JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Amino acid and energy digestibility in ten samples of distillers dried grain with solubles fed to growing pigs

H. H. Stein, M. L. Gibson, C. Pedersen and M. G. Boersma

J Anim Sci 2006. 84:853-860.

Amino acid and energy digestibility in ten samples of distillers dried grain with solubles fed to growing pigs[1,2]

H. H. Stein,*[3] M. L. Gibson,† C. Pedersen,* and M. G. Boersma*

*Department of Animal and Range Sciences, South Dakota State University, Brookings 57007
and †Dakota Gold Research Association, Sioux Falls, SD 57059

ABSTRACT: The objective of this experiment was to measure the digestibilities of energy, CP, and AA in 10 samples of corn distillers dried grain with solubles (DDGS) and in corn fed to growing pigs. Twelve growing barrows (initial BW: 34.0 ± 1.41 kg) were allotted to an 8 × 12 Youden square design with 8 periods and 12 animals. Ten of 12 diets were based on the 10 DDGS samples (66.7%), 1 diet was based on corn (97%), and the last diet was a N-free diet based on cornstarch and sucrose. Chromic oxide (0.3%) was included in all diets as an inert marker. Pigs were provided their respective diets at a level of 3 times their estimated energy requirement for maintenance. The apparent (AID) and standardized (SID) ileal digestibilities for CP and AA were measured in the 10 samples of DDGS and in corn using the direct procedure, but the apparent total tract digestibilities for DM and GE were estimated using the difference procedure. The concentration of DE in each sample of DDGS and in corn was also calculated. The results of the experiment indicated variation among the different sources of DDGS in AID and SID for Lys, which ranged from 35.0 to 55.9% and 43.9 to 63.0%, respectively. For Met, the SID varied between 73.9 and 84.7%. However, the variability among samples in the SID for CP, and for the indispensable AA other than Lys and Met, was relatively low and ranged between 6 and 8 percentage units (i.e., from 64.0 to 70.6%, 74.1 to 80.1%, and 67.4 to 75.3% for Thr, Trp, and Ile, respectively). The SID for Trp in corn (72.8%) was lower ($P < 0.05$) than in DDGS, but for the remaining indispensable AA, except Arg, the SID for corn were greater ($P < 0.01$) than for DDGS. The DE concentration in the 10 samples of DDGS varied ($P < 0.001$) from 3,382 to 3,811 kcal of DE per kg of DM. For corn, the DE was 3,845 kcal per kg of DM. It is concluded that the AID and SID for Lys vary among samples of DDGS, but for most other AA the AID and SID are relatively similar and vary only 6 to 8 percentage units among different samples. Future work should focus on identifying the reasons for the variation in the digestibility of Lys to avoid processing procedures that are detrimental to Lys digestibility.

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

 J. Anim. Sci. 2006. 84:853–860

INTRODUCTION

Distillers dried grain with solubles (**DDGS**) is a coproduct of the ethanol industry that is increasingly being included in diets for swine. The ethanol may be produced from corn, sorghum, barley, or wheat, and the composition of the resulting DDGS is characterized by the grain that was used. However, even when the same grain is used, variability in the chemical composition of the DDGS may be observed (Cromwell et al., 1993; Spiehs et al., 2002). This variability is likely caused by differences in the effectiveness of the fermentation, drying temperatures, or the amounts of solubles that are added to the distillers dried grain.

Because DDGS has also gone through heat treatment, there is a risk that the digestibility of Lys may be reduced in some cases because of Maillard reactions (Cromwell et al., 1993). Apparent ileal digestibilities (**AID**) of only 27% have been reported for Lys in DDGS, which indicates that some sources of DDGS might have been overheated (Fastinger and Mahan, 2005).

For the swine industry to include DDGS in the feed formulations, it is important that a consistent product is available. Therefore, Broin and Associates (Sioux Falls, SD) have introduced a branded product called Dakota Gold, which is produced at 10 different ethanol plants in the Midwest and has a constant concentration

[1]Publication No. 3478 from the South Dakota Agric. Exp. Stn. Journal Series.

[2]Financial support from Dakota Gold Research Association, Sioux Falls, SD, and from the South Dakota Corn Utilization Council, Sioux Falls, is greatly appreciated.

[3]Corresponding author: hans.stein@sdstate.edu

Received April 14, 2005.

Accepted November 7, 2005.

Table 1. Analyzed composition of dried distillers grain with solubles (DDGS), as-fed basis

