Aquaculture Research, 2004, **35**, 365–370

Evaluation of growth, feed utilization, and economics of hybrid tilapia, *Oreochromis niloticus* × *Oreochromis aureus*, fed diets containing different protein sources in combination with distillers dried grains with solubles

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Abstract

A feeding trial was conducted in aquaria with juvenile hybrid tilapia (*Oreochromis niloticus* × *Oreochromis aureus*) to evaluate the use of different protein sources in combination with distillers dried grains with solubles (DDGS). Twelve 110-L glass aquaria were stocked with 28 juvenile (2.7 ± 0.5-g) hybrid tilapia per aquarium. Three replicate aquaria were randomly assigned to each of the four dietary treatments. Diets were isonitrogenous and isocaloric. The control diet contained 12% fish meal and 41% soybean meal as the primary protein sources (Diet 1). Each experimental diet contained 30% DDGS by weight, in combination with 8% fish meal and 34% soybean meal (Diet 2), 26% meat and bone meal (MBM), and 16% soybean meal (Diet 3), or 46% soybean meal alone (Diet 4). Fish were fed to apparent satiation twice a day for 10 weeks. There were no significant differences ($P > 0.05$) in average weight gain, specific growth rate (SGR), feed conversion ratio (FCR), and protein efficiency ratio (PER) among tilapia fed Diets 1, 2, and 3. Fish fed Diet 4 had significantly lower ($P < 0.05$) average weight gain, SGR, and PER than fish fed Diets 1 and 3. Relative cost per unit weight gain for Diets 1, 2, and 3 were statistically similar ($P > 0.05$), while cost per unit weight gain for Diet 4 was significantly higher ($P < 0.05$) than other diets. Diet 3 represented approximately a 20% cost savings compared with the control diet, with no reduction in growth. This study indicates that diets without fish meal containing 30% DDGS in combination with MBM and soybean meal provide good growth in tilapia. A diet without animal protein did not support acceptable growth.

Keywords: tilapia, protein, distillers grains

Introduction

Since diet costs account for over 50% of production costs for most aquatic species, one way to increase production profitability is to reduce diet costs. Protein is generally the most expensive dietary component; therefore, determination of less-expensive sources of protein which provide good growth is advantageous for diet manufacturers and aquaculture producers alike. Other factors including inconsistent supply and environmental concerns with using fish meal in aquaculture diets make evaluation of alternative protein sources a high priority for fish nutritionists. Tilapia diets without fish meal have generally resulted in reduced growth under intensive culture conditions (Davis & Stickney 1978; Jackson, Capper & Matty 1982; El-Sayed 1990). However, research has shown that by combining complimentary animal and plant protein sources nutrient utilization can be improved (Webster, Tidwell, Goodgame, Yancey & Mackey 1992; Brown, Twibell, Jonker & Wilson 1997; Webster, Thompson, Morgan, Grisby & Gannam 2000).

Distillers dried grains with solubles (DDGS) are primary residues from yeast fermentation of cereal grains and are a by-product of the bourbon and

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ethanol distilling process. These by-products contain approximately 26–28% protein, closely matching the protein requirements of tilapia (25–35%) (Lim 1989). Compared with many species, tilapia can utilize relatively high levels of plant feedstuffs (Twibell & Brown 1998). Wu, Warner, Rosati, Sessa & Brown (1996) evaluated inclusion of DDGS at 30% of the total diet fed to tilapia and reported good growth. Tidwell, Coyle, VanArnum, Weibel & Harkins (2000) compared the growth of Nile tilapia (*Oreochromis niloticus*) raised in cages and fed either a sinking DDGS pellet (97.5% DDGS, 2.5% binder, 0% vitamins, minerals, and fish meal) or a sinking commercial catfish (*Ictalurus punctatus*) diet. While those receiving the catfish diet grew 25% faster, cost of gain was 43% lower for fish fed the DDGS pellets. The authors concluded that efficient and economical tilapia growth can be obtained using direct feeding of DDGS in situations where optimal growth is not essential.

