Effects of Dietary Fiber Concentrations Supplied by Corn Bran on Feed Intake, Growth, and Feed Efficiency of Channel Catfish

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Abstract
The present study examined the effects of dietary fiber and digestible energy on the feed intake, growth, and feed efficiency of juvenile channel catfish *Ictalurus punctatus*. Fish with an initial weight of 9.8 ± 0.1 g/fish (mean ± SD) were stocked in 110-L flow-through aquariums and fed for 9 weeks with practical diets that contained graded levels of fiber supplied by corn bran. As total dietary fiber (TDF) increased, feed consumption and weight gain increased and then decreased, showing a quadratic response. Maximum feed consumption occurred at a TDF level of 27.0% (5.7% crude fiber, 19.1% neutral detergent fiber [NDF]). Channel catfish appear to have some ability to adapt to increased dietary fiber by increasing feed intake to satisfy their energy requirements. Maximum weight gain was achieved at a TDF level of 23.4% (5.0% crude fiber, 15.7% NDF), indicating that the presence of dietary fiber at certain levels is beneficial to the fish. The maximum tolerance level for TDF by channel catfish was estimated to be 32.1% (6.6% crude fiber, 24.9% NDF). Feed efficiency, hepatosomatic index, and body fat decreased linearly with increasing dietary fiber. The maximum fiber tolerance levels may be used as upper limits for fiber when formulating practical diets for catfish containing corn by-products.

Fish generally cannot digest or utilize dietary fiber because of the lack of certain enzymes, such as \( \alpha \)-cellulase, and appropriate fiber-utilizing microorganisms in the digestive system. As traditional feedstuffs, such as soybean meal and corn, become more expensive, more alternative feed ingredients, such as corn gluten feed and distillers dried grains with solubles, are being used in commercial channel catfish *Ictalurus punctatus* diets. These alternative feedstuffs contain higher levels of fiber than traditional feedstuffs. Knowing the levels of dietary fiber that channel catfish can tolerate will allow fish nutritionists to better formulate the diets that optimize catfish growth and feed efficiency at a lower cost.

Fiber is an inherent dietary component. It serves as a source of bulk that facilitates the passage of ingesta through the digestive tract (Ensminger et al. 1990). There have been few reports on the optimum levels of dietary fiber for fish. Dupree and Sneed (1966) reported that channel catfish grew faster on a chemically defined diet containing 21% cellulose than on a basal diet without cellulose. Leary and Lovell (1975) found that channel catfish fed practical diets containing 14–20% crude fiber (mostly cellulose) gained significantly less weight than fish fed a basal diet containing 2% crude fiber, and fish fed a diet with 8% fiber had intermediate weight gain, but not significantly different from fish fed diets containing 2, 14, or 20% fiber. Channel catfish diets are generally recommended to contain less than 7% crude fiber (Lovell 1989; Robinson et al. 2004). Rainbow trout *Oncorhynchus mykiss* fed a diet containing 10% cellulose had intermediate weight gain compared with fish fed diets containing either 0% or 20% cellulose (Hilton et al. 1983). Weight gain and dry matter digestibility generally decreased as dietary cellulose levels increased, although the trout had some ability to adapt to increased dietary fiber by increasing feed consumption and gastric evacuation rate. A dietary fiber level of less than 10% was recommended for rainbow trout. Nile tilapia *Oreochromis*
niloticus fed a diet containing 10% cellulose had reduced weight gain, feed efficiency, intestinal glucose absorption, and blood glucose concentrations relative to fish fed a basal diet without cellulose (Shiau et al. 1989). Dioundick and Stom (1990) reported that Mossambique tilapia O. mossambicus tolerated 5.0–7.5% cellulose in the diet without affecting growth and feed efficiency, but at 10% dietary cellulose, growth was depressed. Recently, Glencross (2009) demonstrated that as dietary fiber levels increased, digestibility of dry matter, protein, and energy by rainbow trout generally decreased, and different fiber classes had distinctly different effects on dietary nutrient digestibility.

Dietary fiber represents the indigestible or non-utilizable portion of carbohydrates of plant-based feedstuffs and includes lignin, cellulose, hemicelluloses, pectin and gums, β-glucans, and part of fructan polysaccharides (NRC 2011). Earlier studies with channel catfish (Dupree and Sneed 1966; Leary and Lovell 1975) used cellulose as the dietary fiber source, which may not represent all types of fiber in a commercial catfish diet. The present study was initiated to examine the effects of dietary fiber concentrations, supplied by corn bran in practical diets, on growth, feed efficiency, and body composition of channel catfish.

