Asian-Aust. J. Anim. Sci.
Vol. 22, No. 7 : 1016 - 1025
July 2009

www.ajas.info

Energy and Nutrient Digestibility in Four Sources of Distillers Dried Grains with Solubles Produced from Corn Grown within a Narrow Geographical Area and Fed to Growing Pigs*

H. H. Stein, S. P. Connot and C. Pedersen[1]**

Department of Animal and Range Sciences, South Dakota State University, Brookings, 57007, USA

ABSTRACT : Two experiments were conducted to determine energy and nutrient digestibility in four sources of distillers dried grains with solubles (DDGS) produced from corn and fed to growing pigs. The objective was to test the hypothesis that energy and nutrient digestibility in DDGS does not vary if samples are procured from ethanol plants that use similar production technologies and use corn that is grown within a narrow geographical area. The four sources of DDGS that were used were procured from ethanol plants that were less than 10 yr old and located within 250 km of each other. In Exp. 1, five growing barrows (initial BW = 71.4 kg) that were fitted with a T-canula in the distal ileum were allotted to a 5×5 Latin square design and used to measure apparent (AID) and standardized (SID) ileal digestibility of AA in the four sources of DDGS. Results of this experiment showed that the SID of CP and all AA except Cys and Pro were greater ($p<0.05$) in two of the DDGS sources than in the other two sources. Exp. 2 was conducted to measure the concentration of DE and ME and the apparent total tract digestibility (ATTD) of energy, N, P, ether extract, NDF, and ADF in corn and in the same four sources of DDGS as used in Exp. 1. Five pigs (initial BW = 29.7 kg) that were placed in metabolism cages and allotted to a 5×5 Latin square design were used. Results of Exp. 2 showed that the average DE and ME in DDGS were 4,072 and 3,750 kcal/kg DM, respectively, which was less ($p<0.01$) than the DE and ME in corn (4,181 and 4,103 kcal/kg DM, respectively). The average ATTD for P in DDGS was 56.1%, which was greater ($p<0.01$) than the ATTD for P in corn (31.9%). The ATTD for ADF in DDGS was also greater ($p<0.05$) than in corn, but the ATTD for ether extract and NDF were greater ($p<0.05$) in corn than in DDGS. It is concluded that energy and nutrient digestibility vary among sources of DDGS even when the DDGS is procured from ethanol plants that use corn grown within a narrow geographical region. Thus, factors other than corn growing region are responsible for the variability of energy and nutrient digestibility in DDGS. (**Key Words** : Amino Acids, Digestibility, Distillers Dried Grains with Solubles, Energy, Phosphorus, Pigs)

INTRODUCTION

The apparent (AID) and standardized (SID) ileal digestibility of amino acids (AA) in distillers dried grains with solubles (DDGS) produced from corn vary among sources (Cromwell et al., 1993; Fastinger and Mahan, 2006; Stein et al., 2006). It was suggested that the digestibility of AA in DDGS is plant specific and that some of the older plants producing DDGS are more likely to produce products with a low digestibility than newer plants (Spiehs et al., 2002; Fastinger and Mahan, 2006). It has, however, been shown that values for AID and SID also vary among sources of DDGS obtained from newer plants (Stein et al., 2006). Likewise, the concentration of DE and ME also vary among sources of DDGS (Pedersen et al., 2007). It is, therefore, clear that factors other than the age and design of the ethanol plant and process technologies are responsible for some of the variation in the nutritive value of DDGS. One of the reasons that have been suggested for this variation is that different corn hybrids with different climatic requirements are grown in different regions of the United States and that this may influence the composition of DDGS (Belyea et al., 2004). If this is correct, then the variability among sources of DDGS is expected to be less if the DDGS is sourced from ethanol plants located within a narrow geographical area than across different regions, because it is assumed that the corn grown within such a

* This manuscript is based on research supported by Ajinomoto Lysine Inc., Chicago, IL 60631, USA and by Novus Intl. Inc., Charles, MO 63304, USA.

** Corresponding Author: Hans H. Stein. Tel: +1-217-333-0013, Fax: +1-217-333-7088, E-mail: hstein@illinois.edu

[1] Schothorst Feed Research, Lelystad, Netherlands.

Received August 29, 2008; Accepted January 16, 2009

Table 1. Analyzed composition of distillers dried grains with solubles (DDGS) used in both experiments and the corn used in Exp. 2 (as-is basis)

