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Differences in Growth in Blue Catfish *Ictalurus furcatus* and Channel Catfish *I. punctatus* Fed Low-Protein Diets With and Without Supplemental Methionine and/or Lysine

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Abstract

Three feeding experiments were conducted to evaluate growth and body composition in blue catfish *Ictalurus furcatus* or channel catfish *I. punctatus* when fed diets containing 22% protein with or without supplemented methionine and/or lysine. All experiments were conducted in 110-L aquaria that were part of a recirculating system. In Experiment 1, 15 juvenile blue catfish (2.7 g) were randomly stocked into aquaria and fed one of three diets containing different (22%, 27%, and 32%) percentages of protein. Fish were fed twice daily to excess for 10 wk. In Experiment 2, juvenile blue catfish (5.4 g) were randomly stocked into aquaria and fed one of six diets containing either 22% (diet 1) or 32% (diet 2) protein. The diet containing 22% protein (diet 1) had either 0.3% crystalline L-methionine (diet 3), 0.4% crystalline L-lysine (diet 4), or 0.3% L-methionine + 0.4% L-lysine (diet 5) added. A sixth diet was formulated to contain 32% protein and 0.2% crystalline L-methionine. Fish were fed in excess for 12 wk. In Experiment 3, juvenile channel catfish (10.3 g) were stocked and fed diets 1–4 from Experiment 2, twice daily in excess for 8 wk.

In Experiment 1, after 10 wk, final individual weight, weight gain (%), and specific growth rate (SGR) of blue catfish fed diets containing three protein levels were not significantly different ($P > 0.05$) and averaged 12.9 g, 378%, and 2.2%/d, respectively. Fish fed the diet containing 27% protein had higher ($P < 0.05$) whole-body protein (65.4%) compared to fish fed diets containing either 22% or 32% protein. In Experiment 2, final weight, weight gain (%) and SGR of blue catfish were not significantly ($P > 0.05$) different among diets and averaged 24.7 g, 355%, and 1.8%/d, respectively. Percentage whole-body protein and lipid were not significantly ($P > 0.05$) different between fish fed diets containing 22% or 32% protein. In Experiment 3, channel catfish fed a diet containing 32% protein had significantly ($P < 0.05$) higher final individual weight, weight gain (%), and SGR compared to fish fed diets containing 22% protein, with and without supplemental methionine or lysine.

Results indicate that blue catfish may be able to utilize a diet with 22% protein, and that addition of crystalline methionine and/or lysine did not improve growth. However, channel catfish grown in aquaria did not appear to have similar growth when fed a diet containing 22% protein compared to fish fed 32% protein, even when supplemental methionine or lysine was added. Further research on blue catfish and the use of a low-protein diet (22% protein) needs to be conducted in ponds.

Diet cost is the largest single variable cost associated with a catfish aquaculture operation and of all dietary components (protein, lipid, carbohydrate), protein is the most expensive. Therefore, decreasing the amount of protein in a diet could reduce diet costs. Robinson and Li (1997) calculated that diet cost could be lowered by $2 to $3/ton for each percentage of protein that is reduced, and that a typical producer uses between 12 to 15 tons of diet/ha/per yr. Thus, a sizeable reduction in the operating budget for diet cost could be realized if diets with low protein (<27%) could be fed

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to fish, if no adverse effects on growth occurred.

Protein requirements of channel catfish *Ictalurus punctatus* have been well documented and the percentage protein of diets used for grow-out by most producers is between 28% to 32%. However, fish nutritionists have successfully attempted to reduce the level of protein in a catfish diet. Gatlin et al. (1986) reported that a diet with 27% crude protein could be fed to juvenile channel catfish fed to satiation. Robinson and Li (1993) fed channel catfish stocked in ponds to satiation and reported no differences in growth among fish fed diets containing either 26, 28, 32, or 35% crude protein. Robinson and Li (1997) fed diets containing either 20, 24, 26, 28, or 31% protein to channel catfish in ponds and found that weight gain of fish fed a diet containing 24% crude protein was not different compared to fish fed diets containing higher percentages of protein.

While the channel catfish comprises the vast majority of catfish produced each year in the US, there is some interest in culturing the blue catfish *I. furcatus* commercially. Blue catfish have several desirable characteristics that make them of potential interest to producers, including a higher dressing percentage than channel catfish (Dunham et al. 1983), are easier to seine (Chapel 1979), may have similar summer growth rates to channel catfish (Tidwell and Mims 1990; Grant and Robinette 1992), and are resistant to some diseases that cause mortality in channel catfish, such as channel catfish virus (Plumb and Chapel 1978) and enteric septicemia, ESC (Wolters and Johnson 1994). A disadvantage of growing blue catfish is that growth may be slower than channel catfish during the winter (Dunham and Smitherman 1981; Grant and Robinette 1992). Growth rates vary among species of fish and can differ among strains within a species. Species and strains that have been cultured generally have faster growth rates than wild stocks (Li et al. 1998). Blue catfish do not have the history of culture as do channel catfish and growth may be more typical of non-domesticated fish. This paper describes feeding trials in which blue catfish and channel catfish were grown in aquaria and fed diets containing various percentages of protein, with and without supplemental lysine and/or methionine, and the effect on fish growth and body composition.

