JOURNAL OF ANIMAL SCIENCE
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J Anim Sci 2008.86:2180-2189.
doi: 10.2527/jas.2008-0868 originally published online May 9, 2008;

Factors affecting the variability in ileal amino acid digestibility in corn distillers dried grains with solubles fed to growing pigs[1]

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ABSTRACT: Two experiments were conducted to compare the ileal digestibility of AA in distillers dried grains with solubles (DDGS) sourced from different regions (IL, MN, KY), to compare AA digestibility in DDGS and in distillers dried grains (DDG) and to compare AA digestibility in DDGS from ethanol production ($DDGS_{ethanol}$) and DDGS from beverage production ($DDGS_{beverage}$). In Exp. 1, five samples of $DDGS_{ethanol}$ were sourced from Minnesota (MN1, MN2), Illinois (IL1, IL2), and from Kentucky (KY). In Exp. 2, six samples of $DDGS_{ethanol}$, 1 sample of DDG, and 1 sample of $DDGS_{beverage}$ were used to compare values for apparent ileal digestibility and standardized ileal digestibility (SID) of AA between $DDGS_{ethanol}$ and $DDGS_{beverage}$ and between DDG and $DDGS_{ethanol}$. Results of Exp. 1 showed that the SID of Lys in DDGS from MN2 (72.8%) was greater ($P < 0.01$) than in DDGS from MN1 (66.8%), IL1 (66.8%), and KY (65.8%) but not different from IL2 (70.1%). Except for Leu and Glu, no differences in SID for any of the other AA were observed among the 5 sources of DDGS. In Exp. 2, the SID for Lys in $DDGS_{beverage}$ was greater ($P < 0.01$) than in $DDGS_{ethanol}$ (69.3 vs. 64.8%), but for CP and all other AA except His, no differences between the 2 types of DDGS were observed. The SID for most AA in DDG were greater ($P < 0.05$) than in $DDGS_{ethanol}$, which suggests that the AA in the solubles that are added to DDGS may be less digestible than the AA in DDG. In conclusion, results of these experiments confirm that the digestibility of Lys is more variable among sources of DDGS than the digestibility of other AA. However, the SID of AA among DDGS sources within a region can vary as much as among DDGS sources from different regions, and AA in $DDGS_{beverage}$ may be as digestible as AA in $DDGS_{ethanol}$. The digestibility of AA in DDG is greater than in DDGS, which indicates that AA in the solubles have a lower digestibility than AA in DDG.

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

J. Anim. Sci. 2008. 86:2180–2189
doi:10.2527/jas.2008-0868

INTRODUCTION

Distillers dried grains with solubles (**DDGS**) is a by-product of the ethanol and beverage industries that is produced after starch has been fermented. It contains at least three-fourths of the solids of the resultant whole stillage (AFFCO, 2006), which is blended with the condensed solubles (syrup) during drying. If the coarse grain fraction of the whole stillage is dried without the solubles added to it, the product is called distillers dried grains (**DDG**).

Results of previous research indicate that the digestibility of AA in DDGS may vary according to the location of the plant that produced it (Whitney et al., 2000; Fastinger and Mahan, 2006). However, the DDGS used in these studies were sourced from ethanol plants located only in the upper Midwest, and there are no data on the AA digestibility in DDGS sourced from the entire Midwestern region.

The quantity of solubles that is added to the DDG may also contribute to variability in the composition of DDGS (Goodson and Fontaine, 2004), but the digestibility of AA in DDG and DDGS has not been compared. Likewise, the digestibility of AA in DDGS produced in a dry grind ethanol plant (**$DDGS_{ethanol}$**) has not been compared with the digestibility of AA in DDGS produced at a modern beverage plant (**$DDGS_{beverage}$**).

Thus, the objective of the present work was to compare the digestibility of AA in DDGS sourced from ethanol plants located in the northern (i.e., MN), central

[1]Financial support for this work from Evonik Degussa Corp. (Kennesaw, GA), Poet Nutrition (Sioux Falls, SD), and from the South Dakota Corn Utilization Council (Sioux Falls) is appreciated.

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Received January 13, 2008.
Accepted May 7, 2008.

Table 1. Analyzed composition of distillers dried grains with solubles (DDGS) from ethanol plants located in Minnesota, Illinois, and Kentucky, Exp. 1[1]

	DDGS source[2]					
Item	MN1	MN2	IL1	IL2	KY	Mean
CP, %	28.30	26.91	24.45	26.10	26.52	26.46
NDF, %	26.54	29.48	27.97	28.50	29.05	28.31
ADF, %	11.57	12.63	9.87	10.16	10.70	10.99
Starch, %	6.78	5.39	10.35	6.84	7.07	7.29
Indispensable AA, %						
Arg	1.26	1.09	1.13	1.22	1.19	1.18
His	0.74	0.69	0.68	0.70	0.70	0.70
Ile	1.08	0.98	0.90	0.91	0.99	0.97
Leu	3.31	3.21	2.83	3.00	3.00	3.07
Lys	0.79	0.73	0.73	0.74	0.75	0.75
Met	0.52	0.48	0.46	0.52	0.53	0.50
Phe	1.38	1.30	1.19	1.25	1.27	1.28
Thr	1.09	1.01	0.92	0.98	0.95	0.99
Trp	0.23	0.20	0.20	0.22	0.22	0.21
Val	1.42	1.28	1.20	1.22	1.28	1.28
Dispensable AA, %						
Ala	2.08	2.02	1.80	2.05	1.89	1.97
Asp	1.90	1.71	1.61	1.68	1.71	1.72
Cys	0.50	0.48	0.47	0.48	0.51	0.49
Glu	4.79	4.63	4.18	4.47	4.52	4.52
Gly	1.11	1.02	0.98	1.06	1.04	1.04
Pro	2.22	2.17	1.98	2.16	2.17	2.14
Ser	1.36	1.30	1.17	1.27	1.18	1.26

[1]All values adjusted to 88.0% DM.