**METHODS**

Six isonitrogenous and isolipidic practical diets were formulated to contain 28% crude protein and 4% crude fat (Table 1). Corn bran, a natural source of dietary fiber, was used as the fiber source incorporated at 0, 10, 15, 20, 25, and 30% of the diet as fed. These diets met or exceeded all known nutrient requirements of channel catfish (NRC 2011). The corn bran was provided by Bunge Milling, St. Louis, Missouri. Remaining dietary ingredients were obtained from the Delta Western Feed Mill, Indianola, Mississippi, and were from commercial sources. The corn bran contained 15.3% crude fiber, 72.5% neutral detergent fiber (NDF), and 78.2% total dietary fiber (TDF), as analyzed by Eurofins Scientific, Des Moines, Iowa. Crude fiber and TDF of corn bran and experimental diets were analyzed using Association of Official Analytical Chemists methods 962.09 and 991.43, respectively (AOAC International 2000). Neutral detergent fiber was analyzed by means of the ANKOM method (ANKOM Technology 2003). The diets were prepared as sinking pellets according to procedures described previously (Li et al. 1993) and stored at −20°C until used.

Juvenile channel catfish were obtained from the U.S. Department of Agriculture, Agricultural Research Service’s Catfish Genetics Research Unit, Stoneville, Mississippi. Forty fish were stocked into each of thirty, 110-L, flow-through aquariums at the Thad Cochran National Warmwater Aquaculture Center (NWAC), Mississippi State University, Stoneville. The aquariums were supplied with well water (flow rate: approximately 1 L/min) and continuous aeration. Water temperature and dissolved oxygen (DO) were monitored in the aquariums once daily with a YSI oxygen meter (Yellow Springs Instruments, Yellow Springs, Ohio) and maintained at 30 ± 1°C and at or above 5 mg/L DO, respectively. A natural diurnal cycle of 14 h light: 10 h dark was used. The water temperature was regulated by a computer controlled heat exchanger.

**TABLE 1.** Ingredient and proximate compositions of experimental diets for channel catfish.

<table>
<thead>
<tr>
<th>Ingredient and composition</th>
<th>0</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ingredient (%, as fed)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean meal (dehulled)</td>
<td>42.25</td>
<td>42.90</td>
<td>43.22</td>
<td>43.55</td>
<td>43.87</td>
<td>44.20</td>
</tr>
<tr>
<td>Corn grain</td>
<td>37.55</td>
<td>26.84</td>
<td>21.49</td>
<td>16.13</td>
<td>10.78</td>
<td>5.42</td>
</tr>
<tr>
<td>Corn bran</td>
<td>0.00</td>
<td>10.00</td>
<td>15.00</td>
<td>20.00</td>
<td>25.00</td>
<td>30.00</td>
</tr>
<tr>
<td>Corn oil</td>
<td>0.00</td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>Other ingredientsa</td>
<td>20.20</td>
<td>20.20</td>
<td>20.20</td>
<td>20.20</td>
<td>20.20</td>
<td>20.20</td>
</tr>
<tr>
<td><strong>Proximate analysis (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry matter</td>
<td>88.93</td>
<td>89.85</td>
<td>90.24</td>
<td>90.09</td>
<td>90.14</td>
<td>90.60</td>
</tr>
<tr>
<td>Crude proteinb</td>
<td>28.98</td>
<td>28.94</td>
<td>29.18</td>
<td>29.60</td>
<td>29.60</td>
<td>28.48</td>
</tr>
<tr>
<td>Crude fatb</td>
<td>3.90</td>
<td>3.88</td>
<td>4.02</td>
<td>4.13</td>
<td>4.21</td>
<td>4.15</td>
</tr>
<tr>
<td>Crude fiberb</td>
<td>3.4</td>
<td>4.8</td>
<td>5.4</td>
<td>5.9</td>
<td>6.8</td>
<td>7.6</td>
</tr>
<tr>
<td>Neutral detergent fiberb</td>
<td>7.9</td>
<td>14.1</td>
<td>17.0</td>
<td>23.3</td>
<td>24.3</td>
<td>27.5</td>
</tr>
<tr>
<td>Total dietary fiberb</td>
<td>14.7</td>
<td>22.6</td>
<td>25.8</td>
<td>29.4</td>
<td>32.9</td>
<td>36.2</td>
</tr>
<tr>
<td>Digestible energy (kcal/g)c</td>
<td>2.84</td>
<td>2.65</td>
<td>2.56</td>
<td>2.47</td>
<td>2.38</td>
<td>2.29</td>
</tr>
</tbody>
</table>