Materials and Methods

Experiment 1

Three sinking pelleted diets (2.5-mm diameter) were formulated with practical, commercially-available ingredients and were produced at the Abernathy Salmon Culture and Technology Center, Longview, Washington using a laboratory model California pellet mill without steam conditioning. Diets were cut into pieces (1.5–4 mm) small enough to be consumed by the fish used in the feeding trial. Diets contained various percentages (22%, 27%, and 32%) of protein and were formulated to be similar to some diets used by the catfish industry (Table 1). Fish meal comprised a constant percentage (8.5%) of the dietary protein among diets. Pellet stability was not measured; however, pelleted diets used at the Abernathy Salmon Culture and Technology Center are produced using similar conditions, and water stability is extremely high (Ann Gannam, personal communication).

Percentage protein of the diets was determined by the peroxide Kjeldahl method (Hach et al. 1987), percentage fat was determined by the acid-hydrolysis method, percentage ash was determined by placing diets in a muffle furnace (600 C) for 24 h, and moisture was determined by drying (100 C) until constant weight (AOAC 1990).

The feeding trial was conducted in 12 110-L glass aquaria. Water was recirculated through biological and mechanical filters. The recirculating system consisted of a 1,500-L vertical screen filter system utilizing high-density polyester screens (Red

TABLE 1. *Diet formulations for diets fed to blue catfish for 10 wk containing various percentages of protein (Experiment 1).*

Ingredient	Diet no. (% protein)		
	1 (22%)	2 (27%)	3 (33%)
Menhaden fish meal (67%)	2.8	3.4	4.0
Soybean meal (50%)	18.0	30.0	42.0
Wheat mids	10.0	10.0	10.0
Corn meal	59.9	47.3	34.7
Meat and bone meal	5.0	5.0	5.0
Vitamin and mineral mix[a]	2.0	2.0	2.0
Stay-C	0.05	0.05	0.05
Monocalcium phosphate	1.0	1.0	1.0
Menhaden oil	1.25	1.25	1.25
Chemical analysis			
Moisture (%)	10.4	10.2	10.3
Protein (%)[b]	21.7	27.5	33.2
Lipid (%)[b]	5.6	5.6	5.1
Ash (%)[b]	5.5	6.4	7.0

[a] Vitamin mix provided the following (mg or IU/kg of diet): biotin, 0.36 mg; B_{12}, 0.036 mg; E, 304 IU; folic acid, 10 mg; K, 5.6 mg; niacin, 134 mg; pantothenic acid, 64 mg; B_6, 18.7 mg; riboflavin 32 mg; thiamin, 26.0 mg; D 267 IU; A, 4,000 IU; ethoxyquin, 60 mg. Mineral mix was Rangen's catfish mineral mix with selenium added at 3.0 mg/kg of diet.

[b] Dry-matter basis.

Ewald, Inc., Karnes City, Texas, USA) and a can filter filled with plastic "bio-balls" which removed particulate material and provided substrate for *Nitrosomonas* and *Nitrobacter* bacteria. Continuous aeration was provided by a blower and airstones. Water replacement rate for the system was approximately 3% of total volume per day. In the unlikely event that nitrite levels exceeded acceptable values for fish, chloride levels were maintained at approximately 100 mg/L, by addition of foodgrade NaCl, to minimize potential adverse effects to fish health (Perrone and Meade 1977). Each aquarium was supplied with water at a rate of 4.8 L/min and siphoned daily to remove uneaten feed and feces. All aquaria sides and back were covered in black plastic to minimize disturbances resulting when personnel were present in the laboratory. Continuous illumination was supplied by fluorescent ceiling lights.

Water temperature and dissolved oxygen were measured every other day using a YSI Model 58 oxygen meter (YSI Industries, Yellow Springs, Ohio, USA). Total ammonia-nitrogen (TAN) and nitrite were measured every other day using a DREL 2000 spectrophotometer (Hach Co., Loveland, Colorado, USA). Total alkalinity and chloride were monitored twice weekly using the titration method of the DREL 2000; pH was monitored three times weekly using an electronic pH meter (pH pen; Fisher Scientific, Cincinnati, Ohio, USA).

Juvenile blue catfish were obtained from the Kentucky Department of Fish and Wildlife and had an average weight (± SE) of 2.65 ± 0.34 g. Fifteen fish were randomly stocked into each aquarium with four replications per treatment. To eliminate stress of handling, fish were not weighed for the duration of the feeding trial until the study concluded when all fish from each aquarium were batch-weighed. All fish were fed to excess twice daily (0730 and 1600 h) for 10 wk; however, the amount of diet fed at each feeding was recorded for each aquarium. At the start and conclusion of the feeding trial, a number of fish were randomly sampled (15 at stocking and eight fish per aquarium at conclusion), killed by lowering the body temperature in a freezer, the fish were cut into smaller pieces and homogenized in a blender, stored in polyethylene bags, and frozen for subsequent protein, fat, and moisture analysis. Protein was determined by macro-Kjeldahl, fat was determined by ether extraction, and moisture was determined by placing a 10-g sample in an oven (100 C) to be dried until constant weight (AOAC 1990).

Growth performance and feed conversion were measured in terms of final individual fish weight (g), percentage weight gain, survival (%), and specific growth rate (SGR, %/d). Specific growth rate was calculated as follows: SGR (%/d) = $((\ln W_f - \ln W_i)/T) \times 100$, where W_f is the weight of fish at time f; W_i is the weight of fish at time 0; and T is the culture period in days.