[2]MN1 and MN2 were sourced from 2 different plants in Minnesota, IL1 and IL2 were sourced from 2 different plants in Illinois, and KY was sourced from Kentucky.

(i.e., IL), or southern (i.e., KY) corn-producing area in the United States. The second objective was to compare the AA digestibility of DDG and DDGS. The third objective was to compare the AA digestibility of DDGS produced from 2 types of alcohol extraction facilities (i.e., dry grind ethanol plants and alcoholic beverage plants).

MATERIALS AND METHODS

Two digestibility experiments were conducted using ileal-cannulated growing pigs. The animal part of both experiments was conducted at South Dakota State University (Brookings), and experimental protocols were reviewed and approved by the Institutional Animal Care and Use Committee at South Dakota State University.

Animals, Housing, and Experimental Design

In Exp. 1, twelve barrows (initial BW: 37.0 ± 5.6 kg) were allotted to a replicated 4 × 6 Youden square design (Anderson and McLean, 1974) with 4 periods and 6 diets. In Exp. 2, nine barrows (initial BW: 76.0 ± 9.2 kg) were used in a 7 × 9 Youden square design with 7 periods and 9 diets. All barrows were the offspring of SP-1 boars that were mated to Line 13 sows (Ausgene Intl. Inc., Gridley, IL), and they were surgically fitted with a T-cannula in the distal ileum (Stein et al., 1998). Pigs were housed in an environmentally controlled room (22°C) with fully slatted pens (1.2 × 1.8 m). A feeder and a nipple drinker were installed in each pen.

Diets, Feeding, and Sample Collection

In Exp. 1, five sources of corn DDGS from dry grind fuel ethanol plants were used (Table 1). Two of the DDGS samples were from Minnesota (MN1, MN2), 2 were from Illinois (IL1, IL2), and 1 sample was from Kentucky (KY). All samples were collected from different ethanol plants. Five diets based on each of the 5 DDGS sources and a N-free diet were formulated (Tables 2 and 3). In Exp. 2, one sample of DDG, 1 sample of $DDGS_{beverage}$, and 6 samples of $DDGS_{ethanol}$ were used (Table 4). Eight diets based on each of the coproducts and a N-free diet were formulated (Tables 2 and 5). The DDG was from Minnesota, the $DDGS_{beverage}$ was sourced from Kentucky, and the 6 samples of $DDGS_{ethanol}$ that were used in Exp. 2 were sourced from Illinois (2 samples), Indiana, Wisconsin, North Dakota, and Minnesota. Samples of each source of DDG and DDGS were collected on arrival and stored at 4°C until analyzed.

In both experiments, feed was provided in the amount of 3 times the estimated daily ME requirement for maintenance (i.e., 106 kcal of ME per kg of $BW^{0.75}$, NRC, 1998). The daily feed allowance was divided into 2 equal meals that were fed at 0800 and 1700 h.

The initial 5 d of each period were considered an adaptation period to the diet, and ileal digesta were collected on d 6 and 7 of each period as described previously (Stein et al., 2006). All collected digesta were stored at −20°C, and all samples were lyophilized and ground before chemical analyses.

Chemical Analyses

Samples of ingredients, diets, and ileal digesta were analyzed for DM (procedure 4.1.06; AOAC, 2000), CP, and AA at Degussa Analytical Nutrition Laboratory in Hanau, Germany. Amino acids were analyzed by cation exchange chromatography (method 994.12; AOAC, 1995). Analysis for Met and Cys were performed by initially oxidizing the samples with performic acid (Llames and Fontaine, 1994). Tryptophan was analyzed after hydrolysis in 4 *M* barium hydroxide at 110°C for 20 h (Llames and Fontaine, 1994). Tyrosine was not analyzed. Diets were also analyzed for Ca (procedure 4.8.03; AOAC, 2000) and P (procedure 3.4.11; AOAC, 2000), and all ingredients were analyzed for ADF and NDF (procedure 4.6.03; AOAC, 2000) and starch (Xiong et al., 1990). All samples of diets and ileal digesta were analyzed for Cr (procedure 9.2.39; AOAC, 2000) after nitric acid-perchloric acid wet ash sample preparation.

Calculations and Statistical Analysis

The apparent ileal digestibilities (**AID**), basal ileal endogenous losses, and standardized ileal digestibilities (**SID**) of CP and AA were calculated for DDG and each source of DDGS as described by Stein et al. (2006). Data were analyzed by ANOVA using the MIXED procedure (SAS Inst. Inc., Cary, NC). The pig was the experimental unit. Pig and period were considered random effects, and diet was the fixed effect. Least squares means were calculated and separated using the PDIFF option of SAS. In Exp. 1, the CONTRAST option of SAS was used to compare data from DDGS sourced from different regions. The CONTRAST option was also used in Exp. 2 to compare data for DDG and DDGS and to compare data for $DDGS_{beverage}$ and $DDGS_{ethanol}$. In all analyses, a probability of $P < 0.05$ was considered significant.

RESULTS

Exp. 1

The AID of CP and all AA except Arg, Lys, Leu, and Trp were similar among the 5 sources of DDGS (Table 6). The mean AID for Lys was 63.1% and ranged from 60.3 to 67.4%. The AID of Lys was greater ($P < 0.05$) in DDGS from MN2 than in DDGS from MN1, IL1, and KY but not different from IL2. The DDGS from Minnesota had a greater AID for Arg ($P < 0.05$) and Lys ($P < 0.05$) than DDGS from Kentucky, whereas DDGS from Illinois had a greater ($P < 0.01$) AID for Leu compared with DDGS from MN.

