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Digestibility of dietary fiber in distillers coproducts fed to growing pigs[1]

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ABSTRACT: The objective of this work was to measure the apparent ileal digestibility (AID) and the apparent total tract digestibility (ATTD) of dietary fiber in different sources of distillers dried grains with solubles (DDGS) and to calculate hindgut fermentation of dietary fiber in DDGS fed to growing pigs. Diets, ileal digesta, and fecal samples from pigs fed corn or diets containing 1 of 28 sources of distillers coproducts were analyzed for fiber. Of the 28 sources of coproducts, 24 sources were corn DDGS (C-DDGS), 1 source was sorghum DDGS (S-DDGS), 1 source was DDGS from a blend of sorghum and corn (SC-DDGS), 1 source was C-DDGS from beverage production ($\text{DDGS}_{\text{beverage}}$), and a source of corn distillers dried grain (DDG) was also included in the experiment. Total dietary fiber (TDF) and DM were analyzed in all DDGS sources, ileal digesta, and fecal samples. Hindgut fermentation was calculated by subtracting values for AID from values for ATTD. In 10 sources of DDGS and in ileal and fecal samples from pigs fed those sources, crude fiber, ADF, NDF, insoluble dietary fiber (IDF), and soluble dietary fiber (SDF) were also determined. Concentrations of CP, ether extract, and ash were also analyzed in these samples, and concentrations of organic residue (OR) were calculated by subtracting the concentration of CP, ether extract, and water from OM. The AID and the ATTD of TDF differed ($P < 0.01$) among sources of C-DDGS. The average AID of TDF in 10 sources of C-DDGS (21.5%) was not different ($P > 0.05$) from the AID of TDF in corn (16.5%), but the ATTD and the hindgut fermentation of TDF in the 10 sources of C-DDGS (44.5 and 23.0%, respectively) were greater ($P < 0.05$) than in corn (23.1 and 6.6%, respectively). The AID of crude fiber, NDF, IDF, SDF, and TDF were not different between C-DDGS and S-DDGS, but the AID of ADF was greater ($P < 0.01$) in S-DDGS (57.4%) than in C-DDGS (36.8%). The ATTD of OR in S-DDGS (72.5%) and SC-DDGS (68.4%) were less ($P < 0.05$) than in C-DDGS (77.1%), but the ATTD of ADF, NDF, IDF, SDF, and TDF were not different among the 3 sources of DDGS. The AID, ATTD, and hindgut fermentation of TDF were not different between DDGS from an ethanol plant and DDGS from a beverage plant. The average AID, ATTD, and hindgut fermentation of TDF in the 24 sources of C-DDGS were 23.0, 47.3, and 24.4%, respectively. It is concluded that the AID and ATTD of fiber differ among sources of DDGS and those differences may contribute to differences in the digestibility of energy in DDGS.

Key words: dietary fiber, digestibility, distillers coproduct, distillers dried grains with solubles, pig

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INTRODUCTION

Dietary fiber is the sum of carbohydrates and lignin that are resistant to digestion by mammalian enzymes in the small intestine, but they may be partially or completely fermented in the hindgut (AACC, 2001; IOM, 2006). Methods to measure dietary fiber include the crude fiber analysis (Mertens, 2003), the ADF and NDF procedures (Van Soest, 1963), and the total dietary fiber (**TDF**) procedure, which may separate dietary fiber into insoluble dietary fiber (**IDF**) and soluble dietary fiber (**SDF**; Prosky et al., 1992). An alternative to analyzing samples for dietary fiber is to calculate the concentration of organic residue (**OR**) by subtracting CP, ash, moisture, ether extract, sugar, and starch from 100 (de Lange, 2008).

The greater concentration of dietary fiber in distillers dried grains with solubles (**DDGS**) compared with corn and soybean meal may be one of the primary reasons for the decreased digestibility of energy in DDGS compared with corn (Stein and Shurson, 2009). The efficiency of energy utilization in fibrous feed ingredients

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Table 1. Ingredient composition of experimental diets, as-fed basis[1]

Ingredient, % of diet	DDGS	DDG	Corn
DDGS	66.70	—	—
DDG	—	66.70	—
Corn	—	—	97.00
Cornstarch	27.00	27.00	—
Sucrose	3.00	3.00	—
Soybean oil	1.00	1.00	—
Limestone	1.35	1.35	0.80
Dicalcium phosphate	—	—	1.05
Chromic oxide	0.30	0.30	0.30
Salt	0.30	0.30	0.50
Vitamin premix[2]	0.10	0.10	0.10
Micromineral premix[3]	0.25	0.25	0.25
Total	100.00	100.00	100.00

[1] DDGS = distillers dried grains with solubles; DDG = distillers dried grain.

