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Effects of distillers dried grains with solubles on amino acid, energy, and fiber digestibility and on hindgut fermentation of dietary fiber in a corn-soybean meal diet fed to growing pigs

P. E. Urriola and H. H. Stein[1]

Department of Animal Sciences, University of Illinois, Urbana 61801

ABSTRACT: The objective of this experiment was to measure the effect of distillers dried grains with solubles (DDGS) on the digestibility of AA, energy, and fiber, on the fermentation of fiber, and on the first appearance of digesta at the end of the ileum, in the cecum, and in the feces of growing pigs fed a corn-soybean meal-based diet. Sixteen pigs (initial BW = 38.0 ± 1.6 kg) were prepared with a T-cannula in the distal ileum and a T-cannula in the cecum and allotted to 2 treatments. In period 1, all pigs were fed a corn-soybean meal diet. In periods 2, 3, and 4, pigs were fed the control diet or a diet containing corn, soybean meal, and 30% DDGS. First appearance of digesta at the end of the ileum, in the cecum, and over the entire intestinal tract was measured at the end of period 4. The apparent ileal digestibility (AID) and the apparent total tract digestibility (ATTD) of nutrients were measured, and the concentration of VFA was analyzed in ileal, cecal, and fecal samples. The AID of Lys (74.1%) in the DDGS diet was less ($P < 0.05$) than in the control diet (78.6%), but the AID of most other AA and GE, NDF, and total dietary fiber (TDF) were not different between the 2 diets. The ATTD of GE (81.0%), NDF (57.2%), TDF (55.5%), and DM (81.7%) were less ($P < 0.05$) in the DDGS diet than in the control diet (86.0, 69.3, 66.0, and 87.2%, respectively). The concentration of VFA in ileal, cecal, and fecal samples was not different between pigs fed the 2 diets. The pH of ileal and cecal digesta from pigs fed the DDGS diet (6.3 and 5.5) was greater ($P < 0.01$) than from pigs fed the control diet (5.8 and 5.3). The ATTD of DM, GE, ADF, NDF, and TDF did not change with collection period, but the AID of ADF, NDF, and TDF increased ($P < 0.05$) from period 2 to period 4. The concentration of all VFA, except isobutyrate, was greater ($P < 0.05$) in cecal samples from period 4 compared with period 2, and the concentration of all VFA except propionate and isovalerate were greater ($P < 0.05$) in fecal samples collected in period 4 compared with those collected in period 2. The first appearance of digesta at the end of the ileum, in the cecum, and in the feces was not affected by DDGS. In conclusion, pigs fed the diet containing DDGS had less digestibility of Lys, GE, ADF, NDF, and TDF than pigs fed the control diet. The digestibility of DM and GE was not influenced by collection period, but the concentration of VFA in cecal digesta and feces increased with the length of time pigs received the diets.

Key words: digestibility, distillers dried grain with solubles, energy, fiber, pig

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INTRODUCTION

The apparent total tract digestibility (**ATTD**) of energy and the apparent ileal digestibility (**AID**) of AA are less in distillers dried grains with solubles (**DDGS**) than in corn (Stein et al., 2006; Pedersen et al., 2007; Urriola et al., 2009a). This may be a result of the fiber concentration in DDGS because DDGS contains approximately 3 times more dietary fiber than corn (Stein and Shurson, 2009). The reason dietary fiber reduces digestibility of energy and AA is that fiber has less digestibility, induces an increase in endogenous nutrient losses, and increases the rate of passage (Grieshop et al., 2001; Souffrant, 2001). Dietary fiber in DDGS consists mainly of insoluble dietary fiber (Urriola et al., 2009b) that may increase the water-binding capacity and bulkiness of the diet (Potkins et al., 1991; Cherbut et al., 1994). The AID and ATTD of dietary fiber varies among sources of DDGS (Urriola et al., 2009b), but there is no information on the effects of DDGS on digestibility of AA, energy, and fiber in mixed diets containing corn, soybean meal, and DDGS.

[1]Corresponding author: hstein@uiuc.edu
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The digestibility of energy may change as pigs adapt to the presence of fiber in the diet (Longland et al., 1993) and fermentation of fiber increases over time. This results in greater production of VFA and greater absorption of energy (Castillo et al., 2007), but there are no data on the time it takes for pigs to adapt to the presence of DDGS in the diet.

The first objective of this experiment was to test the hypothesis that AID and ATTD of energy and nutrients is less in a diet containing 30% DDGS than in a corn-soybean meal diet. The second objective was to test the hypothesis that the digestibility of nutrients and energy will increase if pigs are allowed to adapt to the presence of DDGS in the diet. The third objective was to test the hypothesis that digesta from diets containing DDGS will appear sooner at the end of the ileum, in the cecum, and in the feces than digesta from pigs fed no DDGS.

MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois at Urbana–Champaign.

Animals, Housing, and Diets

Sixteen growing barrows (initial BW = 38.0 ± 1.6 kg) that were the offspring of line 337 boars mated to C-22 females (Pig Improvement Company, Hendersonville, TN) were surgically prepared with a T-cannula with an inner diameter of 1.6 cm in the distal ileum (Stein et al., 1998). Another T-cannula (2.1 cm i.d.) was inserted in the mid-cecum. The ileal cannula was exteriorized immediately behind the last rib, whereas the cecal cannula was exteriorized approximately 10 cm caudal to the ileal cannula. After surgeries, pigs were allowed to recover for 30 d, and a corn-soybean meal diet was provided on an ad libitum basis during this time. All pigs were housed in individual pens (1.2 × 1.5 m) that had a nipple drinker, a feeder, and a fully slatted tri-bar floor. The room temperature was between 20 and 22°C throughout the experiment.

Two diets were formulated to contain similar concentrations of total Lys without using crystalline Lys. The control diet was based on corn and soybean meal, and the DDGS diet contained corn, soybean meal, and 30% DDGS (Table 1). Because of the greater concentration of GE, CP, and dietary fiber in DDGS than in corn and soybean meal, the concentration of these components was greater in the DDGS diet than in the control diet. Titanium dioxide (Chicago Sweeteners, Chicago, IL) was included at 3 g/kg in both diets as an indigestible marker. Vitamins and minerals were included in both diets to meet or exceed nutrient requirements of growing pigs (NRC, 1998).

Table 1. Composition of experimental diets, as-fed basis

	Distillers dried grains with solubles, %	
Item	0	30
Ingredient, %		
Ground corn	78.75	54.60
Soybean meal (48% CP)	18.00	12.50
Distillers dried grains with solubles	—	30.00
Cornstarch	1.00	1.00
Ground limestone	0.75	1.00
Dicalcium phosphate	0.80	0.20
Salt	0.40	0.40
Vitamin mineral premix[1]	0.30	0.30
Calculated concentration		
ME, kcal·kg^{-1}	3,336	3,350
CP, %	15.10	18.70
Lys, standardized ileal digestible, %	0.66	0.66
Ether extract, %	3.30	5.60
NDF, %	9.10	19.00
Total dietary fiber, %	10.00	16.20

[1]The vitamin-micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A, 11,128 IU; vitamin D_3, 2,204 IU; vitamin E, 66 IU; vitamin K, 1.42 mg; thiamin, 0.24 mg; riboflavin, 6.58 mg; pyridoxine, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid, 23.5 mg; niacin, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Experimental Design and Sample Collection

Pigs were randomly allotted to 2 treatment groups with 8 pigs per treatment in a randomized complete block design. Feed was provided to each pig at a daily amount of 3.4 times the maintenance requirement for energy (i.e., 106 kcal of ME per kg of $BW^{0.75}$; NRC, 1998). The calculated ME of the control diet and the DDGS diet was 3,336 and 3,350 kcal·kg^{-1}, respectively.

The daily feed allotments were divided into 2 equal meals that were provided at 0800 and 1700 h. Pigs were fed experimental diets during four 9-d periods. During the first period, all pigs were fed the control diet. During the next 3 periods, pigs on each treatment group were fed 1 of the 2 treatment diets, and the same diet was provided during all 3 periods.

Feces were collected via grab sampling in the morning of d 5 of each period. The pH of the fecal samples was measured immediately after collection using a pH meter (model Accumet Basic, Fisher Scientific, Pittsburgh, PA). Twenty grams of each fecal sample were mixed with 2 *N* HCl in a 1:1 ratio and stored at −20°C until analyzed for concentrations of VFA. The remaining feces were stored in plastic bags at −20°C. One sample of cecal digesta was collected every 2 h from 0700 to 1700 h on d 6 and 7 of each collection period, and ileal digesta were collected continuously from 0730 to 1630 h on d 8 and 9. The procedures for collection and storage of cecal and ileal digesta were similar to the procedure for ileal digesta described by Cervantes-Pahm and Stein (2008). However, from each bag of cecal and ileal digesta, a subsample of 10% was collected and mixed with 2 *N* HCl at a 1:1 ratio. These samples were combined within pig and collection period and stored at −20°C until analyzed for VFA. The pH of the first cecal and the first ileal sample collected from each pig after 1000, 1200, 1400, and 1600 h on each collection day was also measured as described for the fecal samples.