DDGS is a relatively inexpensive protein source (approximately US\$0.12 kg^{-1}) which could be incorporated into least-cost diet formulations in locations where transportation costs are not cost-prohibitive. A mixture of protein sources in combination with DDGS could improve growth, utilization, and may reduce or eliminate the need for fish meal in diets for tilapia. This study was designed to compare diets using different plant and animal protein sources in combination with 30% DDGS on growth, feed conversion ratio (FCR), and production efficiency of tilapia.

Materials and methods

Experimental system and animals

Twenty-eight juvenile hybrid tilapia (*O. niloticus* × *O. aureus*) (average individual weight ± SE of 2.7 ± 0.5 g) were randomly stocked into each of 12 110-L glass aquaria with three replicate aquaria per dietary treatment. For a 1-week conditioning period, fish in all tanks were fed a control diet which was based on a model formula by Lim (1989) and contained 30% protein and 8% lipid. Thereafter, fish were fed one of the four experimental diets. Fish were fed all they would consume for 10 min, twice daily (08:30 and 15:30 hours) for a period of 10 weeks. All fish from each aquaria were bulk weighed at the beginning of the experiment and again every 3 weeks until the conclusion of the feeding trial.

Water was recirculated through a common biological and mechanical filter system so that all replicates shared similar water quality. The recirculating biofiltration system was a 1000-L vertical flow bead filter (Bubble Bead Filter, Aquatic Ecosystems, Apopka, FL, USA) to remove particulate matter and provide substrate for nitrifying bacteria. Continuous aeration was provided using a blower and air stones. The water replenishment rate for the system was approximately 5% of volume per day. Each aquarium was supplied with water at a flow rate of approximately 5 L min^{-1} and cleaned using siphon daily. Black plastic (4 mm) was used to cover the back and sides of all aquaria to minimize disturbances. Illumination was supplied with florescent ceiling lights with 24-h light (Webster, Tidwell & Yancey 1991).

Water temperature and dissolved oxygen were measured daily using a YSI Model 58 oxygen meter (YSI Industries, Yellow Springs, OH, USA). Total ammonia-nitrogen and nitrite-nitrogen were measured three times weekly using a DREL 2000 spectrophotometer (Hach Company, Loveland, CO, USA); pH was measured three times weekly using an electronic pH meter (pH pen; Fisher Scientific, Cincinnati, OH, USA). Total alkalinity was maintained above 50 mg L^{-1} by weekly additions of sodium bicarbonate (Boyd 1990).

Experimental diets

Diet 1 (control) was formulated from practical ingredients according to a model formula presented by Lim (1989) and contained 12% menhaden fish meal (Table 1). The three experimental diets (Diets 2–4) were based on the control diet, but modified to reduce or eliminate the use of fish meal. Each experimental diet contained 30% DDGS by weight in combination with: 8% fish meal and 34% soybean meal (Diet 2), 26% meat and bone meal (MBM) and 16% soybean meal (Diet 3), and 46% soybean meal alone (Diet 4). Diets were formulated to be isonitrogenous (30% protein) and isocaloric (3.1 kcal g^{-1}) based on gross energy values of 5.64 kcal g^{-1} protein, 4.11 kcal g^{-1} carbohydrate, and 9.44 kcal g^{-1} fat (NRC 1993).

To prepare the diets, ingredients were ground into small particle sizes (approximately 250 μm) in a Wiley mill (Wiley Mill No. 1, Arther H. Thomas, Philadelphia, PA, USA). Ingredients were mixed thoroughly and water was added to obtain a 25% moisture level. Diets were then passed through a mincer with a die and made into 0.4-mm diameter strands and air dried (24 °C) for 24 h. The dry diets were broken up and sieved to an appropriate pellet size for size of fish (Luquet 1991). Semi-dry pellets were stored frozen (−20 °C) until fed.

