ELSEVIER

Aquaculture 189 (2000) 133–144

Aquaculture

www.elsevier.nl/locate/aqua-online

The influence of replacing fish meal partially in the diet with soybean meal on growth and body composition of juvenile tin foil barb (*Barbodes altus*)

Adrian Elangovan *, K.F. Shim

Nutrition Laboratory, Department of Biological Sciences, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260, Singapore

Received 8 November 1999; received in revised form 1 March 2000; accepted 2 March 2000

Abstract

Juvenile *Barbodes altus* (0.90 ± 0.02 g body weight) were fed 42% crude protein diets in which dietary protein was supplied by brown fish meal (FM) (60% crude protein) or an isonitrogenous mixture of soybean (defatted, with hulls, 44% crude protein) and FM. Diet 1 was a control diet containing 73% FM (100% fish meal protein (FP)) as a protein source and without any soybean meal (SP). Diets 2–4 contained 27%, 37%, and 52% SBM with FM (ratios of FP to soybean meal protein (SBM) were 3:1, 2:1, and 1:1, respectively). Fish fed the diet containing FP/SP ratio of 1:1 had significantly ($P < 0.05$) lower weight gain and feed efficiency than fish fed with the other diets. There was no significant difference in body weights of fish fed with the other three diets. When compared to the control (Diet 1), fish fed with the other three diets did not show any significant difference in body protein content. However, body fat content was significantly higher in fish fed with the control diet than the fish fed with diets containing FP/SP ratios of 2:1 and 1:1. Whole-body ash content was significantly lower in fish fed with a diet containing fish-protein/soy-protein ratio of 1:1 than in those fed the other diets. The results of the present study indicate that SBM may be included in the diet up to 37% as a substitute for FM, replacing about 33% of FP.

Keywords: Barbodes altus; Nutrition; Fish meal; Soybean meal

* Corresponding author. Tel.: +65-8742708; fax: +65-7792486.
E-mail address: scip4129@nus.edu.sg (A. Elangovan).

0044-8486/00/$ - see front matter
PII: S0044-8486(00)00365-3

1. Introduction

Soybean meal (SBM), having high protein content and favourable amino acid profile that closely meets the requirements of fish, is consistently available and reported to be palatable to most species of fish (Lim and Akiyama, 1992). Refstie et al. (1997) reported that rainbow trout would rapidly adapt to dietary SBM. Diets with SBM are palatable and readily accepted by Atlantic salmon, previously adapted to fish meal (FM)-based diets (Refstie et al., 1998). Solvent-extracted SBM is more palatable for small seabass than extruded or steamed full-fat SBM (Boonyaratpalin et al., 1998). In some fish, palatability of diets containing soybean products may be improved by adding other protein sources, such as corn gluten meal, blood meal, blue mussel meat and krill (Arndt et al., 1999; Kikuchi, 1999).

Many studies have shown considerable success in partial or total replacement of FM with SBM and other soybean products in diets for various fish species (Reinitz, 1980; Mohsen and Lovell, 1990; Vivyakarn et al., 1992; Webster et al., 1992a,b, 1995; Olli et al., 1995; Boonyaratpalin et al., 1998; Quartararo et al., 1998; Arndt et al., 1999). The discrepancy among researchers regarding the use of SBM as a protein source for fish may be related to the quality and processing of SBM, variation in diet formulation, and differences in fish species, size and culture systems. The main limitations in the use of SBM are attributed to the low level of methionine and the presence of anti-nutritional factors (Wilson and Poe, 1985; Olli et al., 1994a). On the other hand, heat treatment of soybeans improved growth performance and feed utilization in trout (Sandholm et al., 1976), common carp (Nour et al., 1989), and coho salmon (Arndt et al., 1999). Viola et al. (1983) reported that heating SBM at 105°C for 30–90 min destroyed most of the protease inhibitors present. However, heating may cause loss of essential amino acids (Plakas et al., 1985).

Soybeans contain many antinutritional factors, such as, protease inhibitors, non-digestible carbohydrates, lectins, saponins, phytates, and possibly allergenic storage proteins (Liu, 1997). Among several soybean compounds which have been implicated in hindering digestion in fish (Spinelli et al., 1983; Olli and Krogdahl, 1994; Bureau et al., 1998; Storebakken et al., 1998; Refstie et al., 1999), non-starch polysaccharides may play a leading role. Refstie et al. (1999) have demonstrated a negative effect of soybean non-starch polysaccharides on digestion and absorption of lipid in Atlantic salmon. Non-starch polysaccharides are probably also responsible for a slower rate of gastro-intestinal passage in fish fed diets with SBM when compared to FM (Storebakken et al., 1999). Inclusion of non-starch polysaccharides (guar galactomannans and alginates) in the diets for salmonid fish reduces the availability of nutrients when compared to non-starch polysaccharide free diets (Storebakken, 1985; Storebakken and Austreng, 1987). In chickens, the digestibility of dry matter coincided with the content of non-digestible soybean non-starch polysaccharides and a similar trend was also seen in Atlantic salmon for digestibility of organic matter (Refstie et al., 1999). In addition, this non-digestible fraction of carbohydrates results in a relatively low digestible energy content in SBM. Multi-enzyme preparations designed to act on SBM non-starch polysaccharide substrates failed to induce any improvement in the growth of broilers fed SBM diets (Irish and Balnave, 1993). Phytate in SBM may reduce bioavailability of protein and minerals (Spinelli et al., 1983; NRC, 1993; Storebakken et al., 1998). Phytate-phosphorus is unavailable or poorly available to monogastric animals, including fish (NRC, 1993). Improved absorption and retention of phosphorus from diets containing SBM with phytase supplementation has been demonstrated in rainbow trout (Riche and Brown, 1996; Lanari et al., 1998) and common carp (Kim et al., 1996). Moreover, Phytic acid affects the activation of trypsinogen and stability of trypsin (Caldwell, 1992).

