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Replacement of Soybean Meal in Channel Catfish, *Ictalurus punctatus*, Diets with Cottonseed Meal and Distiller's Dried Grains with Solubles

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Abstract

Two pond experiments were conducted to evaluate cottonseed meal (CSM), distiller's dried grains with solubles (DDGS), and supplemental lysine as replacements for soybean meal (SBM) in channel catfish diets. In Experiment 1, fish fed diets in which SBM was totally replaced with CSM gained similar weight as fish fed control diet, but fish fed CSM diet in Experiment 2 had 9.5% lower weight gain than fish fed control diet. In both experiments, feed conversion increased significantly for fish fed CSM diet. There were no consistent trends in body composition of fish fed CSM diet versus control diet. Fish fed the DDGS + SMB diet had higher (Experiment 1) or similar (Experiment 2) weight gain than fish fed control diet. Feed conversion ratio was significantly lower in both experiments for fish fed SBM + DDGS diet than that of fish fed control diet. Body fat tended to be higher in fish fed SBM + DDGS diet compared to fish fed control diet. It appears that about 50% of SBM can be replaced with CSM + lysine in catfish diets without negatively affecting fish performance. Further, DDGS can be used up to at least 30% when the diet is supplemented with lysine.

Channel catfish, *Ictalurus punctatus*, are typically fed a diet comprised primarily of soybean meal (SBM), corn, and wheat middlings plus a small amount of fish meal, fat, and nutrient supplements (Robinson et al. 2001). Because SBM is a relatively expensive protein source, it would be advantageous to replace all or part of the SBM with more economical protein sources. Two products that we are interested in are cottonseed meal (CSM) and distiller's dried grains with solubles (DDGS). CSM is a locally available product that is generally priced competitively (on a protein basis) with SBM. It is highly palatable to catfish and can be used at levels of 10–15% or higher if supplemental lysine is used without detrimental effects on fish performance (Robinson and Brent 1989; Robinson 1991; Robinson and Li 1993, 1994a, 1994b; Li and Robinson 2006). Also, the use of CSM is not limited by direct toxic affects of gossypol, a compound present in CSM (Dorsa et al. 1982; Li and Robinson 2006). Rather, the factor limiting the use of high levels of CSM in catfish feeds is lysine. That is, gossypol binds to lysine making part of the total lysine inherent in the seed biologically unavailable; thus, if high levels of CSM are used in catfish diets, supplemental lysine must be used.

DDGS, although currently not locally available, may become abundant as ethanol plants come on line as a result of new energy policies and an abundant corn crop in the Southern United States. The product has been successfully used in commercial catfish feeds and experimental diets at levels of 15–30% as a replacement for animal proteins and SBM (Webster et al. 1991; Robinson et al. 2001). DDGS are highly palatable to catfish but contain about 45% of the lysine found in SBM, and therefore, as with CSM, their use at high levels in catfish feeds would require the use of supplemental lysine. Research has shown that all the animal protein in catfish diets can be replaced with SBM, and a portion of the SBM can be replaced by other plant proteins. However, how much of the SBM can be replaced by other plant protein sources is unknown. Therefore, we evaluated a series of diets to replace part or all of the SBM in catfish feeds with CSM and/or DDGS along with supplemental lysine.

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Materials and Methods

Experiment 1

Five practical diets, in which SBM was partially or totally replaced with CSM or a combination of CSM, DDGS, and supplemental lysine (Table 1), were formulated based on digestible nutrients and energy to meet or exceed all known nutritional requirements of channel catfish (NRC 1993; Robinson et al. 2001). The digestible energy (DE) of each diet was estimated based on tabular values of NRC (1993) and Robinson et al. (2001). The experimental diets were not formulated to be isocaloric because in commercial feed formulations, there is no practical method to adjust DE value and maintain dietary fat and fiber levels in desirable ranges. The diets were manufactured as extruded floating pellets in an experimental feed mill at the Delta Western Research Center (DWRC), Indianola, MS, USA. Fresh lots of each feed were manufactured monthly. All dietary ingredients were obtained from the DWRC and were from commercial sources. Dietary crude protein levels (Table 1) were verified by the combustion method (AOAC 2000) using an FP-2000 protein determinator (Leco Corp., St. Joseph, MI, USA), and crude fat levels were determined by acid hydrolysis followed by ether extraction (AOAC 2000) using a Soxtec system (Foss North America, Inc., Eden Prairie, MN, USA)

Fingerling channel catfish averaging 48 g/fish were stocked into twenty-five, 0.04-ha ponds at a density of 14,820 fish/ha at the DWRC. Five ponds were randomly allotted to each dietary treatment in a complete randomized design. Fish were fed once daily to apparent satiation for 330 d in two growing seasons (from mid-April to the end of September). During each growing season, fish were allowed to eat as much as they would consume in 20 min to achieve apparent satiation. Amounts of diet consumed by the fish in each pond were recorded daily to determine diet consumption per fish at the end of the study.

