



Effects of various corn distillers by-products on growth, feed efficiency, and body composition of channel catfish, *Ictalurus punctatus*

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Abstract

A study was conducted to examine the use of corn distillers' by-products in diets and the effects of additional dietary fat on channel catfish, *Ictalurus punctatus*, performance. Juvenile channel catfish (initial weight: 12.6 g per fish) were stocked in flow-through aquaria and fed one of six practical diets for 9 weeks. Fish fed the control + fat diet consumed more diet and had higher feed efficiency ratio (FER) than fish fed the control diet, but weight gain was not significantly different between fish fed these two diets. Fish fed the diet containing 300 g kg⁻¹ distillers dried grains with solubles (DDGS) consumed more diet and gained more weight, but had similar FER compared with fish fed the control + fat diet. The diet containing 200 g kg⁻¹ high-protein distillers grains (HPDDG) resulted in similar diet consumption, weight gain and FER as the control + fat diet. Fish fed the diet containing 100 g kg⁻¹ distillers solubles (DS) consumed more diet, but had similar weight gain and FER compared with fish fed the 300 g kg⁻¹ DDGS diet. The presence of distillers solubles in the diet (300 g kg⁻¹ DDGS, 100 g kg⁻¹ DS, 100 g kg⁻¹ EDS diets) appears to increase diet consumption, weight gain, and FER over the control diets with or without additional fat.

KEY WORDS: channel catfish, corn distillers by-products, feed efficiency ratio, growth, *Ictalurus punctatus*, nutrition

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Introduction

Global production of ethanol as an automotive fuel has increased rapidly in recent years, which has resulted in an

increasing supply of by-products associated with its production. The U.S. production of distillers dried grains with solubles (DDGS), which is the major by-product of ethanol production, reached 14.6 million tons in 2007, more than five times of that produced in 2000 (Renewable Fuels Association 2008). As supplies increase, prices of distillers' grains will become more competitive which should increase their use in animal feeds, thus reducing feed cost. Other by-products from the corn ethanol industry in the USA including distillers solubles (DS), high-protein distillers dried grains (HPDDG) and DS from the corn endosperm (EDS) are also available and can be used in diets for various farmed animals including channel catfish, *Ictalurus punctatus*. The HPDDG comes from the EDS fraction of the corn kernel and is produced using a new corn fraction technology in ethanol production. The new process also results in a soluble product, i.e. EDS. Except for DDGS, other distillers by-products have not been evaluated in channel catfish diets.

Early aquarium and net cage studies demonstrated that up to 350 g kg⁻¹ DDGS without lysine supplementation (Webster *et al.* 1991, 1992, 1993) and up to 700 g kg⁻¹ with lysine supplementation (Webster *et al.* 1991) could be used to partially replace soybean meal and fish meal in channel catfish diets without affecting fish growth. Recently Lim *et al.* (in press) reported no differences in the growth of juvenile channel catfish fed diets containing up to 400 g kg⁻¹ DDGS. In a pond study with channel catfish, Robinson & Li (2008) reported that up to 300–400 g kg⁻¹ DDGS with supplemental lysine could be used in food fish diets. They also noted that feed efficiency ratio (FER) was improved in fish fed diets containing 300–400 g kg⁻¹ DDGS. It was not clear whether the improved FER of fish fed diets containing DDGS was caused by the increased dietary fat level, because of high levels of fat (about 90 g kg⁻¹) contained in the feedstuff, or by other compounds present in the product. Therefore, the present study was conducted to examine the

use of various distillers by-products to partially replace soybean meal in the diet and the effects of additional dietary fat on channel catfish growth, FER, and body proximate composition.