[2] Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as vitamin A acetate; vitamin D_3, 1,648 IU as D-activated animal sterol; vitamin E, 55 IU as α-tocopherol acetate; vitamin K_3, 4.4 mg as menadione dimethylpyrimidinol bisulphite; thiamine, 3.3 mg as thiamine mononitrate; riboflavin, 9.9 mg; pyridoxine, 3.3 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; and biotin, 0.17 mg.

[3] Provided the following quantities of minerals per kilogram of complete diet: Cu, 26 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 0.31 mg as potassium iodate; Mn, 26 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 130 mg as zinc oxide.

such as DDGS in pigs is affected by the digestibility of dietary fiber and the production of VFA (Bindelle et al., 2008). Values for the apparent total tract digestibility (**ATTD**) of ADF and NDF in DDGS have been reported (Guo et al., 2004; Stein et al., 2009), but no values for the ATTD of TDF, IDF, SDF, or OR are available. Likewise, hindgut fermentation of fiber in DDGS has not been measured, but fiber fermentation can provide energy to pigs. The first objective of this study, therefore, was to measure the apparent ileal digestibility (**AID**), the ATTD, and the hindgut fermentation of dietary fiber and OR in DDGS and to compare these values with the AID and ATTD and hindgut fermentation in corn and distillers dried grain (**DDG**). The second objective was to determine the relationship between the ATTD of TDF and the ATTD of crude fiber, ADF, NDF, IDF, SDF, and OR.

MATERIALS AND METHODS

Animal Care and Use Committee approval was not obtained for this study because no animals were used.

Samples

Samples of DDGS, diets containing DDGS, ileal digesta, and feces from 3 experiments (Stein et al., 2006; Pahm et al., 2008; Urriola et al., 2009) designed to measure AID and ATTD of nutrients in DDGS were used. The diets contained 66.7% DDGS or DDG. Corn was included in 1 of the experiments, and the only source of dietary fiber in the diets was DDGS, DDG, or corn (Table 1). In each of the 3 experiments, pigs were allotted to Youden square designs with 7 or 8 replicates per sample. Ileal digesta and fecal samples were collected according to standard procedures described by Stein et al. (2006), Urriola et al. (2009), and Pahm et al. (2008) in Exp. 1, 2, and 3, respectively. Experiment 1 was designed to compare the digestibility of nutrients in 10 sources of DDGS produced from corn (**C-DDGS**) to the digestibility of nutrients in corn grain (Table 2). In Exp. 2, the digestibility of 8 sources of C-DDGS was compared with the digestibility of nutrients in 1 source of DDGS produced from sorghum (**S-DDGS**) and in 1 source of DDGS produced from a blend of sorghum and corn (**SC-DDGS**; Table 3). In Exp. 3, the digestibility of nutrients in DDGS produced by 6 dry-grind ethanol plants (**DDGS$_{\text{ethanol}}$**) was compared with the digestibility of nutrients in 1 source of DDG and 1 source of DDGS from a beverage plant (**DDGS$_{\text{beverage}}$**; Table 4).

Chemical Analyses

Ingredients that were used in Exp 1, 2, and 3 were analyzed for DM (method 930.15; AOAC International, 2007), CP (method 990.03; AOAC International, 2007), starch (method 979.10; AOAC International, 2007),

Table 2. Analyzed composition of corn and distillers dried grains with solubles (DDGS) and diets containing each source of DDGS used in Exp. 1 (as-fed basis)[1]

		Sources of DDGS										
Item	Corn	1	2	3	4	5	6	7	8	9	10	Mean
DDGS, %												
DM	85.4	89.2	88.7	86.8	88.9	89.2	87.1	88.6	90.8	90.0	89.4	88.9
CP	7.9	27.6	27.9	27.2	29.0	26.7	24.6	26.6	28.4	29.1	27.3	27.4
Starch	—	7.0	7.9	5.2	5.6	7.0	6.9	6.4	5.4	7.4	6.1	6.5
TDF[2]	—	30.4	31.1	30.2	30.3	29.6	31.3	29.3	31.4	29.9	29.2	29.2
Diet, %												
TDF	8.0	19.9	18.8	21.5	21.8	18.4	21.2	19.7	20.0	20.3	19.6	20.1

[1] Samples from Stein et al. (2006).

[2] TDF = total dietary fiber.

Table 3. Analyzed composition of distillers dried grains with solubles (DDGS) produced from corn, sorghum (S-DDGS), and a blend of sorghum and corn (SC-DDGS) used in Exp. 2 (as-fed basis)[1]