Data were analyzed by analysis of vari-

TABLE 2. *Diet formulations for practical diets containing two protein levels (22% and 32%) with and without supplemental L-methionine (M) and/or L-lysine (L). All six diets were fed in Experiment 2; diets 1 through 4 were fed in Experiment 3.*

	Diet no. (% protein)					
Ingredient	1 (22%)	2 (32%)	3 (22% + M)	4 (22% + L)	5 (22% + M + L)	6 (32% + M)
Menhaden fish meal	2.8	4.0	2.8	2.8	2.8	4.0
Soybean meal	18.0	42.0	18.0	18.0	18.0	42.0
Wheat midds	10.0	10.0	10.0	10.0	10.0	10.0
Corn meal	58.54	33.34	58.24	58.14	57.84	33.14
Meat and bone meal	5.0	5.0	5.0	5.0	5.0	5.0
Vitamin mix[a]	0.9	0.9	0.9	0.9	0.9	0.9
Mineral mix[b]	0.9	0.9	0.9	0.9	0.9	0.9
Stay C	0.05	0.05	0.05	0.05	0.05	0.05
Monocalcium phosphate	1.0	1.0	1.0	1.0	1.0	1.0
Menhaden oil	1.25	1.25	1.25	1.25	1.25	1.25
L-lysine	0.0	0.0	0.0	0.4	0.4	0.0
L-methionine	0.0	0.0	0.3	0.0	0.3	0.2
CMC[c]	1.5	1.5	1.5	1.5	1.5	1.5
Choline chloride	0.055	0.055	0.055	0.055	0.055	0.055
Chemical analysis						
Moisture (%)	11.1	11.1	9.4	9.4	9.6	9.5
Protein (%)[d]	21.4	32.5	22.0	21.7	21.6	32.2
Lipid (%)[d]	5.0	4.5	5.2	5.3	5.2	4.6
Ash (%)[d]	4.6	5.8	4.5	4.6	4.7	5.9
Lysine (% of diet)	0.99	1.67	1.03	1.34	1.34	1.69
Methionine (% of diet)	0.32	0.46	0.60	0.33	0.59	0.63
Cystine (% of diet)	0.24	0.34	0.25	0.26	0.24	0.34

[a] Vitamin mix provided the following (mg or IU/kg of diet): Biotin, 0.36 mg; B_{12}, 0.036 mg; E, 304 IU; folic acid, 10 mg; K, 5.6 mg; niacin, 134 mg; pantothenic acid, 64 mg; B_6, 18.7 mg; riboflavin, 32 mg; thiamin, 26.0 mg; D, 267 IU; A, 4,000 IU; ethoxyquin, 60 mg.

[b] Mineral mix was Rangen's catfish mineral mix with selenium added at 3.0 mg/kg of diet.

[c] CMC = carboxymethylcellulose.

[d] Dry-matter basis.

ance (ANOVA) using the SAS ANOVA procedure (SAS 1988) for significant differences among treatment means. 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). Significance was tested at the P = 0.05 level.

Experiment 2

Six sinking pelleted diets were formulated with commercially-available ingredients and contained either 22% or 32% protein, with and without supplementation with L-methionine and/or L-lysine (Table 2). Diets 1 and 2 (Table 2) were formulated to contain 22% and 32% protein, respectively. Ingredient composition of diet 3 was the same as diet 1 except that 0.3% methionine (L-methionine, Sigma Chemical Corp., St. Louis, Missouri, USA) was added. The percentage available methionine (% in diet) in diet 3 was the same as diet 2. Diet 4 was formulated similar to diet 1 except that 0.4% lysine (L-lysine, Sigma Chemical Corp., St. Louis, Missouri, USA) was added to the diet (Li and Robinson 1998). Diet 5 was formulated similar to diet 1 except that 0.4% L-lysine and 0.3% L-methionine were added to the diet. Diet 6 was formulated similar to diet 2 except that 0.2% L-methionine was added to exceed the methionine requirement for channel catfish. All crystalline amino acids were assumed to be 100% available. All known amino acid re-

TABLE 3. *Essential amino acid (EAA) composition (% of protein) and percentage requirement met in channel catfish (in parentheses) for diets in Experiments 2 and 3. EAA composition was from analyses and percentage requirement met was calculated from tabular values (NRC 1993).*

	Diet no.					
EAA	1	2	3	4	5	6
Arginine	5.1 (119)	5.7 (133)	5.1 (119)	5.3 (123)	5.2 (121)	5.7 (133)
Histidine	2.4 (160)	2.4 (160)	2.5 (167)	2.5 (167)	2.6 (173)	2.4 (160)
Isoleucine	3.2 (123)	3.5 (135)	3.2 (123)	3.3 (127)	3.2 (123)	3.5 (135)
Leucine	7.2 (206)	6.8 (194)	7.2 (206)	7.4 (211)	7.3 (209)	6.9 (197)
Lysine	4.6 (92)	5.1 (102)	4.7 (94)	6.2 (124)	6.2 (124)	5.3 (106)
Meth. + Cys.[a]	2.6 (113)	2.5 (109)	3.9 (170)	2.7 (117)	3.8 (165)	3.0 (130)
Phenyl. + Tyr.[b]	5.7 (114)	6.1 (122)	5.8 (116)	6.0 (120)	5.9 (118)	6.2 (124)
Threonine	3.5 (175)	3.6 (180)	3.6 (180)	3.6 (180)	3.6 (180)	3.7 (185)
Tryptophan	1.1 (220)	1.2 (240)	1.1 (220)	1.2 (240)	1.1 (220)	1.3 (260)
Valine	4.1 (137)	4.0 (133)	4.0 (133)	4.1 (137)	4.0 (133)	4.0 (133)

