Title: Digestibility of dietary fiber from distillers co-products fed to growing pigs – **NPB #07-170**

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I. Industry Summary:

The rapidly increasing production of ethanol is generating large amounts of distillers' co-products that are available for swine feeding programs. These co-products can help reduce feed cost. There are several challenges, however, when including such co-products in swine diets. An example of these co-products is distillers dried grains with solubles (**DDGS**). The greater concentration of dietary fiber in DDGS than in corn and soybean meal has been constantly mentioned among the factors that cause those challenges. The efficiency by which the pig will utilize the energy in DDGS is directly affected by the digestibility of dietary fiber. To measure the digestibility of dietary fiber in DDGS is, therefore, the first step towards optimization of the utilization of energy from DDGS.

Dietary fiber is the sum of carbohydrates that are resistant to digestion and absorption in the small intestine and that are susceptible to partial or complete degradation (fermentation) in the large intestine (AACC, 2000). There are, however, no data on the digestibility of dietary fiber in DDGS by growing pigs. Therefore, the objective of these experiments was to measure the digestibility of dietary fiber in DDGS by growing pigs and to measure the difference in

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fermentation capacity among different sources of DDGS. The apparent ileal (**AID**) and apparent total tract digestibility (**ATTD**) was measured and the fermentation of dietary fiber in DDGS was calculated by subtracting values for AID from values for ATTD. Ileal and fecal samples from 3 experiments were analyzed.Results show that the AID, ATTD, and fermentation of total dietary fiber (TDF) among corn DDGS sources are different. The AID of TDF ranged between 12.6 and 38.2%, the ATTD of TDF ranged between 23.4 and 57.0%, and the fermentation of TDF ranged from 10.5 to 38.6%. Those differences in digestibility and fermentation properties of the different sources of DDGS can explain the variation in digestibility of energy that has been previously reported. This suggests that the digestibility of dietary fiber in DDGS needs to be improved to increase the digestibility of energy.

The soluble dietary fiber (SDF) is degraded and absorbed faster than the insoluble dietary fiber (IDF). The AID of SDF was 64.4% while the AID of IDF was only 20%. This indicates that sources of DDGS with greater concentration of SDF have a greater feeding value than sources with greater concentration of IDF. Also, processes that increase the concentration of SDF help in improving the utilization of dietary fiber by pigs.

Results also showed that there is no difference in AID or ATTD of TDF between DDGS produced from corn and DDGS produced from sorghum. These data also suggest that DDGS from the fuel ethanol and the DDGS from beverage production are similar in terms of digestibility of dietary fiber. However, the AID of TDF is greater in DDGS than in distillers dried grains (DDG), but there is no difference in the ATTD of TDF between DDGS and DDG.

In conclusion, data from these experiments suggest that the digestibility and fermentation of the dietary fiber in DDGS is less than 50%. This low digestibility of fiber in DDGS is the reason why energy and DM digestibility is lower in DDGS than in corn. It is necessary, therefore, to identify factors that may increase the fermentation of dietary fiber in DDGS to increase the digestibility of energy from DDGS.

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Scientific Abstract:

The objective of these experiments was to measure the apparent ileal (AID) and apparent total tract digestibility (ATTD) of fiber in different sources of distillers dried grains with solubles (DDGS) and to calculate the fermentation capacity of those feed ingredients. The diets, ileal digesta, and fecal samples from 3 experiments were analyzed for fiber and chromium to calculate AID and ATTD of fiber. In total there were 27 sources of DDGS from corn (C-DDGS), 1 source of DDGS from sorghum (S-DDGS), 1 source of DDGS that blended corn and sorghum (CS-DDGS), 1 source of DDGS from beverage ($DDGS_{beverage}$), and 1 source of corn distillers dried grains (DDG). The fermentation was calculated in all 3 experiments by subtracting values for AID from values for ATTD. Dietary fiber was analyzed in all experiments using the total dietary fiber (TDF) procedure. In 1 of the 3 experiments, fiber was also analyzed using the crude fiber, ADF, NDF, insoluble dietary fiber (IDF), and soluble dietary fiber (SDF) procedures. Samples from 2 experiments were analyzed for ether extract, DM, CP, and ash. The organic residue (OR) was calculated by subtracting CP, ether extract, ash, and water in diets, ileal and fecal samples from 100%. The results of 3 experiments showed that the AID (12.6 to 38.2%), the ATTD (23.4 to 57.0%), and fermentation (10.5 to 38.6%) of TDF differ ($P < 0.05$) among sources of DDGS. Those differences might be a result of differences in the processing of the DDGS or be caused by differences in the composition of the fiber among corn sources. The AID and ATTD of DM and OR in DDGS was lower ($P < 0.05$) than the AID of DM (75.2%) and OR (77.0%) and the ATTD of DM (87.5%) and OR (89.4%) in corn; these results agree with the lower digestibility of energy that has been reported for DDGS compared with corn. The AID of crude fiber, NDF, IDF, SDF, and TDF in C-DDGS was not different than in S-DDGS. The AID of ADF was greater ($P < 0.01$) in S-DDGS than in C-DDGS. The AID of NDF, IDF, TDF, and OR was lower ($P < 0.01$) in CS-DDGS than in C-DDGS. The ATTD of OR in S-DDGS (72.5%) and in CS-DDGS (68.4%) were lower than the ATTD of OR in C-DDGS. The AID, ATTD, and fermentation of TDF in $DDGS_{ethanol}$ were not different than in $DDGS_{beverage}$. It is concluded that the AID and ATTD of fiber differ among DDGS sources and that those differences can account for differences in digestibility of energy.