Item	DDGS source				Corn[1]
	1	2	3	4	
DM (%)	88.72	88.92	91.74	87.70	86.81
GE (kcal/kg)	5,049	5,010	5,030	4,878	3,998
CP (%)	28.37	27.08	29.17	28.06	8.32
Ether extract (%)	12.23	12.58	10.01	12.19	2.80
ADF (%)	14.60	13.15	16.15	11.60	2.19
NDF (%)	37.25	33.66	41.50	30.81	8.78
P (%)	0.63	0.71	0.59	0.78	0.19
Indispensable AA (%)					
Arg	1.25	1.25	1.39	1.36	-
His	0.77	0.75	0.84	0.78	-
Ile	1.13	1.06	1.16	1.08	-
Leu	3.81	3.45	3.90	3.43	-
Lys	0.82	0.89	0.99	0.93	-
Met	0.70	0.63	0.71	0.66	-
Phe	1.56	1.44	1.60	1.44	-
Thr	1.62	1.54	1.71	1.55	-
Trp	0.23	0.24	0.27	0.26	-
Val	1.49	1.41	1.52	1.44	-
Dispensable AA (%)					
Ala	2.19	2.03	2.21	2.07	-
Asp	1.90	1.82	1.94	1.91	-
Cys	0.40	0.37	0.41	0.37	-
Glu	5.34	4.84	5.40	5.06	-
Gly	1.06	1.04	1.06	1.09	-
Pro	2.20	1.97	2.21	2.02	-
Ser	0.98	0.94	1.02	0.95	-
Tyr	1.27	1.17	1.31	1.19	-

[1] The concentration of AA in corn was not analyzed.

narrow area is relatively uniform and of similar genetic background. However, there are no data to confirm this assumption and no research has been conducted to measure variability in energy and nutrient digestibility in DDGS collected from within a narrow geographical area. From a practical standpoint, this is an important question because most producers and feed mills source their DDGS within relatively small geographical areas. It was, therefore, the objective of this research to test the hypothesis that the digestibility of energy, AA, P, N, ADF, and NDF in DDGS is constant if the DDGS is procured from ethanol plants that are located within a narrow geographical area.

MATERIALS AND METHODS

Animals, housing, and experimental design

Two experiments were conducted and 5 growing barrows (Ausgene Intl. Inc., Gridley, IL) were used in each experiment. The initial BW of the pigs was 71.4±2.4 kg and 27.9±1.6 kg for the animals used in Exp. 1 and Exp. 2, respectively, assuming that values obtained for animals at these weights are representative for the entire growing-finishing period. The animals used in Exp. 1 were surgically equipped with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998). In both experiments, pigs were housed individually in metabolism cages in an environmentally controlled building. Room temperature was maintained at 22°C and a feeder and a nipple drinker were installed in each crate. Pigs were allotted to a 5×5 Latin square design in both experiments. The animal work of the experiments was completed at South Dakota State University and both experiments were approved by the Institutional Animal Care and Use Committee at South Dakota State University.

Ingredients, diets, and feeding

Four sources of DDGS were obtained from dry-grind ethanol plants located in Eastern South Dakota and Western Minnesota within a distance of less than 150 km from South Dakota State University. All plants were constructed after 1998. The 4 plants all used similar production technologies and they all used locally grown corn that was grown and harvested within the same growing season. One batch of DDGS was obtained from each plant and this batch was used in both experiments (Table 1). A commercial source of corn was obtained locally and used in Exp. 2.

Table 2. Composition (as-is basis) of experimental diets (Exp. 1)

Item	DDGS[1] source				N-free
	1	2	3	4	
Ingredients (%)					
DDGS	62.00	62.00	62.00	62.00	-
Cornstarch	17.75	17.75	17.75	17.75	73.82
Sugar	15.00	15.00	15.00	15.00	15.00
Chromic oxide	0.25	0.25	0.25	0.25	0.25
Soybean oil	3.00	3.00	3.00	3.00	3.00
Limestone	1.25	1.25	1.25	1.25	0.25
Dicalcium phosphate	-	-	-	-	2.45
Potassium carbonate	-	-	-	-	0.40
Magnesium oxide	-	-	-	-	0.08
Solka floc[2]	-	-	-	-	4.00
Salt	0.40	0.40	0.40	0.40	0.40
Vitamin premix[3]	0.10	0.10	0.10	0.10	0.10
Micromineral premix[4]	0.25	0.25	0.25	0.25	0.25
Analyzed composition					
DM (%)	93.21	92.26	92.20	91.04	94.42
CP (%)	17.91	17.24	18.50	17.61	0.21
Ether extract (%)	10.30	10.56	9.19	10.19	2.90
ADF (%)	10.71	9.66	9.26	7.27	3.80
NDF (%)	20.26	18.84	27.53	18.54	4.25
P (%)	0.40	0.45	0.38	0.51	0.40
Indispensable AA (%)					
Arg	0.80	0.82	0.88	0.86	0.02
His	0.50	0.49	0.55	0.50	-
Ile	0.72	0.69	0.74	0.69	0.01
Leu	2.41	2.20	2.46	2.18	0.03
Lys	0.52	0.58	0.63	0.60	0.01
Met	0.44	0.42	0.44	0.43	-
Phe	0.99	0.92	1.02	0.93	0.02
Thr	1.0	0.96	1.07	1.02	0.02
Trp	0.14	0.14	0.16	0.12	-
Val	0.96	0.94	0.98	0.92	0.01
Dispensable AA (%)					
Ala	1.38	1.33	1.39	1.34	0.02
Asp	1.21	1.18	1.25	1.25	0.03
Cys	0.25	0.25	0.27	0.25	-
Glu	3.41	3.12	3.38	3.24	0.04
Gly	0.67	0.70	0.68	0.71	0.01
Pro	1.41	1.31	1.41	1.30	-
Ser	0.61	0.60	0.65	0.62	0.01
Tyr	0.80	0.75	0.83	0.77	0.01

[1] DDGS = Distillers dried grains with solubles. [2] Fiber Sales and Development Corp., Urbana, OH.