	DDGS source									
Item	1	2	3	4	5	6	7	8	9	10
DM, %	89.18	88.73	86.78	88.92	89.15	87.11	88.61	90.78	89.97	89.43
CP, %	27.63	27.98	27.23	29.04	26.74	24.60	26.61	28.36	29.07	27.28
GE, kcal/kg	4,837	4,803	4,773	4,800	4,798	4,705	4,760	4,984	4,909	4,851
P, %	0.76	0.78	0.70	0.69	0.85	0.85	0.77	0.74	0.94	0.79
Starch, %	7.00	7.92	5.20	5.57	6.97	6.90	6.40	5.39	7.41	6.06
ADF, %	11.20	8.00	10.30	11.20	9.30	10.20	12.40	13.10	11.50	11.60
NDF, %	41.70	37.10	39.30	39.70	39.50	41.30	37.90	44.60	39.50	40.70
Indispensable AA, %										
Arg	1.12	1.12	1.11	1.06	1.01	1.01	1.10	1.12	1.23	1.16
His	0.80	0.78	0.74	0.78	0.74	0.69	0.78	0.78	0.84	0.77
Ile	0.98	1.06	1.06	1.08	0.98	0.94	1.01	1.04	1.07	1.01
Leu	3.07	3.19	3.24	3.30	3.01	2.79	3.05	3.19	3.24	3.08
Lys	0.82	0.85	0.78	0.76	0.68	0.74	0.82	0.71	0.88	0.83
Met	0.61	0.58	0.61	0.65	0.60	0.54	0.60	0.62	0.70	0.65
Phe	1.35	1.37	1.36	1.39	1.29	1.19	1.3	1.36	1.41	1.33
Thr	1.04	1.00	0.95	0.99	0.98	0.89	0.98	1.00	1.07	1.01
Trp	0.18	0.19	0.18	0.17	0.12	0.16	0.17	0.18	0.20	0.17
Val	1.37	1.48	1.44	1.49	1.36	1.28	1.41	1.41	1.47	1.41
Dispensable AA, %										
Ala	1.72	1.84	1.79	1.88	1.71	1.58	1.73	1.77	1.86	1.79
Asp	1.99	1.99	2.00	1.96	1.90	1.78	1.91	1.91	2.04	1.95
Cys	0.76	0.69	0.70	0.71	0.66	0.64	0.68	0.67	0.75	0.72
Glu	3.27	3.69	3.51	3.78	3.51	3.05	3.33	3.48	3.74	3.50
Gly	0.97	1.01	0.98	1.00	0.95	0.88	0.98	0.97	1.05	1.00
Pro	1.93	1.98	2.08	2.04	1.97	1.74	1.93	1.97	1.93	1.91
Ser	1.18	1.06	1.00	1.06	1.08	0.95	1.06	1.12	1.16	1.12
Tyr	0.87	0.93	0.90	0.87	0.92	0.83	0.92	0.99	1.02	0.96
All AA, %	24.36	25.14	24.58	25.32	23.80	22.00	24.13	24.63	25.98	24.75

of crude nutrients (i.e., CP, 28.2%; fat, 10.7%; ADF, 11.9%; and NDF, 27.2%). However, it is not known if the product is also consistent in terms of AA and energy digestibility.

Therefore, the objective of the current experiment was to test the hypothesis that DDGS from Dakota Gold has a constant digestibility of energy, CP, and AA in growing pigs regardless of the origin of the samples.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

Twelve growing barrows (initial BW: 34.0 ± 1.41 kg) originating from the matings of SP-1 boars to line 13 sows (Ausgene Intl., Gridley, IL) were fitted with a T-cannula near the distal ileum using procedures adapted from Stein et al. (1998). After the surgery, pigs were housed individually in 1.2 × 1.8 m pens in an environmentally controlled room (22°C) and allowed a 2-wk recuperation period before the experiment was initiated. During that period, a standard corn soybean meal-based grower diet (18% CP) was provided. After the recuperation period, pigs were allotted to an 8 × 12 Youden square design (Anderson and McLean, 1974) with 8 periods and 12 animals. Each experimental period lasted 7 d. The experiment was approved by the Institutional Animal Care and Use Committee at South Dakota State University.

Ingredients, Diets, and Feeding

Ten samples of Dakota Gold DDGS were obtained from 10 ethanol plants located in the Midwest (Table 1). All plants produced ethanol from corn. In addition to the 10 sources of DDGS, a sample of corn was obtained from a commercial source.

Twelve diets were prepared (Tables 2 and 3). Ten diets consisted of 1 of the 10 samples of DDGS (66.7%) and cornstarch, sucrose, soybean oil, minerals, and vitamins. In all of these diets, DDGS was the sole source of CP and AA. A corn-based diet (97% corn) and a N-free diet were also formulated. The N-free diet was used to estimate the basal ileal endogenous losses (**IAA_{end}**) of CP and AA. The only energy-containing ingredients in the N-free diet were cornstarch, soybean oil, and sucrose. These ingredients were included in the N-free diet in quantities that were 3 times those in the diets containing DDGS. In all diets, chromic oxide was included at 0.3% as an inert marker. Vitamins and minerals were included to meet or exceed estimated nutrient requirements for growing pigs (NRC, 1998). Inorganic P in the form of dicalcium phosphate was included in the corn-diet and the N-free diet, but because of the high P-concentration in DDGS, no inorganic P was included in the diets containing DDGS. Limestone was included in all diets to bring the calculated Ca:P ratio to 1.2:1. Because the feed ingredients included in the N-free diet were assumed to contain no K and Mg, these

Table 2. Ingredient composition (%) of experimental diets, as-fed basis

Ingredient, % of diet	DDGS[1]	Corn	N-free
DDGS	66.70	—	—
Corn	—	97.00	—
Cornstarch	27.00	—	81.00
Soybean oil	1.00	—	3.00
Sucrose	3.00	—	9.00
Solka floc[2]	—	—	3.00
Limestone	1.35	0.80	—
Dicalcium phosphate	—	1.05	2.50
Chromic oxide	0.30	0.30	0.30
Salt	0.30	0.50	0.45
Vitamin premix[3]	0.10	0.10	0.10
Micromineral premix[4]	0.25	0.25	0.25
Potassium carbonate	—	—	0.30
Magnesium oxide	—	—	0.10
Total	100	100	100

[1]Distillers dried grain with solubles.

[2]Fiber Sales and Development Corp., Urbana, OH.

[3]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as vitamin A acetate; vitamin D_3, 1,648 IU as D-activated animal sterol; vitamin E, 55 IU as 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 kilogram of complete diet: Cu, 26 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 0.31 mg as potassium iodate; Mn, 26 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 130 mg as zinc oxide.

minerals were supplied in the form of potassium carbonate and magnesium oxide, respectively. It was assumed that K and Mg were present in diets containing corn or DDGS in quantities sufficient to meet the requirements of animals.