The reasons for the differences in digestibility of fiber among DDGS sources should be the focus of future research.

II. INTRODUCTION

The digestibility of energy and dry matter in distillers dried grains with soluble (**DDGS**) is lower than the digestibility of energy and dry matter in corn, despite a greater concentration of gross energy in DDGS (Pedersen et al., 2007). The concentration of digestible energy (DE) in DDGS is, therefore, not greater than in corn. The reason for the low digestibility of energy and dry matter in DDGS is that there is more fiber in DDGS than in corn. To increase the digestibility of energy in DDGS, it is, therefore, necessary to understand how the fiber in DDGS is digested, and how much fermentable fiber is present in DDGS.

III. OBJECTIVES

The main objective of this proposal was to estimate the efficiency of digestion and fermentation of dietary fiber in DDGS fed to growing pigs. The specific aims included:

- Measurement of ileal and total tract digestibility of dietary fiber in corn, in 26 different sources of DDGS from corn (**C-DDGS**), 1 source of DDGS from sorghum (**S-DDGS**), 1 source that blended corn and sorghum DDGS (**CS-DDGS**), 1 source of DDGS from beverage plant (**$\mathbf{DDGS_{beverage}}$**), and in 1 source of distillers dried grain (**DDG**).
- Calculation of fermentable fiber in those same sources as above.
- To estimate the variation in ileal and total tract digestibility of dietary fiber in DDGS among ethanol plants.

IV. MATERIALS AND METHODS

Samples for this project were obtained from 3 experiments that were conducted in our group. These experiments were designed to measure the amino acid digestibility using ileal cannulated pigs. However, for this project all ileal and fecal samples were analyzed for fiber. Pigs were arranged in Youden square designs with 7 or 8 replicates per sample. Ileal digesta and fecal samples were collected according to standard procedures. Experiment 1 (Stein et al., 2006), was designed to compare the digestibility of 10 sources of C-DDGS with the digestibility of corn grain. In experiment 2 (Urriola et al., 2007), the digestibility of 8 sources of C-DDGS was compared with the digestibility of 1 source of S-DDGS and 1 source of SC-DDGS. Experiment 3 (Pahm et al., 2008), was designed to compare the digestibility of DDGS produced in 6 dry grind ethanol plants (**$DDGS_{ethanol}$**) with the digestibility of 1 source of DDG, and 1 source of $DDGS_{beverage}$. Full descriptions of the animal procedures that were followed to collect the samples are published elsewhere (Stein et al., 2006; Urriola et al., 2007, Pahm et al., 2008).

Chemical Analyses

Samples of ingredients, diets, ileal digesta, and feces from pigs fed the DDGS containing diets in Exp. 1 were analyzed for DM (Official Method 4.1.06; AOAC, 2000), CP (Official Method 990.03; AOAC, 2000), ether extract (EE; Official Method 920.39; AOAC, 2000), ash (Official Method 942.05; AOAC, 2000), and total dietary fiber (**TDF**) using Official Method 985.29 (AOAC, 2006). The concentration of chromium in diets, ileal digesta, and feces was analyzed following Official Method 9.2.39 (AOAC, 2000). In Exp. 2, ingredients, diets, ileal digesta, and feces were analyzed for ADF (Official Method 973.18; AOAC, 2006), NDF (Holst, 1973), and crude fiber (Official Method 978.10; AOAC, 2000) in addition to analyses conducted on samples from Exp. 1. In this experiment, the TDF analysis also included insoluble dietary fiber (**IDF**) following Official Method 985.29 (AOAC, 2000) and soluble dietary fiber (**SDF**) was calculated by the difference between TDF and IDF. In Exp. 3, samples were analyzed for TDF, DM, and chromium following the same procedures used in Exp. 1.

Calculations and Statistical Analysis

The apparent ileal digestibility (**AID**) and the apparent total tract digestibility (**ATTD**) of TDF were calculated in all 3 experiments using the equation described by Stein et al (2007). In Exp. 1, the concentration of organic residue (**OR**) in the diets was calculated using the equation:

$OR_{diet} = 100 – (CP + EE + ash + water+ starch_{extra} + sucrose_{extra})$, where $starch_{extra}$ and $sucrose_{extra}$ were the added corn starch and sucrose that was included in the diet; this starch and sucrose was assumed to be 100% digestible. Therefore, the calculation of OR in ileal digesta and feces was as follows:

$$OR_{ileal\ and\ feces} = 100 – (CP + EE + ash + water).$$

The fermentation of nutrients in the large intestine was calculated as follows:

$$Fermentation_{Nu} = ATTD_{Nu} – AID_{Nu};$$

where $ATTD_{Nu}$ is the amount of apparent total tract digestible nutrient, DM, or energy (g) and AID_{Nu} is the amount of apparent ileal digestible nutrient, DM, and energy (g) in the small intestine.

In all 3 experiments, the UNIVARIATE procedure of SAS (SAS Inst, Inc., Cary, NC) was used to determine normal distribution of the data, equal variances, and to identify outliers. An observation was considered an outlier if the value was more than 3 SD away from the mean and was removed from the analysis. Data were analyzed by ANOVA using the MIXED procedure of SAS. The pig was the experimental unit. Pig and period were considered random effects, and diet was considered a fixed effect. The CONTRAST option of SAS was used to compare the digestibility of DDGS and corn in Exp. 1, to compare the digestibility of C-DDGS, S-DDGS, and CS-DDGS in Exp. 2, and to compare the digestibility of $DDGS_{ethanol}$, $DDGS_{beverage}$, and DDG in Exp. 3. In all analyses the differences were considered significant when $P < 0.05$.