	Source of corn-DDGS										
Item[2]	1	2	3	4	5	6	7	8	Mean	S-DDGS	SC-DDGS
DDGS, %											
DM	90.5	90.6	90.5	90.5	89.7	89.6	89.0	87.5	89.7	91.6	92.7
CP	29.4	28.7	27.4	27.3	27.5	27.3	31.9	28.0	28.4	32.7	30.6
Starch	7.8	9.1	5.2	8.2	6.5	6.6	6.5	6.2	7.0	7.1	6.0
Crude fiber	6.1	6.8	7.4	6.5	6.4	6.6	6.3	6.5	6.6	9.8	8.1
ADF	10.8	11.0	12.0	12.0	10.0	11.5	10.6	11.1	11.1	22.8	16.5
NDF	36.2	40.4	43.2	34.6	35.9	36.8	36.3	37.5	37.6	40.7	39.5
IDF	28.7	32.5	33.8	30.0	31.0	31.1	28.3	30.5	30.7	34.1	35.4
SDF	0.0	0.8	1.1	1.6	0.8	1.6	1.5	1.3	1.1	1.2	0.4
TDF	28.7	33.3	34.9	31.6	31.8	32.7	29.8	31.8	31.8	32.2	35.8
OR	44.5	48.2	47.1	49.3	46.8	46.5	44.1	45.6	46.5	45.6	46.9
Diet, %											
Crude fiber	3.4	4.2	5.8	4.3	4.2	4.5	4.2	4.2	4.4	6.1	5.7
ADF	6.9	7.2	8.7	7.2	6.7	7.3	7.7	7.5	7.4	15.3	11.0
NDF	21.3	23.5	28.3	25.0	23.5	24.1	24.7	24.1	24.3	25.9	26.3
IDF	20.2	22.1	27.1	20.8	21.4	20.4	24.7	21.4	22.2	22.9	25.6
SDF	0.0	1.1	0.3	1.1	0.6	2.9	1.7	1.3	1.3	4.1	2.6
TDF	20.2	23.2	27.4	21.9	22.0	23.3	27.4	22.7	23.5	26.9	28.2
OR	33.6	33.8	34.5	35.7	33.6	33.5	32.3	31.7	33.6	32.6	33.5

[1] Samples from Urriola et al. (2009).

[2] IDF = insoluble dietary fiber; SDF = soluble dietary fiber; TDF = total dietary fiber; OR = organic residue.

ADF (method 973.18; AOAC International, 2007), NDF (Holst, 1973), and TDF (method 985.29; AOAC International, 2007). Ingredients used in Exp. 2 were also analyzed for crude fiber (method 978.10; AOAC International, 2007) and IDF (method 985.29; AOAC International, 2007), and the concentration of SDF in these ingredients was calculated as the difference between TDF and IDF.

Diets, ileal digesta, and feces from Exp. 1 were also analyzed for DM and TDF, and the concentration of chromium in these samples was analyzed after nitric acid-perchloric acid wet ash sample preparation (method 990.08; AOAC International, 2007). Diets, ileal digesta, and fecal samples from Exp. 2 were analyzed for DM, CP, ether extract, ash, starch, TDF, chromium, crude fiber, ADF, NDF, and IDF, and the concentration of SDF was calculated. Diets, ileal digesta, and feces from Exp. 3 were analyzed for TDF, DM, and chromium.

Calculations

The AID and ATTD of TDF were calculated for samples used in all 3 experiments according to Stein et al. (2007). For samples used in Exp. 2, the concentration of OR in the diets were calculated using the following equation:

$$\mathrm{OR}_{\mathrm{diet}}\ (\%) = \mathrm{OM} - [\mathrm{CP} + \text{ether extract} + (100 - \mathrm{DM}) + \mathrm{starch}_{\mathrm{added}} + \mathrm{sucrose}_{\mathrm{added}}],$$

where $\mathrm{starch}_{\mathrm{added}}$ and $\mathrm{sucrose}_{\mathrm{added}}$ were the added cornstarch and sucrose that were included in the diet. Starch

Table 4. Analyzed composition of distillers dried grains with solubles (DDGS) used in Exp. 3 (as-fed basis)[1]

	$\mathrm{DDGS}_{\mathrm{ethanol}}$ source								
Item	1	2	3	4	5	6	Mean	$\mathrm{DDGS}_{\mathrm{beverage}}$	DDG[2]
DDGS, %									
DM	88.9	87.0	88.4	88.7	86.9	87.8	88.0	89.7	88.5
CP	26.4	25.4	24.7	29.0	24.7	25.5	26.0	26.3	26.1
Starch	11.4	7.3	7.0	8.1	7.4	9.6	8.0	7.3	3.8
TDF[3]	31.7	29.5	31.5	32.4	28.6	30.6	30.7	38.5	43.9
Diet, %									
TDF	21.7	21.9	23.3	21.3	21.2	22.7	22.0	28.3	28.1

[1] Samples from Pahm et al. (2008). $\mathrm{DDGS}_{\mathrm{ethanol}}$ = corn distillers dried grains with solubles produced from ethanol plants; $\mathrm{DDGS}_{\mathrm{beverage}}$ = corn distillers dried grains with solubles produced at a beverage plant.

[2] DDG = distillers dried grain.