The SID of CP and all AA except Leu, Lys, and Glu did not differ among sources of DDGS (Table 7). The mean SID of Lys was 68.5%, and the SID of Lys was greater ($P < 0.05$) for DDGS from MN2 than from MN1, IL1, and KY but not different from IL2. The DDGS from Illinois had a greater ($P < 0.01$) SID for Leu than the DDGS from Minnesota, whereas the DDGS from Kentucky had a greater ($P < 0.05$) SID of Arg and Leu compared with DDGS from Minnesota. However, DDGS from Minnesota had a greater ($P < 0.05$) SID of Lys than DDGS from Kentucky, but there was no influence of region on the SID of other AA.

Exp. 2

The mean CP, NDF, ADF, and starch concentration in the 6 $DDGS_{ethanol}$ sources were 25.54, 29.13, 11.61, and 8.55%, respectively (Table 4). The CP, NDF, ADF, and starch concentration in $DDGS_{beverage}$ were 25.55, 31.67, 11.64, and 7.32%, respectively, and these values were within the range of values observed in $DDGS_{ethanol}$. The concentration of CP, NDF, ADF, and starch in DDG were 28.77, 37.29, 18.19, and 3.83%, respectively. These values were greater than in $DDGS_{ethanol}$ and $DDGS_{beverage}$. However, the concentration of starch was lower in DDG compared with both types of DDGS.

Table 2. Ingredient composition of experimental diets, Exp. 1 and 2 (as-fed basis)

Ingredient (%)	N-free diet	DDG and DDGS diets[1]
DDG or DDGS	—	66.70
Cornstarch	81.22	27.07
Dextrose	9.00	3.00
Soybean oil	3.00	1.00
Cellulose[2]	3.00	—
Limestone	—	1.35
Dicalcium phosphate	2.40	—
Salt	0.40	0.40
Chromic oxide	0.30	0.30
Micromineral premix[3]	0.15	0.15
Vitamin premix[4]	0.03	0.03
Potassium carbonate	0.40	—
Magnesium oxide	0.10	—

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

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

[3]Provided the following quantities of microminerals per kilogram of complete diet: Cu, 26.0 mg as copper sulfate; Fe, 125.0 mg as iron sulfate; I, 0.31 mg as potassium iodate; Mn, 26.0 mg as manganese sulfate; Se, 0.30 mg as sodium selenite; and Zn, 130 mg as zinc oxide.

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

Table 3. Analyzed composition of experimental diets, Exp. 1 (as-fed basis)[1]

		DDGS source[2]				
Item	N-free	MN1	MN2	IL1	IL2	KY
CP, %	0.20	18.53	18.20	15.61	17.14	17.58
Ca, %	0.40	0.44	0.47	0.47	0.47	0.40
P, %	0.31	0.44	0.46	0.46	0.51	0.50
Indispensable AA, %						
Arg	—	0.82	0.72	0.71	0.80	0.76
His	—	0.49	0.46	0.41	0.47	0.44
Ile	—	0.73	0.66	0.57	0.62	0.61
Leu	—	2.16	2.14	1.77	1.93	1.93
Lys	—	0.52	0.49	0.47	0.49	0.48
Met	—	0.33	0.32	0.28	0.33	0.33
Phe	—	0.90	0.86	0.75	0.82	0.82
Thr	—	0.70	0.67	0.58	0.61	0.62
Trp	—	0.16	0.13	0.13	0.14	0.14
Val	—	0.95	0.86	0.76	0.83	0.81
Dispensable AA, %						
Ala	—	1.36	1.34	1.12	1.22	1.22
Asp	—	1.25	1.14	1.02	1.09	1.11
Cys	—	0.33	0.31	0.29	0.32	0.33
Glu	—	3.12	3.08	2.62	2.87	2.91
Gly	—	0.74	0.68	0.63	0.69	0.67
Pro	—	1.47	1.44	1.26	1.36	1.39
Ser	—	0.86	0.85	0.73	0.77	0.80

[1]All values adjusted to 88.0% DM.
[2]MN1 and MN2 were sourced from Minnesota, IL1 and IL2 were sourced from Illinois, and KY was sourced from Kentucky.

Table 4. Analyzed composition of distillers dried grains with solubles from ethanol plants ($DDGS_{ethanol}$), distillers dried grains (DDG), and distillers dried grains with solubles from a beverage plant ($DDGS_{beverage}$), Exp. 2 (as-fed basis)[1,2]

	$DDGS_{ethanol}$ source								
Item	1	2	3	4	5	6	Mean	DDG	$DDGS_{beverage}$
CP, %	24.99	24.75	25.64	25.97	26.13	25.77	25.54	28.77	25.55
NDF, %	30.26	28.29	26.67	29.44	26.70	33.39	29.13	37.29	31.67
ADF, %	12.18	13.08	11.41	10.33	10.24	12.43	11.61	18.19	11.64
Starch, %	11.44	7.46	6.96	8.09	7.56	9.78	8.55	3.83	7.32
Indispensable AA, %									
Arg	1.08	0.95	1.11	1.13	1.16	1.02	1.08	1.15	1.17
His	0.62	0.56	0.63	0.63	0.63	0.62	0.62	0.68	0.62
Ile	0.91	0.87	0.96	0.94	0.95	0.97	0.93	1.08	0.94
Leu	2.89	2.85	2.98	2.93	2.82	3.00	2.91	3.69	2.76
Lys	0.63	0.54	0.73	0.74	0.74	0.65	0.67	0.81	0.81
Met	0.46	0.46	0.48	0.46	0.47	0.51	0.47	0.56	0.48
Phe	1.22	1.22	1.27	1.26	1.23	1.26	1.24	1.52	1.28
Thr	0.91	0.90	0.98	0.99	0.97	0.96	0.95	1.10	0.90
Trp	0.19	0.18	0.20	0.21	0.22	0.21	0.20	0.22	0.22
Val	1.21	1.15	1.28	1.25	1.28	1.30	1.25	1.39	1.23
Dispensable AA, %									
Ala	1.81	1.80	1.84	1.88	1.84	1.87	1.84	2.16	1.73
Asp	1.63	1.56	1.71	1.76	1.75	1.69	1.68	1.86	1.64
Cys	0.49	0.44	0.46	0.43	0.46	0.42	0.45	0.54	0.48
Glu	4.28	4.17	4.33	4.36	4.34	4.35	4.31	5.06	4.44
Gly	0.99	0.93	0.99	1.01	1.05	0.99	0.99	1.00	0.98
Pro	2.08	1.97	2.04	2.03	2.01	2.07	2.03	2.50	2.26
Ser	1.17	1.17	1.23	1.25	1.20	1.18	1.20	1.45	1.13