Feed was supplied to the pigs at a daily level of 3 times the estimated maintenance requirement for energy (i.e., 106 kcal of ME per kg of $BW^{0.75}$; NRC, 1998). The ME was calculated (NRC, 1998) as 3,081, 3,317, and 3,813 kcal of ME per kg (as-fed basis) in the DDGS diets, the corn diet, and the N-free diet, respectively. The daily allotments of feed were divided into 2 equal meals. Throughout the experiment, pigs were given free access to water from a nipple drinker.

Data and Sample Collection

Pig weights were recorded at the beginning of each period and the amount of feed supplied each day was recorded. The initial 4 d of each period were considered an adaptation period to the diet. Fecal samples were collected (grab-sampling) in the morning of d 5 and d 6 and stored at –20°C until analyzed. Ileal digesta were collected for 10 h on d 6 and d 7. A 225-mL plastic bag was attached to the cannula barrel using a cable tie, and digesta flowing into the bag were collected. Bags were removed whenever they were filled with digesta, or at least every 30 min, and stored at –20°C. Upon the completion of 1 experimental period, animals were deprived of feed overnight, and the following morning a new experimental diet was offered.

Table 3. Analyzed composition of experimental diets, as-fed basis

	Distillers dried grain with solubles source											
Item	1	2	3	4	5	6	7	8	9	10	Corn	N-free
DM, %	90.70	91.44	89.86	91.15	92.08	89.98	90.72	91.77	91.01	90.64	85.37	89.58
CP, %	18.12	18.89	18.43	20.17	17.86	18.23	19.07	19.18	19.04	18.81	7.63	0.33
GE, kcal/kg	4,459	4,455	4,420	4,427	4,500	4,366	4,418	4,522	4,481	4,464	3,787	3,964
P, %	0.54	0.57	0.52	0.49	0.61	0.58	0.54	0.52	0.58	0.56	0.38	0.43
Indispensable AA, %												
Arg	0.76	0.83	0.75	0.58	0.70	0.73	0.74	0.80	0.84	0.83	0.36	0.02
His	0.52	0.54	0.51	0.49	0.47	0.50	0.50	0.53	0.53	0.54	0.23	0.02
Ile	0.68	0.69	0.70	0.66	0.65	0.65	0.67	0.68	0.68	0.67	0.26	0.01
Leu	2.07	2.27	2.13	2.14	2.13	2.06	2.13	2.26	2.19	2.19	0.91	0.03
Lys	0.54	0.54	0.54	0.45	0.44	0.52	0.52	0.50	0.58	0.59	0.23	0.01
Met	0.37	0.41	0.38	0.42	0.37	0.37	0.39	0.50	0.51	0.50	0.16	0.01
Phe	0.90	0.96	0.91	0.94	0.89	0.88	0.89	0.95	0.92	0.93	0.37	0.01
Thr	0.67	0.72	0.69	0.72	0.64	0.68	0.69	0.74	0.73	0.74	0.29	0.01
Trp	0.14	0.13	0.14	0.13	0.13	0.13	0.14	0.14	0.15	0.15	0.04	0.00
Val	0.93	0.98	0.96	0.92	0.91	0.90	0.93	0.94	0.94	0.93	0.37	0.02
Dispensable AA, %												
Ala	1.19	1.33	1.26	1.34	1.22	1.17	1.22	1.31	1.31	1.31	0.56	0.02
Asp	1.19	1.36	1.24	1.28	1.20	1.18	0.20	1.50	1.48	1.54	0.52	0.02
Cys	0.41	0.45	0.41	0.45	0.40	0.40	0.43	0.56	0.54	0.54	0.18	0.01
Glu	2.50	2.78	2.66	2.93	2.65	2.48	2.52	2.99	2.96	2.95	1.49	0.07
Gly	0.67	0.71	0.68	0.73	0.66	0.64	0.67	0.73	0.74	0.73	0.31	0.01
Pro	1.28	1.46	1.19	1.25	1.55	1.27	1.31	1.49	1.47	1.48	0.61	0.00
Ser	0.71	0.79	0.75	0.81	0.70	0.73	0.75	0.85	0.84	0.85	0.36	0.01
Tyr	0.65	0.69	0.67	0.72	0.62	0.66	0.66	0.71	0.72	0.70	0.28	0.01
All AA, %	16.39	17.83	16.74	17.12	16.52	16.5	16.56	18.39	18.31	18.36	7.65	0.37

Chemical Analysis

At the conclusion of the experiment, ileal samples were thawed, pooled within animal and diet, and a subsample was taken for chemical analysis. A sample of each diet and of each of the samples of DDGS and corn were collected as well. Digesta samples were lyophilized and ground through a 1-mm screen before chemical analysis. The fecal samples were dried in a forced air oven (60°C) and ground before chemical analysis. The feed ingredients, the diets, and the ileal digesta samples were analyzed for DM (procedure 4.1.06, AOAC, 1998) and for CP (procedure 990.03, AOAC, 2000). The fecal samples also were analyzed for DM, and starch was analyzed in all DDGS samples (procedure 996.11; AOAC, 2000). The concentration of P was determined in all the DDGS samples and in the diets (procedure 968.08D, AOAC, 2000). Amino acids were analyzed in DDGS, diets, and ileal samples on a Beckman 6300 Amino Acid Analyzer (Beckman Instruments Corp., Palo Alto, 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 (procedure 4.1.11, alt. 3, AOAC, 1998). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (procedure 4.1.11, alt.1, AOAC, 1998). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (procedure 988.15, AOAC, 1995). Chromium concentrations of diets, ileal digesta, and fecal samples were determined after nitric acid-perchloric acid wet ash sample preparation (procedure 990.08, AOAC 2000). The energy concentration in diets, feed ingredients, and fecal samples were determined using bomb calorimetry (Parr Instrument 1563, Moline IL).