[a] Methionine + cystine.
[b] Phenylalanaine + tyrosine.

quirements of channel catfish were satisfied (Table 3) except for lysine requirement for diet 1 and diet 3 (92% and 94% of requirement, respectively; NRC 1993). Since only a small amount of crystalline amino acids was added to some of the experimental diets, pH was not adjusted.

In the diets requiring the addition of amino acids, the amino acids were premixed in corn meal that was used in the diets, then blended by hand into the rest of the ingredients. Each diet was then mixed for 3 min in a mixer, the choline was added, and the diet was mixed for an additional 6 min. After mixing, the diet was made into 3.0-mm diameter pellets using a small compaction-type pellet mill (California Pellet Mill, San Francisco, California, USA), without steam conditioning. Diets were allowed to cool, and addition of fish oil was then sprayed on. Analyses of the diets for moisture, protein, lipid, and ash were as described in Experiment 1.

The feeding trial was conducted in 24 110-L aquaria and all conditions were as described in Experiment 1 unless otherwise mentioned here. Juvenile blue catfish were purchased from a commercial supplier (Southland Fisheries Corp., Hopkins, South Carolina, USA) and had an average weight (± SE) of 5.4 ± 0.3 g. Twenty fish were randomly stocked into each aquarium with four replications per treatment. All fish were fed to excess twice daily (0730 and 1630) for 12 wk. At the conclusion of the experiment, five fish from each aquarium were frozen for subsequent whole-body composition. Fish were homogenized in a blender and analyzed for moisture, protein, and lipid as described in Experiment 1.

Growth performance, feed conversion, and body composition were measured, and data analyzed as described in Experiment 1, except that feed conversion ratio (FCR) was calculated using the equation: FCR = total dry diet fed (g)/total wet weight gain (g).

Experiment 3

Four sinking pelleted diets from Experiment 2 were fed to juvenile channel catfish. The diets were: 1) a diet containing 22% protein; 2) a diet containing 32% protein; 3) a diet containing 22% protein + L-methionine; and 4) a diet containing 22% protein + L-lysine (Table 2). The feeding trial was conducted in 16 110-L aquaria and all conditions were as described previously. Fish were fed twice daily (0730 and 1530) to excess for 8 wk.

Juvenile channel catfish were obtained from a commercial supplier (Jones' Fish Hatchery, Williamsburg, Kentucky, USA)

TABLE 4. *Final mean (± SE) individual weight, percentage weight gain, specific growth rate (SGR), and percentage survival of blue catfish fed one of three diets with various (22, 27, or 33%) percentages of protein for 10 wk (Experiment 1). Values are means ± SE of four replications. Means in the same column with different superscripts are significantly different* ($P < 0.05$).

	Diet no. (% protein)		
	1 (22%)	2 (27%)	3 (33%)
Final indiv. weight (g)	12.8 ± 1.2[a]	10.7 ± 1.4[a]	15.1 ± 2.2[a]
Weight gain (%)	375 ± 44[a]	298 ± 52[a]	460 ± 81[a]
SGR (%/day)	2.22 ± 0.13[a]	1.95 ± 0.17[a]	2.41 ± 0.24[a]
Survival (%)	100 ± 0.0[a]	100 ± 0.0[a]	100 ± 0.0[a]
Whole-body analysis			
Moisture (%)	77.3 ± 0.5[a]	78.1 ± 0.7[a]	77.4 ± 0.9[a]
Protein (%)[1]	58.9 ± 2.0[b]	65.4 ± 2.5[a]	58.2 ± 1.0[b]
Lipid (%)[1]	24.7 ± 1.7[a]	26.1 ± 2.5[a]	26.7 ± 1.9[a]

[1] Dry-matter basis.

and had an average initial weight (± SE) of 10.3 ± 0.6 g. Twelve fish were stocked into each aquarium and there were four replications per treatment. At the conclusion of the Experiment, three fish from each aquarium were randomly sampled and used for whole-body proximate analysis as described previously.

Results

Experiment 1

Over the duration of the study, these water-quality parameters averaged (± SE): water temperature, 27.5 ± 0.2 C; dissolved oxygen, 7.01 ± 0.12 mg/L; TAN, 0.10 ± 0.03 mg/L; nitrite, 0.012 ± 0.002 mg/L; total alkalinity, 134 ± 7 mg/L; chlorides, 120 ± 10 mg/L; pH, 8.7 ± 0.02. During the study, these averages were within acceptable limits for fish growth and health (Boyd 1979).

After 10 wk, final individual weight, percentage weight gain, specific growth rate (SGR), and percentage survival of blue catfish fed diets containing three protein levels were not significantly different ($P > 0.05$) among treatments and averaged 12.9 g, 378%, 2.19%/d, and 100%, respectively (Table 4). Since fish were fed to excess, no data on amount of diet fed were recorded. While there was no significant difference in final individual weight, there was a wide range among treatments.