After the conclusion of period 4, pigs were fed their respective diets for another 3 d to measure the time it takes for digesta to appear at the end of the ileum, in the cecum, and in the feces. On d 3 of this last period, the morning meal for each pig was mixed with 5 g/kg of chromic oxide. Pigs were allowed to eat their meal, and the start of eating was considered time zero. The ileal cannula of each pig was opened 1 h after the morning meal was fed to observe if green digesta were present in the cannula. The cannula was closed again if no green digesta were present, and the cannula was opened every 15 min thereafter until green digesta were detected. The time of first appearance of green digesta was recorded. From that time, the cecal cannula was opened every 15 min, and the time for the first appearance of green color in the cecal digesta was recorded. During the next 36 h, feces were scored every 30 min from all pigs, and the first time green feces appeared was recorded.

Sample Processing and Chemical Analysis

At the conclusion of each experimental period, samples were thawed and mixed within animal and a subsample was collected for chemical analysis. Ileal and fecal samples were lyophilized and ground before analysis.

Samples of corn, soybean meal, DDGS, diets, ileal digesta, and feces were analyzed for DM (method 930.15; AOAC International, 2007), CP (method 990.03; AOAC International, 2007), ADF (method 973.18; AOAC International, 2007), NDF (Holst, 1973), and total dietary fiber (**TDF**; method 985.29; AOAC International, 2007). Energy was also analyzed in these samples using a bomb calorimeter (model 6300, Parr Instruments, Moline, IL). Amino acids were analyzed on an AA analyzer (model No. L8800, Hitachi High Technologies America Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6 *N* HCl for 24 h at 110°C (method 982.30 E[a]; AOAC International, 2007). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (method 982.30 E[b]; AOAC International, 2007). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (method 982.30 E[c]; AOAC International, 2007). All diets and ileal digesta samples were analyzed for titanium (Myers et al., 2004). Water-binding capacity was measured by weighing 1 g of sample into a centrifuge tube. This sample was then mixed with 30 mL of distilled water (Robertson et al., 2000). After stirring, samples were allowed to settle and were centrifuged for 20 min at 2,500 × *g* at 25°C. The supernatant was removed, and sample weights were recorded. Values for water-binding capacity were expressed as the amount of water retained by the pellet (g/g of DM).

The ileal, cecal, and fecal samples that were preserved in HCl were thawed and stirred, and 1 mL was mixed with 9 mL of distilled water. One milliliter of this mixture was added to 4 mL of 25% metaphosphoric acid and vortexed. Samples were analyzed for VFA following the procedure described by Erwin et al. (1961). Briefly, a gas chromatograph (Hewlett-Packard 5890A series II, Hewlett-Packard, Palo Alto, CA) was standardized with a glass column (180 cm × 4 mm i.d.) packed with 10% SP-1200/1% H_3PO_4 on 80/100+ mesh Chromosorb WAW (Supelco Inc., Bellefonte, PA). Nitrogen was used as the carrier with a flow rate of 75 mL/min. Oven, detector, and injector temperatures were set at 125, 175, and 180°C, respectively.

Calculations

The AID of CP, AA, ADF, NDF, TDF, DM, and energy were calculated for each diet as described previously (Stein et al., 2007), and the ATTD of ADF, NDF, TDF, DM, and energy was also calculated using this equation. The fermentation of DM, energy, ADF, NDF, and TDF in the large intestine was calculated by subtraction of the amount (g) of ileal digested nutrient or DM from the amount (g) of total tract digested nutrient or DM. Fermentation of energy was calculated by subtracting the amount (kcal) of ileal digested energy from the amount of total tract digested energy (kcal).

The ileal flow of DM, ADF, NDF, and TDF was calculated using the following equation:

$$\text{Flow}_{\text{nutrient}} = \text{Nutrient}_{\text{digesta}} \times (\text{Marker}_{\text{diet}}/\text{Marker}_{\text{digesta}}),$$

where $\text{Flow}_{\text{nutrient}}$ is the flow of ADF, NDF, or TDF (g/kg of DMI); $\text{Nutrient}_{\text{digesta}}$ is the concentration of ADF, NDF, and TDF in ileal digesta (g/kg of DM); $\text{Marker}_{\text{diet}}$ is the concentration of titanium in the diet (g/kg of DM); and $\text{Marker}_{\text{digesta}}$ is the concentration of titanium in ileal digesta (g/kg of DM). The flow over the entire intestinal tract was calculated using the same equation and the ileal and fecal flow of energy (kcal/kg of DMI), and the ileal, cecal, and fecal flow of VFA were also calculated using this equation. The first appearance of digesta in the intestinal tract of pigs was calculated as the difference between the time the green marker was fed and the time it appeared in ileal, cecal, or fecal samples.