Materials and methods

Six 280 g kg⁻¹ crude protein, practical diets (Table 1) were formulated to meet or exceed all known nutrient requirements of channel catfish (NRC 1993). Diet descriptions are as follows:

Diet 1 – all-plant-protein diet (control)

Diet 2 – same as Diet 1 except with additional oil (control + fat)

Diet 3 – 300 g kg⁻¹ DDGS

Diet 4 – 200 g kg⁻¹ HPDDG

Diet 5 – 100 g kg⁻¹ DS (300 g kg⁻¹ wet product)

Diet 6 – 100 g kg⁻¹ EDS (300 g kg⁻¹ wet product).

The distillers by-products were provided by Poet, LLC (Sioux Falls, SD, USA) and other dietary ingredients were obtained from the Delta Western Feed Mill, Indianola, MS, USA and were from commercial sources. The 100 g kg⁻¹ solubles (based on 900 g kg⁻¹ dry matter) used in Diets 5 and 6 were based on the estimated ratio of distillers dried grains to DS ratio (2 : 1) in a typical DDGS product provided by the supplier. Diets 2–6 were formulated to contain similar

levels of fat (56 g kg⁻¹) based on the fat level of Diet 3. The diets were prepared as sinking pellets according to procedures described previously (Li *et al.* 1993).

Juvenile channel catfish were obtained from the USDA Agriculture Research Service's Catfish Genetics Research Unit, Stoneville, MS, USA. Forty fish were stocked into each of thirty 110-L flow-through aquaria at the National Warmwater Aquaculture Center (NWAC), Mississippi State University, Stoneville, MS, USA. The aquaria were supplied with well water (flow rate: approximately 1 L min⁻¹) and continuous aeration. Water temperature and oxygen were monitored in the system once daily using a YSI oxygen meter (Yellow Springs Instruments, Yellow Springs, OH, USA) and maintained at 30 ± 1 °C and >5 mg L⁻¹ respectively. A diurnal light : dark cycle was regulated at 14 : 10 h.

Before initiation of the experiment, the fish were conditioned for 2 weeks and fed Diet 1 (the control diet) once daily to apparent satiation at 08:00 hours. After conditioning, all fish were pooled and graded to a uniform size, and 20 fish were restocked in each aquarium. Initial fish weight was determined and averaged 12.6 g per fish. Fish were fed to apparent satiation (in about 40 min) once daily for 9 weeks. Satiation was achieved by first feeding an amount of diet based on percentage of fish body weight (less than satiation), followed by feeding several times from a preweighed diet container. Diet consumption was monitored and recorded at

Table 1 Ingredient and proximate compositions of experimental diets (expressed as g kg⁻¹ on an as-fed basis)

	Diets					
	Control	Control + fat	30 g kg ⁻¹ DDGS ¹	20 g kg ⁻¹ HPDDG ²	10 g kg ⁻¹ DS ³	10 g kg ⁻¹ EDS ⁴
Ingredient						
Soybean meal (dehulled)	409.7	416.5	267.5	253.0	381.2	388.2
Corn meal (cooked)	413.0	383.4	252.5	345.4	339.7	316.0
Distillers products	0.0	0.0	300.0	200.0	100.0	100.0
Lysine HCl	0.0	0.0	3.0	3.9	0.0	0.0
Dicalcium phosphate	10.3	10.3	10.0	12.8	8.8	9.5
Catfish offal oil	15.0	15.0	15.0	15.0	15.0	15.0
Corn oil	0.0	22.8	0.0	17.9	3.3	19.3
Other ingredients ⁵	152.0	152.0	152.0	152.0	152.0	152.0
Proximate analysis⁶						
Dry matter	899.4 ± 1.1	895.6 ± 13.5	898.3 ± 6.8	903.6 ± 5.6	889.6 ± 5.6	896.6 ± 3.7
Crude protein ⁷	284.5 ± 5.2	288.8 ± 3.7	288.1 ± 3.3	287.2 ± 5.0	282.7 ± 2.8	283.1 ± 4.0
Crude fat ⁷	28.7 ± 1.9	53.4 ± 0.6	57.7 ± 2.4	51.5 ± 3.9	50.5 ± 2.4	53.3 ± 2.0

¹ Distillers dried grains with solubles (292 g kg⁻¹ crude protein, 81 g kg⁻¹ crude fat).