Barbodes altus, commonly known as tin foil barb, is an economically important aquarium fish and widely cultured in Singapore and Malaysia for export. This is also an important food fish, cultured in floating cages in Vietnam and feeds on a wide variety of animal and plant matter (Rainboth, 1996). In one of our previous experiments, the protein requirement of juvenile *B. altus* was determined to be 42% of the diet (Elangovan and Shim, 1997). Fish farmers in Singapore and Malaysia predominantly use commercial diets to rear *B. altus*. Most of the commercial diets contain FM as the main source of protein, and rising cost of FM increases the production cost of fish feed. The objective of this experiment was to study the potential of SBM as a partial replacement for FM in the diet of *B. altus*.

2. Materials and methods

2.1. Experimental diets

Mechanically extracted (defatted) and heat treated SBM with hulls (44% crude protein, 3.5% crude fat, 7% ash; as is basis) and brown FM from tuna (60% crude protein, 9.6% crude fat, 15% ash; as is basis) were purchased from Marine Feeds Private, Singapore. Four isoenergetic diets were formulated to contain various percentages of SBM as partial replacement for FM. All diets were isonitrogenous and contained 42% protein, as we have previously reported, the protein requirement of *B. altus* for maximum growth was 42% of the diet (Elangovan and Shim, 1997). Diet 1 is with 73% FM and without any SBM served as the control. Diets 2, 3 and 4 contained 27%, 37%, and 52% SBM and 55%, 49%, and 36% FM, respectively (ratio of fish meal protein (FP) to soybean meal protein (SP), 3:1, 2:1 and 1:1, respectively). The composition and proximate analysis of the experimental diets are given in Table 1.

SBM was ground to powder form in a mill. All dry ingredients were mixed thoroughly for 30 min in a Kenwood food mixer. Then, oil was added and the diets were mixed again for 10 min. The prepared diets were packed in separate plastic bags and stored at −30°C. Wet feed was prepared weekly. The calculated amount of dry feed for a week for each tank was mixed with an equal amount of distilled water to form a paste (wet feed) and stored at 4°C. Fish were fed at a rate of 6% body weight daily, as two equal feedings in the morning (0900) and evening (1600). During the course of the experiment, fish in all tanks ate all the food as soon as they were fed and no food was left over. Fish were bulk-weighed every 2 weeks and counted to record growth and determine the daily ration for the subsequent fortnight. The feeding trial was carried out for 8 weeks.

Table 1
Composition and proximate analysis of experimental diets (g/100 g diet)

Ingredient	Diet 1	Diet 2	Diet 3	Diet 4
	Control	FP:SP[a]		
	100% FP	3 FP:1 SP	2 FP:1 SP	1 FP:1 SP
Fish meal[b]	73.0	54.8	48.5	36.0
Soybean meal[b]	–	26.7	36.5	51.5
Cod liver oil	4.0	3.0	2.0	1.0
Dextrin	4.5	2.5	1.5	0.5
Cellulose	7.5	2.0	0.5	–
CMC[c]	3.0	3.0	3.0	3.0
Mineral mix[d]	6.0	6.0	6.0	6.0
Vitamin mix[e]	2.0	2.0	2.0	2.0
Proximate composition analysed				
Crude protein	43.26	42.76	42.81	42.18
Crude lipid	12.52	11.99	11.15	11.91
Ash	12.31	10.92	9.71	9.68
GE[f] (kJ/g)	18.03	18.74	18.87	18.95
P/E[g]	24.27	22.81	22.59	22.25

