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Effect of partially or totally replacing fish meal with soybean meal on growth of blue catfish (*Ictalurus furcatus*)

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ABSTRACT

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A 12-week feeding trial was conducted in aquaria with juvenile (6 g) blue catfish to examine effects of substituting soybean meal for fish meal in a prepared diet. Four isonitrogenous (34% protein) and isocaloric (2.4 kcal digestible energy/g) diets were formulated to contain 13, 9, 4, and 0% menhaden fish meal (67% crude protein). Soybean meal (44% crude protein) was added in increasing percentages (48, 55, 62, and 69%) to the respective diets. A fifth diet, otherwise identical to the diet containing 0% fish meal and 69% soybean meal, was prepared with soybean meal that had been heated at 105°C for 60 min prior to diet preparation. After 12 weeks, fish fed a diet with 13% fish meal had a significantly ($P<0.05$) higher individual body weight than fish fed any of the other diets. There was no significant difference ($P>0.05$) in body weights of fish fed the other four diets. No significant differences ($P>0.05$) were found in percentage survival, food conversion ratio, and protein efficiency ratio among diets. Growth of blue catfish was similar to that reported for channel catfish juveniles. However, these data suggest that blue catfish juveniles require at least 13% fish meal in a diet containing 34% crude protein for optimal growth.

INTRODUCTION

Fish meal is one of the most expensive ingredients in prepared fish diets. Fish nutritionists have tried to use less expensive plant protein sources to partially or totally replace fish meal. Of all the plant protein feedstuffs, soybean meal is considered to be the most nutritious and is used as the major protein source in many fish diets (Lovell, 1988). However, growth has tended to be reduced in fish fed diets with soybean meal replacing all the fish meal (Cowey et al., 1971; Lovell et al., 1974; Jackson et al., 1982). One possible

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reason for this decreased growth is activity of protease (trypsin) inhibitors in crude or inadequately heated soybean meal (Dabrowski and Kozak, 1979; Wilson and Poe, 1985). A second possible reason may be suboptimal amino acid balance of soybean meal. Murai et al. (1986) reported that the nutritional value of soy flour for carp, *Cyprinus carpio*, was improved by the addition of essential amino acids, especially methionine. A third possible explanation may be that the energy content of soybean meal is lower than that of fish meal in diets for fish (Viola et al., 1982; Hilton and Slinger, 1986).

Heat-treated full-fat soybean meal has been included in fish diets at high percentages with positive results (Reinitz et al., 1978; Viola et al., 1983. Wee and Shu, 1989). Viola et al. (1983) reported that heating soybean meal at 105°C for 30–90 min destroyed most of the trypsin inhibitors present. However, excessive heating may cause loss of essential amino acids (Plakas et al., 1985).

Blue catfish, *Ictalurus furcatus*, possess several attributes that could make them a desirable culture species in temperate regions of the United States. They have a higher dressing percentage than white or channel catfish (Dunham et al., 1983) and a lower optimum growing temperature (24°C) than channel catfish (30°C). Moreover, blue catfish are easier to seine (Chappell, 1979) and have higher individual weight gains in temperate regions than channel catfish (Tidwell and Mims, 1990). At present, no data on the nutritional requirements of blue catfish have been reported. The purpose of this study was to evaluate commercially available soybean meal as a partial or total replacement for fish meal in a diet for blue catfish.

MATERIALS AND METHODS

Experimental diets

Five experimental diets were formulated to contain various percentages of soybean meal (SBM) as partial or total replacements for fish meal. Diet 1, with 48% SBM and 13% fish meal, which is similar to a high-quality commercial channel catfish diet, served as the control. Diets 2, 3, and 4 contained 55, 62, and 69% SBM, and 9, 4, and 0% fish meal, respectively (Table 1). A fifth diet was identical to diet 4 except that the SBM had been heated (105°C for 60 min) in a drying oven prior to addition. Amino acid compositions of the diets were determined from tabular values provided for diet ingredients (NRC, 1983). All diets were isonitrogenous (34% protein) and isocaloric (2.4 kcal digestible energy/g) (Table 1).