V. RESULTS

Experiment 1

The concentration of TDF among sources of DDGS varied from 18.6 to 31.4%, while the concentration of TDF in corn was 9.7% (Table 2).The AID of TDF (12.6% to 38.2%), DM (63.6 to 67.2%), and OR (20.1 to 39.0%) varied ($P < 0.01$) among sources of DDGS (Table 5). There was no difference, however, between the AID of TDF in corn (16.5%) and in DDGS, and the AID of DM (75.2%) and OR (77.0%) were greater ($P <$

0.01) in corn than in DDGS. The ATTD of TDF (23.4 to 57.0%), DM (74.7 to 78.3%), and OR (45.1 to 60.6%) varied ($P < 0.01$) among DDGS sources. The ATTD of DM (87.5%) and OR (89.4%) were also greater ($P <$ 0.01) in corn than in DDGS, and the ATTD of TDF (44.5%) tended to be greater ($P < 0.10$) in DDGS than in corn (23.1%). There was no difference among DDGS sources in the fermentation of TDF and DM in the large intestine but the fermentation of OR (18.8 to 30.2%) tended to differ ($P = 0.06$). The fermentation of OR (12.3%) was lower ($P < 0.01$) in corn grain than in DDGS, but the fermentation of DM was not different between corn and DDGS. However, the fermentation of TDF in corn was greater ($P < 0.05$) than in DDGS.

Experiment 2

There was a wide range in the concentration of starch (1.62 to 3.68%), ADF (9.74 to 25.0%), NDF (37.4 to 47.9), TDF (38.7 to46.3%), IDF (33.6 to 40.4), and SDF (4.6 to 8.5%) among C-DDGS sources (Table3). 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 C-DDGS sources (Table 6). Sorghum DDGS had a greater ($P < 0.01$) AID of ADF (57.4%) than C-DDGS, but lower ($P < 0.01$) AID of OR (41.6%). The AID of NDF (37.9%), IDF (4.8%), and TDF (15.9%) were lower in CS-DDGS than in C-DDGS.

The ATTD of crude fiber (21.7 to 51.2%), ADF (36.2 to 64.3%), NDF (39.5 to 65.8%), IDF (5.8 to 51.0%), SDF (85.9 to 95.3%), TDF (23.4 to 56.4%), and OR (72.4 to 81.3%) differ ($P < 0.01$) among sources of C-DDGS. The ATTD of OR was lower ($P < 0.05$) in S-DDGS (72.5%) than in C-DDGS. There were no differences in the ATTD of crude fiber, ADF, NDF, IDF, SDF, and TDF between S-DDGS and C-DDGS. There was a tendency ($P < 0.10$) for a lower ATTD of NDF (51.5%), IDF (28.6%), and TDF (39.2%) in CS-DDGS than in C-DDGS.

The fermentation of crude fiber, ADF, NDF, IDF, SDF, TDF, and OR were different ($P < 0.01$) among sources of C-DDGS. The fermentation of ADF was lower ($P < 0.05$) in S-DDGS than the average fermentation of ADF in sources of C-DDGS. The fermentation of OR, however, was greater ($P< 0.01$) in S-DDGS than in C-DDGS. The fermentation of ADF was lower in S-DDGS than in C-DDGS. The fermentation of OR in CS-DDGS was greater ($P < 0.01$) than the average fermentation among C-DDGS sources.

Experiment 3

The concentration of TDF among $DDGS_{ethanol}$ varied from 28.5 to 32.4% and was smaller than the concentration of TDF in $DDGS_{beverage}$ (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 $DDGS_{ethanol}$ sources but there was no difference between $DDGS_{beverage}$ (13.2%) and $DDGS_{ethanol}$ (Table 7). The AID of TDF in DDG (0.73%) was lower ($P < 0.01$) than the AID of TDF in $DDGS_{ethanol}$. However, the ATTD of TDF in DDG (43.8%) was not different from the ATTD of TDF in $DDGS_{ethanol}$ and $DDGS_{beverage}$ (46.4%). The fermentation of TDF in the large intestine tended to be greater ($P < 0.10$) in DDG (42.8%) than in $DDGS_{ethanol}$ (22.7 to 38.1%) and $DDGS_{beverage}$.(33.7%). There were no differences in the fermentation of TDF among $DDGS_{ethanol}$ sources.

VI. Discussion

Experiment 1

The production process of DDGS produces a concentration of 3 times the levels of nutrients in the corn grain. Such effect can be observed in this experiment by a greater concentration of all nutrients as compared to corn. The concentration of OR is greater in corn containing diet because no starch and sugars were added it.

This is the first experiment providing data on the AID and ATTD of TDF in DDGS. The observed differences in AID and ATTD of TDF and DM among DDGS sources could affect the digestible energy. Pedersen et al. (2007) measured the ATTD of gross energy in 10 DDGS sources. The source of DDGS with the lowest ATTD of energy was 73.9% and the source with the greatest ATTD of energy was 82.8%. This difference in digestibility of energy might be explained partially by a difference in digestibility of fiber among sources of DDGS. The digestibility of TDF might be affected by the processing of the corn in the ethanol plants or by the digestibility of TDF of the corn used in production of the DDGS.