[1]All values adjusted to 88.0% DM.
[2]$DDGS_{ethanol}$ source 1, 2, 3, 4, 5, and 6 were produced by ethanol plants located in Illinois, Indiana, Wisconsin, Minnesota, Illinois, and North Dakota, respectively. DDG was sourced from an ethanol plant in Minnesota, and $DDGS_{beverage}$ was sourced from Kentucky.

Table 5. Analyzed composition of experimental diets, Exp. 2 (as-fed basis)[1,2]

Item	N-free	$DDGS_{ethanol}$ source 1	2	3	4	5	6	DDG	$DDGS_{beverage}$
CP, %	0.24	16.49	15.13	16.61	17.40	16.79	16.64	18.83	16.89
Ca, %	0.37	0.47	0.44	0.37	0.63	0.50	0.43	0.41	0.45
P, %	0.34	0.46	0.45	0.42	0.53	0.48	0.48	0.26	0.44
Indispensable AA, %									
Arg	—	0.70	0.58	0.75	0.75	0.78	0.65	0.76	0.77
Ile	—	0.58	0.55	0.62	0.61	0.63	0.60	0.72	0.59
Leu	—	1.90	1.78	2.00	1.93	1.92	1.88	2.43	1.81
Lys	—	0.42	0.34	0.52	0.51	0.53	0.44	0.55	0.54
Met	—	0.29	0.27	0.31	0.29	0.30	0.30	0.35	0.30
Phe	—	0.80	0.76	0.86	0.83	0.84	0.79	1.00	0.84
Thr	—	0.60	0.55	0.65	0.65	0.66	0.61	0.71	0.60
Trp	—	0.13	0.11	0.13	0.14	0.14	0.13	0.14	0.15
Val	—	0.77	0.72	0.82	0.81	0.83	0.80	0.92	0.78
Dispensable AA, %									
Ala	—	1.18	1.11	1.24	1.24	1.26	1.17	1.41	1.13
Asp	—	1.05	0.97	1.12	1.14	1.17	1.07	1.20	1.08
Cys	—	0.31	0.27	0.29	0.29	0.31	0.29	0.35	0.32
Glu	—	2.79	2.58	2.86	2.84	2.93	2.72	3.31	2.94
Gly	—	0.64	0.58	0.66	0.67	0.71	0.63	0.66	0.65
Pro	—	1.35	1.22	1.34	1.29	1.32	1.27	1.60	1.48
Ser	—	0.77	0.71	0.84	0.83	0.83	0.77	0.92	0.79

[1]All values adjusted to 88.0% DM.

[2]Distillers dried grains with solubles from ethanol plants ($DDGS_{ethanol}$) source 1, 2, 3, 4, 5, and 6 were produced by ethanol plants located in Illinois, Indiana, Wisconsin, Minnesota, Illinois, and North Dakota, respectively. Distillers dried grains was sourced from an ethanol plant in Minnesota, and distillers dried grains with solubles from a beverage plant ($DDGS_{beverage}$) was sourced from Kentucky.

Table 6. Apparent ileal digestibility (%) of CP and AA in distillers dried grains with solubles (DDGS) from ethanol plants in Minnesota, Illinois, and Kentucky, Exp. 1[1]

Item	DDGS source[2] MN1	MN2	IL1	IL2	KY	Mean	SEM	*P*-value	*P*-value for contrast IL vs. MN	IL vs. KY	MN vs. KY
CP	70.1	71.2	68.0	71.8	69.2	70.1	1.79	0.315	0.588	0.646	0.364
Indispensable AA											
Arg	82.5^{y}	81.3^{xy}	78.2^{x}	81.0^{xy}	78.4^{x}	80.3	1.24	0.047	0.056	0.297	0.012
His	77.1	76.8	76.2	78.2	74.7	76.6	1.24	0.274	0.801	0.064	0.090
Ile	76.8	76.3	74.6	76.3	74.3	75.7	1.53	0.470	0.367	0.419	0.123
Leu	81.0^{x}	82.0^{xy}	84.7^{z}	84.3^{yz}	83.6^{yz}	83.1	1.16	0.026	0.002	0.440	0.054
Lys	61.8^{xy}	67.4^{z}	61.2^{xy}	64.7^{yz}	60.3^{x}	63.1	2.30	0.009	0.270	0.143	0.020
Met	84.3	83.7	82.4	82.8	82.6	83.2	1.08	0.452	0.110	1.000	0.184
Phe	80.5	80.1	79.3	80.0	79.6	79.9	1.31	0.928	0.548	0.926	0.555
Thr	66.6	65.3	64.2	66.0	64.2	65.2	2.11	0.749	0.583	0.628	0.347
Trp	64.3^{z}	56.4^{x}	57.3^{x}	62.8^{yz}	59.5^{xy}	60.1	2.52	0.011	0.867	0.798	0.690
Val	74.7	74.1	73.5	75.2	72.9	74.1	1.67	0.708	0.949	0.336	0.303
Dispensable AA											
Ala	78.0	78.6	78.4	79.2	77.8	78.4	1.27	0.895	0.635	0.444	0.697
Asp	67.1	65.4	66.1	68.5	66.3	66.7	2.04	0.684	0.463	0.564	0.985
Cys	66.9	66.1	67.4	72.2	68.4	68.2	2.21	0.097	0.040	0.467	0.306
Glu	79.8	80.3	82.7	82.8	81.1	81.3	1.21	0.084	0.006	0.157	0.336
Gly	56.5	54.6	48.4	56.7	48.3	52.9	3.20	0.079	0.250	0.194	0.029
Pro	60.0	55.4	49.8	58.3	47.6	54.2	6.04	0.236	0.360	0.214	0.051
Ser	72.3	72.1	71.5	73.0	71.8	72.1	1.73	0.956	0.977	0.789	0.804