In preparing the diets, dry ingredients were first ground to a small particle size (approximately 250 μm) in a Wiley mill. Ingredients were thoroughly mixed and water was added to obtain a 30% moisture level. Diets were passed through a mincer with die into 0.8-mm diameter "spaghetti-like" strands and were dried (25°C) for 16 h using a convection oven. After drying, the diets

TABLE 1

Ingredients and chemical composition[1] of experimental diets containing various percentages of soybean meal fed to juvenile blue catfish[2]

	Diet No.				
	1	2	3	4	5
Ingredients (%)					
Fish meal (67% protein)	13.00	9.00	4.00	0.00	0.00
Soybean meal (44% protein)	48.00	55.00	62.00	69.00	69.00
Ground corn	33.50	29.50	26.50	23.00	23.00
Cod-liver oil[4]	3.00	4.00	4.50	5.25	5.25
Premix[5]	1.00	1.00	1.00	1.00	1.00
Monocalcium phosphate	0.50	0.50	1.00	1.00	1.00
CMC binder[6]	1.00	1.00	1.00	0.75	0.75
Chemical analysis					
Dry matter (%)	89.50	85.50	90.50	85.00	87.50
Protein (%)[7]	34.01	34.31	33.90	33.67	34.75
Lipid (%)[7]	7.85	6.71	5.97	7.62	8.05
DE[8]	2.39	2.44	2.46	2.50	2.50
P:E ratio[9]	142.3	140.6	137.8	134.7	139.0
Trypsin inhibitor[10]	1.5	2.1	2.6	2.9	2.8
Available phosphorus (%)[11]	0.73	0.69	1.10	1.06	1.06

[1]Mean value of three replications.
[2]Diet 5 was identical to diet 4 except that soybean meal was heated (105°C for 60 min) prior to addition.
[3]Menhaden fish meal. shipped from Virginia, was used as the source of the fish meal and purchased from a commercial feed mill (Farmers Feed, Inc., Lexington, KY).
[4]BHT was added at a rate of 0.02%.
[5]Premix supplied the following vitamins and minerals per kg of diet: retinol palmitate (A), 4532 IU; cholecalciferol (D_3), 2266 IU; alpha-tocopherol (E), 75 IU; menadione (K), 11 mg; cyanocobalamine (B_{12}), 20 mg; ascorbic acid (C), 778 mg; folic acid, 2.2 mg; riboflavin (B_2), 13.2 mg; pantothenic acid, 35.2 mg; niacin, 88.0 mg; choline chloride, 516 mg; thiamine (B_1), 11 mg; pyridoxine (B_6), 11 mg; Zn (as $ZnSO_4$), 173 mg; Fe (as $FeSO_4$), 60 mg; Cu (as $CuSO_4$), 7.5 mg; I (as $CaIO_3$), 3.75 mg; Co (as $CoSO_4$), 1.6 mg; Mn (as $MnSO_4$), 180 mg; Al (as $AlK(SO_4)_2$), 1.0 mg; Se (as Na_2SeO_3), 0.3 mg; K (as KCl), 3474 mg; and Na (as Na_2PO_4), 1932 mg.
[6]CMC = carboxymethylcellulose.
[7]Moisture-free basis.
[8]DE = digestible energy in kcal/g of diet; based on estimated values of the diet ingredients for channel catfish (NRC, 1983).
[9]Protein-to-energy ratio in mg protein/kcal of DE.
[10]Measured in trypsin inhibitor units (TIU)/mg of diet.
[11]Based on estimated values of the diet ingredients and availability for channel catfish (NRC, 1983).

were broken up and sieved into convenient pellet sizes. Cod-liver oil was sprayed onto dried pellets immediately prior to storage. Marine fish oil was used to supply essential *n*-3 fatty acids (Satoh et al., 1989). All diets were frozen (−15°C) until immediately prior to feeding. Percentage protein of diets was determined using a LECO FP-228 nitrogen determinator (LECO