[a] FP = fish meal protein (brown fish meal from tuna), SP = soybean meal protein (mechanically extracted and heat treated soybean meal).
[b] Purchased from Marine Feeds Private Ltd., Singapore.
[c] Carboxymethylcellulose.
[d] Mineral mix contains (g/kg diet): $CaHPO_4 \cdot 2H_2O$, 18.00; $CaCO_3$, 14.00; $MgSO_4 \cdot 7H_2O$, 5.10; $FeSO_4 \cdot 7H_2O$, 1.00; $NaHCO_3$, 6.88; $MnSO_4 \cdot H_2O$, 0.35; KIO_3, 0.01; $CoCl_2 \cdot 6H_2O$, 0.002; $Na_2MoO_4 \cdot 2H_2O$, 0.008; $NaSeO_3$, 0.002; KH_2PO_4, 11.996; $ZnCO_3$, 0.15; $CuSO_4 \cdot 5H_2O$, 0.03; NaCl, 2.47; $Al_2(SO_4)_3$, 0.02.
[e] Vitamin mix contains (g/100 g of mix): thiamin, 0.100; pyridoxine, 0.100; folic acid, 0.025; ascorbic acid, 2.00; pantothenic acid, 0.300; myo-inositol, 2.00; biotin, 0.010; niacin, 0.750; cyanocobalamin, 0.001; riboflavin, 0.100; retinol acetate, 0.040; tocopheryl acetate, 0.200; menadione, 0.400; cholecalciferol, 0.003; dextrin, 93.971.
[f] GE = gross energy.
[g] P/E = protein to energy ratio in mg protein/kJ.

2.2. Experimental procedure

Juvenile tin foil barbs (*B. altus*) were obtained from a private farm in Singapore and stocked in the experimental tanks (89 × 44 × 45 cm) for 2 weeks before the beginning of the experimental regime, in order to condition the fish to the laboratory system and handling procedures. During the acclimatization period, the fish were fed a commercial diet (37% protein). At the start of the growth trial, uniform-sized fish (0.90 ± 0.02 g body weight) were randomly distributed into 12 tanks, with three replicates per diet. Thirty fish were stocked in each tank. The tanks were connected to a continuous recirculatory system, in which dechlorinated freshwater from a holding tank was recirculated through biological and mechanical filters and sterilized with UV light. Continuous aeration was provided to each tank through air stones connected to a central air compressor. Water flow rate was maintained at 2.3 l/min. Water temperature and pH were measured every 3 days. The water temperature varied between 27°C and 30°C and the pH ranged from 6.5 to 7.3 during the experimental period.

2.3. Final sampling and chemical analyses

Prior to final weighing and sampling for chemical analysis, fish were starved for 24 h. At the termination of the experiment, seven fish from each tank were randomly collected for proximate analysis. Fish were killed by immersing in ice water. Diets and fish carcass samples were analysed for crude protein, crude fat, ash, and moisture according to the methods described by the Association of Official Analytical Chemists (AOAC, 1990). Water content was measured by drying samples at 105°C to constant weight in an oven (Memmert, Germany). Crude protein was determined using a Kjeltec autoanalyser (Tecator Kjeltec Auto 1030 Analyser, Sweden). Protein was calculated as $N \times 6.25$. Crude fat was estimated using Soxhlet apparatus (Tecator Soxtec System HT 1043 Extraction Unit, Sweden) with petroleum ether and ash by heating at 550°C for 24 h in a Thermolyne type 6000 programmable ashing furnace (Carbolite Furnaces, model CSF 1100). The energy content of the diets was determined by a ballistic bomb calorimeter (Gallenkamp, England).

2.4. Calculation of fish performance and statistical analysis

$$\text{Feed conversion ratio (FCR)} = \frac{\text{Dry feed consumed (g)}}{\text{Wet weight gain (g)}}$$

$$\text{Protein efficiency ratio (PER)} = \frac{\text{Wet weight gain (g)}}{\text{Protein consumed (g)}}$$

$$\text{Specific growth rate (SGR)} = \frac{[\ln \text{final weight (g)} - \ln \text{initial weight (g)}]}{\text{Time (days)}} \times 100$$

Data were analyzed by one-way analysis of variance (ANOVA) using SAS ANOVA procedure (SAS, 1987). Duncan's multiple-range test was used to compare differences among means. The level of significance was chosen at $P < 0.05$ and the results are presented as means $\pm$ standard error of the mean (SEM).

3. Results

The weight gain response and feed performance data of *B. altus* fed diets containing different percentages of SBM and FM are shown in Table 2. Among the treatments, the weight gain of fish fed with Diets 1–3 were not significantly different from each other. However, weight gain of the fish fed with Diet 4, containing FP and SP in the ratio 1:1, was significantly lower than fish fed the control (Diet 1) and other diets. FCR ranged

Table 2
Mean initial body weight, weight gain, FCR, SGR, PER, and survival of *B. altus* fed test diets containing different ratios of FP and SP for 8 weeks[1]