TABLE 1. *Ingredient and proximate composition of experimental diets (percentage, as fed) used in Experiment 1.*

	Main dietary protein source				
Ingredient	SBM	SBM + CSM	CSM	CSM + DDGS	SBM + DDGS
SBM (48%)[a]	42.50	20.00	0.00	0.00	30.00
CSM (41%)	0.00	27.65	53.75	44.00	0.00
DDGS (29%)	0.00	0.00	0.00	18.75	30.00
Menhaden fish meal (61%)	1.00	1.00	1.00	1.00	1.00
Corn grain	33.90	28.85	27.40	25.85	28.38
Wheat middlings	20.00	20.00	15.00	7.50	8.00
Lysine HCl[b]	0.00	0.40	0.75	0.80	0.28
Dicalcium phosphate	1.00	0.50	0.50	0.50	0.75
Vitamin mix[c]	0.05	0.05	0.05	0.05	0.05
Trace mineral mix[c]	0.05	0.05	0.05	0.05	0.05
Menhaden oil[d]	1.50	1.50	1.50	1.50	1.50
DE/P ratio[e] (kcal/g)	10.3	9.9	9.5	9.4	9.8
Proximate composition (%)					
Dry matter	90.2 ± 0.8	90.4 ± 0.7	90.6 ± 1.4	92.0 ± 1.2	91.7 ± 0.5
Crude protein[f]	28.1 ± 0.6	28.2 ± 0.5	28.5 ± 0.6	27.6 ± 1.1	27.2 ± 0.8
Crude fat[f]	5.7 ± 0.6	7.0 ± 1.7	5.8 ± 0.0	7.5 ± 0.4	7.1 ± 0.5

SBM = soybean meal; CSM = cottonseed meal; DDGS = distiller's dried grains with solubles.

[a] Numbers in parentheses represent percentage crude protein.

[b] Contained 78% lysine.

[c] Same as described by Robinson et al. (2001).

[d] Sprayed on the finished pellets.

[e] DE/P ratio = digestible energy to crude protein ratio. The DE was estimated based on tabular values of NRC (1993) and Robinson et al. (2001).

[f] 90% dry matter basis.

During the growing season, water temperature and dissolved oxygen were measured in early morning, mid-afternoon, and throughout the night using a YSI model 58 polarographic oxygen meter (Yellow Springs Instrument Co., Yellow Springs, OH, USA). Emergency aeration was provided by a 0.5-horsepower electrical aerator (Model AF-55, Air-O-Lator Corp., Kansas City, MO, USA) and used in each pond when dissolved oxygen levels decreased to 4 mg/L (Tucker and Robinson 1990). Aerators were turned off at about 0700 h when dissolved oxygen levels began to increase. Total ammonia–nitrogen, nitrite–nitrogen (NO_2^-–N), and pH were measured weekly during each growing season at approximately 1300–1600 h using a field kit (Hach Chemical Co., Loveland, CO, USA). Water quality was maintained in ranges considered adequate for optimum fish performance (Tucker and Robinson 1990). Chloride concentration was maintained at ≥50 mg/L to alleviate possible nitrite toxicity. Dead fish were removed from ponds, weighed, and recorded for correction of feed conversion ratio (FCR) at the end of the study.

At the end of the study, 30 fish from each pond ranging from approximately 680 to 1135 g/fish were selected and stunned by a 40-V electric pulse (Sylvesters, Inc., Louisville, MS, USA). Fish from each pond were weighed collectively and headed mechanically (Baader North America, Indianola, MS, USA). The fish were then eviscerated, and the visceral fat was removed manually. Finally, the dressed carcasses were filleted and skinned by a fillet machine (Baader) and trimmed manually. Weight data were recorded for whole weight, visceral fat, head-gutted carcass, shank fillet, and nugget. Yield was determined as a percentage of whole fish weight. Fillets (1 fillet per fish, 10 fish per pond) were stored at −20 C for subsequent proximate analyses. After fish were sampled for processing, all fish from each pond were harvested, counted, and weighed.