TABLE 2

Amino acid composition of control (diet 1) and experimental diets containing various percentages of soybean meal (amino acids expressed as percentage of diet)[1]

	Diet No.				
Amino acid	1	2	3	4	5
Arginine	1.98	2.00	1.87	1.90	1.92
Cystine	0.41	0.42	0.45	0.45	0.45
Histidine	1.09	1.21	1.11	0.97	1.52
Isoleucine	1.45	1.37	1.48	1.40	1.39
Leucine	2.55	1.94	2.51	2.00	2.48
Lysine	1.92	1.85	1.79	1.83	1.73
Methionine[2]	0.71	0.66	0.54	0.57	0.58
Phenylalanine[3]	2.20	1.92	2.20	2.09	2.06
Threonine	1.27	1.22	1.27	1.23	1.21
Tryptophan	0.38	0.38	0.40	0.41	0.40
Tyrosine	0.90	0.81	0.88	0.91	0.88
Valine	1.77	1.77	1.63	1.53	1.44

[1]Values are means of two replications.
[2]Approximately 60% of cystine can substitute for methione (Lovell, 1989).
[3]Approximately 50% of tyrosine can substitute for phenylalanine (Lovell, 1989).

Corp., St. Joseph, MI) (Sweeney and Rexroad, 1987) and percentage fat was determined by ether extraction (AOAC, 1984). Digestible-energy (DE) and available-phosphorus values were estimated from the diet ingredients as established for channel catfish (NRC, 1983). Diets were also analyzed for trypsin inhibitor activity (Table 1) and amino acid composition (Table 2) (AOAC, 1984).

Experimental system and animals

The feeding trial was conducted in 20 37.5-l glass aquaria. Water was recirculated through biological and mechanical filters. The recirculating system was a 2000-l vertical screen filter system utilizing high-density polyester screens (Red Ewald, Inc., Karnes City, TX) to remove particulate material and provide substrate for *Nitrosomonas* and *Nitrobacter* bacteria. Continuous aeration was provided by a blower and air stones. Water exchange rate for the system was approximately 3% of total volume per day. Chloride levels were maintained at approximately 1000 mg/l (by addition of food-grade NaCl) to minimize potential adverse effects of nitrite to fish health (Perrone and Meade, 1977). Each aquarium was supplied with water at a rate of 1.6 l/min and cleaned daily. Black plastic covered the back and sides of all aquaria to minimize disturbances resulting when personnel were present in the laboratory (Hale and Carlson, 1972). Illumination was supplied by fluorescent ceiling lights with an 18:6 h per day light:dark cycle.

Water temperature and dissolved oxygen were measured daily using a YSI Model 57 (YSI Industries, Yellow Springs, OH). Total ammonia and nitrite were measured twice weekly using a DREL/5 spectrophotometer (Hach Company, Loveland, CO). Total alkalinity, hardness, and chlorides were monitored once each week using the DREL/5; pH was monitored weekly using an electronic pH meter (Accumet 900; Fisher Scientific, Cincinnati, OH). Over the duration of the study these water-quality parameters averaged ($\pm$s.d.): water temperature, 26.3 ± 1.6°C; dissolved oxygen, 6.93 ± 0.46 mg/l; total ammonia, 0.4 ± 0.4 mg/l; nitrite, 0.05 ± 0.01 mg/l; total alkalinity, 107.0 ± 24.8 mg/l; hardness, 190.3 ± 21.7 mg/l; chlorides, 678.6 ± 60.0 mg/l; pH, 7.7 ± 0.2.