² High-protein distillers dried grains without soluble (418 g kg⁻¹ crude protein, 38 g kg⁻¹ crude fat).

³ Distillers solubles (900 g kg⁻¹ dry matter basis; 202 g kg⁻¹ crude protein, 208 g kg⁻¹ crude fat).

⁴ Distillers solubles from corn endosperm (900 g kg⁻¹ dry matter basis; 193 g kg⁻¹ crude protein, 52 g kg⁻¹ crude fat).

⁵ Includes 50 g kg⁻¹ cottonseed meal, 50 g kg⁻¹ wheat middlings, 30 g kg⁻¹ meat and bone/blood meal (pork product), 0.5 g kg⁻¹ vitamin premix, 0.5 g kg⁻¹ ascorbyl monophosphate, 10 g kg⁻¹ trace mineral mix, and 20 g kg⁻¹ carboxymethyl cellulose as pellet binder. Vitamin and trace mineral premixes were the same as described by Robinson & Li (2007).

⁶ Value represent mean ± SD (*n* = 2, two batches per diet).

⁷ Expressed as 90 g kg⁻¹ dry matter basis.

each feeding. Dead fish, if any, were removed from the aquarium and weighed. Aquaria were cleaned weekly.

Fish in each aquarium were counted and group weighed every 3 weeks. At the end of the feeding period, diet consumption and weight gain per fish, FER, and survival were calculated. Feed efficiency ratio was determined as follows:

$$\text{FER} = \frac{[\text{final fish weight, g per tank}] - [\text{initial fish weight, g per tank}] + [\text{weight gain of dead fish, g per tank}]}{[\text{total feed fed, g per tank}]}$$

After the final fish number and weight were determined, five fish from each aquarium were killed by an overdose (500 mg L⁻¹) of tricaine methanesulfonate (MS-222TM; Argent Chemical Laboratories, Redmond, WA, USA). Fillet samples were removed from these fish, pooled by aquarium and stored at -20 °C for subsequent proximate analyses. The fillet samples were homogenized into a paste by means of a Grindomix GM-200 Knife Mill (Retsch GmbH, Haan, Germany) and part of the sample was lyophilized with a Freezone Freeze Dry System (Labconco, Kansas City, MO, USA) for 16–18 h for protein and fat analyses. Proximate analyses were performed in duplicate on the composite samples with methods described by AOAC (2000). Crude protein of diet and fillet samples was analysed by combustion method with the FP-2000 protein determinator (Leco Corporation, St. Joseph, MI, USA), crude fat by ether extraction with the Soxtec System (Foss North America, Inc., Eden Prairie, MN, USA), moisture by oven drying with a mechanical convection oven (Precision, Winchester, VA, USA), and ash with a muffle furnace (Type 30400; Barnstead Thermolyne Corporation, Dubuque, IA, USA).

Data were subjected to one-way analysis of variance (ANOVA) and the Fisher's protected least-significant-difference procedure (Steel *et al.* 1997) with the Statistical Analysis System version 9.1 software (SAS Institute 2004). Aquaria were the experimental units and variation among aquaria within a treatment was used as the experimental error in tests of significance. A significance level of 0.05 was used.