Pedersen et al. (2007) observed that DDGS had a similar concentration of DE and ME as corn despite its greater concentration of GE. The reason for this observation was explained by the lower AID and ATTD of DM and OR in DDGS than in corn.

Experiment 2

There is a greater concentration of ADF in the sorghum DDGS sample, this observation is in agreement with greater concentration of ADF in sorghum than in corn that Pedersen et al. (2007) reported. The concentration of IDF in C-DDGS, S-DDGS, and CS-DDGS is mainly insoluble. This observation is in agreement with Serena et al. (2008), who reported that in fiber in grains from distillery were insoluble.

A greater AID of soluble dietary fiber in source 1 suggests a greater value of this source over the others in terms of digestibility of fiber. However, this might not give a greater value to this source in terms of energy digestibility, because this energy will be absorbed as VFA. The VFA absorbed before the end of the ileum should have the same value as VFA absorbed in the large intestine. Greater ATTD of soluble fiber might be the best indicator of greater energy value of the source of DDGS. Therefore, to identify ethanol processes that increase the solubility of the fiber might be necessary. Gualberto et al. (1997) observed that extrusion increased the soluble portion of TDF in wheat, oats, and rice bran. Similar processes might be applied to DDGS to increase the ATTD of fiber.

The only difference observed in this experiment between C-DDGS and S-DDGS was that S-DDGS had a greater AID of ADF than C-DDGS. The difference between NDF and ADF is due to hemicelluloses. In this experiment there was no difference in AID of NDF but the AID of ADF was different. This suggests that the composition of celluloses in sorghum might be more fermentable than cellulose from corn.

All sources of DDGS had a similar ranking when compared across all procedures used to measure digestibility of fiber (e. i. crude fiber, ADF, NDF, IDF, SDF, and TDF). However, SDF ranked source 1 with the greater AID and ATTD. The main difference between the detergent fiber procedure (ADF and NDF) and the TDF procedure is that the detergent procedure does not consider soluble fiber, while the TDF procedure accounts for it (Cambell et al., 1997). Therefore, the ranking of the sources of DDGS by SDF is different from the ranking obtained by the other fiber procedures. The difference in ranking demonstrates that TDF is a better procedure to determine fiber digestibility when evaluating feed ingredients with high concentration of soluble fiber.

Experiment 3

There was a greater concentration of TDF in $DDGS_{beverage}$ and DDG, but these values were within the range of the concentration of TDF among DDGS sources in Exp 1 and in Exp 2. Therefore, there is no difference in concentration of TDF between $DDGS_{beverage}$ and $DDGS_{ethanol}$. There is also no difference in the concentration of TDF between DDG and DDGS from the other experiments.

The reason for the lower AID of TDF in DDG than in DDGS may be that DDG does not contain soluble carbohydrates that are easily fermented before the terminal ileum. However, there was no difference in ATTD suggesting that the IDF fraction in both DDG and DDGS is fermented in the large intestine at a similar rate.

The fact that there was no difference in AID and ATTD of TDF between $DDGS_{ethanol}$ and $DDGS_{beverage}$ is in agreement with the conclusions of Pahm et al. (2008) who compared the AID of AA between these 2 sources of DDGS and observed no differences. This indicates that the production process of $DDGS_{beverage}$ does not influence the composition and digestibility of DDGS to a greater extent than the production of $DDGS_{ethanol}$. This also suggests a similar digestibility of energy in both co-products, but such data have not been published yet.

The data from these experiments show that there are differences in digestibility and fermentation of fiber among sources of DDGS. The reason for those differences may be due to differences in the production of DDGS among ethanol plants or in the digestibility and fermentation of the grain used in the distillation process. Future research should focus on identifying processes in the production of DDGS that can lead to greater fermentation of TDF in DDGS. If DDGS with a greater fermentation capacity can be produced it will be more valuable because of a greater energy value.

Table 1. Ingredient composition (%) of the experimental diets, as-is basis

Ingredient, % of diet	Corn	$DDGS_{ethanol}$[1]	$DDGS_{beverage}$[2]	S-DDGS[3]	SC-DDGS[4]	DDG[5]
Corn	97.00	-	-	-	-	-
DDGS	-	66.70	66.70	66.70	66.70	66.70
Cornstarch	-	27.00	27.00	27.00	27.00	27.00
Sucrose	-	3.00	3.00	3.00	3.00	3.00
Soybean oil	-	1.00	1.00	1.00	1.00	1.00
Limestone	0.80	1.35	1.35	1.35	1.35	1.35
Dicalcium phosphate	1.05	-	-	-	-	-
Chromic oxide	0.30	0.30	0.30	0.30	0.30	0.30
Salt	0.50	0.30	0.30	0.30	0.30	0.30
Vitamin premix[6]	0.10	0.10	0.10	0.10	0.10	0.10
Micromineral premix[7]	0.25	0.25	0.25	0.25	0.25	0.25
Total	100	100	100	100	100	100

[1]Distillers dried grains with solubles produced in an ethanol plant.

[2]Distillers dried grains with solubles produced in a beverage plant.

[3]Distillers dried grains with solubles produced from sorghum.

[4]Distillers dried grains with solubles produced from a blend of corn and sorghum.

[5]Distillers dried grains.

[6]Provided the following quantities of vitamins per kg of complete diet: vitamin A, 10,990 IU as vitamin A acetate; vitamin D3, 1,648 IU as D-activated animal sterol; vitamin E, 55 IU as

alpha tocopherol acetate; vitamin K3, 4.4 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 3.3 mg as thiamine mononitrate; riboflavin, 9.9 mg; pyridoxine, 3.3 mg as pyridoxine hydrochloride; vitamin B12, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; and biotin, 0.17 mg.