[3] Provided the following quantities of vitamins per kg 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, 88 IU as alpha tocopherol acetate; vitamin K_3, 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 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.

[4] 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, 0.31 mg as sodium selenite; and Zn, 130 mg as zinc oxide.

In Exp. 1, five diets were formulated (Table 2). Four of the diets contained 62% of one of the sources of DDGS, which was the sole source of CP and AA in the diets. A nitrogen-free diet was also used. Chromic oxide (0.25%) was included in all diets as an inert marker; vitamins and minerals were included at levels that met or exceeded current requirement estimates for growing pigs (NRC, 1998).

In Exp. 2, five diets were also used (Table 3). The basal diet consisted of corn (96.7%), limestone, salt, and vitamin- and micromineral premixes. The remaining four diets were formulated by mixing the basal diet and each of the four sources of DDGS in a 1:1 ratio. Therefore, the inclusion of corn, limestone, salt, vitamin premix, and micromineral

Table 3. Composition (as-is basis) of experimental diets (Exp. 2)

Item	Corn	DDGS[1] source			
		1	2	3	4
Ingredients (%)					
Corn	96.7	48.35	48.35	48.35	48.35
DDGS	-	50.00	50.0	50.0	50.0
Limestone	2.20	1.10	1.10	1.10	1.10
Salt	0.60	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.10	0.05	0.05	0.05	0.05
Micromineral premix[3]	0.40	0.20	0.20	0.20	0.20
Analyzed composition					
DM (%)	87.75	91.30	91.11	90.87	90.52
GE, kcal/kg	3,843	4,463	4,430	4,452	4,403
CP (%)	8.03	19.99	18.84	19.74	19.11
Ether extract (%)	2.74	7.31	7.36	6.21	6.50
ADF (%)	2.02	8.25	7.42	8.27	5.31
NDF (%)	9.15	24.32	22.93	26.69	22.49
P (%)	0.19	0.37	0.42	0.36	0.45

[1] DDGS = Distillers dried grains with solubles.

[2] Provided the following quantities of vitamins per kg in the corn diet and half of that amount in the remaining diets: vitamin A, 10,990 IU as vitamin A acetate; vitamin D_3, 1,648 IU as D-activated animal sterol; vitamin E, 88 IU as alpha tocopherol acetate; vitamin K_3, 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 B_{12}, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg.

[3] Provided the following quantities of minerals per kg in the corn diet and half of that amount in the remaining diets: Cu, 42 mg as copper sulfate; Fe, 200 mg as iron sulfate; I, 0.50 mg as potassium iodate; Mn, 42 mg as manganese sulfate; Se, 0.50 mg as sodium selenite; Zn, 208 mg as zinc oxide.

premix in these four diets was 50% of the inclusion in the basal diet while the other 50% of the diet consisted of DDGS.

In Exp. 1, daily feed allotments were calculated as three times the estimated energy requirement for maintenance (i.e., 106 kcal ME/kg $BW^{0.75}$; NRC, 1998). The BW of each pig was recorded at the beginning of each period and this value was used to calculate the feed allowance for the following period. In Exp. 2, the daily feed allowance was calculated at the beginning of each period as 2.5 times the energy requirement for maintenance for the smallest pig. In both experiments, the daily feed allotments were divided into two equal meals that were provided at 0800 and 1630. Water was available from nipple drinkers at all times.

Sample collections

In Exp. 1, each experimental period lasted 7 d with the initial 5 d being an adaptation period to the diet. On d 6 and 7 of each period, ileal digesta were collected for 8 h by opening the cannula and attaching a 225 ml plastic bag to the cannula barrel using an autolocking cable tie. All digesta that flowed into the bags were collected and bags were replaced as soon as they were filled with digesta or at least every 30 min.

In Exp. 2, each period lasted 12 d. Following a 5-d adaptation period, fecal materials were collected using the marker to marker approach as previously described (Adeola, 2001). Fecal materials were collected twice daily and stored at -20°C. Urine collections commenced after feeding the morning meal on d 6 and ceased after feeding the morning meal on d 11. Urine was collected over a preservative of 6 N sulfuric acid twice daily during the collection period and at each collection, a 20% sub-sample was collected and stored at -20°C.