Juvenile blue catfish were obtained from a commercial producer (Danbury Fish Farms, Danbury, TX) and subsequently were acclimated in aquaria for 1 week while being fed a medicated (Romet) pelleted diet (Zeigler Bros., 38% crude protein). Ten fish were randomly stocked into each aquarium, with four replications per treatment. At the start of the study, individual fish weight and length were not significantly different ($P > 0.05$) among treatments, pooled, and averaged 7.9 ± 0.3 g and 98.5 ± 2.4 mm, respectively. To minimize stress of handling, fish from each aquarium were weighed at the beginning of the experiment and then every 4 weeks until the conclusion of the feeding trial. Total length of each fish was measured at the beginning of the experiment and at the conclusion of the experiment. All fish were fed to satiation twice daily (08.00 and 16.00 h) for 12 weeks. At the start and conclusion of the feeding trial, a number of fish were sacrificed by decapitation (20 fish at stocking and 5 fish per aquarium at conclusion), homogenized in a blender, stored in polyethylene bags, and frozen for subsequent protein and lipid analysis. After homogenization, a 15-g sample was dried in an oven (95°C for 24 h) for moisture determination.

Growth performance and feed conversion were measured in terms of final individual fish weight (g), total length (mm), survival (%), specific growth rate (SGR, %/day), food conversion ratio (FCR), food intake on a percentage-of-body-weight basis, and protein efficiency ratio (PER). Growth response parameters were calculated as follows:

$$\mathrm{SGR}\ (\%/\mathrm{day}) = ((\ln W_t - \ln W_i)/T) \times 100$$

where W_t is weight of the fish at time t, W_i is weight of the fish at time 0, and T is the culture period in days;

$$\mathrm{FCR} = \text{total dry feed fed (g)/total wet weight gain (g)};$$

$$\text{food intake} = (DFI \times 100)/((W_{t+1} + W_t)/2)$$

where DFI is mean daily dry food intake per fish (t, $t+1$) and W_t, W_{t+1} are the averaged wet weights at the start (t) and conclusion ($t+1$) of the experimental period (Richardson et al., 1985);

PER = wet weight gain (g)/amount of protein fed (g).

Two fish were randomly sampled from each aquarium for histopathological examination. Fish were killed by decapitation. Liver and gill arch were removed from each fish and placed into separate vials with Bouin's solution. Samples were embedded in paraffin, sectioned, and stained with hematoxylin and eosin. Sections were examined with a microscope.

Statistical analysis

Data were analyzed by analysis of variance (ANOVA) using the SAS ANOVA procedure (Statistical Analysis Systems, 1988). Duncan's multiple-range test was used to compare differences among individual means. All percentage and ratio data were transformed to arc sin values prior to analysis (Zar, 1984).

RESULTS AND DISCUSSION

Blue catfish fed the control (48% soybean meal and 13% fish meal) diet were significantly longer (total length) than fish fed diets 4 and 5 (69% soybean meal and 0% fish meal) ($P<0.05$), but not relative to fish fed diet 2 (55% soybean meal and 9% fish meal) and diet 3 (62% soybean meal and 4% fish meal) (Table 3). Final weights of blue catfish fed the control diet were significantly higher ($P<0.05$) than noted for fish fed any of the experimental diets. Specific growth rate (SGR) for blue catfish fed the control diet was significantly higher (2.18) ($P<0.05$) than obtained for fish fed diets 3, 4, and 5 (1.84, 1.85, and 1.76, respectively), but not significantly different from that of fish fed diet 2 (1.96) ($P>0.05$). These data indicate that growth of blue catfish is greater when fed a diet containing 13% fish meal and 48% soybean meal than when fed diets containing greater percentages of soybean meal and less fish meal. This is in agreement with studies reported on carp, *Cyprinus carpio* (Nandeesha et al., 1989); tilapia, *Oreochromis niloticus*×*O. aureus* (Shiau et al., 1990); rainbow trout, *Oncorhynchus mykiss* (Reinitz, 1980); and channel catfish, *Ictalurus punctatus* (Moshen and Lovell, 1990).