Results

Significant differences among dietary treatments were observed for diet consumption, weight gain and FER, but not for survival (Table 2). Fish fed the control + fat diet consumed significantly more diet and had a higher FER than fish fed the control diet, but weight gain was not significantly different between fish fed these two diets. Fish fed the 300 g kg⁻¹ DDGS diet consumed more diet and gained more weight, but had a similar FER compared with fish fed the control diet with additional fat. The 200 g kg⁻¹

Table 2 Mean¹ feed consumption, weight gain, feed efficiency ratio and survival of juvenile channel catfish fed various experimental diets for 9 weeks

Diet description	Feed consumption ² (g per fish)	Weight gain ³ (g per fish)	Feed efficiency ratio ²	Survival (%)
Control	81.9 d	116.5 c	0.703 c	100.0
Control + fat	91.3 c	124.8 c	0.731 b	99.0
300 g kg ⁻¹ DDGS ⁴	103.5 b	137.2 ab	0.752 ab	100.0
200 g kg ⁻¹ HPDDG ⁵	92.5 c	124.2 c	0.744 ab	100.0
100 g kg ⁻¹ DS ⁶	111.7 a	144.1 a	0.775 a	100.0
100 g kg ⁻¹ EDS ⁷	103.3 b	133.4 b	0.775 a	100.0
Pooled SEM	2.8	3.0	0.009	0.4

¹ Mean values represent average values of five tanks per diet. Mean values within each column followed by different letter were different ($P \leq 0.05$, the Fisher's protected least-significant-difference procedure).

² Based on 900 g kg⁻¹ dry matter of the diet.

³ Initial weight was 12.6 g per fish.

⁴ Distillers dried grains with solubles (292 g kg⁻¹ crude protein, 81 g kg⁻¹ crude fat).

⁵ High-protein distillers dried grains without solubles (418 g kg⁻¹ crude protein, 38 g kg⁻¹ crude fat).

⁶ Distillers solubles (900 g kg⁻¹ dry matter basis; 202 g kg⁻¹ crude protein, 208 g kg⁻¹ crude fat).

⁷ Distillers solubles from corn endosperm (900 g kg⁻¹ dry matter basis; 193 g kg⁻¹ crude protein, 52 g kg⁻¹ crude fat).

HPDDG diet resulted in similar diet consumption, weight gain, and FER as the control + fat diet. Fish fed the 100 g kg⁻¹ DS diet had higher diet consumption and weight gain, but had a similar FER compared with fish fed the 100 g kg⁻¹ EDS diet. Compared with the 300 g kg⁻¹ DDGS diet, the 100 g kg⁻¹ DS diet resulted in significantly higher diet consumption, but similar weight gain and FER.

Fish fed diets containing distillers by-products had lower levels of protein in the fillet than fish fed the control diet (Table 3). There were no significant differences in fillet protein levels among fish fed diets containing distillers by-products. Fish fed the 100 g kg⁻¹ EDS diet had a lower level of fillet protein than fish fed the control and control + fat diets. Fillet fat concentration was significantly higher in fish fed the control + fat diet and the 200 g kg⁻¹ HPDDG, 100 g kg⁻¹ DS and 100 g kg⁻¹ EDS diets than that in fish fed the control diet. Fillet fat level in fish fed the 300 g kg⁻¹ DDGS diet was intermediate, not significantly different from that of fish fed either the control diet or diets containing distillers by-products. Fish fed the control + fat diet, and the 200 g kg⁻¹ HPDDG and 100 g kg⁻¹ DS diets had a significantly lower moisture level in the fillet than fish fed the control diet, but fish fed the 300 g kg⁻¹ DDGS and 100 g kg⁻¹ EDS diets had an intermediate level of fillet moisture.

Table 3 Mean¹ fillet protein, fat and moisture concentrations of juvenile channel catfish fed various experimental diets for 9 weeks

Diet description	Fillet protein ² (g kg ⁻¹)	Fillet fat ² (g kg ⁻¹)	Fillet moisture (g kg ⁻¹)
Control	170.6 a	61.7 b	755.6 a
Control + fat	168.5 ab	75.1 a	743.6 b
300 g kg ⁻¹ DDGS ³	167.5 bc	69.4 ab	749.7 ab
200 g kg ⁻¹ HPDDG ⁴	166.1 bc	78.2 a	743.3 b
100 g kg ⁻¹ DS ⁵	166.2 bc	78.7 a	741.6 b
100 g kg ⁻¹ EDS ⁶	165.3 c	74.5 a	747.4 ab
Pooled SEM	1.1	3.5	3.1

¹ Mean values represent average values of five tanks with five fish per tank. Mean values within each column followed by different letter were different ($P \leq 0.05$, the Fisher's protected least-significant-difference procedure).