[3] TDF = total dietary fiber.

and sucrose were assumed to be 100% digestible in the small intestine. Therefore, the calculations of OR in ileal digesta and feces were as follows:

$$\mathrm{OR}_{\text{ileal or feces}}\ (\%) = \mathrm{OM} - [\mathrm{CP} + \text{ether extract} + (100 - \mathrm{DM})].$$

The hindgut fermentation of nutrients was calculated using the following equation (Högberg and Lindberg, 2004):

$$\text{hindgut fermentation } (\%) = \mathrm{ATTD} - \mathrm{AID}.$$

For samples used in Exp. 2, the AID, ATTD, and the hindgut fermentation of crude fiber, ADF, NDF, IDF, and SDF were also calculated using this equation.

Statistical Analysis

In all 3 experiments, the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC) was used to determine normal distribution of the data and equal variances and to identify outliers. An observation was considered an outlier if the value was more than 3 SD away from the grand mean. No outliers were identified in any of the 3 experiments. Data were analyzed by ANOVA using the MIXED procedure of SAS (Littell et al., 1998). The pig was considered the experimental unit. Pig and period were random effects, and DDGS source was considered a fixed effect. The LSMeans procedure in SAS was used to calculate mean values. The CONTRAST option of SAS was used to compare the digestibility of DDGS and corn in Exp. 1, C-DDGS, S-DDGS, and SC-DDGS in Exp. 2, and $\mathrm{DDGS}_{\mathrm{ethanol}}$, $\mathrm{DDGS}_{\mathrm{beverage}}$, and DDG in Exp. 3. In all analyses, the differences were considered significant if $P < 0.05$. The PROC REG procedure of SAS was used to determine the relationship between the ATTD of TDF and the ATTD of IDF, SDF, ADF, NDF, crude fiber, and OR that were estimated in Exp. 2.

RESULTS

Exp. 1

The concentration of TDF varied from 18.6 to 31.4% among the 10 sources of DDGS and starch concentration was between 5.2 and 7.9% (Table 2). The AID of TDF (12.6 to 25.9%) also varied ($P < 0.01$) among the 10 sources of DDGS (Table 5). There was no difference between the mean AID of TDF in DDGS (21.5%) and the AID of TDF in corn (16.5%). The ATTD of TDF (30.5 to 52.4%) also varied ($P < 0.01$) among the 10 DDGS sources. The mean ATTD of TDF was greater ($P < 0.05$) in the 10 DDGS sources (44.5%) than in corn (23.1%). There was no difference among DDGS sources in hindgut fermentation of TDF, but the mean hindgut fermentation of TDF in C-DDGS (23.1%) was greater ($P < 0.01$) than in corn grain (6.6%).

Exp. 2

There was variation in the concentration of crude fiber (6.1 to 7.4%), ADF (9.7 to 12.9%), NDF (37.4 to 44.4%), IDF (28.3 to 33.8%), SDF (0.0 to 1.6%), and TDF (28.7 to 34.9%) among the 8 sources of C-DDGS (Table 3). The concentration of TDF in S-DDGS (32.2%) was similar to the average for C-DDGS (31.8%) and for SC-DDGS (35.8%). The AID of crude fiber (13.7 to 42.8%), ADF (28.2 to 47.0%), NDF (37.5 to 52.1%), IDF (5.9 to 33.6%), SDF (56.4 to 81.7%), TDF (19.6 to 38.2%), and OR (38.4 to 67.0%) were different ($P < 0.01$) among the 8 sources of C-DDGS (Table 6). The AID of ADF in S-DDGS (57.4%) was greater ($P < 0.01$) than the mean AID of ADF in C-DDGS (36.8%), and the AID of crude fiber in S-DDGS (38.6%) tended ($P = 0.07$) to be greater than the mean AID of crude fiber in C-DDGS (31.0%). However, the AID of OR in S-DDGS (41.6%) was less ($P < 0.01$) than in C-DDGS (58.6%), but the AID for NDF, IDF, SDF, and TDF were not different in S-DDGS compared with C-DDGS. The AID of NDF (37.9%), IDF (4.8%), and TDF (15.9%) were less ($P < 0.01$) in SC-DDGS than in C-DDGS, but the AID of crude fiber, ADF, and SDF were not different between SC-DDGS and C-DDGS.

The ATTD of crude fiber (36.3 to 51.2%), ADF (51.8 to 64.3%), NDF (51.6 to 65.8%), IDF (29.3 to 51.0%), SDF (89.4 to 95.3%), TDF (39.4 to 56.4%), and OR (72.4 to 81.3%) were different ($P < 0.01$) among the 8 sources of C-DDGS. There were no differences in the ATTD of crude fiber, ADF, NDF, IDF, SDF, and TDF between S-DDGS and the mean of the 8 sources of C-DDGS. However, the ATTD of OR was less ($P < 0.05$) in S-DDGS (72.5%) and SC-DDGS (68.4%) than in the 8 sources of C-DDGS (77.1%). The ATTD of IDF (28.6%) in SC-DDGS was less ($P = 0.05$) than in C-DDGS, and there was a tendency ($P < 0.10$) for a reduced ATTD of NDF (51.5%) and TDF (39.2%) in SC-DDGS compared with C-DDGS. For crude fiber, ADF, and SDF, no differences between SC-DDGS and C-DDGS were observed.

