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Amino acid digestibility of distillers dried grains with solubles, produced from sorghum, a sorghum-corn blend, and corn fed to growing pigs[1,2]

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ABSTRACT: The objective of this experiment was to measure the concentration and digestibility of CP and AA in distillers dried grains with solubles (DDGS) produced from sorghum (S-DDGS) or a blend of sorghum and corn grains (SC-DDGS), and to compare these values with the digestibility of CP and AA in corn-based DDGS (C-DDGS). Eleven growing barrows (initial BW = 44.6 ± 6.5 kg) were surgically fitted with a T-cannula in the distal ileum and allotted to a Youden square design with 11 diets and 8 periods. One diet contained 66.7% S-DDGS, 1 diet contained 66.7% SC-DDGS, 8 diets contained 66.7% C-DDGS, and 1 diet was N-free. Chromic oxide (0.3%) was used in all diets as an indigestible marker. The direct procedure was used to measure apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of CP and AA in the 10 sources of DDGS. Results of the experiment showed that the AID of Lys was not different among S-DDGS, SC-DDGS, and C-DDGS. The mean SID of CP, Arg, and Lys in C-DDGS were not different from values obtained in S-DDGS and SC-DDGS. The SID of Trp in S-DDGS (72.0%) was greater ($P < 0.01$) than in C-DDGS (64.9%), but there was no difference between C-DDGS and SC-DDGS (62.4%). The SID of CP and all AA were different among the 8 sources of C-DDGS ($P < 0.01$). Among the indispensable AA, Lys had the greatest variation and the SID ranged from 55.7 to 68.7%. The concentration of total and digestible AA was highly correlated (r^2) for Arg (0.88), Ile (0.85), Leu (0.82), Phe (0.84), and Trp (0.84), but reduced r^2 values were observed for Lys (0.66) and Thr (0.39). A low correlation between the concentration and digestibility of AA indicates that it is desirable to develop in vitro procedures to predict digestible AA concentration in DDGS. In conclusion, SID values for CP and Lys in S-DDGS and SC-DDGS are within the range of values obtained in C-DDGS, but for many other AA, SID values in S-DDGS and in SC-DDGS are less than in C-DDGS.

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

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INTRODUCTION

The global production of biofuels is expected to continuously expand (Farrell et al., 2006; Dinneen, 2008). Corn is the primary feedstock used in the United States for ethanol production, but as the industry expands, ethanol producers will likely use increasing amounts of other grains, such as sorghum (Wang et al., 2008). The concentration of starch in sorghum is similar to corn, but sorghum requires less rainfall during the growing season than corn and usually is less expensive than corn (Klopfenstein et al., 2008). In 2005, more than 1.3 million metric tons of sorghum grains were used for ethanol production in the United States (Wang et al., 2005), which resulted in the production of approximately 420,000 t of sorghum distillers dried grains with solubles (**S-DDGS**).

The concentration of DE and ME in S-DDGS has been determined (Feoli et al., 2007) and the digestibility of AA in corn-based DDGS (**C-DDGS**) has

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Table 1. Analyzed nutrient composition of the sources of distillers dried grains with solubles, as-fed basis