[7]Provided the following quantities of minerals per kg 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.

Table 2. Analyzed composition of experimental diets in Exp 1, % as is[1]

Sample	DM	CP	Fat	Ash	OR[2]	TDF
Distillers dried grains with solubles						
1	89.2	27.6	10.1	4.3	47.2	30.4
2	88.7	28.0	9.5	4.0	47.3	31.1
3	86.8	27.2	10.4	4.0	45.2	30.2
4	88.9	29.0	8.6	4.2	47.1	30.3
5	89.2	26.7	8.9	4.7	48.8	29.6
6	87.1	24.6	8.9	4.5	49.1	31.3
7	88.6	26.6	9.1	4.6	48.3	29.3
8	90.8	28.4	10.3	4.2	47.9	31.4
9	90.0	29.0	10.5	4.4	46.0	29.9
10	89.4	27.3	10.8	4.5	46.9	18.6
Corn	93.9	11.2	3.2	1.5	78.0	9.7
Diets						
1	90.7	18.1	5.6	4.6	32.3	19.9
2	91.4	18.9	6.5	4.6	31.4	18.8
3	89.9	18.4	6.8	4.8	29.8	21.5
4	91.2	20.2	5.9	5.2	29.8	21.8
5	92.1	17.9	7.4	5.5	31.3	18.4
6	90.0	18.2	6.3	6.1	29.3	21.2
7	90.7	19.1	6.0	6.2	29.4	19.1
8	91.8	19.2	7.2	5.0	30.4	19.2

9	91.0	19.0	4.1	5.1	32.7	19.0
10	90.6	18.8	6.5	4.9	30.4	18.8
Corn	85.4	7.63	4.0	5.2	69.5	7.6

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

[2] OR = 100 – (CP + EE + ash + water + $starch_{extra}$ + $sucrose_{extra}$). $Starch_{extra}$ and $sucrose_{extra}$ represents the added corn starch and sucrose that was included in the diet.

Table 3. Analyzed composition of experimental diets in Exp 2, % as is[1]

Sample	DM	CP	Fat	Ash	Starch	OR[2]	ADF	NDF	TDF	IDF	SDF
Ingredients											
C-DDGS[3]											
1	91.2	32.7	8.0	5.1	3.15	45.4	11.61	40.66	43.81	38.78	5.03
2	93.4	30.6	8.9	4.0	4.10	49.9	10.80	44.40	46.31	37.34	2.36
3	91.3	29.4	10.7	4.6	1.50	46.6	12.92	43.47	43.68	35.58	8.10
4	91.1	28.7	9.4	4.6	3.63	48.4	9.74	37.43	38.71	33.58	5.13
5	90.7	27.4	10.7	4.9	1.62	47.7	10.28	39.50	44.03	36.42	7.61
6	91.6	27.3	8.8	5.0	2.17	50.5	10.98	41.85	44.95	40.37	4.58
7	89.6	27.5	10.0	5.1	2.69	47.0	12.07	40.07	44.30	35.76	8.54
8	91.7	27.3	11.2	5.4	2.68	47.8	10.73	41.90	44.93	39.80	5.12
S-DDGS[4]	91.3	31.9	9.5	4.7	3.68	45.2	24.96	47.90	49.43	43.45	5.98
CS-DDGS[5]	93.4	28.0	10.6	4.8	1.68	50.0	16.65	44.07	44.84	38.48	6.36
Diets											
C-DDGS											
1	93.8	17.4	7.5	5.3	21.8	33.5	7.3	24.9	28.88	20.01	8.87
2	93.8	18.6	6.5	4.8	23.4	33.8	7.0	26.1	26.66	22.25	4.42
3	93.4	16.7	6.3	5.9	14.4	34.5	9.7	33.1	37.04	31.36	5.68
4	93.7	16.1	6.4	5.4	20.7	35.7	7.4	24.7	26.09	22.75	3.34
5	92.8	16.8	7.1	5.4	20.3	33.6	6.7	25.8	25.93	21.95	3.98
6	93.6	16.6	7.7	5.8	17.5	33.5	7.8	26.4	28.70	23.89	4.81
7	93.5	19.2	6.5	5.5	12.4	32.3	7.6	27.6	29.32	25.38	3.94

8	92.7	17.8	7.4	5.7	14.4	31.7	7.0	27.7	31.16	26.43	4.73
S-DDGS	93.2	20.3	5.2	5.1	10.8	32.6	16.2	29.3	31.65	26.90	4.75
CS-DDGS	93.7	19.3	5.5	5.5	10.2	33.5	11.2	29.3	30.86	25.61	5.26

[1]Samples from Urriola et al. (2007).

[2]OR = 100 – (CP + EE + ash + water + $starch_{extra}$ + $sucrose_{extra}$). $Starch_{extra}$ and $sucrose_{extra}$ represents the added corn starch and sucrose that was included in the diet.

[3]Distillers dried grains with solubles produced from corn.

[4]Distillers dried grains with solubles produced from sorghum.

[5]Distillers dried grains with solubles produced from a blend of corn and sorghum.

