target body protein deposition rate determined by genetic potential, rather than a target daily DE intake (Encarnacao et al., 2004). Animals will seek to eat sufficient of a nutritionally balanced food to try to follow a genetically determined growth path where maximal protein accretion and associated carcass lean growth rate determine nutrient requirements for growth and composition (Schinkel and de Lange, 1996; Jobling, 2001).

The fact that in this experiment, the diets 19.5L and 21.5L had the higher FCR values suggests that nutrient dense feed could be an effective tool to improve feed utilization and minimize waste outputs. It appears that the fish that were fed 19.5L and 21.5L diets did not grow as well as the others because the higher amount of lipid reduced consumption, and therefore decreased growth. The fish with the higher growth consumed more feed and consumed a higher amount of lipid than the fish fed the high lipid diet.

Because protein retention is generally regulated by non-protein energy input of the diet, PER is a good measure of the “protein sparing effect” of lipid (Lie et al., 1988). Fish fed on 15.5% and 18% resulted in significant differences in PER (1.7±0.06 and 1.7 ±0.05, respectively) compared with the rest of the treatments. Many studies in fingerlings seabass have demonstrated the result of a protein sparing effect of lipid (Morales and Oliva-Teles, 1995; Dias et al., 1998; Peres and Oliva-Teles, 1999, 2001, 2002; Boujard et al., 2004).

No significant differences in muscle dry matter, protein, lipid or energy content were observed in white seabass offered the experimental diets. However, there was a strong relationship between the dietary lipid levels and the levels of lipid in the liver. This agrees with many other studies that have shown that dietary lipid levels correlate strongly with liver lipid content but not with muscle composition (Peres and Oliva-Teles, 2001; Nanton et al., 2001). The HSI also increased with increasing lipid levels in test diets.

The accumulation of fat in the liver of white seabass fingerlings fed the diets 19.5L and 21.5L suggests that white seabass have a limited ability to metabolize lipids. The white seabass may be similar to the Asian seabass, which are known to accumulate excess lipid in the liver because they have only a limited capacity to oxidize lipid as a source of metabolic energy (Williams et al., 2003).

In conclusion, white seabass fingerlings (27 days old, 0.65±0.05 g, 32±3.2 mm) performed best with the diets containing 15.5% and 18% lipid when protein concentration was 61.45±0.07%. Reduced growth and increased body fat were evident when dietary energy increased from 24.2 to 24.9 kJ g$^{-1}$. More work is needed to determine the precise dietary protein and carbohydrate requirements for this profitable aquaculture species.

Acknowledgements

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