Table 2. Analyzed nutrient composition of experimental diets, as-fed basis

	Distillers dried grains with solubles, %	
Item	0	30
GE, kcal/kg	3,897	4,294
CP, %	14.8	18.5
Acid hydrolyzed ether extract, %	3.07	7.42
ADF, %	2.85	4.65
NDF, %	11.3	15.1
Total dietary fiber, %	12.4	17.0
Water-binding capacity, g/g	1.81	1.96
Indispensable AA, %		
Arg	0.89	0.99
His	0.39	0.48
Ile	0.59	0.69
Leu	1.43	1.94
Lys	0.74	0.77
Met	0.26	0.35
Phe	0.71	0.88
Thr	0.53	0.66
Trp	0.18	0.19
Val	0.73	0.87
Dispensable AA, %		
Ala	0.83	1.15
Asp	1.35	1.46
Cys	0.27	0.35
Glu	2.67	3.12
Gly	0.59	0.72
Pro	0.95	1.22
Ser	0.64	0.80
Tyr	0.51	0.67
All AA	13.8	16.6

Statistical Analyses

The UNIVARIATE procedure (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. The AID data for periods 2, 3, and 4 were analyzed by the MIXED procedure of SAS. The REPEATED statement was used to model the effect of collection period on AID and ATTD values using the individual pig as the subject from which repeated observations were recorded (Littell et al., 1998). Digestibility values from period 1 were used as the covariate for each pig to correct for differences in digestibility among pigs. Main effects were period and DDGS. The interaction between period and DDGS was included in the initial model and considered significant at $P \leq 0.05$, but if it was not significant, the interaction was removed and only main effects were included in the final model. Least squares means were calculated using the LSMEANS statement of SAS. The contrast option was used to identify linear and quadratic effects of collection period on digestibility values. Pig was the experimental unit for all analyses. Differences among main effects were considered significant if $P < 0.05$ and were considered a trend if the P-value was between 0.05 and 0.10. Data for first appearance of the digesta at the end of the ileum, in the cecum, and in the feces were also analyzed by the MIXED procedure of SAS using pig as a random variable and DDGS as the fixed effect.

RESULTS

All pigs were successfully cannulated at the distal ileum and in the mid-cecum. Pigs recovered from surgery without complications. The BW of pigs at the start of period 1, 2, 3, and 4 was 71.7 ± 6.4, 75.4 ± 6.6, 84.8 ± 10.0, and 95.4 ± 8.3 kg, respectively. The final BW at the end of period 4 was 103.7 ± 9.2 kg. The analyzed nutrient concentration in the diets was similar to calculated values (Table 2). The control diet had less GE (3,897 kcal/kg), CP (14.8%), ADF (2.85%), NDF (11.3%), and TDF (12.4%) than the diet containing 30% DDGS (GE, 4,294 kcal/kg; CP, 18.5%; ADF, 4.65%; NDF, 15.1%; and TDF, 17.0%). Whenever effects of period were analyzed, no differences between period 2 and 3 were observed. Therefore, values for period 3 are not reported.

Apparent Ileal Digestibility, Apparent Total Tract Digestibility, and Hindgut Fermentation

The AID of Lys and Asp were less ($P < 0.05$) in the DDGS diet than in the control diet (Table 3), and the AID for Leu and Ala were greater ($P < 0.05$) in the DDGS diet than in the control diet. There was also a tendency ($P < 0.10$) for the digestibility of Met and Tyr to be greater in the DDGS diet than in the control diet, but there were no differences in the AID of CP or any other AA between the 2 diets, and there was no effect of period on the AID of CP or AA.

The AID of GE, NDF, and TDF were not affected by inclusion of 30% DDGS in the diet (Table 4). The AID of DM in the DDGS diet (71.2%) was less ($P < 0.01$) than the AID of DM in the control diet (74.0%). In contrast, the AID of ADF in the DDGS diet (33.8%) was greater ($P < 0.01$) than in the control diet (13.1%). The ATTD of DM (81.7%), GE (81.0%), NDF (57.2%), and TDF (55.5%) were also less ($P < 0.05$) in the DDGS diet than in the control diet (87.2, 86.0, 69.3, and 66.0, respectively). The AID of ADF, NDF, and TDF increased (linear, $P < 0.05$) from period 2 (21.0, 38.5, and 32.2%, respectively) to period 4 (29.4, 44.7, and 39.8, respectively). However, there was no effect of period on the ATTD of DM, GE, ADF, NDF, and TDF.

The hindgut fermentation of DM (11.5%), GE (8.9%), ADF (21.0%), NDF (18.1%), and TDF (20.5%) were less ($P < 0.05$) in the DDGS diet than in the control diet (13.9, 13.2, 41.1, 26.8, and 29.9%, respectively). The hindgut fermentation of ADF, NDF, and TDF was reduced (linear, $P < 0.05$) from period 2 (36.0, 27.2, and 31.1%, respectively) to period 4 (28.2, 20.7, and 23.2%, respectively).