Food conversion ratio (FCR), food intake, and protein efficiency ratio (PER) were not significantly different among treatments ($P>0.05$) (Table 3). Food conversion values were slightly higher than reported in the literature (Robinson et al., 1985; Gatlin and Phillips, 1989); however, they were consistent with FCR values found in other studies (Andrews and Stickney, 1972; Tidwell et al., 1990; Webster et al., in press). The somewhat higher FCR values may be due to the use of small (37.5-l) aquaria. Fish tend to agitate the water during feeding and may break apart diet pellets rapidly. Small particles of diet could then be removed through the standpipe, skewing the FCR values upward. Protein gain in fish fed the control diet was significantly higher than

TABLE 3

Effects of increasing percentage of soybean meal and decreasing percentage of fish meal in prepared diets on growth of blue catfish[1]

	Diet No.				
	1	2	3	4	5
Length (mm)	165.5±4.1[a]	156.3±2.3[ab]	155.6±2.0[ab]	154.3±0.9[b]	150.4±5.5[b]
Final weight (g)	37.45±2.16[a]	31.20±1.66[b]	29.73±1.93[b]	28.25±0.76[b]	27.45±3.02[b]
Survival (%)	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0
FCR[2]	2.13±0.10	2.46±0.09	2.34±0.25	2.37±0.06	2.49±0.22
Food intake[3]	4.71±0.35	5.17±0.17	4.48±0.39	4.88±0.16	5.08±0.48
SGR[4]	2.18±0.07[a]	1.96±0.07[ab]	1.84±0.07[b]	1.85±0.03[b]	1.76±0.13[b]
PER[5]	1.39±0.06[a]	1.20±0.05[a]	1.30±0.13[a]	1.24±0.03[a]	1.21±0.10[a]

[1]Values are means±s.e. of four replications. Means within a row having different superscripts were significantly different ($P<0.05$).
[2]FCR = food conversion ratio: total dry diet fed (g)/total wet weight gain (g).
[3]Food intake (% body weight) = $(DFI\times100)/((W_{t+1}+W_t)/2)$ where DFI is mean daily dry food intake per fish (t, $t+1$) and W_t, W_{t+1} are the averaged wet weights at the start (t) and conclusion ($t+1$) of the study period.
[4]SGR = specific growth rate (%/day): $(\ln W_t - \ln W_i/T)\times100$, where W_t is weight of fish at time t, W_i is weight of fish at time 0, and T is the culture period in days.
[5]PER = protein efficiency ratio: wet weight gain (g)/amount of protein fed (g).

TABLE 4

Whole-body moisture, protein, and lipid percentages of juvenile blue catfish fed diets containing increasing percentages of soybean meal and decreasing percentages of fish meal[1]

Diet No.	Moisture (%)	Protein[2] (%)	Fat[2] (%)
1	71.11±0.92	47.17±6.15	37.21±0.78[ab]
2	71.27±0.22	48.10±1.28	29.31±1.47[c]
3	70.10±0.21	46.46±2.12	34.48±1.14[ab]
4	71.19±0.40	44.67±1.14	38.40±1.51[a]
5	71.22±1.32	48.06±2.49	31.01±3.05[bc]

[1]Values are means±s.e. of four replications. Means within a column having different superscripts were significantly different ($P<0.05$).
[2]Moisture-free basis.

in fish fed any of the other diets ($P<0.05$) (Table 3). Survival was 100% for all diets.

No significant differences in percentage body protein and moisture were found among treatments ($P>0.05$) (Table 4). However, whole-body lipid percentages for fish fed diets 1, 3, and 4 were significantly higher than those for fish fed diet 2 ($P<0.05$). Body lipid content did not seem to be related to growth rate, food intake, or percentage lipid and energy content in the diet. All diets were similar in percentage lipid and energy content, and no significant difference ($P > 0.05$) in food intake was found among treatments. Histopathological examination indicated that there were no differences in liver and gill tissues from fish fed different diets. Livers of all fish had highly vacuolated hepatocytes indicating fish had consumed the diets.