Table 4. Analyzed composition of experimental diets in Exp 3, % as is[1]

Sample	DM	CP	TDF
Ingredients			
$DDGS_{ethanol}$[2]			
1	84.3	29.3	31.74
2	88.9	25.9	29.51
3	88.5	24.9	31.50
4	87.0	28.5	32.41
5	88.4	25.1	28.59
6	88.7	25.8	30.59
$DDGS_{beverage}$[3]	87.6	29.7	38.48
DDG[4]	89.7	29.5	43.91
Diets			
$DDGS_{ethanol}$			
1	84.3	16.5	21.7
2	88.9	15.1	21.9
3	88.5	16.6	23.3
4	87.0	17.4	21.3
5	88.4	16.8	21.2
6	88.7	16.6	22.7
$DDGS_{beverage}$	87.6	16.7	28.3
DDG	89.7	18.8	28.1

[1]Samples from Pahm et al. (2008)

[2]Distillers dried grains with solubles from ethanol producing plant.

[3]Distillers dried grains with solubles from beverage producing plant.

[4]Distillers dried grains.

Table 5. Apparent ileal digestibility (AID, %), apparent total tract digestibility (ATTD, %), and calculated fermentation in the large intestine (%) of total dietary fiber (TDF), DM, and organic residue (OR) in corn and in 10 sources of corn based distillers dried grains with solubles (DDGS) by growing pigs. Exp. 1[1,2]

		DDGS source													DDGS vs. corn[3]	
Item	Corn	1	2	3	4	5	6	7	8	9	10	Mean	SEM	*P* - value	SEM	*P* - value
AID																
TDF	16.5	25.2	19.7	24.8	25.6	12.6	25.9	21.9	19.7	24.6	14.7	21.5	2.58	< 0.01	17.7	0.23
DM	75.2	66.2	67.2	65.8	63.8	65.2	67.1	65.6	63.9	68.0	63.6	65.6	1.14	< 0.01	3.10	< 0.01
OR[4]	77.0	33.0	32.3	26.4	20.1	27.9	29.1	24.1	22.5	39.0	25.0	27.9	2.15	< 0.01	2.99	< 0.01
ATTD																
TDF	23.1	45.1	46.1	52.4	50.0	43.9	49.0	44.2	47.1	36.8	30.5	44.5	4.76	< 0.01	7.77	0.05
DM	87.5	75.3	78.3	77.6	74.7	77.7	76.8	75.4	75.5	77.5	75.4	76.4	0.94	< 0.01	1.10	< 0.01
OR	89.4	55.3	60.6	56.5	48.7	59.8	47.8	45.1	51.8	60.1	55.2	54.1	4.13	< 0.01	1.21	< 0.01
Fermentation																
TDF	36.7	19.8	26.5	27.6	24.4	31.3	23.1	22.3	27.5	11.7	16.4	23.1	5.80	0.22	16.3	0.03
DM	12.3	9.07	11.2	11.8	10.8	12.5	9.73	9.74	11.6	9.42	11.79	10.8	1.43	0.70	2.96	0.29

OR	12.4	22.4	28.3	30.0	28.6	31.9	18.8	20.9	29.3	21.1	30.2	26.2	4.45	0.06	2.03	< 0.01

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

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

[3]Contrast of corn against all DDGS sources.

[4]OR = 100 – (CP + EE + ash + water + $starch_{extra}$ + $sucrose_{extra}$). $Starch_{extra}$ and $sucrose_{extra}$ represents the added corn starch and sucrose that was included in the diet.

Table 6. Apparent ileal digestibility (AID, %), apparent total tract digestibility (ATTD, %), and fermentation in the large intestine (%) of crude fiber, ADF, NDF, insoluble dietary fiber (IDF), soluble dietary fiber (SDF), total dietary fiber (TDF), and organic residue (OR) in 8 sources of corn based distillers dried grains with solubles (C-DDGS), one sorghum based DDGS (S-DDGS), and one blend of corn and sorghum DDGS (CS-DDGS) by growing pigs. Exp. 2[1,2]

Item	C-DDGS									S-DDGS	CS-DDGS	SEM	*P*-value	Contrasts	
	1	2	3	4	5	6	7	8	Mean					S vs. C DDGS	CS vs. C DDGS
AID															
Crude fiber	13.7	19.2	42.8	35.3	34.0	36.2	31.7	34.7	31.0	38.6	30.7	5.50	< 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	4.02	< 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	4.22	< 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	6.94	< 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	3.63	< 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	5.91	< 0.01	0.30	< 0.01
OR[3]	66.5	65.5	67.0	65.1	67.0	53.9	38.4	45.0	58.6	41.6	32.9	2.60	< 0.01	< 0.01	< 0.01
ATTD															