Whole-body analysis showed no significant differences ($P > 0.05$) in percentage moisture and lipid among treatments and averaged 77.6% and 25.8%, respectively (Table 4). Blue catfish fed a diet containing 27% protein had significantly ($P < 0.05$) higher whole-body protein (65.4%) compared to fish fed diets containing 22% and 33% protein (58.9% and 58.2%, respectively).

Experiment 2

Water quality parameters for the duration of the experiment averaged (± SE): dissolved oxygen, 7.09 ± 0.06 mg/L; temperature, 27.3 ± 0.2 C; TAN, 0.14 ± 0.01 mg/L; nitrite, 0.034 ± 0.008 mg/L; alkalinity, 134 ± 7 mg/L; chlorides, 128 ± 6 mg/L; pH, 8.7 ± 0.2.

After 12 wk of feeding, final individual weight, percentage weight gain, percentage survival, and SGR of blue catfish fed diets containing either 22% or 32% protein, with and without supplemental L-methionine and/or L-lysine, were not significantly different ($P > 0.05$) among treatments and averaged 24.7 g, 355%, 96.7%, and 1.78%/d, respectively (Table 5).

Percentage whole-body protein of blue catfish was not significantly different ($P > 0.05$) among treatments and averaged 51.3% (Table 5). Fish fed a diet containing 32% protein and 0.2% added L-methionine

TABLE 5. *Final mean individual weight, percentage weight gain, percentage survival, specific growth rate (SGR), feed conversion ratio (FCR), and whole-body composition of juvenile blue catfish fed diets containing two protein levels, with and without supplemental L-methionine (M) and/or L-lysine (L) (Experiment 2). Values are means (± SE) of four replications. Means in the same row with the same superscript are not significantly different* (P > *0.05).*

	Diet no.					
	1	2	3	4	5	6
Final weight (g)	25.2 ± 1.5[a]	26.1 ± 2.4[a]	25.4 ± 2.9[a]	21.2 ± 2.9[a]	25.2 ± 0.7[a]	25.2 ± 1.4[a]
Weight gain (%)	373 ± 52[a]	381 ± 28[a]	353 ± 68[a]	269 ± 40[a]	357 ± 38[a]	395 ± 39[a]
Survival (%)	97.5 ± 1.4[a]	97.5 ± 1.4[a]	96.3 ± 2.4[a]	98.8 ± 1.3[a]	98.8 ± 1.1[a]	91.3 ± 5.9[a]
SGR (%/day)[1]	1.83 ± 0.13[a]	1.86 ± 0.07[a]	1.76 ± 0.18[a]	1.54 ± 0.12[a]	1.80 ± 0.10[a]	1.89 ± 0.09[a]
Whole-body analysis						
Moisture (%)	73.1 ± 0.2[b]	73.9 ± 0.4[ab]	73.4 ± 0.3[b]	73.2 ± 0.5[b]	73.2 ± 0.8[b]	74.9 ± 0.3[a]
Protein (%)[2]	48.9 ± 0.8[a]	53.3 ± 0.6[a]	52.8 ± 4.9[a]	50.0 ± 1.2[a]	48.5 ± 1.6[a]	54.0 ± 3.3[a]
Lipid (%)[2]	32.3 ± 0.9[a]	30.7 ± 1.5[ab]	31.9 ± 1.3[a]	30.2 ± 2.0[ab]	30.9 ± 0.9[a]	26.2 ± 1.7[b]

[1] Specific growth rate was calculated as: SGR (%/day) = (ln W_f − ln W_i/T) × 100; where W_f is the final weight, W_i is the initial weight, and T is the culture period in days.
[2] Dry-matter basis.

had a significantly higher ($P < 0.05$) percentage moisture (74.9%) compared to fish fed diets containing 22% protein (diet 1; 73.1%), 22% protein + 0.4% L-lysine (diet 4; 73.2%), and 22% protein + 0.4% L-lysine + 0.3% L-methionine (diet 5; 73.2%); however, were not different from fish fed a diet containing 32% protein (diet 2; 73.8%) and a diet containing 22% + 0.3% L-methionine (diet 6; 74.9%). Whole-body lipid was lower ($P < 0.05$) in fish fed a diet containing 32% protein + 0.2% L-methionine (diet 6; 26.2%) compared to fish fed diet 1 (32.3%), diet 3 (30.9%), and diet 5 (30.9%), but was not different than fish fed diet 2 and diet 4.

Experiment 3

Water quality parameters for the duration of the experiment averaged (± SE): dissolved oxygen, 7.2 ± 0.1 mg/L; temperature, 28.1 ± 0.2 C; TAN, 0.16 ± 0.4 mg/L; nitrite, 0.058 ± 0.005 mg/L; alkalinity, 115 ± 11 mg/L; chlorides, 86 ± 8 mg/L; pH, 8.3 ± 0.5.

Channel catfish juveniles fed a diet containing 32% protein had significantly higher ($P < 0.05$) final individual weight (54.6 g), percentage weight gain (446%), and SGR (3.01%/d) compared to fish fed a diet containing 22% protein (diet 1), 22% protein + L-methionine (diet 3), and 22% protein + L-lysine (diet 4) (Table 6). There were no differences ($P > 0.05$) in percentage survival among all treatments. Percentage whole-body moisture, protein, and lipid were not different ($P > 0.05$) among treatments and averaged 71.9%, 46.5%, and 34.2%, respectively (Table 6).