Table 3. Effects of period and distillers dried grains with solubles (DDGS) on apparent ileal digestibility of AA by growing pigs[1]

	Period 2		Period 4			*P*-value[2]	
Item	0% DDGS	30% DDGS	0% DDGS	30% DDGS	SEM	DDGS	Period[3]
CP, %	75.6	74.2	75.0	72.7	2.1	0.79	0.81
Indispensable AA							
Arg	87.9	86.1	87.9	86.7	0.8	0.12	0.20
His	83.1	81.3	82.7	81.1	1.1	0.17	0.47
Ile	79.3	78.2	78.5	78.1	1.1	0.74	0.51
Leu	82.0	83.6	81.8	84.1	0.9	<0.01	0.56
Lys	78.6	74.1	77.1	73.3	1.6	0.01	0.40
Met	82.2	82.8	83.6	85.1	1.0	0.08	0.16
Phe	81.1	81.4	80.5	81.2	1.0	0.21	0.56
Thr	70.4	69.8	68.1	68.9	2.1	0.45	0.63
Trp	81.6	80.0	76.6	75.8	1.9	0.70	0.05
Val	76.9	75.7	75.8	75.0	1.4	0.71	0.54
Mean	80.6	80.0	79.8	79.9	1.1	0.79	0.55
Dispensable AA							
Ala	76.3	78.5	76.0	78.8	1.3	<0.01	0.36
Asp	78.2	74.8	76.8	74.1	1.5	0.04	0.64
Cys	74.4	72.6	70.9	71.9	2.0	0.89	0.28
Glu	84.8	82.9	83.0	82.4	1.1	0.27	0.55
Gly	65.5	65.8	59.8	62.2	3.0	0.32	0.23
Pro	78.8	77.9	76.9	77.0	1.8	0.79	0.55
Ser	78.2	77.5	77.0	78.2	1.4	0.36	0.96
Tyr	82.0	82.9	80.8	82.7	1.1	0.07	0.55
Mean	79.5	78.4	77.6	77.7	1.4	0.96	0.52
All AA	79.5	78.6	78.1	78.2	1.3	0.86	0.55

[1]In period 1, all pigs were fed the control diet and the digestibility values obtained in period 1 were used as a covariate to correct the values for periods 2, 3, and 4.

[2]There was no interaction ($P > 0.05$) between DDGS and period. Therefore, only main effects are reported.

[3]Data for period 3 were not different ($P > 0.05$) from period 2 for any of the variables that were measured.

Table 4. Effects of distillers dried grains with solubles (DDGS) and period on apparent ileal digestibility, apparent total tract digestibility, and hindgut fermentation of DM, energy, ADF, NDF, and total dietary fiber (TDF) by growing pigs[1,2]

	DDGS, %				Period[3]			
Item	0	30	SEM	*P*-value	2	4	SEM	*P*-value
Apparent ileal digestibility, %								
DM	74.0	71.2	1.0	<0.01	72.0	73.5	0.9	0.31
GE	72.7	72.0	1.1	0.47	71.9	73.2	0.9	0.46
ADF	13.1	33.8	1.9	<0.01	21.0	29.4	2.3	0.03
NDF	42.1	39.1	1.5	0.17	38.5	44.7	1.9	0.05
TDF	35.4	35.0	1.6	0.85	32.2	39.8	2.0	0.02
Apparent total tract digestibility, %								
DM	87.2	81.7	0.4	<0.01	86.4	86.1	0.5	0.07
GE	86.0	81.0	0.6	<0.01	84.4	84.3	0.5	0.13
ADF	56.1	54.8	2.5	0.60	57.5	59.0	2.0	0.51
NDF	69.3	57.2	1.9	<0.01	66.0	65.6	1.6	0.16
TDF	66.0	55.5	1.9	<0.01	63.7	63.4	1.6	0.15
Hindgut disappearance, %								
DM	13.9	11.5	0.8	0.03	14.2	12.2	0.9	0.14
GE	13.2	8.9	0.9	<0.01	12.4	11.0	1.1	0.21
ADF	41.1	21.0	2.7	<0.01	36.0	28.2	3.1	0.05
NDF	26.8	18.1	1.9	<0.01	27.2	20.7	2.3	0.03
TDF	29.9	20.5	2.0	<0.01	31.1	23.2	3.4	0.01

[1]In period 1, all pigs were fed the control diet and the digestibility value from period 1 for each pig was used as a covariate to correct the values for periods 2, 3, and 4.

[2]There was no interaction ($P > 0.05$) between DDGS and period. Therefore, only main effects are reported.

[3]Data for period 3 were not different ($P > 0.05$) from period 2 for any of the variables that were measured.