	Diet			
	1 (100% FP)	2 (3 FP:1 SP)	3 (2 FP:1 SP)	4 (1 FP:1 SP)
Initial weight (g/fish)	0.92 ± 0.01	0.91 ± 0.02	0.92 ± 0.01	0.90 ± 0.02
Weight gain (g/fish)	5.17 ± 0.10^a	5.09 ± 0.23^a	5.09 ± 0.17^a	3.23 ± 0.57^b
SGR	3.35 ± 0.08^a	3.34 ± 0.09^a	3.35 ± 0.04^a	2.67 ± 0.24^b
FCR	1.50 ± 0.02^b	1.48 ± 0.04^b	1.49 ± 0.06^b	2.01 ± 0.22^a
PER	1.57 ± 0.01^a	1.59 ± 0.05^a	1.57 ± 0.06^a	1.11 ± 0.09^b
Survival (%)	100	100	96.7	100

[1] Data are mean values of three replicates. Values are mean ± SEM. Means within a row having different superscripts were significantly different ($P < 0.05$).

from 1.48 to 2.01 and PER varied from 1.11 to 1.57 among the treatments. PER and FCR were significantly lower and higher, respectively, in fish fed with Diet 4 than that of fish fed with the other three diets. However, FCR and PER were not significantly different among fish fed with Diets 1–3. Survival of fish in the treatments ranged from 96.7% to 100%. The general health and appearance of all test fish were good and the fish in all treatments were very active.

The whole body composition of fish after 8 weeks of growth trial is given in Table 3. Whole-body moisture content significantly increased as the amount of SBM in the diets increased. Conversely, the whole-body lipid significantly decreased. The reduction in whole-body ash seemed numerically linear as the FP was replaced with SBM crude protein from 25% to 50% in the diets. However, ash content was significantly lower in fish fed with Diet 4 (1 FP/1 SP), containing 37% SBM than in those fed with the other three diets, but whole-body ash content was not significantly different among the fish fed with Diets 1–3. Crude protein content was highest in fish fed with Diet 3 and it was not significantly different from that of fish fed with Diets 1 and 2. However, the crude protein content of fish fed with Diet 4 was significantly lower than that of fish fed with Diet 3, but not significantly different from that of fish fed with Diets 1 and 2.

Table 3
Whole body composition (% wet weight) of *B. altus* after 8 weeks of feeding test diets containing different ratios of FP and SP[1]

Diet	As percentage of wet weight			
	Moisture (%)	Crude protein	Crude fat	Ash
1 (100% FP)	73.44 ± 0.16^d	16.52 ± 0.12^{ab}	7.70 ± 0.10^a	3.55 ± 0.03^a
2 (3 FP:1 SP)	74.02 ± 0.08^c	16.58 ± 0.10^{ab}	7.03 ± 0.30^{ab}	3.53 ± 0.03^a
3 (2 FP:1 SP)	74.70 ± 0.09^b	16.98 ± 0.08^a	6.61 ± 0.20^b	3.43 ± 0.09^a
4 (1 FP:1 SP)	75.73 ± 0.08^a	16.38 ± 0.21^b	6.77 ± 0.14^b	3.17 ± 0.02^b

[1] Data are mean values of three replicates. Values are mean ± SEM. Means within a column having different superscripts were significantly different ($P < 0.05$).

4. Discussion

The inclusion of SBM up to 37% in the diet, replacing about 33% of the FP, did not affect the growth rate when compared with the control diet containing 73% FM (100% FP). This is in agreement with results obtained with several fish species. Vivyakarn et al. (1992) reported that substitution of 55% FP with SBM (without crystalline amino acids) did not impair growth and feed efficiency in yellowtail. Watanabe et al. (1992) demonstrated that SBM could be included as a protein source up to 30% in place of FM (substitution of about 55% FM) in soft-dry pellets for yellowtail. Olli and Krogdahl (1995) reported that replacement up to 20% of high quality FP with SP in diets for Atlantic salmon was suitable without growth reduction. Further, a few reports on very high substitution of FP with SBM supplemented with amino acids or other protein sources in the diets of fishes have also been documented. Substituting 75% of FP with SBM was possible in the diet of hybrid striped bass with methionine supplements (Gallagher, 1994). McGoogan and Gatlin (1997) grew red drum successfully with diets in which 90% of FP was replaced by SBM with additions of amino acids. Webster et al. (1995) suggested that a methionine supplemented diet with an all plant protein source (SBM) could totally replace FM in a diet for blue catfish, without adverse effects on weight gain or body composition, when the protein level was 35% and fish were fed to satiation. Moreover, Kikuchi (1999) has shown that about 45% of FP can be replaced with defatted SBM in combination with blood meal or corn gluten meal and blue mussel meal without any amino acid supplement.