			Corn DDGS[3]								
Item, %	S[1]	SC[2]	C1	C2	C3	C4	C5	C6	C7	C8	Mean
DM	91.2	93.4	91.3	91.1	90.7	91.6	89.6	91.7	91.3	93.4	91.3
CP	32.7	30.6	29.4	28.7	27.4	27.3	27.5	27.3	31.9	28.0	28.4
Crude fat	8.0	8.9	10.7	9.4	10.7	8.8	10.0	11.2	9.5	10.6	10.1
NDF	34.7	36.3	32.8	35.2	34.8	29.5	29.4	36.5	33.3	34.6	33.3
ADF	25.3	17.2	11.3	11.6	12.7	11.4	9.6	12.6	11.7	12.0	11.6
Ash	11.9	5.8	2.9	2.6	3.1	2.4	1.6	3.1	3.1	3.2	2.75
Indispensable AA											
Arg	1.10	1.31	1.29	1.32	1.24	1.17	1.16	1.21	1.46	1.18	1.25
His	0.71	0.80	0.79	0.75	0.74	0.71	0.71	0.73	0.85	0.72	0.75
Ile	1.36	1.14	1.04	1.01	1.00	0.99	0.98	1.00	1.25	1.01	1.04
Leu	4.17	3.66	3.50	3.31	3.13	2.94	3.08	3.08	3.60	3.10	3.22
Lys	0.68	0.91	0.83	0.77	0.87	0.83	0.84	0.86	1.02	0.76	0.85
Met	0.53	0.58	0.55	0.54	0.53	0.48	0.48	0.51	0.58	0.50	0.52
Phe	1.68	1.51	1.43	1.36	1.32	1.25	1.29	1.29	1.55	1.31	1.35
Thr	1.07	1.15	1.08	1.06	1.03	0.98	1.02	1.01	1.15	1.05	1.05
Trp	0.35	0.29	0.23	0.24	0.24	0.22	0.22	0.22	0.28	0.23	0.24
Val	1.65	1.49	1.41	1.36	1.36	1.30	1.31	1.32	1.59	1.35	1.38
Dispensable AA											
Ala	2.90	2.38	2.15	2.08	2.00	1.90	2.00	1.96	2.21	2.01	2.04
Asp	2.17	2.02	1.90	1.84	1.82	1.74	1.79	1.77	2.21	1.85	1.87
Cys	0.49	0.57	0.48	0.51	0.49	0.46	0.47	0.49	0.55	0.47	0.49
Glu	6.31	5.42	5.10	4.91	4.70	4.44	4.58	4.59	5.50	4.64	4.81
Gly	1.03	1.14	1.13	1.10	1.10	1.06	1.07	1.07	1.24	1.13	1.11
Ser	1.40	1.49	1.41	1.35	1.30	1.18	1.28	1.27	1.43	1.32	1.32
Pro	2.50	2.44	2.46	2.07	2.39	2.03	2.11	2.19	2.43	2.12	2.23
Total AA	30.1	28.3	26.8	25.6	25.3	23.7	24.4	24.6	28.9	24.7	25.5
Lys:CP	2.08	2.98	2.82	2.69	3.18	3.04	3.06	3.15	3.19	2.72	2.98

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

also been measured (Fastinger and Mahan, 2006; Stein et al., 2006; Pahm et al., 2008). However, there are no data on the apparent ileal digestibility (**AID**) or the standardized ileal digestibility (**SID**) of AA in S-DDGS or in blends of sorghum and corn DDGS (**SC-DDGS**). Therefore, the objective of this experiment was to measure the AID and SID of AA in S-DDGS and SC-DDGS and compare these values to the SID of AA in C-DDGS.

MATERIALS AND METHODS

The experimental protocol for this study was approved by the Institutional Animal Care and Use Committee at South Dakota State University where the animal portion of the experiment was conducted.

Animals, Housing, and Experimental Design

Eleven growing crossbred barrows (initial BW = 44.6 ± 6.5 kg) that were the offspring of SP1 boars mated to line 13 females (Ausgene Int. Inc., Gridley, IL) were used in the experiment. Pigs were surgically prepared with a T-cannula in the distal ileum following the procedure described by Stein et al. (1998). After surgery, pigs were housed individually in 1.2 × 1.8 m pens with fully slatted floors in an environmentally controlled room (22°C) and were allowed a 2-wk recuperation period before initiation of the experiment. Pigs were then allotted to an 11 × 8 Youden square design with 11 diets and 8 collection periods.

Ingredients, Diets, and Feeding

One sample of DDGS was collected from 10 different ethanol plants (Table 1). One ethanol plant produced S-DDGS, 1 plant produced SC-DDGS, and 8 plants produced C-DDGS. Ten diets based on each source of DDGS and one N-free diet were formulated (Tables 2 and 3). The N-free diet was used to measure basal ileal endogenous losses of N and AA (**basal** $\mathbf{IAA_{end}}$). Chromic oxide (Fisher Scientific, Fair Lawn, NJ) was added to all diets as an inert marker at 3 g/kg. Additional energy sources in the diets included corn starch, soybean oil, and sucrose. Vitamins and minerals were supplemented to all diets to meet or exceed requirements for growing pigs (NRC, 1998).