Crude fiber	37.6	38.0	50.6	21.7	48.1	36.3	51.2	45.1	41.1	41.6	39.9	4.00	< 0.01	0.88	0.76
ADF	63.1	51.8	62.2	36.2	54.7	53.7	64.3	56.5	55.3	60.7	53.7	4.08	< 0.01	0.13	0.64
NDF	61.0	54.3	60.7	39.5	62.3	51.6	65.8	60.8	57.0	59.3	51.5	3.58	< 0.01	0.42	0.06
IDF	37.1	30.9	5.8	14.2	41.7	29.3	51.0	45.0	31.9	41.3	28.6	4.24	< 0.01	0.30	0.05
SDF	95.3	92.7	92.1	85.9	92.6	89.4	91.3	91.1	91.3	90.9	90.6	1.47	< 0.01	0.78	0.59
TDF	55.0	41.1	52.8	23.4	49.5	39.4	56.4	52.0	46.2	48.8	39.2	4.58	< 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	2.31	< 0.01	0.03	< 0.01
Fermentation															
Crude fiber	27.4	22.6	4.32	16.8	18.0	0.14	29.1	15.5	16.7	6.31	2.25	8.30	< 0.01	0.44	0.21
ADF	32.7	27.4	14.3	1.33	27.3	17.8	39.9	32.3	24.1	6.95	9.55	6.72	< 0.01	0.01	0.04
NDF	22.2	20.0	6.45	11.2	20.6	9.08	29.4	15.5	16.8	15.8	10.2	6.22	< 0.01	0.76	0.51
IDF	30.4	21.6	13.8	14.9	27.7	10.6	31.6	17.1	21.0	17.4	15.3	8.69	< 0.01	0.98	0.77
SDF	13.6	30.8	21.7	35.3	32.9	27.2	35.6	26.8	28.0	24.6	26.7	4.43	< 0.01	0.35	0.52
TDF	25.5	20.9	15.9	10.5	27.5	13.5	31.5	17.3	20.3	18.9	15.7	7.50	< 0.01	0.84	0.73
OR	14.9	13.1	10.1	8.89	14.4	20.6	39.2	27.3	18.6	29.6	33.6	2.87	< 0.01	< 0.01	< 0.01

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

[2]Samples from Urriola et al. (2007).

[3]OR = 100 – (CP + EE + ash + water + $starch_{extra}$ + $sucrose_{extra}$). $Starch_{extra}$ and $sucrose_{extra}$ represents the added corn starch and sucrose that was included in the diet.

Table 7. Apparent ileal digestibility (AID, %), apparent total tract digestibility (ATTD, %), and calculated fermentation in the large intestine (%) of total dietary fiber (TDF), in 6 sources of corn distillers dried grains with solubles produced from ethanol plants ($DDGS_{ethanol}$),1 source of DDGS produced at a beverage plant ($DDGS_{beverage}$), and 1 source of corn distillers dried grains (DDG) by growing pigs. Exp. 3[1,2]

	$DDGS_{ethanol}$							$DDGS_{beverage}$	DDG			P – values[2]	
Item	1	2	3	4	5	6	Mean			SEM	*P* – value	DDG vs. $DDGS_{ethanol}$	$DDGS_{beverage}$ vs. $DDGS_{ethanol}$
AID	13.0	12.8	24.0	11.4	30.8	18.8	18.5	13.2	0.73	4.86	< 0.01	< 0.01	0.29
ATTD	29.3	51.8	52.4	41.3	56.0	57.0	48.0	46.4	43.8	3.49	< 0.01	0.60	0.19
Fermentation	22.7	38.6	28.5	30.1	25.1	38.1	30.5	33.7	42.8	6.02	0.19	0.05	0.59

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

[2]Samples from Pahm et al. (2008).

[3]Contrast of corn against all DDGS sources.

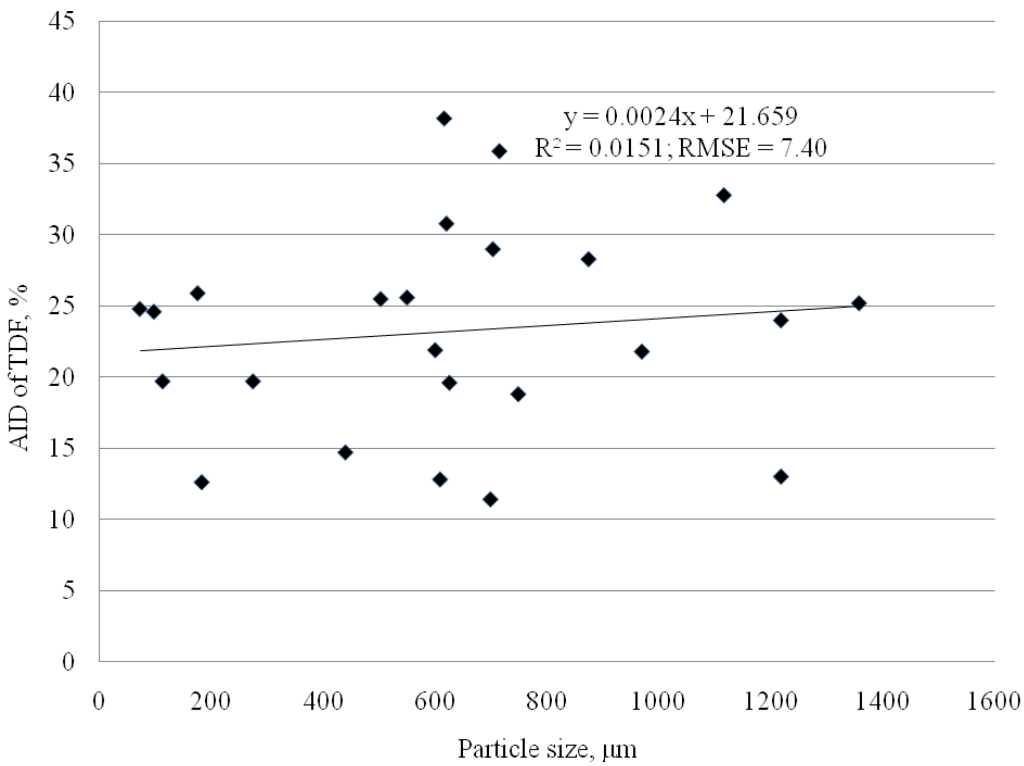

Figure 1. Relationship between particle size (µm) and apparent ileal digestibility (%) of distillers died grains with solubles fed to growing pigs