In this study with juvenile *B. altus*, when SBM was used to replace 50% of the FP (52% SBM in Diet 4), growth was significantly reduced. Growth reduction could have been due to higher FCR and lower PER (Table 2). Higher FCR (poor) and lower PER have also been previously reported in yellowtail (Vivyakarn et al., 1992) and Japanese flounder (Kikuchi, 1999) when SBM was included at high levels in the diet. Replacement of FM with SBM in fish diets has variable success, indicating the wide variation possible in the nutritive value of SBM for various fish species. Previous studies on various fish species have revealed that the level of FM replacement with SBM and growth rate are inversely related (Pongmaneerat and Watanabe, 1992; Reigh and Ellis 1992; Webster et al. 1992b). Several hypotheses have been suggested to explain the results of those studies in which growth was reduced and these could also be the possible reasons in our study. (1) The presence of trypsin inhibitors in crude SBM may cause growth reduction (Wilson and Poe, 1985; Olli et al., 1994a). Inclusion of high dietary levels of crude trypsin inhibitors from soybean reduced protein digestibility in rainbow trout (Krogdahl et al., 1994) and fat digestibility in Atlantic salmon (Olli et al., 1994a). (2) Sub-optimal amino acid balance of SBM may lead to negative effects in fish. Dabrowski et al. (1989) reported decreased amino acid absorption in rainbow trout, especially methionine, if SBM was used above 50% of the total formulation of the diet. Replacement of about 50% of FP by SP in the diets for Japanese flounder (Kikuchi et al., 1994) and red drum (Reigh and Ellis, 1992) did not reduce the growth, if deficient amino acids were properly supplemented. In the present study, weight reduction in *B. altus* when fed with Diet 4 may also be due to low amino acid availability as the diet had 52% SBM in the total formulation. In this study, Diet 4 contained methionine

(0.82%) less than that of control (1.07%) and other diets (Table 4). Therefore, it is presumed that Diet 4 may have contained methionine as a level less than the requirement of *B. altus* and this possibly may have affected growth rate. (3) Fish fed with the Diet 4 had a significant reduction in ash content and this may be related to phytic acid in SBM, which has the ability to reduce the availability of several minerals such as calcium, magnesium, zinc, iron, and phosphorus, compared with FM (NRC, 1993; Lanari et al., 1998; Storebakken et al., 1998). Apparent and true phosphorus availability values for SBM were lower than those of FM when evaluated for rainbow trout, and supplementation of SBM diets with phytase enzyme significantly increased phosphorus availability (Riche and Brown, 1996; Lanari et al., 1998). Decreased weight gain, feed efficiency, and zinc content in the vertebrae of catfish were observed when phytate level was increased from 1.1 to 2.2 in the diets (Satoh et al., 1989).

The reduced carcass fat content with increased SBM in diet is also consistent with earlier findings (Mohsen and Lovell, 1990; Reigh and Ellis, 1992; Olli et al., 1995), even though levels of lipid and gross dietary energy were equal among all diets. Higher level of SBM has been reported to reduce fat digestibility in fish (Olli and Krogdahl, 1994; Olli et al., 1994b). Further, Olli and Krogdahl (1995) have also demonstrated that alcohol-soluble components of SBM comprise antinutrients, which negatively affect fat digestibility, particularly the long chained, saturated and monosaturated fatty acids in Atlantic salmon. This may also be one of the reasons for reduced carcass fat content and growth rate in fish fed with the Diet 4, containing larger proportion (52% of the diet) of SBM. In this study, while SBM was the primary source of carbohydrate-energy in the diets containing high level of SBM, dextrin was the primary carbohydrate-energy in

Table 4
Calculated amino acid composition of control (Diet 1) and experimental diets containing various percentages of soybean meal and fish meal (amino acids as percentage of diet)[a]

Amino acid	Diet 1	Diet 2	Diet 3	Diet 4
	Control	FP:SP[b]		
	100% FP	3 FP:1 SP	2 FP:1 SP	1 FP:1 SP
Arginine	2.50	2.78	2.89	2.97
Histidine	1.27	1.28	1.28	1.24
Isoleucine	1.79	1.88	1.92	1.93
Leucine	2.77	3.00	3.11	3.14
Lysine	2.96	2.98	3.01	2.93
Methionine	1.07	0.96	0.92	0.82
Cystine	0.34	0.45	0.49	0.53
Phenylalanine	1.57	1.77	1.85	1.91
Tyrosine	1.23	1.35	1.39	1.42
Threonine	1.69	1.75	1.77	1.75
Tryptophan	0.42	0.48	0.56	0.54
Valine	2.02	2.06	2.08	2.02

[a]Amino acid composition of the diets was calculated from the tables of feed ingredient composition (NRC, 1993).
[b]FP = fish meal protein; SP = soybean meal protein.