Hindgut fermentation of crude fiber (0.1 to 23.9%), ADF (12.9 to 28.1%), NDF (6.5 to 20.3%), IDF (8.2 to 31.2%), SDF (13.6 to 35.2%), TDF (11.1 to 30.9%), and OR (9.5 to 39.2%) were different ($P < 0.01$) among the 8 sources of C-DDGS. Hindgut fermentation of ADF was less ($P < 0.05$) in S-DDGS and SC-DDGS (3.3 and 12.3%) than in the 8 sources of C-DDGS (21.7%). The hindgut fermentation of OR, however, was greater ($P < 0.01$) in S-DDGS and SC-DDGS (30.9 and 35.5%) than in C-DDGS (18.5%).

Exp. 3

The concentration of TDF varied from 28.6 to 32.4% among the 6 sources of $\mathrm{DDGS}_{\mathrm{ethanol}}$ and was less than the concentration of TDF in $\mathrm{DDGS}_{\mathrm{beverage}}$ (38.5%) and in DDG (43.9%; Table 4). The AID (11.4 to 30.8%) and the ATTD (29.3 to 57.0%) of TDF were different ($P < 0.01$) among the 6 sources of $\text{DDGS}_{\text{ethanol}}$, but there were no differences between the AID and ATTD of TDF in $\text{DDGS}_{\text{beverage}}$ and $\text{DDGS}_{\text{ethanol}}$ (Table 7). The AID of TDF in DDG (0.7%) was less ($P < 0.01$) than the AID of TDF in $\text{DDGS}_{\text{ethanol}}$ (18.5%). However, the ATTD of TDF in DDG (43.8%) was not different from the ATTD of TDF in $\text{DDGS}_{\text{ethanol}}$ (48.0%) and $\text{DDGS}_{\text{beverage}}$ (46.4%). Hindgut fermentation of TDF was greater ($P = 0.05$) in DDG (43.1%) than in $\text{DDGS}_{\text{ethanol}}$ (29.5%) and $\text{DDGS}_{\text{beverage}}$ (33.2%), but there were no differences in the hindgut fermentation of TDF among $\text{DDGS}_{\text{ethanol}}$ sources.

Correlation Among Methods of Measuring Dietary Fiber

There was a good relationship between the ATTD of TDF and the ATTD of NDF ($r^2 = 0.90$), IDF ($r^2 = 0.79$), and ADF ($r^2 = 0.71$; Figure 1), but there was a lesser relationship between the ATTD of TDF and the ATTD of crude fiber ($r^2 = 0.42$). The relationship between the ATTD of TDF and the ATTD of SDF ($r^2 = 0.24$) or OR ($r^2 = 0.21$) was poor.

DISCUSSION

Data from all 3 experiments indicate that dietary fiber in DDGS is composed of a fraction that is fermented before the end of the ileum and a fraction that is fermented in the hindgut. The fraction that is fermented before the end of the ileum may be considered a fast fermentable fraction because the transit time from mouth to ileum averages 2.9 h (Wilfart et al., 2007a,b). In contrast, the fiber that is fermented in the large intestine may be considered a slow fermentable fraction of fiber. The fast fermentable fraction of dietary fiber was present in greater concentrations in sources of DDGS that had the greatest AID values, whereas the slow fermentable fraction was present in greater concentrations in DDGS sources with greater values for hindgut fermentation. This observation explains the average differences in the AID of TDF among sources of C-DDGS in Exp. 1, 2, and 3 (21.5, 28.9, and 18.5%, respectively; average = 23.0%). The average ATTD of TDF was relatively constant among sources of C-DDGS in Exp. 1, 2, and 3 (44.5, 49.5, and 48.0%, respectively; average = 47.3%). Therefore, hindgut fermentation averaged 23.0, 20.6, and 29.5 with an average of 24.4% in the 3 experiments.

The differences in the ATTD of dietary fiber among sources of C-DDGS may be a result of differences in the digestibility of nutrients in the corn grain that was used to produce DDGS (Stein and Shurson, 2009). The digestibility of TDF may also be affected by postharvest processing of corn (Fahey et al., 1993), but the effect of the ethanol plant processing on fiber digestibility in C-DDGS has yet to be determined. However, the greater

Table 5. Apparent ileal digestibility (AID), apparent total tract digestibility (ATTD), and hindgut fermentation (HGF) of total dietary fiber in corn and 10 sources of distillers dried grains with solubles (DDGS) produced from corn and fed to growing pigs,[1] Exp. 1

		Source of corn DDGS											DDGS		DDGS vs. corn[2]	
Item, %	Corn	1	2	3	4	5	6	7	8	9	10	Mean	SEM	*P*-value	SEM	*P*-value
AID	16.5	25.2	19.7	24.8	25.6	12.6	25.9	21.9	19.7	24.6	14.7	21.5	2.6	<0.01	17.7	0.23
ATTD	23.1	45.1	46.1	52.4	50.0	43.9	49.0	44.2	47.1	36.8	30.5	44.5	4.8	<0.01	7.8	0.05
HGF	6.6	19.9	26.4	27.6	24.4	31.3	23.1	22.3	27.5	12.2	15.8	23.0	5.8	0.22	16.3	0.03

[1] Least squares means of 8 pigs per diet.