Chemical analysis

At the conclusion of both experiments, samples were thawed, mixed within animal and diet, and a sub-sample was collected for chemical analysis. All digesta samples from Exp. 1 were lyophilized and finely ground prior to chemical analysis while fecal samples from Exp. 2 were dried at 60°C in a forced air oven and then ground. The concentrations of DM (procedure 4.1.06, AOAC, 2000) and N (Thiex et al., 2002) were analyzed in duplicate samples of DDGS, corn, all diets, ileal digesta, and fecal samples. The N concentration was also determined in all urine samples. The concentration of NDF and ADF (procedure 4.6.03, AOAC, 2000) and ether extract (Thiex et al., 2003) was determined in DDGS, corn, diets, and in fecal samples. These samples were also digested in perchloric acid (procedure 2.3.01, AOAC, 2000) and the concentration of P was determined on a UV-vis spectrophotometer at 650 nm (procedure 3.4.11, AOAC, 2000). Accuracy of this procedure was verified using National Institute of Standards and Technology (US Department of Commerce) reference standard 1570a (standard reference material). Amino acids were analyzed in duplicate samples of DDGS, the 5 diets used in Exp. 1, and in all ileal digesta samples on a Thermo Quest HPLC (Thermo Separation Products, Inc., San Jose, CA), using ninhydrin for post-column

Table 4. Apparent ileal digestibility (%) of CP and AA in four sources of distillers dried grains with solubles (DDGS), Exp. 1[1, 2]

Item	DDGS source				SEM
	1	2	3	4	
CP	58.1[x]	61.8[x]	78.6[y]	74.5[y]	1.81
Indispensable AA					
Arg	73.9[x]	74.4[x]	86.0[y]	84.0[y]	1.81
His	70.1[x]	75.6[y]	87.0[z]	83.9[z]	1.38
Ile	63.6[x]	68.1[x]	82.1[y]	81.2[y]	1.53
Leu	79.0[x]	81.9[x]	90.9[y]	89.9[y]	1.07
Lys	51.3[x]	55.7[x]	75.7[y]	71.4[y]	2.56
Met	76.4[x]	78.3[x]	87.8[y]	87.8[y]	1.29
Phe	74.5[x]	76.3[x]	87.5[y]	86.6[y]	1.25
Thr	67.8[x]	68.7[x]	83.7[y]	80.5[y]	1.25
Trp	41.4[x]	45.5[x]	71.6[y]	64.4[y]	4.03
Val	63.1[x]	68.0[y]	81.3[z]	80.7[z]	1.54
Mean	66.8[x]	67.7[x]	82.7[y]	80.2[y]	2.39
Dispensable AA					
Ala	70.8[x]	73.0[x]	85.1[y]	83.8[y]	1.60
Asp	55.3[x]	56.8[x]	76.4[y]	72.5[y]	2.19
Cys	65.4[x]	71.3[y]	82.7[z]	76.7[y]	1.78
Glu	76.3[x]	79.5[x]	89.7[y]	87.1[y]	1.18
Gly	29.9[x]	34.9[x]	60.2[y]	58.3[y]	5.67
Pro	39.2	29.6	62.8	56.2	12.6
Ser	54.9[x]	58.7[x]	76.5[y]	75.4[y]	1.74
Tyr	78.1[x]	79.5[x]	88.5[y]	87.8[y]	1.36
Mean	66.0[x]	68.5[x]	82.9[y]	80.3[y]	1.53
Mean, all AA	66.4[x]	68.1[x]	82.8[y]	80.3[y]	1.74

[1] Apparent ileal digestibility was calculated as ((intake-excreted)/intake) ×100%. [2] Values are least square means for five pigs per treatment.
[x, y, z] Means within a row lacking a common superscript letter are different ($p<0.05$).

derivatization and nor-leucine as the internal standard. Samples were hydrolyzed with 6 N HCl for 24 h at 110°C (procedure 4.1.11, alternative III; AOAC, 2000). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight prior to hydrolysis (procedure 4.1.11, alternative I; AOAC, 2000). Tryptophan was determined after flushing the samples with nitrogenous gas and 6 N NaOH hydrolysis for 22 h at 110°C (procedure 45.4.04, AOAC, 2000). Gross energy was determined in duplicate samples of corn, DDGS, the five diets used in Exp. 2, and in all urine and fecal samples using bomb calorimetry (Parr Instruments, Moline, IL). The chromium concentration of diets used in Exp. 1 and in ileal digesta samples was determined in triplicate samples by spectrophotometry (Fenton and Fenton, 1979).

Calculations and statistical analysis

Values for AID and SID of CP and AA in each sample of DDGS were calculated from the samples obtained in Exp. 1 (Stein et al., 2007). The ATTD for energy, DM, N, P, ether extract, ADF, and NDF were calculated for the five diets used in Exp. 2 as outlined by Adeola (2001). The samples obtained in Exp. 2, also allowed for calculating energy and N balances for pigs fed these diets (Adeola, 2001). Because the DDGS containing diets contained 50% of the corn diet and 50% DDGS, these values were then used to calculate ATTD of energy, DM, N, P, ether extract, ADF, and NDF in each source of DDGS using the difference procedure (Adeola, 2001). Likewise, the balances of energy and CP and the concentration of DE and ME in each source of DDGS were calculated using the difference procedure (Pedersen et al., 2007).