² On wet-tissue basis.

³ Distillers dried grains with solubles.

⁴ High-protein distillers dried grains without solubles.

⁵ Distillers solubles (900 g kg⁻¹ dry matter basis).

⁶ Distillers solubles from corn endosperm (900 g kg⁻¹ dry matter basis).

Discussion

Robinson & Li (2008) reported that the use of 300–400 g kg⁻¹ DDGS with supplemental lysine to partially replace soybean meal in the diet improved FER of pond-raised channel catfish. Results from the present laboratory study with juvenile channel catfish support this observation. Because DDGS contain a high level of crude fat (about 90 g kg⁻¹) (Dale & Batal 2006) and high dietary fat may affect FER, a control + fat diet (total fat level equal to that of the 300 g kg⁻¹ DDGS diet) was included in the present study to examine the role of dietary fat level on channel catfish growth and FER. Fish fed the control + fat diet had a better FER than fish fed the control diet. This suggests that the increase in dietary fat level is at least partially responsible for the improved FER of fish fed the 300 g kg⁻¹ DDGS diet. However, the increase in dietary fat levels does not account for all improvements in diet consumption and weight gain of fish fed the 300 g kg⁻¹ DDGS diet because this diet resulted in better diet consumption and weight gain than the control + fat diet. Although the FER between fish fed the control + fat diet and the 300 g kg⁻¹ DDGS was not significantly different (0.731 versus 0.752, $P = 0.10$), fish fed diets containing 100 g kg⁻¹ DS and 100 g kg⁻¹ EDS had a significantly higher FER than fish fed the control + fat diet even though these diets had similar fat levels, suggesting that there might be other factors (such as brewers yeast and free amino acids present in the DS) in the diets containing 100 g kg⁻¹ DS and

100 g kg⁻¹ EDS, besides fat, that were also involved in improving fish performance.

The HPDDG does not contain solubles and there were no significant differences in diet consumption, weight gain, and FER between fish fed the 200 g kg⁻¹ HPDDG diet and the control + fat diet. This indirectly supports the assertion that improvements in diet consumption and weight gain of fish fed the 300 g kg⁻¹ DDGS diet and the improvement of diet consumption, weight gain and FER in fish fed the 100 g kg⁻¹ DS and 100 g kg⁻¹ EDS diets in the present study were a result of the solubles present in the diets.

During production of ethanol from corn, yeast, typically brewers yeast, *Saccharomyces cerevisiae*, are used to facilitate the fermentation process. Distillers dried grains with solubles are estimated to contain about 39 g kg⁻¹ yeast cells (Ingledew 1999). Studies conducted with hybrid striped bass, *Morone chrysops* × *Morone saxatilis* (Li & Gatlin 2005), and sea bass, *Dicentrarchus labrax* (Oliva-Teles & Goncalves 2001), show that the use of brewers yeast in the diet improves FER. Yeast cells contain 50–120 g kg⁻¹ nucleic acids from which nucleotide, inosine-5'-monophosphate, is derived (Tacon & Jackson 1985). Inosine-5'-monophosphate has been shown to stimulate gustatory sensory cells in several fish including jack mackerel, *Trachurus symmetricus* (Ikeda *et al.* 1991), largemouth bass, *Micropterus salmoides* (Kubitza *et al.* 1997), and red drum, *Sciaenops ocellatus* (Li *et al.* 2007).