Individual fillet samples were separately ground into a paste using a food processor. A 25-g ground fillet sample from each of 10 fish per pond was pooled and reground and mixed as a composite sample. Part of the composite 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 conducted in triplicate on the composite samples with methods described by AOAC (2000). Crude protein was analyzed by the combustion method using an FP-2000 protein determinator (Leco Corp.), crude fat by ether extraction using a Soxtec system (Foss North America, Inc.), and moisture by oven drying using a mechanical convection oven (Precision, Winchester, VA, USA).

Data on production characteristics, processing yield, and fillet composition were subjected to ANOVA and the Fisher's protected LSD procedure (Steel et al. 1997) using Statistical Analysis System version 8.0 software (SAS Institute, Inc., Cary, NC, USA). Data on survival were arcsine transformed before statistical analysis was performed. Pond was used as the experimental unit, and variation among ponds within a treatment was used as the experimental error in tests of significance. A significance level of $P \leq 0.05$ was used.

Experiment 2

Three diets, in which SBM was replaced in part with DDGS + supplemental lysine or totally with CSM + supplemental lysine, were evaluated in this experiment (Table 2). Fingerling channel catfish averaging 65 g/fish were stocked into fifteen, 0.04-ha ponds at a rate of 14,820 fish/ha at the DWRC. Five ponds were randomly allotted to each dietary treatment in a complete randomized design. Fish were fed once daily to apparent satiation for 120 d in one growing season. Procedures for diet formulation and preparation, pond management, determination of processing yield and fillet composition, water quality analysis, and statistical analysis of the data were the same as described for Experiment 1, except that fish sampled for processing yield determination were smaller than those used in Experiment 1 (approximately 570–795 g).

Results

Experiment 1

There were no significant differences in diet consumption or survival among fish fed

TABLE 2. *Ingredient and proximate composition of experimental diets (percentage, as fed) used in Experiment 2.*

Ingredient	Main dietary protein source		
	SBM	SMB + DDGS	CSM
SBM (48%)[a]	42.50	27.10	0.00
CSM (41%)	0.00	0.00	53.75
DDGS (27%)	0.00	40.00	0.00
Menhaden fish meal (61%)	1.00	1.00	1.00
Corn grain	33.90	25.00	27.40
Wheat middlings	20.00	3.75	15.00
Lysine HCl[b]	0.00	0.40	0.75
Dicalcium phosphate	1.00	1.15	0.50
Vitamin mix[c]	0.05	0.05	0.05
Trace mineral mix[c]	0.05	0.05	0.05
Menhaden oil[d]	1.50	1.50	1.50
DE/P ratio[e] (kcal/g)	10.2	9.9	9.5
Proximate composition (%)			
Dry matter	92.4 ± 0.3	93.6 ± 1.1	93.2 ± 0.1
Crude protein[f]	28.0 ± 0.1	27.5 ± 0.5	28.6 ± 2.5
Crude fat[f]	5.0 ± 0.0	8.3 ± 0.2	5.1 ± 0.4

SBM = soybean meal; CSM = cottonseed meal; DDGS = distiller's dried grains with solubles.

[a] Numbers in parentheses represent percentage crude protein.

[b] Contained 78% lysine.

[c] Same as described by Robinson et al. (2001).

[d] Sprayed on the finished pellets.

[e] DE/P ratio = digestible energy to crude protein ratio. The DE was estimated based on tabular values of NRC (1993) and Robinson et al. (2001).

[f] 90% dry matter basis.

the various experimental diets. Fish fed the diet that contained CSM as the primary protein source gained less weight than fish fed the diets containing SBM + DDGS or SBM + CSM, but weight gain was the same as for fish fed the SBM control diet (Table 3). Fish fed the CSM diet also had the highest feed conversion. FCR was the highest for fish fed CSM diet and lowest for fish fed the SBM + CSM and SBM + DDGS diets. There were no differences in percentage visceral fat, carcass yield, and nugget yield among fish regardless of diet (Table 4). Fish fed the SBM + DDGS diet had a higher percentage of fillet fat and lower moisture compared with fish fed the other diets. There were no other significant differences in fillet proximate composition.

Experiment 2

Diet consumption was significantly lower for the fish fed the SBM + DDGS diet than the control but not different from the fish fed the CSM diet (Table 5). Weight gain decreased for fish fed the CSM diet compared to fish fed the other diets. FCR was the lowest for fish fed the SBM + DDGS diet and highest for fish fed the CSM diet. There were no differences in fish survival. Visceral fat was higher in fish fed the CSM diet compared to fish fed the SBM control diet, and fillet fat was higher in fish fed the SBM + DDGS diet compared to fish fed the CSM diet (Table 6). There were no other differences in fillet proximate composition nor were there differences in carcass, fillet, or nugget yield.