aIncludes 5.0% poultry by-product meal, 5.0% cottonseed meal, 5.0% wheat middlings, 2.0% menhaden fish oil, 1.0% dicalcium phosphate, 2.0% carboxymethyl cellulose (pellet binder), 0.05% vitamin premix, 0.05% L-ascorbyl monophosphate, and 0.1% trace mineral premix. Vitamin and trace mineral premixes were the same as described by Robinson and Li (1996).

bExpressed as 90% dry matter basis.

cThe digestible energy was estimated based on tabular values of Robinson and Li (1996) and NRC (2011).
Before initiation of the experiment, the fish were acclimated for 2 weeks and fed the basal diet (diet 1) once daily to apparent satiation at 0800 hours. After acclimation, all fish were pooled and graded to a uniform size, and 20 fish were collectively weighed and restocked into each aquarium. Initial fish weight was determined to be 9.8 ± 0.1 g/fish (mean ± SD). 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 a 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 each feeding. Dead fish, if any, were removed daily from the aquarium and weighed. Aquariums were cleaned weekly.

At the end of the feeding period, feed consumption and weight gain per fish, feed efficiency ratio (FER), and survival were calculated. Total feed fed was corrected to the 90% dry matter basis. Feed efficiency ratio was determined for fish in each tank as follows:

\[
\text{FER} = \frac{\text{final fish weight} - \text{initial fish weight} + \text{weight of dead fish}}{\text{total feed fed}}.
\]

After the final fish number and weight were determined, five fish from each aquarium were euthanized by an overdose (500 mg/L) of tricaine methanesulfonate (MS-222; Argent Chemical Laboratories, Redmond, Washington), and liver and visceral fat were removed and pooled by aquarium to determine hepatosomatic index (HSI = 100 × liver weight/body weight) and percentage of visceral fat. Fillets were also removed from these fish for proximate nutrient composition analyses. Fillet samples were stored at −20°C until 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 Freezezone Freeze Dry System (Labconco, Kansas City, Missouri) for 16–18 h for protein and fat analyses.

Proximate analyses were performed in duplicate on diets and pooled fillet samples from each aquarium with methods described by AOAC International (2000). Crude protein of diet and fillet samples was analyzed by a combustion method with the FP-2000 protein determinator (Leco Corporation, St. Joseph, Michigan), crude fat was determined by ether extraction with the Soxtec System (Foss North America, Eden Prairie, Minnesota), and moisture content was measured by oven drying with a mechanical convection oven (Precision, Winchester, Virginia).

Linear and quadratic regressions were analyzed on growth, feed consumption, FER, HSI, and percent body fat as a function of TDF by using GraphPad Prism software (GraphPad Software, La Jolla, California). If both linear and quadratic regressions were significant \( (P < 0.05) \), the one with higher \( R^2 \) value was used. For quadratic regressions (total feed fed or weight gain against TDF levels), the maximum total feed fed or weight gain \( (Y_{\text{max}}) \) and their corresponding values of TDF \( (X_{\text{max}}) \) were determined mathematically with the quadratic function. The TDF level above \( X_{\text{max}} \) at which weight gain was the same as that of fish fed the basal diet was considered the tolerance level \( (X_{\text{tol}}) \).

**RESULTS**

Mean survival was 99–100% and did not differ among dietary treatments. As TDF levels increased, feed consumption and weight gain increased and then decreased showing a quadratic response (Figures 1, 2). Maximum feed consumption occurred at a TDF level of 27.0%, which was equivalent to a dietary crude fiber level of 5.7% and a NDF of 19.1%, calculated based on the linear relationship between TDF and crude fiber or NDF of the experimental diets \( (r^2 = 0.98–0.99; \text{figures not shown}) \). Maximum weight gain was achieved at a TDF level of 23.4%, which was equivalent to a dietary crude fiber level of 5.0% and a NDF of 15.7% (Figure 2). The maximum tolerance level for TDF by juvenile channel catfish was estimated to be 32.1% at which level weight gain of fish would be similar to that of fish fed the basal diet. The corresponding maximum tolerance of crude fiber and NDF was 6.6% and 24.9%, respectively. Feed efficiency, HSI, intramuscular fat, and visceral fat decreased linearly (Figures 3, 4, 5), whereas muscle protein and moisture levels (figures not shown) increased with increasing TDF.