Calculations

The AID for AA in the diets containing DDGS or corn was calculated. Because DDGS or corn was the only feed ingredient contributing AA in these diets, these values also represent the digestibility for each of the samples of DDGS or of corn. Eq. [1] was used for these calculations:

$$\text{AID} = [1 - (\text{AAd}/\text{AAf}) \times (\text{Crf}/\text{Crd})] \times 100\%, \quad [1]$$

in which AID is the apparent ileal digestibility of an AA (%), AAd is the concentration of that AA in the ileal digesta (g/kg of DM), AAf is the concentration of that AA in the diets (g/kg of DM), Crf is the chromium concentration in the diet (g/kg of DM), and Crd is the chromium concentration in the ileal digesta (g/kg of DM). The AID for CP was also calculated using this equation.

The IAA_{end} of each AA was determined based on the flow obtained after feeding the N-free diet using Eq. [2]:

$$\text{IAA}_{end} = [\text{AAd} \times (\text{Crf}/\text{Crd})], \quad [2]$$

in which IAA_{end} is the basal ileal endogenous loss of an AA (g/kg of DMI). The endogenous flow of CP was determined using the same equation.

By correcting the AID that was calculated for each sample for the IAA_{end} of each AA, standardized ileal digestibility values (**SID**) were calculated using Eq. [3]:

$$\text{SID} = [\text{AID} + (\text{IAA}_{end}/\text{AAf})], \quad [3]$$

in which SID is the standardized ileal digestibility of an AA (%).

The apparent total tract digestibilities (**ATTD**) of DM and energy in all diets were calculated using Eq. 1. By multiplying the analyzed concentration of GE in the diets by the corresponding ATTD for energy, the DE in each diet was calculated. The DE in each of the DDGS samples was calculated by subtracting one-third of the DE in the N-free diet from the DE in each of the DDGS-containing diets according to the difference procedure (Adeola, 2001). The digestibility of energy in corn was determined using the direct approach (Adeola, 2001).

Statistical Analysis

Data were analyzed statistically using the Proc GLM procedure of SAS (SAS Inst. Inc., Cary, NC). The pig was the experimental unit. The 10 sources of DDGS were compared using an ANOVA with DDGS source, pig, and period as the main effects. A LSD test was performed to separate the means. The values for corn were compared with the values for DDGS using a contrast statement. An alpha level of 0.05 was used to assess significance among means.

RESULTS

All pigs remained healthy throughout the experiment, and no pigs had to be removed from the study. No orts were collected as all pigs consumed their daily allotments of feed throughout the experiment regardless of the diet being offered.

The AID for CP in DDGS varied between 59.3 and 65.0% with the AID in sources 4 and 5 being lower ($P < 0.001$) than in sources 2, 3, 6, and 9 (Table 4). The AID for CP in corn was 51.7%, which was lower ($P < 0.001$) than the AID in DDGS.

The AID for Lys was 35.0 and 40.7%, respectively, for samples obtained from sources 5 and 8. These values were lower ($P < 0.05$) than the values from all the other sources of DDGS. The AID for Lys in DDGS from sources 2 and 4 (49.6 and 49.8%, respectively) were also lower ($P < 0.05$) than the AID for Lys in DDGS from sources 9 and 3 (54.6 and 55.9%, respectively). The AID for Lys for the remaining sources were greater ($P < 0.05$) than the AID for Lys in DDGS from sources 5 and 8, but they were not different from any of the other sources. The AID for Lys in corn (50.6%) was not different from the AID for Lys in DDGS.

The AID for the remaining indispensable AA were less variable than the AID for Lys, but significant differ-

Table 4. Apparent ileal digestibilities (%) of crude protein and amino acids in distillers dried grain with solubles (DDGS) and in corn[1]