diets with the higher level of FM (Table 1). SBM contains approximately 30% carbohydrates, with 10% oligosaccharides (5% sucrose, 4% stacchyose, 1% raffinose), 1% starch, and 20% non-starch polysaccharides (Snyder and Kwon, 1987; Liu, 1997). Non-starch polysaccharides, mainly consisting of cellulose, hemicellulose, and pectins, and oligosaccharides, such as stacchyose and raffinose are not digested and absorbed by monogastric animals (Lim and Akiyama, 1992). Only, sucrose and a trace of starch from SBM are available. Non-starch polysaccharides affect digestion of nutrients negatively (Refstie et al., 1999) and are responsible for a delayed gastrointestinal evacuation in Atlantic salmon (Storebakken et al., 1999). Therefore, it is understandable that to the fish fed with Diet 4, containing 52% SBM, most of the carbohydrates may have been completely unavailable. In contrast, the control and the other two diets contained relatively more dextrin, which may be a good source of blood glucose to the tin foil barb, as many fish (NRC, 1993; Rawles and Gatlin, 1998) utilize dextrin effectively. Hence, difference in digestible energy between SBM and dextrin may have caused differences in available energy among diets. The relative use of dietary carbohydrate by fish varies and appears to be associated with the complexity of the carbohydrate (NRC, 1993). Moreover, it may be possible that *B. altus* fed higher levels of FM might have converted a larger portion of dietary protein to lipid, if amino acid intake was in excess of requirements.

Moisture and fat usually vary inversely in fish flesh, while the protein is more constant (Belal and Assem, 1995). In this study, whole-body moisture content increased and body fat decreased with increasing dietary SBM as has been reported for Atlantic salmon (Olli et al., 1995) and Japanese flounder (Kikuchi et al., 1994). However, no difference in the body-moisture content of rainbow trout (Reinitz, 1980) and blue catfish (Webster et al., 1992b) have been reported when fed wih diets containing various levels of SBM, replacing FM.

5. Conclusion

This study demonstrates that SBM may be used as a source of protein in combination with FM in the diet for juvenile *B. altus*. The results of this experiment suggest that a diet containing 42% crude protein with 2:1 mixture of FP and SP (37% SBM in the diet) was adequate for normal growth in *B. altus*. SBM substitution for FM supplemented with other protein sources and amino acids have shown encouraging results in some fishes (McGoogan and Gatlin, 1997; Quartararo et al., 1998; Kikuchi, 1999). Hence, it is recommended that further evaluation of different types (dehulled and solvent extracted) of SBM and other soybean products (soy flour and soybean protein concentrates) in high percentages in diets supplemented with amino acids or other protein sources on growth of *B. altus* should be conducted in the future.

Acknowledgements

We sincerely thank Mr. Chua Whye Leng for his technical support. We are grateful to Dr. B. Sivaloganathan and A. Sharmila for their help and suggestions. We thank the

Tamil Nadu Collegiate Education Department and the Principal of St. Joseph's College, Tiruchirapalli, Tamil Nadu, India for granting study leave to Adrian Elangovan to carry out this research. This work was carried out during the tenure of a post-graduate scholarship from the National University of Singapore to the first author and supported by the research grant RP 79/82 to Shim Kim Fah from the National University of Singapore.

References

AOAC, 1990. In: Official Methods of Analysis of the Association of Official Analytical Chemists. 15th edn. Association of Official Analytical Chemists, Arlington, VA, p. 1298.

Arndt, R.E., Hardy, R.W., Sugiura, S.H., Dong, F.M., 1999. Efects of heat treatment and substitution level on palatability and nutritional value of soy defatted flour in feeds for coho salmon, *Oncorhynchus kisutch*. Aquaculture 180, 129–145.

Belal, I.E.H., Assem, H., 1995. Substitution of soybean meal and oil for fish meal in practical diets fed to channel catfish, *Ictalurus punctatus* (Rafinesque): effects on body composition. Aquacult. Res. 26, 141–145.

Boonyaratpalin, M., Suraneiranat, P., Tunpibal, T., 1998. Replacement of fish meal with various types of soybean products in diets for Asian seabass, *Lates calcarifer*. Aquaculture 161, 67–78.

Bureau, D.P., Harris, A.M., Cho, C.Y., 1998. The effects of purified alcohol extracts from soy products on feed intake and growth of chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*). Aquaculture 161, 27–43.

Caldwell, R.A., 1992. Effect of calcium and phytic acid on the activation of trypsinogen and the stability of trypsin. J. Agric. Food Chem. 40, 43–47.

Dabrowski, K., Poczyczynski, P., Kock, C., Berger, B., 1989. Effect of partially or totally replacing fish meal protein by soybean meal protein on growth, food utilization and proteolytic enzyme activities in rainbow trout (*Salmo salar*). New in vivo test for exocrine pancreatic secretion. Aquaculture 77, 29–49.

Elangovan, A., Shim, K.F., 1997. Growth response of juvenile *Barbodes altus* fed isocaloric diets with variable protein levels. Aquaculture 158, 321–329.

Gallagher, M.L., 1994. The use of soybean meal as a replacement of fish meal in diets for hybrid striped bass (*Morone saxatilis* × *M. chrysops*). Aquaculture 126, 119–127.

Irish, G.G., Balnave, D., 1993. Non-starch polysaccharides and broiler performance on diets containing soybean meal as the sole protein concentrate. Aust. J. Agric. Res. 44, 1483–1499.

Kikuchi, K., 1999. Use of defatted soybean meal as a substitute for fish meal in diets of Japanese flounder (*Paralichthys olivaceus*). Aquaculture 179, 3–11.