[2] Contrast of corn vs. all DDGS sources.

Table 6. Apparent ileal digestibility (%), apparent total tract digestibility (%), and hindgut fermentation (%) by growing pigs of crude fiber, ADF, NDF, insoluble dietary fiber (IDF), soluble dietary fiber (SDF), total dietary fiber (TDF), and organic residue (OR) in distillers dried grains with solubles (DDGS) produced from corn (C-DDGS), sorghum (S-DDGS), or from a blend of sorghum and corn (SC-DDGS),[1] Exp. 2

	C-DDGS source													Contrast[2]	
Item	1	2	3	4	5	6	7	8	Mean	S-DDGS	SC-DDGS	SEM	*P*-value	S- vs. C-DDGS	SC- vs. C-DDGS
Apparent ileal digestibility															
Crude fiber	13.7	19.2	42.8	35.3	34.0	36.2	31.7	34.7	31.0	38.6	30.7	5.5	<0.01	0.07	0.95
ADF	35.0	28.2	47.0	40.0	32.6	40.8	36.5	34.1	36.8	57.4	41.4	4.0	<0.01	<0.01	0.12
NDF	41.7	37.5	52.1	48.8	45.7	45.1	45.5	50.4	45.9	49.9	37.9	4.2	<0.01	0.18	<0.01
IDF	5.9	9.0	33.6	26.7	13.9	21.1	20.5	29.3	20.0	27.7	4.8	6.9	<0.01	0.14	<0.01
SDF	81.7	62.1	70.2	56.5	59.6	63.8	56.4	64.5	64.4	65.9	63.4	3.6	<0.01	0.59	0.73
TDF	29.0	19.6	38.2	32.8	21.8	28.3	25.5	35.9	28.9	33.4	15.9	5.9	<0.01	0.30	<0.01
OR	66.5	65.5	67.0	65.1	67.0	53.9	38.4	45.0	58.6	41.6	32.9	2.6	<0.01	<0.01	<0.01
Apparent total tract digestibility															
Crude fiber	37.6	38.0	50.6	47.2	48.1	36.3	51.2	45.1	44.3	41.6	39.9	4.0	<0.01	0.88	0.76
ADF	63.1	51.8	62.2	61.7	54.7	53.7	64.3	56.5	58.5	60.7	53.7	4.1	<0.01	0.13	0.64
NDF	61.0	54.3	60.7	57.9	62.3	51.6	65.8	60.8	59.3	59.3	51.5	3.6	<0.01	0.42	0.06
IDF	37.1	30.9	45.8	41.8	41.7	29.3	51.0	45.0	40.3	41.3	28.6	4.2	<0.01	0.30	0.05
SDF	95.3	92.7	92.1	91.7	92.6	89.4	91.3	91.1	92.0	90.9	90.6	1.5	<0.01	0.78	0.59
TDF	55.0	41.1	52.8	49.4	49.5	39.4	56.4	52.0	49.5	48.8	39.2	4.6	<0.01	0.49	0.06
OR	81.3	78.4	76.8	74.6	81.3	74.5	77.6	72.4	77.1	72.5	68.4	2.3	<0.01	0.03	<0.01
Hindgut fermentation															
Crude fiber	23.9	18.8	7.8	11.9	14.1	0.1	19.5	10.4	13.3	3.0	9.2	8.3	<0.01	0.44	0.21
ADF	28.1	23.6	15.2	21.7	22.1	12.9	27.8	22.4	21.7	3.3	12.3	6.7	<0.01	0.01	0.04
NDF	19.3	16.8	8.6	9.1	16.6	6.5	20.3	10.4	13.4	9.4	13.6	6.2	<0.01	0.76	0.51
IDF	31.2	21.9	12.2	15.1	27.8	8.2	30.5	15.7	20.3	13.6	23.8	8.7	<0.01	0.98	0.77
SDF	13.6	30.6	21.9	35.2	33.0	25.6	34.9	26.6	27.6	25.0	27.2	4.4	<0.01	0.35	0.52
TDF	26.0	21.5	14.6	16.6	27.7	11.1	30.9	16.1	20.6	15.4	23.3	7.5	<0.01	0.84	0.73
OR	14.8	12.9	9.8	9.5	14.3	20.6	39.2	27.4	18.5	30.9	35.5	2.9	<0.01	<0.01	<0.01

[1] Least squares means of 8 pigs per diet.