[x–z]Means within the same row lacking a common superscript letter differ ($P \leq 0.05$).

[1]Values are means of 8 observations per treatment.

[2]MN1 and MN2 were sourced from Minnesota, IL1 and IL2 were sourced from Illinois, and KY was sourced from Kentucky.

Table 7. Standardized ileal digestibility (%) of CP and AA of distillers dried grains with solubles (DDGS) from ethanol plants in Minnesota, Illinois, and Kentucky, Exp. 1[1,2]

	DDGS source[3]								*P*-value for contrast		
Item	MN1	MN2	IL1	IL2	KY	Mean	SEM	*P*-value	IL vs. MN	IL vs. KY	MN vs. KY
CP	81.6	82.9	81.7	84.3	81.3	82.4	1.79	0.543	0.590	0.311	0.553
Indispensable AA											
Arg	88.4	91.9	89.3	90.6	92.0	90.4	1.18	0.133	0.079	0.262	0.013
His	80.9	80.8	80.7	82.1	78.9	80.7	1.54	0.369	0.576	0.062	0.140
Ile	80.6	80.6	79.5	80.9	78.9	80.1	1.53	0.763	0.741	0.371	0.241
Leu	83.2[x]	84.2[xy]	87.3[z]	86.7[yz]	86.1[yz]	85.5	1.16	0.010	0.001	0.384	0.032
Lys	66.8[xy]	72.8[z]	66.8[xy]	70.1[yz]	65.8[x]	68.5	2.30	0.009	0.354	0.143	0.028
Met	86.6	86.0	85.0	85.1	84.9	85.5	1.08	0.543	0.157	0.848	0.174
Phe	85.1	84.9	84.8	85.1	84.6	84.9	1.31	0.997	0.971	0.782	0.755
Thr	75.1	74.3	74.5	75.9	73.9	74.7	2.11	0.914	0.735	0.479	0.656
Trp	73.6	67.9	68.7	73.5	70.2	70.8	2.52	0.076	0.817	0.648	0.785
Val	79.3	79.2	79.2	80.5	78.2	79.3	1.67	0.825	0.633	0.300	0.504
Dispensable AA											
Ala	83.0	83.6	84.4	84.7	83.3	83.8	1.27	0.722	0.219	0.337	0.963
Asp	73.5	72.5	74.0	75.9	73.5	73.9	2.04	0.607	0.442	0.458	0.863
Cys	72.1	71.7	73.3	77.6	73.6	73.7	2.21	0.106	0.027	0.339	0.350
Glu	82.9[x]	83.5[xy]	86.3[z]	86.2[yz]	84.4[xy]	84.7	1.21	0.034	0.002	0.112	0.253
Gly	86.3	87.0	83.4	88.6	81.2	85.3	3.20	0.329	0.806	0.143	0.093
Pro	122.6	119.3	122.8	125.9	113.8	120.9	6.04	0.358	0.395	0.047	0.158
Ser	80.0	79.9	80.6	81.6	80.1	80.4	1.73	0.899	0.390	0.541	0.929

[x–z]Means within the same row without a common superscript letter differ ($P \leq 0.05$).

[1]Values are means of 8 observations per treatment.

[2]Standardized ileal digestibilities were calculated by correcting the apparent ileal digestibilities for the basal endogenous losses of CP and AA (g/kg of DMI), which were as follows: CP, 24.23; Arg, 0.87; His, 0.21; Ile, 0.32; Leu, 0.53; Lys, 0.30; Met, 0.09; Phe, 0.47; Thr, 0.68; Trp, 0.17; Val, 0.50; Ala, 0.76; Asp, 0.91; Cys, 0.19; Glu, 1.10; Gly, 2.51; Pro, 10.45; and Ser, 0.75.

[3]MN1 and MN2 were sourced from Minnesota, IL1 and IL2 were sourced from Illinois, and KY was sourced from Kentucky.

The AID for CP and all AA varied ($P < 0.01$) among the 6 sources of $DDGS_{ethanol}$ (Table 8). Sources 3 and 5 had a greater ($P < 0.01$) AID for Lys (69.3 and 70.0%, respectively) than sources 1, 2, 4, and 6 (51.1, 44.4. 58.9, 60.1%, respectively).

The AID of CP and all AA except Gly and Pro were greater ($P < 0.01$) in DDG than in $DDGS_{ethanol}$. The AID of Lys in DDG was 73.4%, compared with a mean of 59.0% in $DDGS_{ethanol.}$. In $DDGS_{beverage}$, the AID for Lys (64.7%) was greater ($P < 0.01$) than in $DDGS_{ethanol}$. However, the AID for His (72.9%), Ala (71.9%), Cys (65.6%), and Gly (30.0%) were lower ($P < 0.01$) in $DDGS_{beverage}$ than in $DDGS_{ethanol}$, but the AID of CP and all other AA were similar for $DDGS_{ethanol}$ and $DDGS_{beverage}$.