Kikuchi, K., Furuta, T., Honda, H., 1994. Utilization of soybean meal as a protein source in the diet of juvenile Japanese flounder. Suisan Zoshoku 42, 601–604.

Kim, K.S., Kim, J.D., Song, J.S., Jeong, K.S., Won, C.H., Woo, Y.B., 1996. Effects of microbial phytase supplementation to soybean meal-based diet on growth and excretion of phosphorus in mirror carp (*Cyprinus carpio*). Korean J. Anim. Nutr. Feedstuffs 20, 109–116.

Krogdahl, A., Lea, T.B., Olli, J.J., 1994. Soybean proteinase inhibitors affect intestinal trypsin activities and amino acid digestibilities in rainbow trout (*Oncorhynchus mykiss*). Comp. Biochem. Physiol. 107A, 215–219.

Lanari, D., D'Agro, E., Turri, C., 1998. Use of nonlinear regression to evaluate the effects of phytase enzyme treatment of plant protein diets for rainbow trout (*Oncorhynchus mykiss*). Aquaculture 161, 345–356.

Lim, C., Akiyama, D.M., 1992. Full-fat soybean meal utilization by fish. Asian Fish. Sci. 5, 181–197.

Liu, K., 1997. In: Soybeans: Chemistry, Technology and Utilization. Chapman & Hall, International Thomson Publishing, Singapore, p. 532.

McGoogan, B.B., Gatlin, D.M. III, 1997. Effects of replacing fish meal with soybean meal in diets for red drum *Sciaenops ocellatus* and potential for palatability enhancement. J. World Aquacult. Soc. 28, 374–385.

Mohsen, A.A., Lovell, R.T., 1990. Partial substitution of soybean meal with animal protein sources in diets for channel catfish. Aquaculture 90, 303–311.

Nour, A.M., Omar, E., Akkada, A.R.A., Gunther, K.D., 1989. Effect of heat treatment on the nutritive value of soybean seeds as a complete diet for common carp (*Cyprinus carpio* L.). Landwirtsch. Forsch. 42, 190–195.

NRC (National Research Council), 1993. In: Nutrient Requirements of Warmwater Fishes and Shellfishes. National Academy Press, Washington, DC, p. 114.

Olli, J.J., Hjelmeland, K., Krogdahl, A., 1994a. Soybean trypsin inhibitors in diets for Atlantic salmon (*Salmo salar*, L): effects on nutrient digestibilities and trypsin in pyloric caeca homogenate and intestinal content. Comp. Biochem. Physiol. 109A, 923–928.

Olli, J.J., Krogdahl, A., 1994. Nutritive value of four soybean products as protein sources in diets for rainbow trout (*Oncorhynchus mykiss* Walbaum) reared in fresh water. Acta Agric. Scand., Sect. A, Anim. Sci. 44, 185–192.

Olli, J.J., Krogdahl, A., 1995. Alcohol soluble components of soybeans seem to reduce fat digestibility in fishmeal-based diets for Atlantic salmon, *Salmo salar* L. Aquacult. Res. 26, 831–835.

Olli, J.J., Krogdahl, A., Vabeno, A., 1995. Dehulled solvent extracted soybean meal as a protein source in diets for Atlantic salmon, *Salmo salar* L. Aquacult. Res. 26, 167–174.

Olli, J.J., Krogdahl, A., Van den Ingh, T.S.G.A.M., Brattis, L.E., 1994b. Nutritive value of soybean products in diets for Atlantic salmon (*Salmo salar*, L.). Acta Agric. Scand., Sect. A, Anim. Sci. 44, 50–60.

Plakas, S.M., Lee, T.C., Wolke, R., Meade, T.L., 1985. Effect of Maillard browning reaction on protein utilization and plasma amino acid response by rainbow trout (*Salmo gairdneri*). J. Nutr. 115, 1589–1599.

Pongmaneerat, J., Watanabe, T., 1992. Utilization of soybean meal as protein source in diets for rainbow trout. Nippon Suisan Gakkaishi 58, 1983–1990.

Quartararo, N., Allan, G.L., Bell, J.D., 1998. Replacement of fish meal in diets for Australian snapper, *Pagrus auratus*. Aquaculture 166, 279–295.

Rainboth, W.J., 1996. Fishes of the Cambodian Mekong. Food and Agriculture Organization, Rome, 95 pp.

Rawles, S.D., Gatlin, D.M. III, 1998. Carbohydrate utilization in striped bass (*Morone saxatilis*) and sunshine bass (*M. chrysops* ♀ × *M. saxatilis* ♂). Aquaculture 161, 201–202.

Refstie, S., Helland, S.J., Storebakken, T., 1997. Adaptation to soybean meal in diets for rainbow trout (*Oncorhynchus mykiss*). Aquaculture 153, 263–272.