Pigs were fed an amount of their respective diet equivalent to 3 times their calculated daily requirement of maintenance energy (106 kcal of ME/kg$^{0.75}$; NRC, 1998). Pig BW was measured at the beginning of each feeding period, and this BW was used to calculate the amount of feed to be fed during the next period. Daily feed allowances were divided into 2 equal rations and

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

Ingredient, % of diet	S-DDGS[1]	SC-DDGS[2]	C-DDGS[3]	N-free
DDGS	66.7	66.7	66.7	—
Cornstarch	27.0	27.0	27.0	81.0
Soybean oil	1.00	1.00	1.00	3.00
Sucrose	3.00	3.00	3.00	9.00
Solka floc[4]	—	—	—	3.00
Limestone	1.35	1.35	1.35	—
Dicalcium phosphate	—	—	—	2.50
Chromic oxide	0.30	0.30	0.30	0.30
Salt	0.30	0.30	0.30	0.45
Vitamin premix[5]	0.10	0.10	0.10	0.10
Micromineral premix[6]	0.25	0.25	0.25	0.25
Potassium carbonate	—	—	—	0.30
Magnesium oxide	—	—	—	0.10
Total	100	100	100	100

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

[2]Distillers dried grains with solubles produced from the blend of sorghum and corn.

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

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

[5]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 α-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.

[6]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.

fed at 800 and 1600 h. Pigs were fed the diets during 5 d of adaptation and 2 d of collection. Ileal digesta samples were collected on d 6 and 7 following the procedures described by Cervantes-Pahm and Stein (2008).

Sample Preparation and Chemical Analysis

Digesta, diets, and DDGS samples were sent to Degussa Analytical Nutrition Laboratory in Hanau, Ger-

Table 3. Analyzed nutrient composition of the experimental diets, as-is basis

			Corn DDGS[3]								
Item	S[1]	SC[2]	C1	C2	C3	C4	C5	C6	C7	C8	N-free
DM	91.3	94.4	90.9	91.1	90.3	90.3	90.3	91.4	92.4	93.2	89.9
CP	20.4	18.6	18.2	18.3	17.3	17.0	17.6	17.5	19.3	18.4	0.20
Indispensable AA											
Arg	0.68	0.80	0.79	0.77	0.77	0.71	0.74	0.76	0.85	0.74	ND[4]
His	0.44	0.49	0.48	0.48	0.47	0.44	0.46	0.46	0.5	0.46	ND
Ile	0.85	0.71	0.64	0.67	0.62	0.59	0.65	0.60	0.68	0.62	ND
Leu	2.65	2.23	2.08	2.12	2.00	1.86	1.97	1.93	2.17	1.98	ND
Lys	0.44	0.56	0.51	0.50	0.53	0.51	0.54	0.55	0.58	0.51	ND
Met	0.32	0.35	0.31	0.33	0.32	0.29	0.30	0.31	0.34	0.29	ND
Phe	1.06	0.93	0.87	0.88	0.84	0.78	0.83	0.82	0.92	0.84	ND
Thr	0.68	0.69	0.65	0.67	0.66	0.63	0.64	0.65	0.72	0.67	ND
Trp	0.23	0.17	0.14	0.15	0.14	0.14	0.14	0.14	0.16	0.15	ND
Val	1.04	0.92	0.85	0.88	0.83	0.78	0.84	0.82	0.9	0.84	ND
Dispensable AA											
Ala	1.82	1.44	1.29	1.33	1.27	1.19	1.26	1.23	1.37	1.28	ND
Asp	1.36	1.23	1.14	1.17	1.15	1.09	1.15	1.13	1.3	1.2	ND
Cys	0.3	0.34	0.31	0.33	0.32	0.27	0.30	0.31	0.33	0.30	ND
Glu	3.96	3.31	3.03	3.13	3.00	2.81	2.92	2.90	3.32	2.98	ND
Gly	0.66	0.70	0.69	0.71	0.70	0.66	0.68	0.68	0.75	0.73	ND
Pro	1.59	1.51	1.45	1.47	1.40	1.29	1.35	1.42	1.56	1.37	ND
Ser	0.88	0.88	0.85	0.86	0.84	0.79	0.80	0.83	0.92	0.86	ND
Total AA	19.0	17.3	16.1	16.5	15.9	14.8	15.6	15.5	17.4	15.8	ND

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

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

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

[4]ND = not determined.

many, for AA analyses. Briefly, after hydrolysis in 6 *N* HCl for 24 h at 110°C, AA samples were analyzed by ion-exchange chromatography using post-column ninhydrin derivatization (Llames and Fontaine, 1994). Analysis for Met and Cys was performed separately after performic acid oxidation. Analysis for Trp was performed following hydrolysis in 4 *M* barium hydroxide at 110°C for 20 h. Crude protein was analyzed following the Dumas procedure (procedure 968.06; AOAC, 2000). Concentrations of NDF and ADF were determined using fiber bags and fiber analyzer equipment (Fiber Analyzer, Ankom Technology, Macedon, NY) following a modification of the procedure of van Soest et al. (1991). The concentration of NDF was analyzed using heat stable α-amylase and sodium sulfite without correction for insoluble ash. The ADF fraction was analyzed in a separate sample. Chromic oxide was analyzed after the sample was ashed at 600°C for 2 h followed by digestion with a phosphoric acid-manganese sulfate solution and potassium bromide (Fenton and Fenton, 1979).