The mean SID for Lys in $DDGS_{ethanol}$ was 64.8% (Table 9), but DDGS sources 3 and 5 had a greater ($P < 0.01$) SID for Lys (73.8 and 74.5%, respectively) compared with sources 1, 2, 4, and 6 (56.8, 51.4, 63.7, and 68.7%, respectively). Likewise, the SID for CP and all other AA varied ($P < 0.05$) among the 6 sources of $DDGS_{ethanol}$.

The SID of CP and all AA except Gly and Pro were greater ($P < 0.05$) in DDG than in $DDGS_{ethanol}$. For Lys, the SID in DDG was 77.9 vs. 64.8% in $DDGS_{ethanol}$. The SID of Lys in $DDGS_{beverage}$ (69.3%) was also greater ($P < 0.01$) than for $DDGS_{ethanol}$. However, lower ($P < 0.01$) SID for His and Cys were obtained in $DDGS_{beverage}$ compared with $DDGS_{ethanol}$. The SID for CP and all other AA were similar for DDGS from beverage and ethanol plants.

DISCUSSION

Effect of Region on Digestibility of AA in DDGS

The nutrient composition and the AID and SID of CP and AA in the 5 sources of DDGS that were used in Exp. 1 were similar to previously reported values (Fastinger and Mahan, 2006; Stein et al., 2006). The differences in the SID of Lys, Leu, and Glu among the 5 DDGS sources as well as the differences in the SID for Lys, Leu, and Arg between Illinois, Minnesota, and Kentucky indicate that both interplant variation and interregion variation in DDGS AA digestibility exist. However, the differences were not consistent and only limited to Lys, Leu, and Arg digestibility. The differences may be due to plant design, processing procedures, and corn-growing conditions that can affect the starch concentration of corn (Mathew et al., 1999). The variability in digestibility of AA that was obtained in this experiment was lower than what has been previously reported (Fastinger and Mahan, 2006; Stein et al., 2006). All 5 sources of DDGS used in this experiment had SID values for AA that were close to average values obtained in previous experiments. However, the

Table 8. Apparent ileal digestibility (%) of CP and AA in distillers dried grains with solubles produced at ethanol plants ($DDGS_{ethanol}$), in distillers dried grains (DDG), and in distillers dried grains with solubles produced at a beverage plant ($DDGS_{beverage}$), Exp. 2[1,2]

	$DDGS_{ethanol}$ source									$DDGS_{ethanol}$		*P*-value for contrast	
Item	1	2	3	4	5	6	Mean	DDG	$DDGS_{beverage}$	SEM	*P*-value	DDG vs. $DDGS_{ethanol}$	$DDGS_{beverage}$ vs. $DDGS_{ethanol}$
CP	56.7^{y}	53.0^{x}	65.1^{u}	60.7^{z}	66.7^{u}	65.8^{u}	61.3	66.7	59.5	1.42	<0.001	0.001	0.222
Indispensable AA													
Arg	68.3^{y}	62.9^{x}	77.0^{uv}	70.9^{yz}	78.6^{v}	73.8^{uz}	71.9	75.0	71.5	1.63	<0.001	0.006	0.857
His	75.9^{y}	67.0^{x}	80.4^{u}	75.2^{y}	80.6^{u}	78.9^{z}	76.3	81.3	72.9	1.10	<0.001	<0.001	<0.001
Ile	73.8^{yz}	65.4^{x}	77.2^{u}	71.2^{y}	78.5^{u}	76.5^{uz}	73.8	80.4	74.0	1.26	<0.001	<0.001	0.764
Leu	83.6^{z}	75.2^{x}	83.6^{z}	79.1^{y}	85.2^{z}	86.0^{u}	82.1	84.4	82.3	1.06	<0.001	0.006	0.888
Lys	51.1^{y}	44.4^{x}	69.3^{u}	58.9^{z}	70.0^{u}	60.1^{z}	59.0	73.4	64.7	1.57	<0.001	<0.001	<0.001
Met	81.0^{y}	71.8^{x}	85.2^{z}	79.1^{y}	83.8^{z}	83.4^{z}	80.7	87.5	80.8	1.10	<0.001	<0.001	0.943
Phe	77.8^{z}	70.9^{x}	81.4^{u}	75.1^{y}	81.8^{u}	80.5^{u}	77.9	83.4	77.8	1.11	<0.001	<0.001	0.939
Thr	64.5^{yz}	56.0^{x}	68.9^{uv}	63.1^{y}	71.6^{v}	67.5^{uz}	65.3	71.4	63.7	1.36	<0.001	<0.001	0.191
Trp	59.2^{y}	48.6^{x}	62.3^{yz}	59.5^{y}	66.2^{z}	61.6^{y}	59.6	63.0	59.4	1.56	<0.001	0.018	0.938
Val	73.1^{y}	64.6^{x}	76.3^{u}	70.6^{y}	77.4^{u}	76.2^{z}	73.0	77.5	71.5	1.26	<0.001	<0.001	0.132
Dispensable AA													
Ala	73.3^{y}	66.5^{x}	77.7^{z}	71.9^{y}	78.9^{z}	77.5^{z}	74.3	78.1	71.9	1.14	<0.001	<0.001	0.015
Asp	61.5^{y}	54.5^{x}	66.5^{z}	61.2^{y}	67.6^{z}	65.9^{z}	62.9	68.6	62.7	1.45	<0.001	<0.001	0.946
Cys	71.2^{yz}	62.4^{x}	74.2^{u}	70.4^{y}	74.8^{u}	73.8^{z}	71.1	77.2	65.6	1.32	<0.001	<0.001	0.001
Glu	79.4^{u}	71.4^{x}	81.7^{v}	76.7^{y}	82.8^{v}	82.6^{v}	79.1	84.6	79.0	1.05	<0.001	<0.001	0.929
Gly	27.6^{x}	27.0^{x}	44.9^{z}	36.6^{y}	51.5^{z}	44.9^{z}	38.7	40.0	30.0	3.36	<0.001	0.395	0.004
Pro	−17.8^{x}	−0.4^{xy}	17.4^{uy}	0.2^{y}	22.9^{u}	18.3^{uy}	6.8	11.5	11.9	8.56	0.001	0.311	0.228
Ser	70.5^{y}	63.8^{x}	75.2^{z}	69.1^{y}	76.7^{z}	74.7^{z}	71.6	76.2	70.0	1.14	<0.001	<0.001	0.075