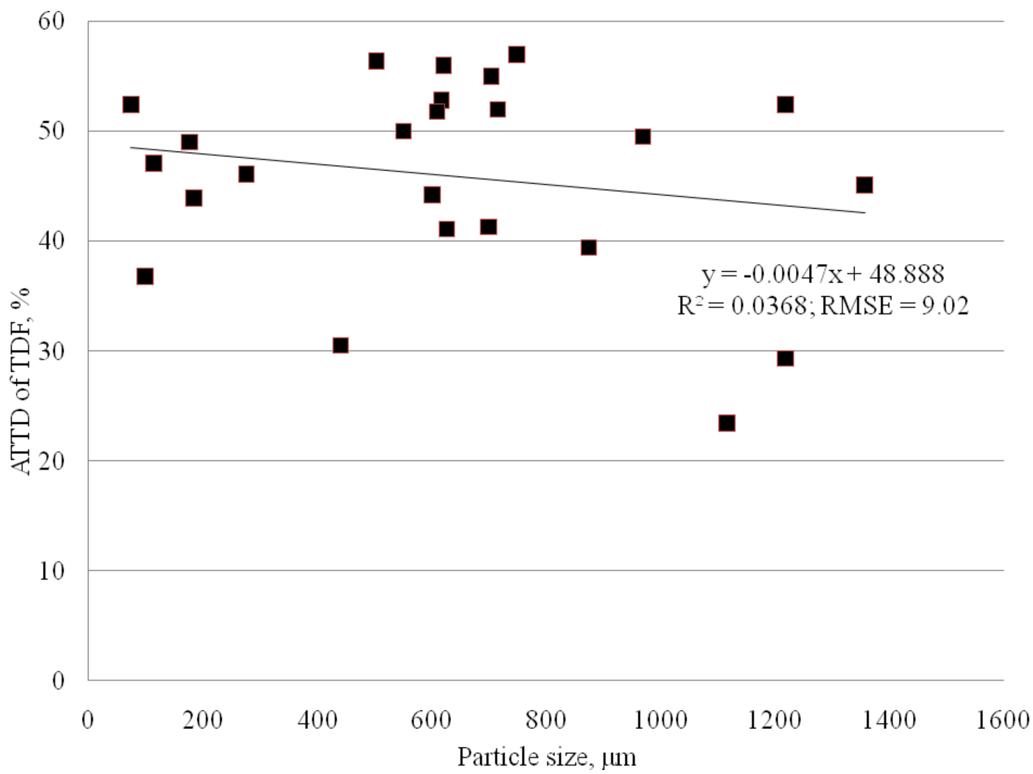

Figure 2. Relationship between particle size (µm) and apparent total tract digestibility (%) of distillers died grains with solubles fed to growing pigs

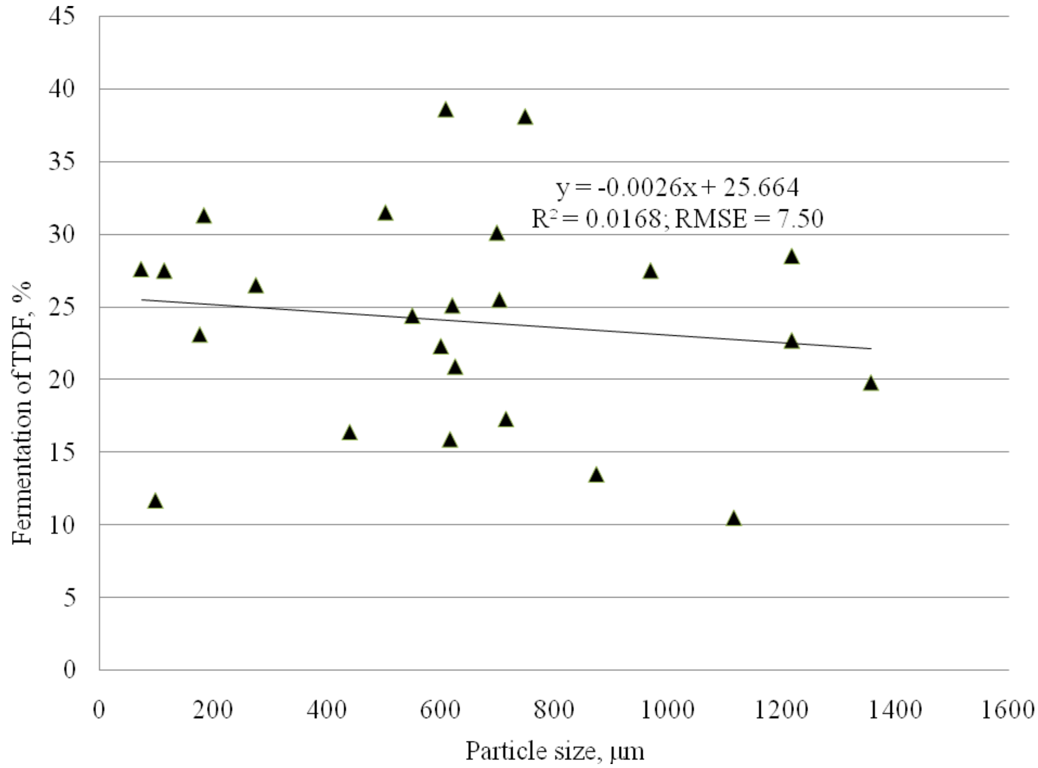

Figure 3. Relationship between particle size (µm) and fermentability of total dietary fiber (%) of distillers died grains with solubles fed to growing pigs