Table 1 Ingredient composition of practical diets with and without 30% distillers grains with solubles (DDGS) in combination with different protein sources

Ingredients	Diet 1 (control) (SBM+FM)	Diet 2 (DDGS+FM)	Diet 3 (DDGS+MBM)	Diet 4 (DDGS+SBM)
DDGS	–	30	30	30
FM	12	8	–	–
MBM	–	–	26	–
SBM	41	34	16	46
Wheat flour	33.3	16.5	18	11.8
Corn oil	3.3	2.1	1.2	2.5
Fish oil	2.4	1.4	0.8	1.7
Choline chloride	0.5	0.5	0.5	0.5
Mineral mix*	0.3	0.3	0.3	0.3
Vitamin mix†	0.2	0.2	0.2	0.2
Ascorbic acid‡	2	2	2	2
Di-calcium phosphate	2	2	2	2
CMC§	3	3	3	3

*Mineral mix was Rangen trace mineral mix F1 for catfish with 0.3-mg selenium kg^{-1} diet added.
†Vitamin mix was the Abernathy vitamin premix no. 2 and supplied the following (mg or IU kg^{-1} of diet): biotin, 0.60 mg; B_{12}, 0.06 mg; E (as alpha-tocopheryl acetate), 50 IU; folic acid, 16.5 mg; myo-inositol, 132 mg; K (as menadione sodium bisulphate complex), 9.2 mg; niacin, 221 mg; pantothenic acid, 160 mg; B_6, 31 mg; riboflavin, 53 mg; thiamin, 43 mg; D_3, 440 IU; A (as vitamin A palimate), 4399 IU; ethoxyquin, 99 mg.
‡Vitamin C (Roche's Stay C at 35% active).
§Carboxymethylcellulose; United States Biochemical, Cleveland, OH, USA.
SBM, soybean meal; FM, fish meal; MBM, meat and bone meal.

Table 2 Percent moisture, protein, lipid, and ash of practical diets with and without 30% distillers grains with solubles (DDGS) in combination with different protein sources as-fed to hybrid tilapia

	Diet 1 (control) (SBM+FM)	Diet 2 (DDGS+FM)	Diet 3 (DDGS+MBM)	Diet 4 (DDGS+SBM)
Moisture	8.3 ± 0.0	7.3 ± 0.0	7.8 ± 0.0	7.3 ± 0.0
Protein	30.4 ± 0.4	30.4 ± 0.2	30.1 ± 0.1	30.3 ± 0.4
Lipid	7.7 ± 0.1	7.8 ± 0.1	7.5 ± 0.0	7.6 ± 0.0
Ash	8.3 ± 0.0	8.3 ± 0.1	9.0 ± 0.0	7.7 ± 0.0

Values are means ± SD of two replicate samples.
SBM, soybean meal; FM, fish meal; MBM, meat and bone meal.

Duplicate samples of each diet were analysed for crude protein, lipid, moisture, ash, and essential amino acid (EAA) composition by a commercial analytical laboratory (Woodson-Tenent Laboratories, Dayton, OH, USA). Table 2 shows the results of analysis of proximate composition of the experimental diets. Table 3 summarizes the EAA composition of the experimental diets.

Data analysis procedures

Growth performance values were calculated as follows: FCR = weight of diet fed (kg)/total wet weight gain (kg); specific growth rate (SGR, g body wt/day) = $(W_f - W_i)/t$, where W_f = final weight, W_i = initial weight, and t = time in days; protein efficiency ratio (PER) = wet weight gain (kg)/amount of protein fed (kg).

Data were subjected to analysis of variance (ANOVA) using Statistix version 4.1 (Analytical Software 1994) to determine treatment effects on growth, feed conversion, survival, PER, and water quality variables. If ANOVA indicated significant treatment effects, the least significant difference (LSD) test was used to determine differences among individual treatment means ($P = 0.05$). All percentage and ratio data were transformed to arc-sin values prior to analysis (Zar 1984). Data are presented untransformed to facilitate interpretation.

Results and discussion

Overall means for water quality parameters were: temperature, 27.4 ± 1.5 °C; dissolved oxygen, 6.1 ± 0.9 mg L^{-1}; pH, 8.0 ± 0.4; total ammonia-nitrogen,

Table 3 Concentrations of essential amino acids (% of protein) in practical diets with and without 30% distillers grains with solubles (DDGS) in combination with different protein sources fed to hybrid tilapia