[2] Contrasts of S-DDGS vs. C-DDGS and SC-DDGS vs. C-DDGS.

Table 7. Apparent ileal digestibility (AID), apparent total tract digestibility (ATTD), and hindgut fermentation (HGF) by growing pigs of total dietary fiber in 6 sources of corn distillers dried grains with solubles produced from ethanol plants ($DDGS_{ethanol}$), corn distillers dried grains with solubles produced at a beverage plant ($DDGS_{beverage}$), and in corn distillers dried grains (DDG),[1] Exp. 3

Item	$DDGS_{ethanol}$ source							$DDGS_{beverage}$	DDG	SEM	*P*-value	*P*-value, contrast	
	1	2	3	4	5	6	Mean					$DDGS_{beverage}$ vs. $DDGS_{ethanol}$	DDG vs. $DDGS_{ethanol}$
AID	13.0	12.8	24.0	11.4	30.8	18.8	18.5	13.2	0.7	4.9	<0.01	0.29	<0.01
ATTD	29.3	51.8	52.4	41.3	56.0	57.0	48.0	46.4	43.8	3.5	<0.01	0.19	0.60
HGF	16.3	39.0	28.4	29.9	25.2	38.2	29.5	33.2	43.1	6.02	0.19	0.59	0.05

[1] Least squares means of 8 pigs per diet.

ATTD of TDF in DDGS compared with corn that was observed in Exp. 1 indicates that processing of the corn during ethanol production (e. g., grinding, heating, and fermentation) may modify the structure of dietary fiber, which may make it more digestible than corn fiber (Le Gall et al., 2009).

The average AID of TDF of the 24 sources of C-DDGS (23.0%) is close to the average AID of TDF (24.0%) that was measured in diets containing a wide variety of feed ingredients (Bach Knudsen and Jørgensen, 2001). The average ATTD of TDF in C-DDGS observed in the present experiments (47.3%) is also comparable with values measured in growing pigs fed corn-bran (48%), but less than values observed when growing pigs are fed sugar beet pulp (Graham et al., 1986; Le Goff et al., 2002).

The differences in the AID and ATTD of TDF among sources of C-DDGS indicate that the digestibility of energy may also vary among these sources. Guo et al. (2004) observed differences in the ATTD of NDF, but no difference in the ATTD of GE among 4 sources of C-DDGS. However, this observation is in contrast with Pedersen et al. (2007) and Stein et al. (2009), who reported that the ATTD of GE in 14 sources of C-DDGS varied between 73.9 and 82.8%. The differences in the digestibility of TDF among sources of C-DDGS measured in the present experiments may be the reason for the reported differences in energy digestibility.

The greater AID and ATTD of SDF compared with IDF indicates that the soluble fraction of dietary fiber is much more fermentable than the insoluble fraction. This observation indicates that processes that increase the concentration of SDF in DDGS may also increase the AID and ATTD of TDF, which in turn is expected to increase the digestibility of energy. Extrusion increases the soluble portion of TDF in wheat, oats, and rice bran (Gualberto et al., 1997), which may explain why the ATTD of energy in DDGS increases after extrusion (Beltranena et al., 2009).

The main difference between the detergent fiber procedures (ADF and NDF) and the TDF procedure is that the detergent procedures do not include soluble fiber, whereas the TDF procedure accounts for both the soluble and the insoluble fractions of dietary fiber (Campbell et al., 1997). Therefore, it is expected that values for TDF represent more accurately the total fiber fraction in a feed ingredient than values for ADF and NDF (Campbell et al., 1997; Cho et al., 1997; Mertens, 2003).

The reason the AID of TDF in DDG is less than the AID of TDF in DDGS may be that most of the SDF is captured in the solubles fraction of the wet distillers grains, and because no solubles are added to the DDG, the concentration of SDF in DDG is less than in DDGS (Pahm et al., 2008). This results in reduced AID values for TDF in DDG compared with DDGS because the AID of SDF is greater than the AID of IDF.

The fact that there were no differences in the AID and ATTD of TDF between $DDGS_{ethanol}$ and $DDGS_{beverage}$ is