Discussion

In the present studies, growth rates were similar to other reports for blue catfish (Webster et al. 1992b, 1995a) and channel catfish (Mohsen and Lovell 1990; Webster et al. 1992a; Li and Robinson 1997; Li et al. 1998; Lim et al. 1998). Blue catfish fed diets containing 22% and 27% protein had similar weight gains as fish fed a diet with 32% protein (Experiment 1) and no improvement was observed if supplemental lysine and/or methionine was added to the diet with 22% protein (Experiment 2). However, channel catfish fed diets with 22% protein, with and without supplemental lysine or methionine, gained less weight than fish fed a 32% protein diet (Experiment 3). It has been shown that channel catfish grown in ponds can be fed diets containing 24–26% protein without adverse ef-

TABLE 6. *Final weight, percentage weight gain, percentage survival, specific growth rate (SGR), feed conversion ratio (FCR), and whole-body composition of juvenile channel catfish fed diets containing two protein levels, with and without supplemental L-methionine (M) or L-lysine (L) (Experiment 3). Values are means (±SE) of four replication. Means in the same row with the same superscript are not significantly different* (P > *0.05)*

	Diet no. (% protein)			
	1 (22%)	2 (32%)	3 (22% + M)	4 (22% ± L)
Final weight (g)	40.3 ± 2.6[b]	54.6 ± 3.0[a]	39.0 ± 3.7[b]	42.0 ± 3.2[b]
Weight gain (%)	278 ± 25[b]	446 ± 44[a]	282 ± 30[b]	313 ± 40[b]
Survival (%)	96.7 ± 1.9[a]	85.0 ± 5.7[a]	83.6 ± 7.8[a]	90.0 ± 4.3[a]
SGR (%/d)[1]	2.36 ± 0.12[b]	3.01 ± 0.16[a]	2.38 ± 0.15[b]	2.35 ± 0.22[b]
Whole-body analysis				
Moisture (%)	71.7 ± 0.6[a]	72.9 ± 0.4[a]	71.2 ± 1.1[a]	71.9 ± 0.4[a]
Protein (%)[2]	46.0 ± 0.7[a]	48.9 ± 0.8[a]	45.7 ± 1.7[a]	45.5 ± 0.6[a]
Lipid (%)[2]	34.8 ± 1.1[a]	33.4 ± 1.3[a]	33.3 ± 1.1[a]	35.4 ± 1.3[a]

[1] Specific growth rate was calculated as: SGR (%/d) = $(\ln W_f - \ln W_i/T) \times 100$; where W_f is the final weight, W_i is the initial weight, and T is the culture period in days.
[2] Dry-matter basis.

fects on growth when fed to satiation (Li and Lovell 1992; Robinson and Li 1997), but that small fish grown in aquaria require a higher percentage of protein in the diet (Bai and Gatlin 1994; Li and Robinson 1998).

It appears that small (<50 g) blue catfish may be able to be fed a low protein diet (22%) without having adverse effects on growth, but that channel catfish need to be fed a diet with a higher percentage of protein. When blue catfish were fed diets containing, 22%, 27%, or 32% protein, there were no significant differences in growth (Experiment 1). However, there was a wide range in the means among treatments. The reason for this wide range in growth data is unclear. One possible explanation might be that since the fish were from a "wild" stock, some fish did not readily adapt to the conditions of the aquarium. Food consumption may have been adversely affected and thus weight gains would depend upon if the fish readily consumed the diet. Indeed, this was the rationale for feeding to excess. With the inconclusive results from the first experiment, a second experiment was conducted in which the lowest protein diet was compared, with and without supplemental amino acids, to a diet with a protein level (32%) similar to a commercial diet. Again, there were no differences in growth among the various diets.

Blue catfish appear to have similar dietary protein requirements as channel catfish. It has been reported that weight gain of blue catfish fed a diet containing 27% protein was similar to that of fish fed a diet containing 36% protein when grown in cages (Webster et al. 1995b). While growth of larger juvenile blue catfish (>80 g) has been reported to be equivalent to channel catfish during the summer (Tidwell and Mims 1990; Grant and Robinette 1992), it appears that growth rates of small (<50 g) blue catfish may be lower than channel catfish when grown in aquaria (Webster et al. 1992b, 1995a).

It has been reported that channel catfish can utilize supplemental lysine in a practical diet (Robinson et al. 1980; Robinson 1992). Robinson and Li (1998) reported that when channel catfish were fed diets containing 20% and 24% protein with supplemental L-lysine added and no animal protein, weight gains were lower than when fish were fed diets containing 28% protein; however, when 8% animal protein was added to the diet, a diet with 24% protein and supplemental L-lysine was suitable for channel catfish compared with the diets with higher protein levels. However, they could not explain this result because all diets appeared to be adequate in available lysine. Bai and Gatlin (1994) reported that addition of 0.4% L-lysine to a semi-purified diet increased weight gains in catfish fed diets containing either 25% or 30% crude protein, compared to fish fed unsupplemented diets. While diets used in that study appeared to meet the requirement of channel catfish based upon analyzed content, the availability of lysine in soy protein may be lower, thus supplementation would have increased the available lysine content providing the beneficial effects observed. In contrast, Li and Robinson (1998) reported that adding 0.4% supplemental lysine to a diet with 24% protein did not improve growth in channel catfish, probably due to the diet having sufficient lysine to meet the requirement. It may be that supplemental lysine improves growth only when the diet is deficient in lysine. But when a diet meets requirements, no beneficial growth effects are observed.