Discussion

The data that we present herein lead to conclusions that are in general agreement with those from earlier studies that we conducted using CSM to replace SBM (Robinson and

TABLE 3. *Mean[a] production characteristics of channel catfish fed diets containing various levels of CSM and distiller's grains in Experiment 1.*

Main dietary protein source	Diet consumption (g/fish)	Weight gain[b] (g/fish)	Feed conversion (diet/gain)	Survival (%)
SBM	2310	1084bc	2.13b	98.2
SBM + CSM	2263	1151ab	1.97c	99.6
CSM	2315	1019c	2.27a	99.2
CSM + DDGS	2288	1093abc	2.10b	99.6
SBM + DDGS	2327	1179a	1.97c	98.5
Pooled SEM	60	30	0.04	0.6

SBM = soybean meal; CSM = cottonseed meal; DDGS = distiller's dried grains with solubles.

[a] Means within each column followed by different letters are different ($P \leq 0.05$).

[b] Mean initial weight was 48.1 g/fish.

TABLE 4. *Mean[a,b] weight for processed fish, visceral fat, processing yield, and fillet composition of channel catfish fed diets containing various levels of CSM and distiller's grains in Experiment 1.*

Main dietary protein source	Weight of processed fish (g/fish)	Visceral fat (%)	Carcass yield[c] (%)	Fillet yield (%)	Nugget yield (%)	Fillet protein (%)	Fillet fat (%)	Fillet moisture (%)
SBM (control)	1019	3.12	67.6	36.8	9.86	16.4	5.93b	76.5a
SBM + CSM	990	3.58	67.1	36.5	9.55	17.0	6.06b	75.7a
CSM	1011	3.50	66.1	35.8	9.40	17.1	6.38b	75.3a
CSM + DDGS	995	3.65	67.0	36.4	9.57	16.6	6.62b	75.7a
SBM + DDGS	1059	3.40	67.0	36.3	9.58	16.5	8.12a	74.1b
Pooled SEM	31	0.19	0.35	0.4	0.12	0.26	0.28	0.5

SBM = soybean meal; CSM = cottonseed meal; DDGS = distiller's dried grains with solubles.

[a] Means represent average values of five ponds per treatment with 30 fish per pond.

[b] Means in each row followed by different letters are different ($P \leq 0.05$).

[c] Carcass yield is a percentage of the carcass (without head and viscera) weight relative to whole fish weight.

Brent 1989; Robinson 1991; Robinson and Li 1993, 1994a, 1994b, 2005; Li and Robinson 2006) and with those of Lim et al. (2004). That is, relatively high levels of CSM + supplemental lysine can be used in channel catfish feeds to replace at least 50% of the SBM but cannot be used to completely replace SBM in catfish diets without negatively affecting fish performance. In the present studies, fish fed diets in which SBM was totally replaced with CSM gained as much weight as fish fed the SBM control diet in Experiment 1, but weight gain of fish in Experiment 2 was about 9.5% lower for fish fed the CSM diet compared to fish fed the SBM control diet.

In both experiments, FCR increased significantly for fish fed the CSM diet. There were no differences or consistent trends in regard to body composition of fish fed the SBM control diet versus the CSM diet. Although catfish may grow relatively well on diets in which all the SBM is replaced with CSM plus supplemental lysine, the diets are not utilized as efficiently. We do not know the reason for this response, but it could be in part because of a significant increase in the fiber content in the high CSM diets, which may have negatively affected nutrient digestibility or reduced available energy. DE was estimated to be lower in the CSM diet compared to the SBM control diet, but this may not have been the case because visceral and fillet fat deposition were as high or higher (visceral fat in Experiment 2) in fish fed the CSM diet as compared with those fed the SBM control diet. Or it could be an imbalance in protein quality that we are unaware of. Another consideration is the concentration of free gossypol in the diet, but this is unlikely that the problem is the result of a direct toxic effect of free gossypol, at least at levels that would have been found in our diets or those typically encountered in catfish diets (Dorsa et al. 1982; Li and Robinson 2006).