	DDGS source											DDGS[2]			Corn vs. DDGS[3]	
Item	1	2	3	4	5	6	7	8	9	10	Corn	SEM	*P*-value	LSD	SEM	*P*-value
CP	61.0	64.1	64.3	59.3	59.3	64.1	61.2	61.9	65.0	62.0	51.7	1.15	0.001	3.17	1.09	0.001
Indispensable AA																
Arg	69.2	74.0	72.8	68.1	68.3	70.9	68.2	70.7	74.9	70.5	62.7	1.24	0.001	3.40	1.06	0.001
His	70.1	72.6	71.1	67.1	66.1	72.3	67.5	68.8	73.0	70.1	73.6	0.86	0.001	2.35	0.83	0.01
Ile	68.0	68.2	71.1	63.1	64.3	70.2	66.0	66.5	69.5	66.6	66.0	0.88	0.001	2.41	0.89	0.30
Leu	76.3	79.7	79.8	73.0	78.9	80.6	73.7	79.3	81.2	78.3	79.8	0.69	0.001	1.90	0.84	0.27
Lys	52.2	49.6	55.9	49.8	35.0	52.0	52.0	40.7	54.6	53.0	50.6	1.53	0.001	4.20	1.89	0.67
Met	74.8	77.6	77.0	71.6	74.3	77.3	73.6	81.0	82.8	80.7	78.2	0.59	0.001	1.63	0.98	0.53
Phe	73.7	76.1	76.1	70.3	73.3	77.1	71.0	75.1	77.3	74.6	74.3	0.70	0.001	1.9	0.79	0.77
Thr	58.5	60.2	61.6	56.6	53.7	61.0	57.9	59.6	63.3	60.6	55.1	1.06	0.001	2.92	1.01	0.01
Trp	72.2	67.0	73.4	66.8	68.4	70.1	71.8	70.0	73.4	72.1	48.9	1.37	0.006	3.75	1.21	0.001
Val	65.8	67.2	69.3	62.6	62.4	67.9	64.1	64.5	68.2	65.2	64.3	0.92	0.001	2.52	0.87	0.28
Mean	69.4	71.9	72.2	66.2	68.0	72.3	67.4	69.9	73.7	70.6	69.0	0.79	0.001	2.18	0.80	0.37
Dispensable AA																
Ala	67.1	72.1	72.2	65.2	68.9	70.3	65.6	69.8	73.4	70.1	68.5	0.98	0.001	2.69	0.94	0.44
Asp	57.0	62.4	62.1	58.7	55.8	60.0	56.4	63.6	66.9	65.5	62.6	0.93	0.001	2.54	1.13	0.33
Cys	64.3	67.9	65.5	61.4	62.0	65.7	63.3	70.7	73.3	72.6	65.5	1.08	0.001	2.96	1.29	0.58
Glu	66.9	71.7	72.6	63.5	69.2	71.8	63.5	71.6	75.4	72.8	76.8	0.99	0.001	2.71	1.44	0.001
Gly	34.9	42.5	40.7	32.7	35.2	33.0	33.3	33.1	44.5	36.1	8.1	2.95	0.001	8.09	2.52	0.001
Pro	22.0	46.8	25.9	20.8	47.2	21.4	17.9	35.1	40.9	31.7	30.7	6.06	0.04	16.64	5.33	0.001
Ser	64.2	67.3	68.9	63.3	63.1	67.9	64.4	69.0	72.3	69.4	67.0	1.08	0.004	2.98	1.01	0.99
Tyr	74.5	76.2	77.5	70.8	73.7	78.2	72.4	76.5	80.1	75.9	72.9	0.71	0.001	1.96	0.86	0.04
Mean	56.7	64.5	61.6	54.5	60.7	59.3	53.8	61.4	66.5	62.4	52.3	1.58	0.001	4.35	1.42	0.001
Mean, all AA	62.6	67.3	66.4	59.5	63.7	65.3	60.0	65.0	69.5	65.9	59.1	1.16	0.001	3.19	1.07	0.002

[1]Values are means for 8 observations per treatment.
[2]Comparison of the 10 DDGS sources.
[3]Comparison of corn vs. all DDGS sources.

ences among the 10 sources of DDGS were observed for all AA. For most of the indispensable AA, the AID for DDGS from sources 2, 3, 6, and 9 were greater ($P <$ 0.05) than the AID measured in sources 4, 5, and 7.

The AID for Arg, Thr, and Trp in corn (62.7, 55.1, and 48.9%, respectively) were lower ($P < 0.01$) than the AID in DDGS. In contrast, the AID for His in corn (73.6%) was greater ($P < 0.01$) than in DDGS. However, for the remaining indispensable AA, the AID in corn was within the range measured in the 10 sources of DDGS.

For the dispensable AA, the variations among samples were relatively low. However, for most of the indispensable AA, the AID in sources 2, 3, 6, 9, and 10 were greater ($P < 0.05$) than the AID in sources 1, 4, 5, 7, and 8. The AID for Glu, Gly, Pro, and Tyr in corn were lower ($P < 0.04$) than in DDGS, but for the other dispensable AA, the AID in corn was within the range measured for DDGS.

The SID for CP and all AA are presented in Table 5. The SID for CP in DDGS from sources 4 and 5 (66.7 and 67.7%, respectively) were lower ($P < 0.05$) than the SID for CP from sources 2, 3, 6, and 9 (72.0, 72.3, 72.1, and 72.8%, respectively). Likewise, for all indispensable AA except Arg, Leu, Lys, and Trp, the SID in sources 4 and 5 were lower ($P < 0.05$) than the SID in sources 2, 3, 6, and 9. For Arg, the SID in sources 4 and 5 were lower ($P < 0.05$) than in sources 2, 3, and 9. For Leu, the SID for sources 4 and 7 were lower ($P < 0.05$) than the SID in all other sources. For Lys, the SID ranged from 56.8 to 63.0% in all sources of DDGS except in sources 5 and 8. These values were not different, but they were greater ($P < 0.05$) than the SID in sources 5 and 8 (43.9 and 48.6%, respectively).

For all dispensable AA except Pro, the SID in DDGS from sources 4 and 7 were lower ($P < 0.05$) than the SID in sources 2, 3, 8, 9, and 10, but other than that, there were only a few differences in SID among the 10 sources of DDGS.

The SID for CP, Arg, and Gly in corn (71.2, 76.7, and 53.5%, respectively) were not different from the SID in DDGS. The SID for Trp and Pro in corn (72.8 and 48.3%, respectively, were lower ($P < 0.05$) than in DDGS. However, for all other AA, the SID for corn were greater (P < 0.01) than in DDGS.