Amino acid	Diet 1 (control) (SBM+FM)	Diet 2 (DDGS+FM)	Diet 3 (DDGS+MBM)	Diet 4 (DDGS+SBM)	Required* by *Oreochromis niloticus*
Arginine	5.77 ± 0.10	5.33 ± 0.01	5.18 ± 0.01	6.06 ± 0.07	4.20
Histidine	2.17 ± 0.03	2.20 ± 0.03	2.14 ± 0.05	2.24 ± 0.03	1.72
Isoleucine	3.76 ± 0.02	3.69 ± 0.02	3.47 ± 0.07	3.72 ± 0.10	3.11
Leucine	6.56 ± 0.06	7.50 ± 0.04	7.79 ± 0.19	7.45 ± 0.05	3.39
Lysine	5.51 ± 0.09	4.74 ± 0.13	3.95 ± 0.05	4.07 ± 0.21	5.12
Meth.	1.59 ± 0.00	1.65 ± 0.04	1.27 ± 0.02	1.55 ± 0.02	2.68
Meth.+cystine	2.88 ± 0.03	3.03 ± 0.04	3.36 ± 0.03	3.00 ± 0.02	3.21
Phen.	4.19 ± 0.03	4.26 ± 0.04	4.29 ± 0.07	4.29 ± 0.00	3.75
Phen.+tyrosine	7.05 ± 0.05	7.30 ± 0.10	6.93 ± 0.10	7.27 ± 0.04	5.54
Threonine	3.67 ± 0.03	3.69 ± 0.02	3.86 ± 0.11	3.51 ± 0.20	3.75
Tryptophan	1.33 ± 0.10	1.20 ± 0.02	1.08 ± 0.04	1.27 ± 0.06	1.00
Valine	4.13 ± 0.02	4.20 ± 0.03	4.92 ± 0.05	4.29 ± 0.04	2.80

*Santiago & Lovell (1988).
The EAA requirements for *O. niloticus* are presented for comparative purposes. Values are means ± SD of two replicate samples.
Meth., methionine; Phen., phenylalanine.

Table 4 Average weight (avg.wt.) gain, percent survival, feed conversion ratio (FCR), and specific growth rate (SGR) of tilapia fed practical diets with and without 30% distillers dried grains with solubles (DDGS) in combination with different protein sources*

	Diet 1 (control) (SBM+FM)	Diet 2 (DDGS+FM)	Diet 3 (DDGS+MBM)	Diet 4 (DDGS+SBM)
Avg. wt. gain (g)	65.4 ± 4.4a	60.5 ± 1.6ab	65.8 ± 5.9a	55.1 ± 2.3b
Survival (%)	98.8 ± 2.1a	100 ± 0.0a	100 ± 0.0a	98.8 ± 2.1a
FCR†	2.1 ± 0.2b	2.4 ± 0.1ab	2.3 ± 0.3ab	2.7 ± 0.2a
SGR (g/day)‡	0.86 ± 0.06a	0.80 ± 0.03ab	0.87 ± 0.08a	0.73 ± 0.03b
PER§	2.05 ± 0.16b	2.36 ± 0.11ab	2.29 ± 0.32b	2.69 ± 0.21a

*Averages are means of three replicate aquaria. Numbers within a row followed by different letters were significantly different ($P<0.05$) by ANOVA.
†FCR = weight of diet fed (kg)/total wet weight gain (kg).
‡SGR = $(W_f - W_i)/t$, where W_f = final weight, W_i = initial weight, and t = time in days.
§PER = wet weight gain (kg)/amount of protein fed (kg).
SBM, soybean meal; FM, fish meal; MBM, meat and bone meal.

0.83 ± 0.33 mg L^{-1} (ranged from 0.25 to 1.48 mg L^{-1}); and nitrite-nitrogen, 0.23 ± 0.19 mg L^{-1} (ranged from 0.01 to 0.68 mg L^{-1}). These values are within suitable conditions for tilapia culture (Stickney 1986).

There were no significant differences ($P>0.05$) in survival of tilapia fed the four diets (Table 4). Overall, survival was high and ranged from 96.4% to 100%. Fish fed actively on all diets and demonstrated similar growth patterns through the duration of the study indicating that palatability or diet acceptance did not differ. Fish fed Diets 2 and 3 had final average weight gain and FCR that were not significantly different ($P>0.05$) from fish fed Diet 1. Fish fed Diet 4 had significantly lower ($P>0.05$) average weight gain than tilapia fed other diets. PER was lower ($P<0.05$) for fish fed Diet 4 than for fish fed Diets 1 and 3; however, was not significantly different ($P>0.05$) from fish fed Diet 2. Fish fed Diet 4 had significantly higher ($P<0.05$) FCR than fish fed the control diet (Diet 1) (Table 4).