[u-z]Means within a row and within $DDGS_{ethanol}$ sources lacking a common superscript letter differ ($P \leq 0.05$).

[1]Values are means of 7 observations per treatment.

[2]$DDGS_{ethanol}$ source 1, 2, 3, 4, 5, and 6 were produced by ethanol plants located in Illinois, Indiana, Wisconsin, Minnesota, Illinois, and North Dakota, respectively. DDG was sourced from an ethanol plant in Minnesota, and $DDGS_{beverage}$ was sourced from Kentucky.

Table 9. Standardized ileal digestibility (%) of CP and AA in distillers dried grains with solubles produced at ethanol plants ($DDGS_{ethanol}$), in distillers dried grains (DDG), and in distillers dried grains with solubles produced at a beverage plant ($DDGS_{beverage}$), Exp. 2[1,2,3]

	$DDGS_{ethanol}$ sources									$DDGS_{ethanol}$ sources		*P*-value for contrast	
Item	1	2	3	4	5	6	Mean	DDG	$DDGS_{beverage}$	SEM	*P*-value	DDG vs. $DDG_{ethanol}$	$DDGS_{beverage}$ vs. $DDGS_{ethanol}$
CP	67.5^{x}	64.8^{x}	76.1^{z}	70.8^{y}	77.3^{z}	74.4^{z}	71.8	76.4	70.3	1.41	<0.001	0.001	0.432
Indispensable AA													
Arg	76.3^{xy}	72.9^{x}	85.7^{u}	78.4^{yz}	86.2^{u}	81.2^{z}	80.1	82.8	79.0	1.59	<0.001	0.028	0.450
His	79.1^{y}	70.7^{x}	83.3^{z}	78.5^{y}	83.7^{z}	83.4^{z}	79.8	84.4	76.2	1.10	<0.001	<0.001	0.004
Ile	77.4^{yz}	69.2^{x}	79.9^{uz}	74.7^{y}	81.8^{u}	81.3^{u}	77.4	83.3	77.7	1.28	<0.001	<0.001	0.581
Leu	85.4^{z}	77.0^{x}	84.9^{z}	80.9^{y}	87.0^{uz}	88.6^{u}	84.0	86.0	84.1	1.07	<0.001	0.022	0.619
Lys	56.8^{y}	51.4^{x}	73.8^{v}	63.7^{z}	74.5^{v}	68.7^{u}	64.8	77.9	69.3	1.57	<0.001	<0.001	0.004
Met	83.1^{y}	73.9^{x}	86.8^{z}	81.2^{y}	85.8^{z}	86.5^{z}	82.9	89.2	82.8	1.10	<0.001	<0.001	0.808
Phe	82.1^{z}	75.3^{x}	85.0^{u}	79.2^{y}	85.8^{u}	84.2^{uz}	81.9	87.0	81.9	1.12	<0.001	<0.001	0.744
Thr	71.6^{y}	63.8^{x}	75.3^{z}	69.7^{y}	78.0^{z}	76.0^{z}	72.4	77.5	70.8	1.36	<0.001	0.001	0.520
Trp	68.7^{y}	59.7^{x}	70.9^{yz}	68.3^{y}	75.0^{z}	68.7^{y}	68.6	71.8	67.9	1.58	<0.001	0.050	0.990
Val	77.0^{yz}	68.7^{x}	79.3^{uz}	74.3^{y}	80.9^{u}	81.8^{u}	77.0	80.7	75.2	1.28	<0.001	0.003	0.367
Dispensable AA													
Ala	77.4^{y}	70.9^{x}	81.8^{z}	75.8^{y}	82.8^{z}	82.4^{z}	78.5	81.8	76.3	1.15	<0.001	0.001	0.067
Asp	67.9^{y}	61.4^{x}	72.2^{z}	67.1^{y}	73.3^{z}	73.1^{z}	69.2	74.3	69	1.46	<0.001	0.001	0.838
Cys	75.6^{y}	67.5^{x}	78.7^{z}	75.1^{y}	79.2^{z}	80.6^{z}	76.1	81.2	69.9	1.33	<0.001	<0.001	0.001
Glu	82.2^{z}	74.3^{x}	84.1^{z}	79.4^{y}	85.3^{u}	86.4^{u}	82.0	87.0	81.6	1.06	<0.001	<0.001	0.965
Gly	53.6^{x}	56.6^{x}	72.9^{uz}	61.2^{xy}	75.7^{y}	66.3^{yz}	64.4	66.1	56.4	3.25	<0.001	0.427	0.009
Pro	32.1^{x}	57.6^{yz}	75.0^{z}	51.5^{xy}	75.3^{z}	54.2^{y}	57.6	55.3	59.8	8.32	0.002	0.734	0.754
Ser	77.0^{y}	70.8^{x}	81.2^{z}	75.1^{y}	82.7^{z}	81.1^{z}	78.0	81.8	76.4	1.14	<0.001	<0.001	0.266

[u–z]Means within a row and within $DDGS_{ethanol}$ sources without a common superscript letter differ ($P \leq 0.05$).