Data were analyzed using the PROC MIXED procedure of SAS (Littell et al., 1996). The animal was the experimental unit in all calculations. An analysis of variance was conducted for results of Exp. 1 comparing the AID and SID values for CP and each AA among the four sources of DDGS. Source of DDGS was the fixed effect and pig and period were random effects. Means were calculated and differences among means were determined using the PDIFF option of SAS. Data from Exp. 2 were analyzed by first comparing values for the four sources of DDGS as described for Exp. 1. The values for the DDGS sources were also compared to the values obtained for corn using a contrast statement in PROC MIXED. In both experiments, a p-value of 0.05 or less was used to assess significance among means.

RESULTS

Pigs readily consumed their daily allotments of feed and all pigs stayed healthy throughout the experiments. The 4

Table 5. Standardized ileal digestibility (SID) of CP and AA (%) in four sources of distillers dried grains with solubles (DDGS), Exp. 1[1, 2]

Item	DDGS source				SEM
	1	2	3	4	
CP	63.5[x]	67.3[x]	83.7[y]	79.7[y]	1.36
Indispensable AA					
Arg	78.3[x]	78.7[x]	89.9[y]	88.0[y]	1.71
His	72.3[x]	77.7[y]	88.9[z]	85.9[z]	1.31
Ile	66.5[x]	71.2[y]	84.9[z]	84.2[z]	1.44
Leu	80.3[x]	83.3[x]	92.2[y]	91.3[y]	1.03
Lys	54.6[x]	58.6[x]	78.4[y]	74.2[y]	2.74
Met	77.8[x]	79.8[x]	89.1[y]	89.2[y]	1.30
Phe	76.4[x]	78.3[x]	89.4[y]	88.6[y]	1.23
Thr	71.6[x]	72.7[x]	87.2[y]	84.1[y]	1.30
Trp	45.9[x]	49.9[x]	75.5[y]	68.9[y]	4.53
Val	65.8[x]	70.8[y]	83.9[z]	83.5[z]	1.50
Mean	73.6[x]	74.6[x]	88.9[y]	86.8[y]	1.63
Dispensable AA					
Ala	73.4[x]	75.7[x]	87.6[y]	86.4[y]	1.41
Asp	59.4[x]	60.9[x]	80.2[y]	76.3[y]	2.28
Cys	68.8[x]	74.7[y]	85.8[z]	79.9[y]	1.82
Glu	78.0[x]	81.2[x]	91.4[y]	88.7[y]	1.14
Gly	46.8[x]	51.0[x]	76.7[y]	73.8[y]	4.57
Pro	64.4	57.8	88.8	84.1	11.4
Ser	59.6[x]	63.4[x]	80.9[y]	77.8[y]	1.87
Tyr	80.1[x]	81.6[x]	90.4[y]	89.9[y]	1.47
Mean	69.6[x]	72.3[x]	86.5[y]	83.9[y]	1.25
Mean, all AA	71.5[x]	73.4[x]	87.6[y]	85.3[y]	1.10

[1] Standardized ileal digestibility was calculated as ((intake-(excreted-basal endogenous losses))/intake)×100%. Basal endogenous losses were calculated from the flow of CP and AA to the distal ileum after feeding the nitrogen-free diet. These losses were determined as (g/kg DMI): CP, 11.1; Arg, 0.37; His, 0.11; Ile, 0.23; Leu, 0.34; Lys, 0.18; Met, 0.06; Phe, 0.20; Thr, 0.41; Trp, 0.06; Val, 0.27; Ala, 0.39; Asp, 0.52; Cys, 0.09; Glu, 0.60; Gly, 1.22; Pro, 3.99; Ser, 0.31; Tyr, 0.17.

[2] Values are least square means for five pigs per treatment.

[x, y, z] Means within a row lacking a common superscript letter are different ($p<0.05$).

samples of DDGS were relatively similar in their concentration of GE and CP (Table 1). However, the concentrations of ether extract, P, ADF, and NDF varied more than 25% among samples.

Ileal amino acid digestibility

The AID for CP was 58.1 and 61.8% in DDGS sources 1 and 2, respectively (Table 4). These values were lower ($p<0.05$) than the values obtained for sources 3 and 4 (78.6 and 74.5%, respectively). For all AA, relatively large differences in AID among DDGS sources were observed. With the exception of Pro, the AID for all AA in DDGS sources 3 and 4 were greater ($p<0.05$) than for DDGS sources 1 and 2. There were no differences between source 3 and 4 except for Cys where DDGS source 3 had a greater AID than source 4 ($p<0.05$). The AID for His, Val, and Cys were greater ($p<0.05$) in DDGS source 2 compared with source 1, but for all other AA, no differences in the AID between source 1 and 2 were observed.