The lysine requirement for channel catfish is 5.1% of protein while the total sulfur amino acid (TSAA) requirement is 2.3% of the protein. In Experiments 2 and 3, the diet with 22% protein had a lysine content of 4.6% of the protein and a TSAA content of 2.6% of the protein so the diet was somewhat deficient in lysine (NRC 1993). However, increasing the lysine content to 6.2% of the protein of the diet, and increasing the TSAA content to 3.9% of the protein did not improve growth. Diets used in Experiments 2 and 3 had more lysine and/or methionine added than would have met requirements to offset any losses due to leeching (Zarate and Lovell 1997).

The reasons for the contradictory results when using crystalline amino acids are unclear. It might be that the diets used were not deficient in amino acids and that adding crystalline amino acids was not necessary. It may also be that crystalline amino acids are more quickly absorbed, as compared to protein-based amino acids, and are utilized for growth by fish less efficiently (Zarate et al. 1999). Since crystalline (free) amino acids are highly water soluble and may leave the stomach more rapidly than particulate matter (Stevens 1988), it may not be unexpected that free amino acids exit the stomach more rapidly than protein-bound amino acids. Cowey and Sargent (1979) suggested that differences in absorption times between free and protein-based amino acids create an amino acid imbalance in tissues so that the fish would catabolize the amino acids rather than being used for protein synthesis. Further, crystalline methionine is rapidly absorbed in fish and degraded to methionine sulphoxide (Murai et al. 1986). Webster et al. (1995a) fed isonitrogenous diets with various levels of L-methionine (0, 0.3, 0.6, and 0.9% of the diet) to juvenile blue catfish and reported no affect on growth. Diets used in that study were formulated to meet the essential amino acid requirements of channel catfish (NRC 1993), since the amino acid requirements of blue catfish are not known.

Whole-body composition values in the present study indicated that feeding low-protein diets to channel and blue catfish had little effect on protein and lipid percentages and were similar to those reported for channel catfish (Garling and Wilson 1976; Mohsen and Lovell 1990; Webster et al. 1992a; Bai and Gatlin 1994; Lim et al. 1998) and blue catfish (Webster et al. 1992b). Supplementation of diets with either L-methionine or L-lysine did not affect whole-body composition. Robinson and Li (1997) and Li and Robinson (1998) reported that feeding low-protein (16–24%) diets to channel catfish increased the percentage of lipid in the fillet.

While several studies have shown that protein level of the fillet is positively correlated to dietary protein level (Li and Lovell 1992; Robinson and Li 1997), the present study did not find differences is whole-body protein levels among fish fed low protein (22%) diet and a diet with 32% protein.

This is in agreement with Li and Robinson (1998) who reported that there was no difference in percentage protein of fillets from channel catfish fed diets containing either 24% or 28% protein.

In conclusion, it appears that fingerling channel catfish have reduced growth when fed a diet containing 22% protein when raised in aquaria; however, blue catfish appear to utilize a low-protein (22%) diet without adverse effects on growth or body composition. Further research on the use of low-protein diets for blue catfish in ponds under commercial production situations needs to be conducted.

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Literature Cited

AOAC (Association of Official Analytical Chemists). 1990. Official methods of analysis, 15th edition. AOAC, Arlington, Virginia, USA.

Bai, S. C. and D. M. Gatlin. 1994. Effect of L-lysine supplementation of diets with different protein levels and sources on channel catfish *Ictalurus punctatus* (Rafinesque). Aquaculture and Fisheries Management 25:465–474.

Boyd, C. E. 1979. Water quality in warmwater fish ponds. Auburn University, Agricultural Experiment Station, Auburn, Alabama, USA.

Chapel, J. A. 1979. An evaluation of twelve genetic groups of catfish for suitability in commercial production. Doctoral dissertation. Auburn University, Auburn, Alabama, USA.

Cowey, C. B. and J. R. Sargent. 1979. Nutrition. Pages 1–69 *in* W. S. Hoar, D. J. Randall, and J. R. Brett, editors. Fish physiology volume VIII. Bioenergetics and growth. Academic Press, New York, New York, USA.

Dunham, R. A. and R. O. Smitherman. 1981. Graph response to winter feeding by blue, channel, white, and hybrid catfishes. Progressive Fish-Culturist 43:62–66.

Dunham, R. A., M. Benchakan, R. O. Smitherman, and J. A. Chapel. 1983. Correlations among morphometric traits of fingerling catfishes and the relationship to dressing percentage at harvest. Journal of the World Mariculture Society 14:668–675.

Garling, D. L. and R. P. Wilson. 1976. Optimum dietary protein to energy ratio for channel catfish fingerlings, *Ictalurus punctatus.* Journal of Nutrition 106:1368–1375.

Gatlin, D. M. III, W. E. Poe, and R. P. Wilson. 1986. Protein and energy requirements of fingerling channel catfish for maintenance and maximum growth. Journal of Nutrition 116:2121–2128.