The ATTD of DM and GE in the corn diet (87.6 and 85.1%, respectively) were greater ($P < 0.001$) than the values in all the diets containing DDGS (Table 6). The ATTD of DM and GE in DDGS from source 2 (72.6 and 70.5%, respectively) was greater ($P < 0.05$) than in the samples from all other sources except source 5. The ATTD of DM for source 5 (70.5%) also was greater (P < 0.05) than the ATTD for sources 4, 7, and 10. Likewise, the ATTD of GE in source 5 (69.0%) was greater ($P <$ 0.05) than the ATTD for GE in sources 1, 4, 7, 8, and 10. However, there were no differences in the ATTD of

Table 5. Standardized ileal digestibilities (%) of crude protein and amino acids in distillers dried grain with solubles (DDGS) and in corn[1,2]

	DDGS source											DDGS[3]			Corn vs. DDGS[4]	
Item	1	2	3	4	5	6	7	8	9	10	Corn	SEM	*P*-value	LSD	SEM	*P*-value
CP	69.2	72.0	72.3	66.7	67.7	72.1	69.0	69.8	72.8	69.9	71.2	1.15	0.001	3.17	1.09	0.45
Indispensable AA																
Arg	75.7	80.0	79.4	74.1	75.5	77.7	74.9	77.0	80.8	76.5	76.7	1.24	0.002	3.40	1.04	0.70
His	73.6	76.0	74.7	70.4	70.0	75.9	71.1	72.3	76.4	73.5	81.6	0.86	0.001	2.35	0.81	0.001
Ile	72.3	72.5	75.3	67.4	68.9	74.7	70.4	70.9	73.9	71.0	77.5	0.88	0.001	2.41	0.88	0.001
Leu	78.6	81.9	82.0	75.1	81.2	83.0	76.0	81.4	83.5	80.5	85.2	0.69	0.001	1.90	0.84	0.001
Lys	59.3	56.8	63.0	57.0	43.9	59.4	59.4	48.6	61.3	59.6	67.7	1.53	0.001	4.20	1.78	0.001
Met	77.4	79.9	79.4	73.9	76.8	79.8	76.0	82.9	84.7	82.6	84.0	0.59	0.001	1.63	0.94	0.003
Phe	77.0	79.3	79.4	73.5	76.7	80.4	74.4	78.3	80.5	77.8	82.5	0.70	0.001	1.91	0.78	0.001
Thr	66.5	67.7	69.2	64.0	62.2	68.8	65.6	67.0	70.6	67.9	73.7	1.06	0.001	2.92	0.97	0.001
Trp	79.0	74.4	80.1	74.1	75.8	77.3	78.5	76.8	79.7	78.4	72.8	1.37	0.04	3.75	1.17	0.02
Val	70.7	71.9	74.0	67.3	67.5	73.0	69.0	69.4	73.1	70.1	76.8	0.92	0.001	2.52	0.87	0.001
Mean	73.5	75.8	76.5	70.8	72.4	76.8	72.2	74.5	77.6	74.6	80.6	0.79	0.001	2.18	0.79	0.002
Dispensable AA																
Ala	72.2	76.7	76.9	69.7	73.9	75.4	70.5	74.4	78.0	74.7	79.3	0.98	0.001	2.69	0.93	0.002
Asp	63.6	68.2	68.4	64.6	62.5	66.6	63.0	68.9	72.3	70.6	77.9	0.93	0.001	2.54	1.04	0.001
Cys	69.2	72.4	70.5	66.0	67.2	70.6	68.1	74.4	77.1	76.4	77.0	1.08	0.001	2.96	1.20	0.004
Glu	71.2	75.5	76.5	67.4	73.3	76.0	67.7	75.2	79.1	76.4	84.1	0.99	0.001	2.71	1.13	0.001
Gly	55.7	62.4	61.1	52.5	56.7	54.7	54.2	52.5	63.5	55.3	53.5	2.95	0.10	8.09	2.48	0.35
Pro	59.4	79.8	65.7	53.7	78.5	58.8	54.4	67.6	73.5	64.0	48.3	6.06	0.03	16.64	5.16	0.03
Ser	71.5	73.9	75.7	69.9	70.6	74.9	71.3	75.1	78.4	75.4	81.4	1.08	0.001	2.98	0.95	0.001
Tyr	78.6	80.1	81.4	74.6	78.0	82.2	76.5	80.3	83.8	79.6	82.5	0.71	0.001	1.96	0.85	0.003
Mean	68.3	74.1	73.3	64.9	71.0	70.6	65.1	71.4	75.5	72.5	75.8	1.58	0.001	4.35	1.36	0.07
Mean, all AA	70.7	74.6	74.6	67.3	71.4	73.4	68.3	72.6	76.3	73.3	77.6	1.16	0.001	3.19	1.04	0.02

[1]Values are means of 8 observations per treatment.
[2]Standardized ileal digestibilities were calculated by correcting the apparent ileal digestibilities for the basal ileal endogenous losses. Basal ileal endogenous losses (g/kg of DMI) were: CP, 16.3; Arg, 0.55; His, 0.20; Ile, 0.33; Leu, 0.53; Lys, 0.43; Met, 0.10; Phe, 0.33; Thr, 0.59; Trp, 0.10; Val, 0.51; Ala, 0.66; Asp, 0.87; Cys, 0.23; Glu, 1.18; Gly, 1.54; Pro, 5.27; Ser, 0.57; and Tyr, 0.29.
[3]Comparison of the 10 DDGS sources.
[4]Comparison of corn vs. all DDGS sources.

DM or GE among DDGS from sources 1, 3, 4, 6, 7, 8, 9, and 10.