Based on EAA composition and EAA requirements (Table 3), the control diet (Diet 1) was marginally deficient in methionine and threonine. Experimental Diets 2, 3, and 4 were deficient in methionine and lysine. All diets were formulated to meet the EAA requirements for Nile tilapia based on standard ingredient composition tables (NRC 1993). The discrepancies may be a result of differences in ingredient quality between the ingredients used and those reported.

Table 5 Average relative diet costs, diet ingredient costs, and costs of gain including only diet ingredient costs based on Chicago prices reported in Feedstuffs, Vol. 75, 27 (7 July 2003)

	Diet 1 (control) (SBM+FM)	Diet 2 (DDGS+FM)	Diet 3 (DDGS+MBM)	Diet 4 (DDGS+SBM)
Relative diet cost	1.0	0.89	0.84	0.79
Diet cost ($\$\,kg^{-1}$)	0.38	0.34	0.32	0.30
Cost of gain ($\$\,kg^{-1}$ gain)*	0.76 ± 0.03b	0.78 ± 0.04b	0.73 ± 0.02b	0.84 ± 0.03a

*Cost of gain = diet cost ($\$\,kg^{-1}$) × FCR, where FCR is the feed conversion ratio.
SBM, soybean meal; FM, fish meal; MBM, meat and bone meal.

Diets 2, 3, and 4 were 11%, 16%, and 21% less expensive than the control diet respectively (Table 5). Fish fed Diet 4 gained less resulting in a significantly higher ($P<0.05$) cost per unit of weight gain than in fish fed other diets. While differences in cost of gain among other diets was not significantly different ($P>0.05$), the overall cost per unit of weight gain was lowest for fish fed Diet 3. Based on these data, the diet containing MBM in combination with DDGS and soybean meal appears to be the most effective and economical substitute for fish meal.

Previous research has shown MBM to be a good protein source in tilapia diets. Wu, Tudor, Brown & Rosati (1999) determined MBM to be a suitable source of protein when fed to Nile tilapia at relatively low levels (6% of dry diet) and combined with corn gluten meal and high lysine corn in fish-meal-free diets. El-Sayed (1998) evaluated MBM as the sole source of protein (40% of dry diet) in diets fed to Nile tilapia and demonstrated that growth rates were not significantly different ($P>0.05$) compared with fish fed a fish-meal-based diet, although the FCR and PER were not as efficient as those of the fish-meal-based diet ($P<0.05$). This experiment demonstrated that the diet containing DDGS and MBM resulted in similar growth, FCR and PER as diets containing FM and was more economical based on ingredient costs.

This study demonstrated DDGS, when used in combination with MBM, to be a suitable protein source for use in tilapia diets at up to 30% of diet. Webster *et al.* (1991) suggested that growth in channel catfish juveniles fed diets with 35–40% DDGS was equivalent to fish fed a standard commercial formulation. In a follow-up study, Webster *et al.* (1992) reported no differences in growth or survival in channel catfish fed diets containing 35% DDGS and either 0%, 4%, 8%, or 12% fish meal, indicating that a diet with all plant protein sources can totally replace fish meal in channel catfish diets without sacrificing weight gain or FCR.

These data indicate that efficient and economical tilapia growth can be obtained by feeding diets without fish meal using a combination of distillery by-products, MBM, and soybean meal. DDGS may be complimentary to animal-based protein sources (i.e. MBM) since growth was similar to diets containing fish meal. However, these data indicate that it is necessary that a portion of the protein be of animal source (meat and bone meal or fish meal). Further research should be conducted to evaluate these diets under pond culture conditions.

Acknowledgments

We thank Aaron VanArnum, Dave Yasharian, and Leigh Anne Bright for daily management of the culture system and Karla Hochstrasser for typing the manuscript. This research was supported by USDA/CREES grant to Kentucky State University under agreement KYX-80-91-04A. Funding was also provided by Kentucky's Regional University Trust Fund to the Aquaculture Program as KSU's Program of Distinction.

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