Grant, J. C. and H. R. Robinette. 1992. Commercially important traits of blue and channel catfish as related to second summer, winter, and third summer growth. Aquaculture 105:37–45.

Hach, C. C., B. K. Bowden, A. B. Kopelove, and S. V. Brayton. 1987. More powerful peroxide Kjeldahl digestion method. Journal of the Association of Official Analytical Chemists 70:783–787.

Li, M. and R. T. Lovell. 1992. Growth, feed efficiency and body composition of second-and third-year channel catfish fed various concentrations of dietary protein to satiety in production ponds. Aquaculture 103:153–162.

Li, M. H. and E. H. Robinson. 1997. Microbial phylase can replace inorganic phosphorus supplements in channel catfish *Ictalurus punctatus* diets. Journal of the World Aquaculture Society 28:402–406

Li, M. H. and E. H. Robinson. 1998. Effects of supplemental lysine and methionine in low protein diets on weight gain and body composition of young channel catfish *Ictalurus punctatus.* Aquaculture 163:297–307.

Li, M. H., E. H. Robinson, and W. R. Wolters. 1998. Evaluation of three strains of channel catfish *Ictalurus punctatus* fed diets containing three concentrations of protein and digestible energy. Journal World Aquaculture Society 29:155–160.

Lim, C., P. H. Klesivs, and D. A. Higgs. 1998. Substitution of canola meal for soybean meal in diets for channel catfish *Ictalurus punctatus.* Journal of the World Aquaculture Society 29:161–168.

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

Murai, T., H. Ogatz, P. Kosutarak, and S. Arai. 1986. Effects of amino acid supplementation and methanol treatment an utilization of soy flour by fingerling carp. Aquaculture 56:197–206.

NRC (National Research Council). 1993. Nutrient requirements of warmwater fish. National Academy Press, Washington, D.C., USA.

Perrone, S. J. and T. L. Meade. 1977. Protective effect of chloride on nitrite toxicity to Coho salmon

(*Oncorhgnctius kisutch*). Journal of The Fisheries Research Board of Canada 34:486–492.

Plumb, J. A. and J. A. Chapel. 1978. Susceptibility of blue catfish to channel catfish virus. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 32: 680–685.

Robinson, E. H. 1992. Use of supplemental lysine in catfish feeds. Aquaculture Magazine 3:94–96.

Robinson, E. H. and M. H. Li. 1993. Protein quality and quantity of catfish feeds. Technical Bulletin 189. Mississippi Aquacultural and Forestry Experiment Station, Mississippi State, Mississippi, USA.

Robinson, E. H. and M. H. Li. 1997. Low protein diets for channel catfish *Ictalurus punctatus* raised in earthen ponds at high density. Journal of the World Aquaculture Society 28:224–229.

Robinson, E. H. and M. H. Li. 1998. Comparison of practical diets with and without animal protein at various concentrations of dietary protein on performance of channel catfish *Ictalurus punctatus* raised in earthen ponds. Journal of the World Aquaculture Society 29:273–280.

Robinson, E. H., R. P. Wilson, and W. E. Poe. 1980. Re-evaluation of the lysine by fingerling channel catfish. Journal of Nutrition 110:2313–2316.

SAS. 1988. SAS/STAT user's guide, release 6.03 edition. SAS Institute, Inc., Cary, North Carolina, USA.

Stevens, C. E. 1988. Comparative physiology of the vertebrate digestive system. Cambridge University Press, Cambridge, United Kingdom.

Tidwell, J. H. and S. D. Mims. 1990. A comparison of second-year growth of blue catfish and channel catfish in Kentucky. Progressive Fish-Culturist. 52:203–204.

Webster, C. D., J. H. Tidwell, L. S. Goodgame, D. H. Yancey, and L. Mackey. 1992a. Use of soybean meal and distiller 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., D. H. Yancey, and J. H. Tidwell. 1992b. Effect of partially or totally replacing fish meal with soybean meal, with various percentages of supplemental L-methionine, in diets for blue catfish, *Ictalurus furcatus*. Aquaculture Research 26:299–306.

Webster, C. D., L. S. Goodgame-Tiu, and J. H. Tidwell. 1995a. Total replacement of fish meal by soybean meal with various percentages of supplemental L-methionine, in diets for blue catfish, *Ictalurus furcatus*. Aquaculture Research 26:299–306.

Webster, C. D., L. G. Tiu, J. H. Tidwell, and E. B. Reed. 1995b. Effects of feeding the repartitioning agent L644,969 on growth and body composition of blue catfish, *Ictalurus furcatus*, fed diets containing two protein levels reared in cages. Aquaculture 134:247–256.

Wolters, W. R. and M. R. Johnson. 1994. Enteric septicemia resistance in blue catfish and three channel catfish strains. Journal of Aquatic Animal Health 6:329–334.

Zarate, D. D. and R. T. Lovell. 1997. Free lysine (L-lysine HCL) is utilized for growth less efficiently than protein-bound lysine (soybean meal) in practical diets by young channel catfish (*Ictalurus punctatus*). Aquaculture 159:87–100.

Zarate, D. D., R. T. Lovell, and M. Payne. 1999. Effects of feeding frequency and rate of evacuation on utilization of dietary free and protein-bond lysine for growth by channel catfish *Ictalurus punctatus*. Aquaculture Nutrition 5:17–22.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, New Jersey, USA.