Table 5. Effects of period and distillers dried grains with solubles (DDGS) on ileal and total tract flow (g or kcal/kg of DMI) of DM, energy, ADF, NDF, and total dietary fiber (TDF) by growing pigs[1,2]

	DDGS, %				Period[3]				
Item	0	30	SEM	*P*-value	2	4	SEM	Linear	Quadratic
Ileal									
DM	239	273	6	<0.01	262	239	7	0.08	0.07
GE	1,220	1,371	36	0.01	1,317	1,254	44	0.38	0.58
ADF	29	35	1	<0.01	33	30	1	0.03	0.17
NDF	75	105	2	<0.01	93	84	3	0.06	0.26
TDF	92	126	3	<0.01	114	102	3	0.03	0.41
Total tract									
DM	118	169	4	<0.01	138	136	5	0.66	<0.01
GE	633	926	19	<0.01	739	746	24	0.34	<0.01
ADF	31	39	1	<0.01	36	33	1	0.29	0.23
NDF	84	120	3	<0.01	102	96	4	0.48	0.13
TDF	103	140	4	<0.01	122	115	5	0.44	0.10

[1]In period 1, all pigs were fed the control diet and digestibility values were used as a covariate to correct the values of periods 2, 3, and 4.
[2]There was no interaction ($P > 0.05$) between DDGS and period. Therefore, only main effects are reported.
[3]Data for period 3 were not different ($P > 0.05$) from period 2 for any of the variables that were measured.

Ileal and Total Tract Flow of DM, GE, ADF, NDF, and TDF

The ileal flow of DM, ADF, NDF, and TDF was greater ($P < 0.01$) in pigs fed the DDGS diet (273, 35, 105, and 126 g/kg of DMI) than in pigs fed the control diet (239, 29, 75, 92 g/kg of DMI; Table 5). The ileal flow of GE was also greater ($P < 0.01$) in pigs fed the DDGS diet (1,371 kcal/kg of DMI) than in pigs fed the control diet (1,220 kcal/kg of DMI). The ileal flow of ADF and TDF decreased (linear, $P < 0.05$) from period 2 (33 and 114 g/kg of DMI) to period 4 (30 and 102 g/kg DMI), and there was a tendency (linear, $P < 0.10$) for a decrease in the ileal flow of NDF and DM from period 2 to period 4.

The total tract flow of DM, ADF, NDF, and TDF were greater ($P < 0.01$) in pigs fed the DDGS diet (169, 39, 120, and 140 g/kg of DMI) than in pigs fed the control diet (118, 31, 84, and 103 g/kg of DMI). The total tract flow of GE was also greater in pigs fed the DDGS diet (926 kcal/kg of DMI) than in pigs fed the control diet (633 kcal/kg of DMI).

Ileal, Cecal, and Fecal pH and Concentration of VFA

The pH of ileal digesta (Table 6) from pigs fed the DDGS diet (6.3) was greater ($P < 0.05$) than the pH of ileal digesta from pigs fed the control diet (5.8). Likewise, the pH of cecal digesta from pigs fed the DDGS diet (5.5) was greater ($P < 0.05$) than the pH of cecal digesta from pigs fed the control diet (5.3). There was, however, no effect of collection period on the pH of feces, and the pH of feces in period 4 was not different from the pH of feces in period 2.

The concentration of VFA in ileal, cecal, and fecal samples was not different between the control diet and the DDGS diet, but the ileal concentrations of isobutyrate, isovalerate, and valerate were below detection levels and are, therefore, not reported. The concentration of acetate (416 mmol/kg), propionate (162 mmol/kg), butyrate (66 mmol/kg), isovalerate (0.8 mmol/kg), and valerate (17.6 mmol/kg) measured in cecal samples in period 2 increased linearly ($P < 0.05$) to 443, 196, 76, 9.8, and 26.4 mmol/kg in period 4. The concentration of acetate (596 vs. 350 mmol/kg), isobutyrate (79 vs. 10 mmol/kg), butyrate (83 vs. 52 mmol/kg), and valerate (33 vs. 21 mmol/kg) also increased (linear $P < 0.01$) in fecal samples from period 2 to period 4, but the concentration of propionate in fecal samples was not affected by collection period.

First Appearance of Digesta

The time from feed was ingested until it first appeared in ileal digesta in pigs fed the control diet (238 min) was not different from the time it took for digesta to appear at the end of the ileum in pigs fed the DDGS diet (225 min; Table 7). Likewise, the time for the first appearance of digesta in the cecum of pigs fed the control diet (263 min) was not different from that of pigs fed the DDGS diet (277 min). The time it took for digesta to appear in the feces of pigs fed the control diet (1,603 min) was not different from the time it took for pigs fed the diet containing DDGS (1,674 min).