TABLE 5. *Mean[a] production characteristics of channel catfish fed diets containing various levels of CSM and distiller's grains in Experiment 2.*

Main dietary protein source	Diet consumption (g/fish)	Weight gain[b] (g/fish)	Feed conversion (diet/gain)	Survival (%)
SBM (control)	1022a	571a	1.79b	95.3
SBM + DDGS	947b	577a	1.64c	95.0
CSM	978ab	517b	1.89a	96.9
Pooled SEM	19	12	0.04	1.3

SBM = soybean meal; CSM = cottonseed meal; DDGS = distiller's dried grains with solubles.

[a] Means within each column followed by different letters are different ($P \leq 0.05$).

[b] Mean initial weight was 65 g/fish.

DDGS is a product that has been used in commercial catfish diets on occasion at levels up to 20% of the diet to partially replace SBM. The inclusion rates were based on a study that we conducted a number of years ago (summarized in Robinson and Li 2005) in which 22.5% DDGS was used to replace part of the SBM and fed to channel catfish in experimental ponds. The present studies demonstrate that up to 30–40% DDGS with supplemental lysine

TABLE 6. *Mean[a,b] weight for processed fish, visceral fat, processing yield, and fillet composition of channel catfish fed diets containing various levels of CSM and distiller's grains in Experiment 2.*

Main dietary protein source	Weight of processed fish (g/fish)	Visceral fat (%)	Carcass yield[c] (%)	Fillet yield (%)	Nugget yield (%)	Fillet protein (%)	Fillet fat (%)	Fillet moisture (%)
SBM (control)	701	3.80b	66.6	35.7	9.13	17.2	7.48ab	74.0
SBM + DDGS	749	4.16ab	66.2	35.1	8.96	17.4	8.37a	72.7
CSM	636	4.76a	65.9	35.1	8.95	17.0	6.43b	75.2
Pooled SEM	34	0.22	0.3	0.3	0.09	0.18	0.47	0.6

SBM = soybean meal; DDGS = dried distiller's grains with solubles; CSM = cottonseed meal.

[a] Means represent average values of five ponds per treatment with 30 fish per pond.

[b] Means in each column followed by different letters are different ($P \leq 0.05$).

[c] Carcass yield is a percentage of the carcass (without head and viscera) weight relative to whole fish weight.

can be used to partially replace SBM in channel catfish diets without adversely affecting fish performance. This is in general agreement with previous aquarium and net cage studies, which showed that up to 30–35% DDGS could be used to partially replace SBM in channel catfish diets (Webster et al. 1991, 1992, 1993).

FCR in the present study was significantly lower in both Experiments 1 and 2 for fish fed the SBM + DDGS diet compared to those fed a SBM control diet. The FCR was not improved when DDGS was used in conjunction with CSM (CSM + DDGS). This implies that the SBM control diet was improved by the addition of DDGS, but we are unable to determine the reason for this response. This has not been seen in previous studies (Webster et al. 1991, 1992, 1993; Robinson and Li 2005). All the diets met or exceeded the nutrient and energy requirements for channel catfish (NRC 1993; Robinson et al. 2001). It appears that we may have underestimated the DE value for DDGS because in Experiment 1, there was a significant increase in fillet fat for fish fed the SBM + DDGS diet compared with those fed the SBM control diet. The difference was not significant in Experiment 2, but both visceral and fillet fat tended to be higher in fish fed the SBM + DDGS diet compared with fish fed the SBM control diet. We saw a similar trend in fillet fat in our earlier study with DDGS. DDGS contain about 9% crude fat (Dale and Batal 2006), which is considerably higher than other commonly used feed ingredients in channel catfish diets. Crude fat concentrations in diets containing DDGS were higher than control diets in the present study. It is anticipated that high dietary fat levels result in more fat deposit in the body. However, the higher fat and possibly higher DE levels in diets containing DDGS would not account for the improved FCR of fish fed this diet because all the experimental diets contained an excess of DE. There were no differences in performance of fish fed the CSM + DDGS diet compared to those fed the SBM control diet.

In conclusion, it appears that about 50% of SBM can be replaced with CSM + supplemental lysine in channel catfish diets without negatively affecting fish performance. Further, DDGS appears to be a suitable ingredient for use in catfish diets at least at levels up to 30% or so when the diet is supplemented with lysine. Because DDGS is a by-product of ethanol production, it is becoming more abundant at an attractive price, which should increase its use in catfish diets. However, historically, the product has not been consistent in nutrient content. Until that problem is resolved, its use in catfish diets will be limited. Based on current ingredient prices, the use of CSM and DDGS to replace SBM would reduce feed cost by 10–20%.

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