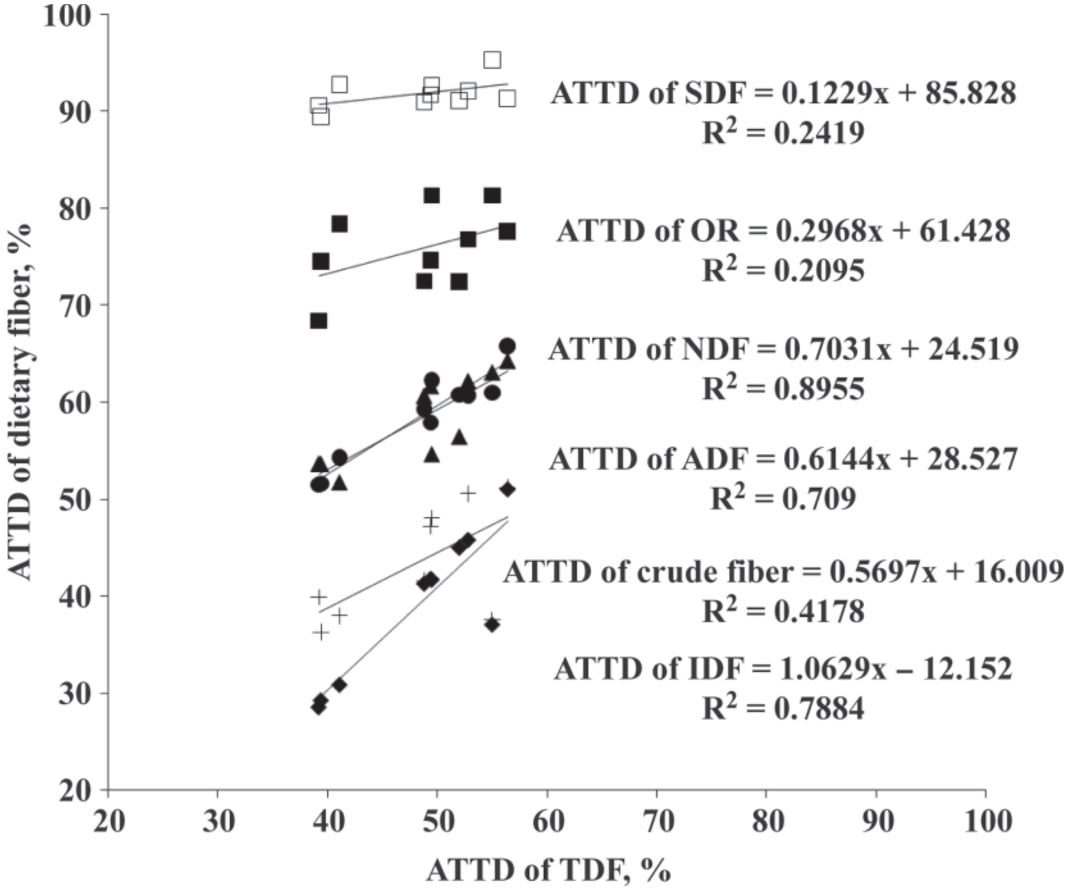

Figure 1. Relationship between the apparent total tract digestibility (ATTD) of total dietary fiber (TDF) and the ATTD of crude fiber (+), ADF (▲), NDF (●), insoluble dietary fiber (IDF; ◆), soluble dietary fiber (SDF; □), and organic residue (OR; ■) in distillers dried grains with solubles fed to growing pigs.

in agreement with observations showing that there is no difference in the AID of AA between these 2 sources of DDGS (Pahm et al., 2008). This indicates that the production processes used in beverage plants have no greater influence on the digestibility of nutrients in DDGS than the processes used in fuel ethanol plants (Pahm et al., 2008). These results also indicate that the digestibility of energy between these sources of DDGS most likely is similar.

The strong relationship between the ATTD of TDF and the ATTD of NDF, ADF or IDF, is most likely a result of the fact that most of the fiber in DDGS is insoluble (Bach Knudsen, 1997). The procedures used for fiber analysis that measure concentrations of insoluble fiber give values that are close to the concentration of TDF (Mertens, 2003). The ATTD of SDF was much greater than the ATTD of IDF, but the concentration of SDF is less in DDGS. As a result, the relationship between the ATTD of TDF and the ATTD of SDF is poor. A strong relationship between the ATTD of TDF and the ATTD of OR was expected because TDF and OR represent the entire fraction of fiber in DDGS. However, results showed that there was no relationship between the ATTD of TDF and the ATTD of OR, which indicates that the procedure that was used to calculate OR did not give an accurate estimate of the concentration of fiber in DDGS.

One of the limitations of using pigs that are equipped with an ileal T-cannula to measure digestibility of dietary fiber is that only a portion of the total digesta and fecal output are collected, which may result in relatively large variations among pigs. However, use of a T-cannula is one of the few methods available for collection of ileal digesta, and without the cannula, it would not be possible to calculate ileal digestibility of fiber in the DDGS sources. In the present work, we attempted to overcome the inherent limitations of use of T-cannulas by using a relatively large number of replications and by allotting pigs to a Youden square design, which is believed to reduce variability (Kuehl, 2000; Kim and Stein, 2009). We also standardized all feeding and collection procedures among pigs.

In conclusion, the AID and ATTD of dietary fiber and OR varies among sources of C-DDGS, and these differences are believed to influence the digestibility of energy. The greater AID and ATTD in DDGS than in corn indicates that fiber digestibility is improved by processing or fermentation in the ethanol plants. However, less than 50% of TDF in DDGS is fermented over the entire intestinal tract, which means that more than 50% of the TDF in DDGS passes through the pigs without being fermented.

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