Replacement of fish meal, one of the most expensive diet ingredients, with soybean meal has had variable success. Growth has often been reduced in direct proportion to the percentage of soybean meal in the diet. Two hypotheses have attempted to explain these results: 1. suboptimal amino acid balance and inadequate available phosphorus in soybean meal, and 2. presence of antinutritional factors (including trypsin inhibitors) in the soybean meal. In relation to the former, soybean meal has one of the best amino acid profiles of any of the plant protein feedstuffs and the profile meets the essential amino acid requirements for channel catfish (Lovell, 1988).

Soybean meal is deficient in available phosphorus, but diets used in the present study contained supplemental phosphorus. Diet 1 contained 0.73% available phosphorus in the diet, while diets 4 and 5 (with 0% fish meal) contained approximately 1.0% available phosphorus. All diets met the minimum requirements for available phosphorus for channel catfish (0.45%) (Lovell, 1978). Liebowitz (1981) showed that when a diet had supplemental phosphorus, soybean meal could replace most of the fish-meal component in a channel catfish diet.

In the present study with blue catfish, when soybean meal was used to replace 31% of the fish-meal protein, growth was reduced. Reinitz (1980) reported growth reduction in rainbow trout fed a diet containing 65% soybean meal and 0% fish meal. Moshen and Lovell (1990) reported higher growth rates in channel catfish juveniles fed a diet with 20% fish meal compared to fish fed diets containing 0, 5, and 10% fish meal. Amino acid analyses indicated that all diets met the amino acid requirements of channel catfish (NRC, 1983). However, the biological value of amino acids from soybean meal may be less than indicated (Murray, 1982). Dabrowski et al. (1989) stated that amino acid availability, especially methionine, was reduced if soybean-meal protein was used in excess of 50% of the diet.

Variable success has been reported for diets containing soybean meal supplemented with amino acids (Rumsey and Ketola, 1975; Dabrowska and Wojno, 1977). Grass carp, *Ctenopharyngodon idella*, fed a diet with a high percentage of soybean meal and supplemental amino acids had lower growth than fish fed a control diet (Dabrowski and Kozak, 1979). Shiau et al. (1987) reported that growth of tilapia, *Oreochromis niloticus* × *O. aureus*, fed a diet containing soybean meal and supplemental methionine was similar to that of fish fed a control diet, whereas fish fed a diet without methionine supplementation had reduced growth. Essential amino acid supplementation of diets containing soy flour improved growth of carp, *Cyprinus carpio*, similar to fish fed a control diet (Murai et al., 1986).

Our data suggest that blue catfish may have an equivalent or higher dietary requirement for methionine than channel catfish. The sulfur amino acid requirements of channel catfish were met by all experimental diets fed to blue catfish during this study. However, higher growth rates were found for fish fed the control diet than for those fed diets containing increased percentages of soybean meal and reduced percentages of fish meal.

It has been reported that trypsin inhibitors in raw or inadequately heated soybean meal can adversely affect growth of trout (Sandholm et al., 1976), carp (Viola et al., 1983), and channel catfish (Robinson et al., 1981; Wilson and Poe, 1985). Heat treatment of soybean meal improves growth in fish and destroys protease inhibitors (Lovell, 1979; Viola et al., 1983; Robinson, 1984; Balogun and Ologhobo, 1989; Wee and Shu, 1989). However, severe heating reduces lysine content and availability (Viola et al., 1983).

In the present study, trypsin inhibitor levels averaged less than 3.0 TIU/mg in all diets (a value of 6.0 TIU/mg of diet is considered to be low; pers. commun. Woodson-Tenent Laboratories). Lysine content was similar in all diets indicating that heat treatment of soybean meal (diet 5) was not severe. However, trypsin inhibitor levels were not reduced by heating (Table 1), possibly due to the already low levels in the soybean meal used.

The present study demonstrates that a diet containing 34% crude protein, with 13% fish meal, is adequate for good growth of blue catfish. However, when the percentage of fish meal is 9% or less in the diet, and there is a concomitant increase in the percentage of soybean meal, growth is reduced. Further research is needed to study the effects on growth in blue catfish of amino acid supplementation, particularly methionine, in diets with a high percentage of soybean meal and a low percentage of fish meal.

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