It has been reported that free amino acids L-proline, L-alanine and L-arginine and their mixtures are effective stimuli for gustatory responses of channel catfish (Caprio 1975, 1982). The 300 g kg⁻¹ DDGS, 200 g kg⁻¹ HPDDG, 100 g kg⁻¹ DS and 100 g kg⁻¹ EDS contained 4.8–6.1 g kg⁻¹ and diets using these ingredients contained 0.4–1.0 g kg⁻¹ of these free amino acids (analysed by Eurofins Scientific Inc., Des Moines, IA, USA, using an AOAC method), whereas other ingredients used in the present study did not contain detectable levels of these free amino acids. However, it is unlikely that these free amino acids played a major role in the improvement of diet intake in fish fed the diets containing DS (300 g kg⁻¹ DDGS, 100 g kg⁻¹ DS and 100 g kg⁻¹ EDS diets) because the 200 g kg⁻¹ HPDDG diet contained levels of free amino acids similar to that of diets containing DS, but the feed consumption of fish fed the 200 g kg⁻¹ HPDDG diet was significantly lower than that of fish fed the diets containing DS.

Fish fillet proximate composition generally reflected the dietary proximate composition. All diets except the control were formulated to contain about the same levels of fat (28.7 g kg⁻¹ for the control versus 50.5–57.7 g kg⁻¹ for all

other diets). With exception for the 300 g kg⁻¹ DDGS diet, elevated dietary fat levels resulted in significantly higher fillet fat levels. This is anticipated as fish body fat deposition increases with increasing dietary fat levels (Robinson & Li 2007; Yildirim-Aksoy *et al.* 2007). In the present study, fish fed the 300 g kg⁻¹ DDGS diet had 69.4 g kg⁻¹ fillet fat, which was not significantly different from that of fish fed the control diet (61.6 g kg⁻¹ fillet fat). However, previous laboratory and pond studies have shown that the use of 300–350 g kg⁻¹ DDGS in the diet significantly increases fat deposition in channel catfish (Webster *et al.* 1991; Robinson & Li 2008). Although the use of 300 g kg⁻¹ of DDGS in the diet increases body fat content of the fish in the present study, the total fat level in the diet was still below the maximum level of 60 g kg⁻¹ recommended for channel catfish (Robinson & Li 2007).

We noted that fish fed the diets containing 200 g kg⁻¹ HPDDG and 300 g kg⁻¹ DDGS had distinct yellow colour on the skin and slight yellow colour on the fillet compared with the greyish colour of fish fed the control and other diets. The 200 g kg⁻¹ HPDDG and 300 g kg⁻¹ DDGS diets contained 14–17 mg kg⁻¹ yellow pigments (lutein and zeaxanthin) (analysed by Craft Technologies, Inc., Wilson, NC, USA, using a HPLC method), which was higher than the 11 mg kg⁻¹ threshold for yellow colouration to show in the catfish flesh (Lovell 1989). Other diets contained 5.9–8.8 mg kg⁻¹ yellow pigments. Yellow pigment concentrations vary from product to product, which have been reported to range from 10.6 to 34 mg kg⁻¹ (Roberson *et al.* 2005). Therefore, yellow pigments in distillers by-products should be monitored before its use to ensure that they do not exceed 11 mg kg⁻¹.

In summary, results from the present study demonstrate that elevated fat levels in diets containing distillers by-products are partially responsible for the improvement in diet consumption and FER of fish fed the distillers by-products. The presence of DS in the diet appears to further increase diet consumption and FER, and also improve weight gain over the control diets with or without additional fat. Dietary levels of 300 g kg⁻¹ DDGS and 100 g kg⁻¹ DS resulted in higher fillet fat compared with the control diet because of high fat content in these ingredients. Distillers by-products contain yellow pigments, which usually vary from plant to plant in concentrations, thus they should be monitored so that the levels do not affect the appearance of the catfish products. Use of distillers by-products to partially replace soybean meal in channel catfish diets could reduce feed cost when the by-products are competitively priced compared with soybean meal and other protein sources.

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