DISCUSSION

Inclusion of DDGS in a corn-soybean meal diet increases the concentration of dietary fiber in the diet. The effects of dietary fiber on energy and nutrient digestibility may be influenced by the physicochemical characteristics of dietary fiber. In DDGS, most of the TDF is insoluble (Urriola et al., 2009b).

The AID of Lys may be reduced by heating and by the addition of solubles to the distilled grains during the production of DDGS (Stein and Shurson, 2009).

Table 6. Effects of period and distillers dried grains with solubles (DDGS) on the pH and concentration of VFA (mmol × kg^{-1} of digesta DM) in the ileal digesta, cecal digesta, and feces of growing pigs[1,2]

	DDGS, %				Period[3]				
Item	0	30	SEM	*P*-value	2	4	SEM	Linear	Quadratic
Ileal digesta									
pH	5.8	6.3	0.0	<0.01	6.1	6.1	0.1	0.47	<0.01
Acetate	550	553	37	0.96	540	533	36	0.48	0.40
Propionate	82	45	4	0.55	162	196	20	0.75	0.48
Cecal digesta									
pH	5.3	5.5	0.0	<0.01	5.4	5.4	0.1	0.69	0.16
Acetate	443	500	37	0.18	416	443	37	<0.01	0.71
Propionate	213	194	43	0.53	162	196	44	<0.01	0.43
Isobutyrate	6.8	4.5	3.6	0.60	2.3	11.3	4.1	0.22	0.40
Butyrate	76	83	7	0.53	66	76	7	0.01	0.65
Isovalerate	5.9	5.9	1.8	0.69	0.8	9.8	10.2	<0.01	0.13
Valerate	24.5	23.5	2.6	0.81	17.6	26.4	2.8	0.03	0.69
Feces									
pH	5.9	5.8	0.1	0.46	5.9	5.8	0.1	0.18	0.86
Acetate	461	458	24	0.91	350	596	28	<0.01	0.89
Propionate	127	149	20	0.46	149	131	25	0.87	0.48
Isobutyrate	36	41	2	0.17	10	79	3	<0.01	0.19
Butyrate	72	66	5	0.41	52	83	5	<0.01	0.26
Isovalerate	25	20	2	0.15	20	27	3	0.06	0.96
Valerate	28	24	3	0.27	21	33	3	<0.01	0.40

[1]In period 1, all pigs were fed the control diet and digestibility values were used as a covariate to correct the values of periods 2, 3, and 4.
[2]There was no interaction ($P > 0.05$) between DDGS and period. Therefore, only main effects are reported.
[3]Data for period 3 were not different ($P > 0.05$) from period 2 for any of the variables that were measured.

The AID of Lys in the DDGS diet was less than the AID of Lys in the control diet, which agrees with the observation that the AID of Lys in DDGS is less than the AID of Lys in corn (Stein et al., 2006). Dietary fiber may reduce the digestibility of AA (Schulze et al., 1994). The DDGS diet contained more TDF (17.0%) than the control diet (12.4%), but there was no difference in the AID of most AA between the 2 diets. The reason for this observation may be that insoluble dietary fiber has only minor effects on the digestibility of dietary AA (Zhu et al., 2005) and on the basal endogenous losses of AA (Leterme et al., 1996). The DDGS diet also contained more ether extract than the control diet, and dietary ether extract may increase the digestibility of AA because high fat digesta moves through the intestinal tract more slowly than low fat digesta (Cervantes-Pahm and Stein, 2008). This may be the reason why the digestibility of only Lys was less in the DDGS diet than in the control diet.

Insoluble fiber have minimal effect on the ileal digestion and absorption of nutrients and energy, which has been demonstrated in several experiments that used different sources of insoluble dietary fiber (Wang et al., 2002; Serena et al., 2008b). It has also been shown that the AID and the ATTD of acid hydrolyzed fat is not affected by dietary amounts of NDF provided as wood cellulose (Kil et al., 2007). Results of this experiment showing that there is no effect of DDGS on the AID of GE and most AA in a corn-soybean meal diet, therefore, are in agreement with previous results.

The less ATTD of DM, GE, NDF, and TDF in the DDGS diet than in the control diet may be due to the less ATTD of NDF and TDF in DDGS than in soybean meal. Dietary fiber in soybean meal is more soluble and contains highly fermentable oligosaccharides such as stachyose and raffinose (Bach Knudsen, 1997; Karr-Lilienthal et al., 2005), whereas corn fiber is mainly insoluble and composed of cellulose and arabinoxylans that are more resistant to hindgut fermentation (Bach Knudsen, 1997; Guillon et al., 2007). It is, therefore, likely that the increased concentration of corn fiber in the DDGS diet is the reason for the decreased ATTD of NDF and TDF in the DDGS diet than in the control diet.