The SID for Cys in DDGS source 3 was greater ($p<0.05$) than in source 4, but for CP and all other AA, no differences in the SID between these 2 sources were observed (Table 5). However, the SID for DDGS sources 3 and 4 were greater ($p<0.05$) for CP and for all AA except Cys and Pro compared with DDGS sources 1 and 2. Greater values for SID were also obtained for His, Ile, Val, and Cys in DDGS source 2 than in source 1 ($p<0.05$), but for CP and all other AA, no differences between sources 1 and 2 were observed. The largest variations in SID among the four sources of DDGS were obtained for Lys and Trp (23.8 and 29.6 percentage units, respectively).

Energy balance and total tract nutrient digestibility

There were no differences in the GE and the N intake among the four sources of DDGS, but pigs fed DDGS had a greater ($p<0.01$) N-intake than pigs fed the corn diet (Table 6). Pigs fed DDGS sources 1 and 2 excreted more ($p<0.01$) GE from DDGS in the feces compared with pigs fed diets containing DDGS sources 3 and 4 (865 and 877 vs. 684 and 660 kcal/d, respectively). However, less ($p<0.01$) GE was excreted from corn (341 kcal/d) than from DDGS. The fecal excretion of N from DDGS was greater ($p<0.01$) from pigs fed DDGS sources 1 and 2 (5.5 and 5.0 g/d, respectively), compared with pigs fed DDGS source 3 (3.6 g/d). The fecal excretion of N from pigs fed DDGS source 4 (4.3 g/d) was not different from the excretion from pigs fed DDGS

Table 6. Concentrations of DE and ME and daily balances of energy and N in corn and in four sources of distillers dried grains with solubles (DDGS), Exp. 2[1]

Item	Corn	DDGS source				DDGS[2]		Corn vs. DDGS[3]	
		1	2	3	4	SEM	p-value	SEM	p-value
GE intake (kcal)	4,470	3,080	3,378	3,164	3,209	359.6	0.945	348.7	0.067
GE in feces (kcal)	341	865^{y}	877^{y}	684^{x}	660^{x}	66.9	0.009	46.2	0.001
GE in urine (kcal)	76	125	208	163	258	43.2	0.181	38.8	0.029
DE (kcal/kg DM)	4,181	$3,922^{x}$	$3,920^{x}$	$4,252^{y}$	$4,194^{y}$	84.5	0.016	76.0	0.006
ME (kcal/kg DM)	4,103	$3,694^{xy}$	$3,575^{x}$	$3,976^{z}$	$3,756^{y}$	63.1	0.002	57.5	0.001
N intake (g)	14.9	30.6	30.7	30.8	30.3	2.30	0.999	2.10	0.001
N in feces (g)	1.8	5.5^{z}	5.0^{yz}	3.6^{x}	4.3^{xy}	0.29	0.002	0.27	0.001
N in urine (g)	6.5	13.2	18.4	11.8	13.6	1.94	0.126	1.79	0.004
N absorption (g)	13.1	25.1	25.8	27.3	26.0	2.13	0.873	1.95	0.001
N retention (g)	6.6	11.9	7.4	15.5	12.4	2.11	0.097	1.97	0.025
N retention (%)	43.5	37.1^{xy}	24.7^{x}	49.1^{y}	41.9^{y}	5.54	0.042	5.74	0.069

[1] Values are means of five observations per treatment. [2] Values are from comparisons of the four DDGS sources.
[3] Values are from comparisons of corn vs. all DDGS sources.
[x, y, z] Means within a row and DDGS source lacking a common superscript letter are different ($p<0.05$).

sources 2 and 3, but less ($p<0.01$) than from source 1. However, the fecal N-excretion from corn (1.8 g/d) was lower ($p<0.01$) than from all the DDGS sources. For both GE and N, no differences in the excretion in urine among the four sources of DDGS were observed but less ($p<0.01$) GE and N was excreted from corn than from DDGS.

The concentration of DE in DDGS sources 3 and 4 (4,252, and 4,194 kcal/kg DM, respectively) were greater ($p<0.05$) than the DE in DDGS sources 1 and 2 (3,922 and 3,920 kcal/kg DM, respectively). However, the concentration of ME in DDGS source 3 (3,976 kcal/kg DM) was greater ($p<0.01$) than for all other sources. The ME in DDGS source 4 was also greater ($p<0.01$) than in source 2 (3,756 vs. 3,575 kcal/kg DM), but the ME in DDGS source 1 (3,694 kcal/kg DM) was not different from the ME in sources 2 and 4. The DE and ME in corn (4,181 and 4,103 kcal/kg DM, respectively) were greater ($p<0.01$) than in DDGS.

Values for the absorption and retention of N were not different among the four sources of DDGS if retention was calculated as g per d. However, the N absorption and retention was greater for DDGS than for corn ($p<0.05$). If N retention was calculated as a percentage of N-intake, pigs consuming DDGS sources 3 and 4 retained more ($p<0.05$) N than did pigs consuming DDGS source 2 (49.1 and 41.9 vs. 24.7%), but the N retention for DDGS source 1 (37.1%) was not different from any of the other sources. Likewise, there was no difference in N-retention between DDGS and corn.