[1]Values are means of 7 observations per treatment.

[2]Standardized ileal digestibilities were calculated by correcting the apparent ileal digestibilities for the basal ileal endogenous losses of CP and AA (g/kg of DMI), which were as follows: CP, 20.12; Arg, 0.64; His, 0.15; Ile, 0.24; Leu, 0.39; Lys, 0.27; Met, 0.07; Phe, 0.39; Thr, 0.48; Trp, 0.14; Val, 0.34; Ala, 0.55; Asp, 0.77; Cys, 0.16; Glu, 0.87; Gly, 1.90; Pro, 7.66; and Ser, 0.57.

[3]$DDGS_{ethanol}$ source 1, 2, 3, 4, 5, and 6 were produced by ethanol plants located in Illinois, Indiana, Wisconsin, Minnesota, Illinois, and North Dakota, respectively. The DDG was sourced from an ethanol plant in Minnesota, and $DDGS_{beverage}$ was sourced from Kentucky.

results of this experiment do not indicate that DDGS from one region is better than DDGS from another region, and it is concluded that the region in which DDGS is produced is not a major contributor to the variability in nutrient concentration and AA digestibility.

Composition of DDG, DDGS$_{ethanol}$, and DDGS$_{beverage}$

The concentrations of CP and AA in DDGS$_{ethanol}$ and DDGS$_{beverage}$ were similar to reported values (Cromwell et al., 1993; Fastinger and Mahan, 2006; Stein et al., 2006), but the CP and AA concentration of DDG was greater than the values reported by NRC (1998). The concentration of CP in the solubles is approximately 16.8% (Larson et al., 1993), whereas the concentration of CP in DDG was 28.77% (as-fed basis). The greater CP concentration in DDG than in DDGS$_{ethanol}$ and DDGS$_{beverage}$ may, therefore, be a result of the lower CP concentration in distillers solubles than in DDG. This observation concurs with data showing that the concentration of AA in distillers solubles produced from barley is at least 50% lower than in DDG produced from barley (Näsi, 1985).

The concentration of NDF in DDGS$_{ethanol}$ and in DDGS$_{beverage}$ was lower than previously reported (NRC, 1998; Fastinger and Mahan, 2006; Stein et al., 2006). This may be a result of the use of more effective enzymes during fermentation, because the use of enzymes may reduce the NDF concentration in DDGS (Näsi, 1985). The ADF and starch concentration of both DDGS sources were within the range of values that have been reported (Belyea et al., 2004; Stein et al., 2006).

Ileal AA Digestibility in DDGS$_{ethanol}$ and DDGS$_{beverage}$

The AID and SID of CP and AA in DDGS were within the range of previously reported values (Fastinger and Mahan, 2006; Stein et al., 2006). However, the SID of most AA in DDGS obtained in the present experiments is greater than the values reported for true ileal AA digestibility of DDGS (NRC, 1998).

The concentration and the SID of most AA in DDGS$_{ethanol}$ were not different from the values in DDGS$_{beverage}$, which indicates that the SID of AA in DDGS is not affected by the type of facility that is used in the production of DDGS. The exception, however, was the SID of Lys, which was greater in DDGS$_{beverage}$ than in DDGS$_{ethanol}$. This observation indicates that the DDGS$_{beverage}$ used in this experiment may have been less heat-damaged than the sources of DDGS$_{ethanol}$ that were used. Although it has been suggested that AA in DDGS produced in plants built before 1990 are less digestible than in DDGS produced in newer plants, the present results indicate that the difference is not related to whether the DDGS originates from an ethanol plant or a beverage plant. The DDGS$_{beverage}$ that was used in this experiment was sourced from a bourbon plant. In the production of bourbon, 70% of the grain is corn, 15% is rye, and 15% is malted barley (Ralph, 2003), whereas only corn was used in the production of the DDGS$_{ethanol}$ that was used in this experiment. The results of the experiment, however, indicate that the inclusion of malted barley and rye at the concentrations used to produce bourbon does not significantly change the composition or the digestibility of AA in the resulting DDGS compared with DDGS produced from fuel ethanol production.

Ileal AA Digestibility in DDG

The greater SID of CP and AA in DDG than in DDGS$_{ethanol}$ is most likely caused by a greater AA digestibility in the whole stillage than in the solubles. This observation concurs with Näsi (1985), who reported that the AID for CP was lower in solubles than in DDG. The digestibility of Lys and Met by cecectomized turkeys in distillers solubles was only 51 and 21%, respectively (Belyea et al., 1998), which also indicates that the digestibility in solubles is low. A contributing factor to the greater digestibility values in DDG than in DDGS may be that less heat is required to dry the DDG if solubles are not added to the stillage. Therefore, the risk of reducing AA digestibility due to heat damage is reduced in DDG compared with DDGS.

In conclusion, results from these 2 experiments indicate that the variability in digestibility of AA among sources of DDGS that have been reported in several experiments is not caused by the region in which the DDGS is produced. Likewise, AA digestibility is similar for DDGS produced by an ethanol plant and by a beverage plant. However, for most AA, the digestibility is greater in DDG than in DDGS. The present data also confirm that the variability of the digestibility of Lys is greater than the variability of the digestibility of other AA, which indicates that heat damage may be a major contributing factor to variability in Lys digestibility. The digestibility of AA in most sources of DDGS is greater than the digestibility of AA reported by NRC (1998).

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