It was expected that the fiber in DDGS would stimulate bowel movement and reduce the time it took for first digesta appearance at the end of the ileum, in the cecum, and in the feces (Bastianelli et al., 1996; Schneeman, 1998; Bindelle et al., 2008). However, in the current experiment, the first appearance of digesta in pigs fed the DDGS diet and the control diet was not

Table 7. Effect of distillers dried grains with solubles (DDGS) on the time (min) of first appearance of digesta at the end of the ileum, in the cecum, and over the total tract in growing pigs

	DDGS, %			
Item	0	30	SEM	*P*-value
Ileal	238	225	18	0.46
Cecal	263	277	22	0.99
Total tract	1,603	1,674	920	0.14

different, despite the greater concentration of TDF in DDGS than in corn and soybean meal. The time it took for digesta to appear at the end of the ileum for pigs fed both diets is similar to previously reported data for growing-finishing pigs fed diets containing no DDGS (Ehle et al., 1982; Kim et al., 2007; Wilfart et al., 2007). The reason for this observation may be that DDGS contains more fat than corn and soybean meal (Spiehs et al., 2002; Stein and Shurson, 2009), and the presence of fat in the small intestine increases the secretion of cholecystokinin, which may reduce gastric emptying (Cervantes-Pahm and Stein, 2008). The lack of an effect of DDGS on marker appearance at the end of the ileum, in the cecum, and over the entire tract indicates that the effects of TDF and fat in DDGS neutralize each other so that the net effect is that first appearance of digesta at the end of the ileum, in the cecum, and in the feces is not changed when DDGS is included in the diet.

It was expected that the AID and the ATTD of nutrients, especially TDF, would increase with time as has been shown in previous experiments (Longland et al., 1993; Castillo et al., 2007). This effect was observed for the AID of ADF, NDF and TDF, but not for the ATTD of DM, GE, ADF, NDF, or TDF. This observation indicates that fermentation in the small intestine increases if fiber is fed for a longer time, but this increase is followed by a reduction in hindgut fermentation so the end result is that the ATTD of fiber is not changed. We are not aware of any other data that have shown this effect of time on the fermentation of fiber in pigs fed DDGS-containing diets.

This experiment used pigs that had a T-cannula installed in the distal ileum, and another T-cannula was installed in the cecum. This allowed for collection of digesta from the distal ileum and from the cecum in the same pigs. The pigs that were used in this experiment tolerated the procedure well and did not seem to have any discomfort from the 2 cannulas. Previous experiments used 2 sets of pigs to collect ileal and cecal digesta for measurements of VFA concentration (Htoo et al., 2007). The ileal cannula is needed for the measurement of ileal digestibility of AA and also allows for measurement of VFA in the ileal digesta. The cecal cannula allows for measurements of VFA in cecal contents, which is an important indicator of cecal fermentation because there is a substantial synthesis of VFA in the cecum (Htoo et al., 2007; Serena et al., 2008a).

Fermentation of branched-chain AA yields branched-chain fatty acids (Macfarlane et al., 1992). The concentration of the branched-chain fatty acids was below the detection limit in ileal digesta, but concentrations of these fatty acids in cecal digesta and in fecal samples were greater than in ileal digesta, which indicates fermentation of undigested protein in the cecum and colon. There were, however, no differences between the 2 treatment groups, which indicates that the greater concentration of CP in the DDGS-containing diet than in the control diet did not increase the synthesis of branched-chain fatty acids in the cecum and colon. The concentration of VFA in feces that were obtained in the current experiment is within the range of reported values for pigs fed diets based on cereal by-products (McBurney and Sauer, 1993; Jensen et al., 1997), but no differences among treatments were observed.

In conclusion, results of this experiment indicate that inclusion of 30% DDGS in a corn-soybean meal diet does not affect ileal digestibility of energy or most AA, but the ileal digestibility of Lys is reduced if DDGS is included in the diet. The total tract digestibility of energy and fiber is also reduced if DDGS is used in the diet because dietary fiber in DDGS is partially resistant to hindgut fermentation and the flow through the intestinal tract of DM and energy increases if DDGS is included in the diet. The pH of the feces and the digesta passage rate are, however, not influenced by the presence of DDGS in the diet. The AID of AA did not change as pigs were fed their diet for a longer time, indicating that a 7-d adaptation period is sufficient for measuring AA digestibility. Likewise, the digestibility of energy was not influenced by the time the diet was fed to the pigs, but the ileal digestibility of ADF, NDF, and TDF increased as pigs were fed their respective diets for a longer period. However, this increase was followed by a reduction in hindgut fermentation of fiber, and the ATTD of ADF, NDF, and TDF was, therefore, not influenced by the time diets were fed to the pigs.

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