**DISCUSSION**

Dietary fiber is a complex group of organic substances of mostly plant origin that cannot be digested by enzymes in the
**FIGURE 2.** Relationship of total dietary fiber and weight gain in channel catfish. \( Y = 29.81 + 2.649X - 0.05662X^2; P < 0.01; R^2 = 0.36, \) where \( Y = \) weight gain and \( X = \) total dietary fiber; \( Y \) reaches a maximum value of 60.79 when \( X_{\text{max}} = 23.4. \) The maximum tolerance level for total dietary fiber, \( X_{\text{tol}} = 32.1 \) at which level weight gain of channel catfish would be similar to that of fish fed the basal diet.

**FIGURE 3.** Relationship of total dietary fiber and feed efficiency of channel catfish. \( Y = 0.702 - 0.003786X; P < 0.01; r^2 = 0.51, \) where \( Y = \) feed efficiency and \( X = \) total dietary fiber.

**FIGURE 4.** Relationship of total dietary fiber and hepatosomatic index of channel catfish. \( Y = 1.918 - 0.009398X; P = 0.03; r^2 = 0.17, \) where \( Y = \) hepatosomatic index and \( X = \) total dietary fiber.

**FIGURE 5.** Relationship of total dietary fiber and percentage body fat of channel catfish. For intramuscular fat, \( Y_{\text{imf}} = 6.345 - 0.08182X; P < 0.01; r^2 = 0.59; \) for visceral fat, \( Y_{\text{vf}} = 4.079 - 0.07321X; P < 0.01; r^2 = 0.75, \) where \( Y_{\text{imf}} = \) intramuscular fat, \( Y_{\text{vf}} = \) visceral fat, and \( X = \) total dietary fiber.
intestinal tract of many nonruminant animals, including fish. A small part of it, however, may be fermented by microorganisms in the lower gut, although microbial activities in the fish gut are limited. In animal nutrition, various analytical methods have been used to determine dietary fiber concentrations in feedstuffs and diets. These include acid detergent fiber (cellulose and lignin), crude fiber (cellulose and part of the hemicelluloses and lignin), NDF (cellulose, lignin, and most hemicelluloses), and recently TDF (cellulose, lignin, hemicelluloses, soluble fibers such as gums, β-glucans, and fructans, and enzyme-resistant starch). For comparative purposes, we analyzed the experimental diets for crude fiber, NDF, and TDF. Dietary fiber in the basal diet was supplied by those inherent in soybean meal, cottonseed meal, corn, and wheat middlings, and additional fiber in the test diets was provided by corn bran, a natural fiber source. Most previous studies used cellulose as a dietary fiber source, which may not represent all types of fiber in a commercial fish diet because different fiber classes may have different effects on dietary nutrient digestibility and fish growth (Glencross 2009). The optimum and tolerance levels of dietary fiber obtained from the present study may be applied to diets containing high levels of corn by-products, such as corn gluten feed, corn germ meal, and corn distillers dried grains with solubles that are currently used in commercial catfish diets because of a similar origin of fiber. However, this may not be true for fibers in diets containing high levels of other fiber-rich feedstuffs such as cottonseed meal, rice bran, or wheat middlings, possibly because of the differences in fiber compositions of various feedstuffs.