The ATTD of DM and GE were greater ($p<0.001$) in corn than in DDGS, but there were no differences among the four sources of DDGS (Table 7). The ATTD for N in DDGS source 3 (88.4%) was greater ($p<0.01$) than the ATTD for N in DDGS sources 1 and 2 (81.8 and 83.7%, respectively). However, the ATTD for N in DDGS source 4 (85.5%) was not different from sources 2 and 3, but greater ($p<0.01$) than for source 1. The ATTD for N in corn (87.8%) was also greater ($p<0.01$) than for DDGS.

The ATTD of P in DDGS source 3 (63.4%) was greater ($p<0.05$) than for DDGS sources 1, 2, and 4 (55.5, 53.7, and 51.9%, respectively), and the ATTD of P in DDGS was greater ($p<0.01$) than in corn (31.9%). The ATTD for ether extract was greater ($p<0.05$) in DDGS sources 1 and 4 (74.6 and 77.1%, respectively) than for DDGS source 2 (66.7%),

Table 7. Apparent total tract digestibility (%) of DM, GE, N, P, ether extract, NDF, and ADF in corn and in four sources of distillers dried grains with solubles (DDGS), Exp. 2[1]

Item	Corn	DDGS source				DDGS[2]		Corn vs. DDGS[3]	
		1	2	3	4	SEM	p-value	SEM	p-value
DM	93.0	70.6	73.7	78.2	77.8	2.74	0.146	2.46	0.001
GE	92.3	71.1	73.1	78.1	78.2	2.33	0.083	2.09	0.001
N	87.8	81.8^{x}	83.7^{xy}	88.4^{z}	85.5^{yz}	1.00	0.002	0.94	0.001
P	31.9	55.5^{x}	53.7^{x}	63.4^{y}	51.9^{x}	2.95	0.031	3.00	0.001
Ether extract	79.6	74.6^{y}	66.7^{x}	71.7^{xy}	77.1^{y}	3.00	0.043	2.91	0.019
NDF	77.3	62.9^{x}	65.3^{xy}	73.9^{yz}	76.2^{z}	3.82	0.027	3.84	0.006
ADF	54.7	66.8	66.7	77.1	70.1	3.86	0.116	4.42	0.011

[1] Values are means of five observations per treatment. [2] Values are from comparisons of the four DDGS sources.
[3] Values are from comparisons of corn vs. all DDGS sources.
[x, y, z] Means within a row and DDGS source lacking a common superscript letter are different ($p<0.05$).

but the ATTD for ether extract in source 3 (71.7%) was not different from any of the other sources of DDGS. In contrast, the ATTD for ether extract in corn (79.6%) was greater ($p<0.05$) than for DDGS.

The ATTD for NDF was greater ($p<0.05$) in DDGS source 4 (76.2%) than in sources 1 and 2 (62.9 and 65.3%, respectively), and the ATTD for source 3 (73.9%) was greater ($p<0.05$) than in source 1, but not different from sources 2 and 4. For ADF, no differences among the four sources of DDGS were observed. However, the ATTD for NDF in corn (77.3%) was greater ($p<0.01$) than in DDGS, whereas the ATTD for ADF in corn (54.7%) was lower ($p<0.05$) than in DDGS.

DISCUSSION

Composition of DDGS samples

The concentrations of CP and AA in the DDGS used in this experiment were 1 to 2 percentage units greater than previously published values (NRC, 1998; Spiehs et al., 2002; Cheon et al., 2008), but within the range of values reported by others (Guo et al., 2004; Stein et al., 2006; Pedersen et al., 2007; Choi et al., 2008). The concentration of ether extract was also greater than the values reported by Spiehs et al. (2002), but close to the values that were measured by Pedersen et al. (2007), by Cheon et al. (2008), and by Choi et al. (2008). Concentrations of ADF were slightly greater than previous values, but the concentration of NDF was intermediate between values reported by Pedersen et al. (2007) and Stein et al. (2006).

Ileal amino acid digestibility

The AID and SID of AA for DDGS sources 1 and 2 are close to earlier estimates (NRC, 1998; Stein et al., 2006). However, DDGS sources 3 and 4 had AID and SID that were considerably greater than previously reported values and these values demonstrate that it is possible to produce DDGS with a relatively high digestibility of AA.

It is likely that high temperatures are responsible for some of the variations in AA digestibility among the four sources of DDGS, because the variability in the SID for Lys and Trp were greater than the variability for most other AA. Both Lys and Trp are susceptible to Maillard reactions if heat is applied in the presence of reducing sugars as is sometimes the case when DDGS is dried. This theory is supported by the fact that the Lys concentration as a percentage of total CP varied among DDGS samples. In DDGS source 1, the Lys:CP ratio was 2.89%, while in sources 2, 3, and 4, this ratio was 3.28, 3.39, and 3.31%, respectively. Because DDGS source 1 also had the lowest digestibility of Lys, it is likely that overheating has converted some of the Lys in this source to undigestible Amadori compounds and other Maillard reaction products.