The concentration of DE in corn was measured as 3,845 kcal/kg (DM basis). This value was greater ($P < 0.001$) than the DE in DDGS that ranged from 3,382 to 3,811 kcal/kg of DM. The DDGS from source 2 had a DE value of 3,811 kcal/kg of DM, which was greater ($P < 0.001$) than the DE in all other samples of DDGS except in source 5 (3,774 kcal/kg of DM). The DE in source 5 was greater ($P < 0.001$) than the DE in source 1, 4, 6, 7, 8, 9, and 10 (3,493, 3,382, 3,519, 3,408, 3,555, 3,583, and 3,459 kcal/kg of DM, respectively) but not different from the DE in source 3 (3,595 kcal/kg of DM). The DE in source 3 also was greater ($P < 0.001$) than the DE in source 4, but among the remaining sources, no differences in the DE concentration were observed.

DISCUSSION

Nutrient Composition of Distillers Dried Grain with Solubles

The concentration of CP in the DDGS used in the current study did not vary from expected values (NRC, 1998; Spiehs et al., 2002). Likewise, with the exception of Trp, the concentrations of all AA in the DDGS samples also agreed with previously reported values (NRC, 1998; Spiehs et al., 2002). Values for ADF concentrations in the DDGS ranged from 8.0 to 13.1% (as fed-basis), which is equivalent to a range of 9.2 to 14.4% on a DM-basis. Values of ADF ranging from 13.8 to 17.1% (DM-basis) were reported by Spiehs et al. (2002), and an average value of 17.4% (DM-basis) also has been reported (NRC, 1998). It is not known why the ADF concentrations were lower in the DDGS used in the current experiment, but it may be a result of more effective enzyme combinations being used in the fermentation process.

The Glu:CP ratio was lower in all the DDGS-based diets than in the corn-based diet, which may have been caused by the yeast that is used in the fermentation process. Yeast prefers to use Glu as an energy source (Sharp and Chambers, 1983).

Digestibility of Crude Protein and Amino Acids

The AID and SID for Met, Cys, and Trp in DDGS were generally greater than published values, but for the remaining indispensable AA, the AID and SID measured in this experiment were in agreement with published values (NRC, 1998). Except for Lys, the lowest AID and SID for the indispensable AA were obtained

Table 6. Apparent total tract digestibility (ATTD) of DM and energy, and the concentration of DE, in distillers dried grain with solubles (DDGS) and in corn[1]

	DDGS source											DDGS[2]			Corn vs. DDGS[3]	
Item	1	2	3	4	5	6	7	8	9	10	Corn	SEM	*P*-value	LSD	SEM	*P*-value
ATTD of DM, %																
Diet	76.0	79.3	77.0	74.9	77.9	76.4	75.2	75.8	76.7	75.2	87.6	0.78	0.02	2.0	0.57	0.001
Ingredient	67.6	72.6	69.1	66.0	70.5	68.3	66.5	67.4	68.7	66.4	—	1.17	0.02	3.3		
ATTD of GE, %																
Diet	73.4	77.6	74.4	72.5	76.7	74.4	72.8	74.2	74.9	73.2	85.1	0.89	0.006	2.2	0.65	0.001
Ingredient	64.1	70.5	65.5	62.7	69.0	65.6	63.2	65.3	66.3	63.8	—	1.33	0.006	3.7		
DE in DM, kcal/kg																
Ingredient	3,473	3,811	3,596	3,382	3,774	3,519	3,408	3,555	3,583	3,459	3,845	68	0.001	184	52	0.001

[1]Values are mean values of 8 observations per treatment.
[2]Comparison of the 10 DDGS sources.
[3]Comparison of corn vs. all DDGS sources.

for Thr. This is also in agreement with published values (NRC, 1998).

Among the 10 samples of DDGS, significant differences in the SID for CP and all AA were obtained. For CP and all AA except Ile, Lys, Trp, and Pro, the numerically highest SID were obtained in DDGS from source 9 and the lowest SID were obtained for CP and all AA except His, Lys, Thr, and Asp in the DDGS from source 4. However, with the exception of the SID of Lys in sources 5 and 8, the variations in SID for CP and all indispensable AA except Met among the DDGS samples were between 5.8 and 8.4 percentage units. For Met, the SID ranged from 73.9 to 84.7%. Previously, AID values for all indispensable AA except Arg in 6 cultivars of field peas were reported to vary from 5.3 to 17.3 percentage units (Fan and Sauer, 1999). Using a rat model, van Wijk et al. (1998) reported variations in AID of 8.5 to 18.9 percentage units for the indispensable AA in 20 cultivars of barley. It seems that with the exception of the values for Lys in sources 5 and 8, the variation obtained in AID and SID for indispensable AA among samples of DDGS obtained in the current study are no greater than the variations reported among different cultivars of field peas and barley, respectively.

The low AID and SID for Lys in the DDGS from sources 5 and 8 may be a result of the Maillard reaction that takes place during heating if reducing sugars are present (Mauron, 1981). Reducing sugars would be present if an incomplete fermentation and starch removal has occurred. The current results indicate that an incomplete fermentation and overheating may have occurred in the 2 plants supplying the DDGS designated as sources 5 and 8.