Refstie, S., Storebakken, T., Roem, A.J., 1998. Feed consumption and conversion in Atlantic salmon (*Salmo salar*) fed diets with fish meal, extracted soybean meal or soybean meal with reduced content of oligosaccharides, trypsin inhibitors, lectins and soya antigens. Aquaculture 162, 301–312.

Refstie, S., Svihus, B., Shearer, K.D., Storebakken, T., 1999. Nutrient digestibility in Atlantic salmon and broiler chickens related to viscosity and non-starch polysaccharide content in different soybean products. Aquaculture 79, 331–345.

Reigh, R.C., Ellis, S.C., 1992. Effects of dietary soybean and fish-protein ratios on growth and body composition of red drum (*Sciaenops ocellatus*) fed isonitrogenous diets. Aquaculture 104, 279–292.

Reinitz, G., 1980. Soybean meal as a substitute for herring meal in practical diets for rainbow trout. Prog. Fish-Cult. 42, 103–106.

Riche, M., Brown, B.P., 1996. Availability of phosphorus from feedstuffs fed to rainbow trout, *Oncorhynchus mykiss*. Aquaculture 142, 269–282.

Sandholm, M., Smith, R.R., Shih, J.C.H., Scott, M.L., 1976. Determination of antitrypsin activity on agar plates: relationship between antitrypsin and biological value of soybean for trout. J. Nutr. 106, 761–766.

SAS, 1987. SAS/STAT Guide for Personal Computers. Version 6.03 edition SAS Institute, Cary, NC, 378 pp.

Satoh, S., Poe, W.E., Wilson, R.P., 1989. Effect of supplemental phytate and/or tricalcium phosphate on weight gain, feed efficiency and zinc content in vertebrae of channel catfish. Aquaculture 80, 155–161.

Snyder, H.E., Kwon, T.W., 1987. In: Soybean Utilization. Van Nostrand-Reinhold, USA, p. 346.

Spinelli, J., Houle, C.R., Wekell, J.C., 1983. The effects of phytates on the growth of rainbow trout (*Salmo gairdneri*) fed purified diets containing varying quantities of calcium and magnesium. Aquaculture 30, 71–83.

Storebakken, T., 1985. Binders in fish feeds: I. Effect of alginate and guar gum on growth, digestibility, feed intake and passage through the gastrointestinal tract of rainbow trout. Aquaculture 47, 11–26.

Storebakken, T., Austreng, E., 1987. Binders in fish feeds: II. Effect of different alginates on digestibility of macronutrients in rainbow trout. Aquaculture 60, 121–131.

Storebakken, T., Kvien, I.S., Shearer, K.D., Grisdale-Helland, B., Helland, S.J., 1999. Estimation of gastrointestinal evacuation rate in Atlantic salmon (*Salmo salar*) using inert markers and collection of faeces by sieving: evacuation of diets with fish meal, soybean meal or bacterial meal. Aquaculture 172, 291–299.

Storebakken, T., Shearer, K.D., Roem, A.J., 1998. Availability of protein, Phosphorus and other elements in fish meal, soy-protein concentrate and phytase-treated soy-protein-concentrate-based diets to Atlantic salmon, *Salmo salar*. Aquaculture 161, 365–379.

Viola, S., Mokady, S., Arieli, Y., 1983. Effects of soybean processing methods on the growth of carp (*Cyprinus carpio*). Aquaculture 32, 27–38.

Vivyakarn, V., Watanabe, T., Aoki, H., Tsuda, H., Sakamoto, H., Okamoto, N., Iso, N., Satoh, S., Takeuchi, T., 1992. Use of soybean meal as a substitute for fish meal in a newly developed soft-dry pellet for yellowtail. Nippon Suisan Gakkaishi 58, 1991–2000.

Watanabe, T., Vivyakarn, V., Kimura, H., Ogawa, K., Okamoto, N., Iso, N., 1992. Utilization of soybean meal as a protein source in a newly developed soft-dry pellet for yellowtail. Nippon Suisan Gakkaishi 58, 1761–1773.

Webster, C.D., Goodgame-Tiu, L.S., Tidwell, J.H., 1995. Total replacement of soybean meal, with various percentages of supplemental L-methionine, in diets for blue catfish, *Ictalurus furcatus* (Lesueu). Aquacult. Res. 26, 299–306.

Webster, C.D., Tidwell, J.H., Goodgame, L.S., Yancey, D.H., Mackey, L., 1992a. Use of soybean meal and distillers grains with solubles as partial or total replacement of fish meal in diets for channel catfish, *Ictalurus punctatus*. Aquaculture 106, 301–309.

Webster, C.D., Yancey, D.H., Tidwell, J.H., 1992b. Effect of partially or totally replacing fish meal with soybean meal on growth of blue catfish (*Ictalurus furcatus*). Aquaculture 103, 141–152.

Wilson, R.P., Poe, W.E., 1985. Effects of feeding soybean meal with varying trypsin inhibitor activities on growth of fingerling channel catfish. Aquaculture 46, 19–25.