Among the remaining AA, the variability in SID was greatest for Gly and Pro. The reason for this observation is most likely that endogenous losses of these 2 AA are generally greater and more variable than endogenous losses of other AA (Stein et al., 2007). This was also the case in this experiment as indicated by the large SEM values and the large basal endogenous losses that were measured for Gly and Pro.

The results of this research showing that there is variability in values for AID and SID in DDGS sourced from ethanol plants that use corn that is grown within a small area indicates that factors other than corn hybrids or growing conditions are responsible for the variability in AA digestibility. To our knowledge, this is the first time such a finding has been reported. This observation has great implications for the practical use of DDGS in swine production because it shows that even when DDGS is sourced from ethanol plants located within a narrow geographical area, variability may be observed among sources of DDGS. Therefore, users of DDGS may want to work with as few suppliers of DDGS as possible, because increasing the number of suppliers may increase the variability in AA digestibility.

Energy balance and total tract digestibility of energy and nutrients

The average concentration of DE and ME in the four sources of DDGS was 4,072 and 3,750 kcal/kg DM, respectively. These values concur with recently reported values for DE and ME in corn DDGS (Spiehs et al., 2002; Pedersen et al., 2007). The variation among samples is also consistent with previously published values, which indicates that as was the case for AA digestibility, even when corn hybrids grown in the same area are used in the production of DDGS, variation among sources of DDGS are obtained. The DE values that were measured in this experiment are 100 to 300 kcal/kg greater than values reported for Chinese DDGS (Guo et al., 2004). However, the DDGS used in the present experiment contained more total GE than the DDGS used by Guo et al. (2004). It is, therefore, possible that the DDGS used in the present experiment contained more ether extract than the DDGS used by Guo et al. (2004), which may explain the differences in DE concentrations between the two experiments.

The average ATTD of GE for the four sources of DDGS was 72.9% whereas the ATTD for GE in corn was 90.8%. Values between 61.0 and 67.7% for the ATTD of GE in DDGS were previously reported (Guo et al., 2004). The lower ATTD for GE in DDGS compared with corn is likely caused by the increased concentration of ADF and NDF in DDGS because the digestibility of ADF and NDF is less than the digestibility of starch (Stein and Bohlke, 2007).

The lower ATTD for N in DDGS than in corn shows that more N from DDGS than from corn was excreted in the feces. The retention of N measured on a percentage basis was not different between corn and DDGS, so the increased excretion of N in the feces indicates that N excretion may have been shifted from urine to feces in the pigs fed DDGS. This shift may have been facilitated by the increased concentration of ADF and NDF in DDGS compared with corn because high concentrations of fiber in the hindgut of pigs may shift N excretion from urine to feces (Zervas and Zijlstra, 2002).

The average ATTD for P in the four sources of DDGS was 56.1%. This value is in close agreement with the values of 59 and 55.5% that were recently reported for ATTD of P in corn DDGS (Pedersen et al., 2007; Widyaratne and Zijlstra, 2007). The ATTD for P in corn that was measured in this experiment is also close to the value of 28% that was reported by Bohlke et al. (2005).

Values for ATTD of ether extract were greater in corn than in DDGS, but the reason for the difference between the two feed ingredients is not known because all the oil in DDGS came from corn. It is, however, possible that the digestibility of ether extract in DDGS was suppressed because of the high dietary concentration of fiber in DDGS, because dietary fiber has a negative impact on the digestibility of ether extract (Just, 1982; Noblet and Shi, 1993). High dietary fiber may also increase the endogenous losses of fat because of increased microbial activity in the hindgut, which will reduce the ATTD of fat (Back Knudsen and Hansen, 1991).

The results from the current research indicate that the ATTD for both ADF and NDF in DDGS is between 60 and 75%. The ATTD values for NDF are in close agreement with values reported by Guo et al. (2004), but the values for ADF are much lower than those published by Guo et al. (2004). We do not have an explanation for the difference in ATTD values of ADF between the present experiment and the values reported by Guo et al. (2004). The relatively high concentration of ADF and NDF in DDGS and the relatively low digestibility of these nutrients is likely the reason for the low digestibility of DM and energy in DDGS compared with corn. It is, therefore, apparent that it is necessary to increase the digestibility of ADF and NDF in DDGS if energy digestibility is to be increased.

Results of this research rejected the hypothesis that the digestibility of energy and nutrients in DDGS is constant if the DDGS is sourced from newer dry-grind ethanol plants located within a narrow geographical area. This research demonstrate that the variability in the digestibility of energy and nutrients in DDGS that has previously been reported cannot be eliminated if DDGS is sourced from ethanol plants located within a narrow geographic area and using locally grown corn. The variability in AID and SID of AA and in DE and ME in the four sources of DDGS used in this research was similar to the variability that has previously been reported for DDGS sourced across larger geographical regions. The implication of these results is that variability in energy and nutrient digestibility in DDGS cannot be reduced by purchasing DDGS from plants using similar varieties of corn and similar production technologies. Therefore, swine producers, feed mills, and other users of DDGS cannot eliminate variation in DDGS simply by sourcing the product from ethanol plants located within a narrow geographical region.

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