The reason why the AID for most AA in corn were similar to DDGS whereas the SID for most AA in corn were greater than in DDGS is that feed ingredients with a low CP and AA concentration usually have low AID because IAA_{end} contribute relatively more to the ileal output of AA compared with feed ingredients with a moderate or high concentration of CP and AA (Fan et al., 1994; Pedersen and Boisen, 2002). When SID are calculated, the influence of the IAA_{end} is eliminated, which explains why the values for corn increased relative to the values for the DDGS samples. The fact that the SID for most AA in corn are greater than they are in DDGS indicate that not all the AA in DDGS are utilized as well as they are in corn. Because DDGS contains more fiber than corn and because fiber negatively influences the digestibility of AA (Mosenthin et al., 1994; Lenis et al., 1996), the reduced SID for some AA in DDGS may have been caused by the increased fiber concentration in DDGS. It is also possible that some of the AA may have been altered by the microbes during the fermentation process and used in the synthesis of microbial protein, which in turn could result in differences in AA digestibility values.

Dry Matter and Energy Digestibility

The results of the current experiment indicate that the DE concentration in DDGS ranges from 3,382 to

3,811 kcal of DE per kg of DM. The average value for the 10 samples (3,556 kcal of DE per kg of DM) is slightly greater than the value of 3,440 kcal of DE per kg of DM that has been published (NRC, 1998). Previously, Spiehs et al. (2002) calculated the DE in 11 or 12 samples of DDGS from each of 10 ethanol plants in the Midwest and reported average values for each plant ranging from 3,879 to 4,084 kcal of DE per kg of DM.

The ATTD for GE varied from 62.7 to 70.5% among the 10 samples of DDGS. The samples that had the highest ATTD for GE also had the highest ATTD for DM, and it seems that DM digestibility is a good predictor of energy digestibility. The variation in the ATTD for GE is similar to the variation reported among 5 cultivars of barley (Fairbairn et al., 1999). The highest value for DE was obtained for the DDGS from source 2. This sample also had the lowest concentration of ADF and the highest concentration of starch. The highest concentrations of ADF were found in sources 7 and 8 and these sources had concentrations of starch and DE that were among the lowest of all samples. Thus, it seems that the DE in DDGS to some degree is related to the concentration of starch and ADF in the sample, but not all differences in DE concentrations can be explained by the concentration of these 2 nutrients.

IMPLICATIONS

Results from the present experiment indicate that the digestibility of amino acids in distillers dried grain with solubles varies among sources. The largest variations are found for lysine, which may be a result of heat damage in some samples of distillers dried grain with solubles. For most amino acids, the apparent and standardized digestibilities agree with previously published values, and the variation among samples of distillers dried grain with solubles is similar to variations reported for other feed ingredients. The concentration of energy in distillers dried grain with solubles also varies among samples.

LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. Page 903 in Swine Nutrition, 2nd ed. A. J. Lewis and L. L. Southern, ed. CRC Press, Washington, DC.

Anderson, V. L., and R. A. McLean. 1974. Design of Experiments. A Realistic Approach. Marcel Dekker, Inc., New York, NY.

AOAC. 1995. Official Methods of Analysis. 15th ed. Assoc. Anal. Chem., Arlington, VA.

AOAC. 1998. Official Methods of Analysis. 16th ed. Assoc. Anal. Chem., Arlington, VA.

AOAC. 2000. Official Methods of Analysis. 17th ed. Assoc. Anal. Chem., Arlington, VA.

Cromwell, G. L., K. L. Herkelman, and T. S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grain with solubles fed to chicks and pigs. J. Anim. Sci. 71:679–686.

Fairbairn, S. L., J. F. Patience, H. L. Classen, and R. T. Zijlstra. 1999. The energy content of barley fed to growing pigs: Characterizing the nature of its variability and developing prediction equations for its estimation. J. Anim. Sci. 77:1502–1512.

Fan, M. Z., and W. C. Sauer. 1999. Variability of apparent ileal amino acid digestibility in different pea samples for growing-finishing pigs. Can. J. Anim. Sci. 79:467–475.

Fan, M. Z., W. C. Sauer, R. T. Hardin, and K. A. Lien. 1994. Determination of apparent ileal amino acid digestibility in pigs: Effect of dietary amino acid level. J. Anim. Sci. 72:2851–2859.

Fastinger, N. D., and D. C. Mahan. 2005. Apparent and true ileal amino acid and energy digestibility and weanling pig performance of five sources of distillers dried grain with solubles. J. Anim. Sci. 83(Suppl. 2):54. (Abstr.)

Lenis, N. P., P. Bikker, J. van der Meulen, J. Th. M. van Diepen, J. G. M. Bakker, and A. W. Jongbloed. 1996. Effect of dietary neutral detergent fiber on ileal digestibility and portal flux of nitrogen and amino acids and on nitrogen utilization in growing pigs. J. Anim. Sci. 74:2687–2699.

Mauron, J. 1981. The Maillard reaction in food; A critical review from the nutritional standpoint. Prog. Nutr. Sci. 5:5–35.

Mosenthin, R., W. C. Sauer, and F. Ahrens. 1994. Dietary pectin's effect on ileal and fecal amino acid digestibility and exocrine pancreatic secretions in growing pigs. J. Nutr. 124:1222–1229.

NRC. 1998. Pages 110–142 in Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Pedersen, C., and S. Boisen. 2002. Tabulated values for apparent and standardized values in different feedstuffs to pigs. Acta Agric. Scand. Sect. A. Anim. Sci. 52:121–140.

Sharp, J. L., and D. L. Chambers. 1983. Aggregation response of *Anastrepha suspensa* (Diptera: Tephritidae) to proteins and amino acids. Environ. Entomol. 12:923–928.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient data for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639–2645.

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical Note: A technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436.

van Wijk, H. J., P. J. Moughan, S. M. Hodginson, P. P. Jansen, and G. Pearson. 1998. Variation in apparent and true ileal amino acid digestibility in barley using a rat model. Anim. Feed Sci. Technol. 76:9–22.