In the present study, feed consumption of juvenile channel catfish increased as TDF levels increased and reached the maximum feed consumption at a TDF of 27.0% of diet (5.7% crude fiber and 19.1% NDF). This suggests that channel catfish have some ability to adapt to increased dietary fiber by increasing feed consumption to fulfill their energy requirements. The ability of fish to increase feed consumption (by increasing stomach volume and gastric evacuation rate) in response to high-fiber diets has been reported previously for rainbow trout (Hilton et al. 1983). This adaptation mechanism is common in other farm animals because animals generally eat to fulfill their energy requirements. The present study also demonstrated that as dietary fiber increased, weight gain increased and then decreased with the optimum TDF level being observed at 23.4% of the diet (5.0% crude fiber and 15.7% NDF). Dupree and Sneed (1966) reported that channel catfish grew faster on a chemically defined diet containing 21% cellulose than on a basal diet without cellulose. Levels of cellulose below 21% were not evaluated. Dioundick and Stom (1990) also reported that juvenile Mozambique tilapia fed a fish-meal-based diet containing 2.5–5.0% cellulose gained more weight than fish fed a basal diet without cellulose. These results support the contention that the presence of dietary fiber at a low level is beneficial to the fish possibly because it facilitates the passage of ingesta through the digestive tract at an optimal rate for better digestion and absorption of nutrients. However, excessive dietary fiber reduces nutrient digestibility and absorption, resulting in depressed fish growth (Hilton et al. 1983; Glencross 2009).

There is limited information on the tolerance levels of dietary fiber by fish and most of the published literature involves either cellulose or crude fiber. Leary and Lovell (1975) reported that channel catfish could tolerate about 8% crude fiber (mostly cellulose) in the diet. Hilton et al. (1983) recommended a dietary fiber (cellulose) level of less than 10% for rainbow trout based on growth and dry matter digestibility. Similarly, Shiau et al. (1989) found that Nile tilapia fed a diet containing 10% cellulose had reduced weight gain, feed efficiency, glucose absorption, and blood glucose concentrations relative to fish fed a basal diet without cellulose. Mozambique tilapia could tolerate about 7.5% cellulose in the diet without affecting their growth and FER (Dioundick and Stom 1990). In the present study, the maximum tolerance level for TDF by juvenile channel catfish was estimated to be 32.1% (6.6% crude fiber and 24.9% NDF). The tolerance level for crude fiber was slightly below the tolerance level of 8% previously reported for channel catfish (Leary and Lovell 1975).

In the present study, FER decreased linearly as TDF levels increased. This is generally anticipated because fish cannot convert dietary fiber to body mass, and diets containing high levels of fiber have lower levels of digestible carbohydrates and less digestible energy (DE) that are available for growth and metabolism. Similar results have been reported for other fish species (Shiau et al. 1989; Dioundick and Stom 1990; Dias et al. 1998). Hepatosomatic index, visceral fat, and intramuscular fat also decreased with increasing TDF levels. This is mainly because as TDF levels increased, DE or the DE to digestible protein (DE : DP) ratio decreased resulting in reduced liver weight and body fat deposition. There is strong evidence that DE and DE : DP ratio influence the body fat concentration of channel catfish (Reis et al. 1989; Li and Lovell 1992; Li and Robinson 1999). In the present study, feed consumption increased as TDF levels increased from 15% to 27% as an adaptation of the fish to increased dietary fiber to meet their energy requirements. However, with extra DE provided by the increased feed intake in fish fed high-fiber diets, the total DE consumed was probably still below that provided by the basal diet because body fat levels decreased linearly as TDF levels increased.

Results from the present study should be considered as the combined effect of increasing dietary fiber and decreasing digestible carbohydrates or DE because they are closely interrelated, especially at high dietary fiber levels. As the type and levels of dietary fiber vary from feedstuff to feedstuff, other nutrients, such as amino acids, fatty acids, and minerals also vary. However, it is unlikely that slight variations in these nutrients among different diets have affected the results of the present study. Soybean meal levels varied only slightly among different diets. All diets contained similar lipid and mineral levels. During formulation of the experimental diets, corn grain in the basal diet was replaced with corn bran resulting in various dietary fiber levels. As the level of corn grain decreased and corn
bran increased, lipid levels decreased slightly; therefore corn oil was added so that all diets contained the same lipid level. In addition, all other dietary ingredients remained the same for all diets.

In summary, a TDF level of 23.4% (5.0% crude fiber and 15.7% NDF) appears to be optimum for maximum weight gain of juvenile channel catfish. The maximum tolerance level for TDF was estimated to be 32.1% (6.6% crude fiber and 24.9% NDF). Because crude fiber and NDF are less expensive to analyze, their tolerance levels may be used as the upper limit when formulating practical diets for use in catfish feeds containing corn by-products. However, the tolerance level of dietary fiber may vary depending on digestible carbohydrates, DE, or DE : DP ratio of feedstuffs included in feed formulae. Further studies on the effects of fiber from other feedstuffs and type of fiber on channel catfish performance are warranted.

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