Calculations and Statistical Analysis

Values for AID, basal IAA_{end}, and SID of AA and CP were calculated as described previously (Stein et al., 2007). Data were analyzed by the MIXED procedure (SAS Inst. Inc., Cary, NC) using the following model:

$$Y_{ijkl} = \mu + P_i + Pe_j + D_k + e_{ijkl},$$

where P_i = 1 to 11 pigs; Pe_j = 1 to 8 periods; D_k = 1 to 10 diets; $P_i \sim N(0, \sigma^2)$; $P_j \sim N(0, \sigma^2)$; $a_{l:i} \sim N(0, \sigma^2)$; and $e_{ijkl} \sim N(0, \sigma^2)$, where Y is the AID or SID of each AA, P = random effect of pigs, Pe = random effect of experimental period, and D = fixed effect of the 10 DDGS sources. The pig was the experimental unit. Least squares means were calculated for CP and each AA in each source of DDGS using the Tukey's procedure. Outliers were identified by normal-quantile, by box-plot, and by the predicted vs. residual plot procedure (Oehlert, 2000). Equal variances of the means were tested in PROC UNIVARIATE of SAS. Orthogonal contrasts were used to compare the mean of all C-DDGS sources to S-DDGS or SC-DDGS and to compare S-DDGS with SC-DDGS. Regression equations between the concentration of total and digestible AA in C-DDGS were calculated using PROC REG of SAS. Values were considered different at $P < 0.05$.

RESULTS

Chemical Composition of DDGS Sources

The concentration of CP, NDF, and ADF were greater in S-DDGS (32.7, 34.7, and 25.3%, respectively) and in SC-DDGS (30.6, 36.3, and 17.2%, respectively) than in C-DDGS (28.4, 33.3, and 11.6%, respectively; Table 1). In contrast, the concentration of crude fat was less in S-DDGS (8.0%) and SC-DDGS (8.9%) compared with C-DDGS (10.1%). There were differences among the 8 sources of C-DDGS in CP (27.3 to 31.9%), crude fat (8.8 to 11.2%), NDF (29.4 to 36.5%), ADF (9.6 to 12.7%), and ash (1.6 to 3.2%). The concentration of Lys and Arg were less in S-DDGS than in C-DDGS and SC-DDGS, but C-DDGS samples had less Ile, Leu, Phe, Trp, and Val concentrations than S-DDGS and SC-DDGS.

Apparent Ileal AA Digestibility in DDGS

The average AID for CP, Lys, Thr, Asp, and Gly of all C-DDGS sources were not different from the AID of S-DDGS and SC-DDGS (Table 4). The AID of Arg, His, Leu, Met, and Glu were less ($P < 0.05$) in S-DDGS than in any sample of C-DDGS or SC-DDGS. Histidine, Leu, Ala, and Ser AID in SC-DDGS were less ($P < 0.05$) than in C-DDGS. The AID of Trp (67.2%) in S-DDGS was greater ($P < 0.01$) than in C-DDGS (57.1%) and in SC-DDGS (55.8%).

The AID for CP in C-DDGS ranged from 57.6% in source 5 to 70.9% in source 1. Source 2 had the greatest ($P < 0.01$) AID for 10 of the 17 AA that were measured followed by source 1 that had a greater ($P < 0.01$) AID for Arg, His, Lys, Thr, Gly, Ser, and Pro than source 2, or any other source. Source 6 had the least ($P < 0.01$) AID in 11 of the 17 AA that were measured followed by source 5 that had the least AID for Arg, Lys, Met, Phe, Thr, Trp, Ala, Glu, Gly, and Pro. In C-DDGS, the AID of Lys (51.9 to 64.6%) and Trp (48.2 to 64.5%) had greater variation than the AID of any other indispensable AA.

Standardized Ileal AA Digestibility in DDGS

The average basal endogenous loss of N was 2.98 g/kg of DMI (data not shown), which is within the range of values (1.1 to 3.2 g/kg of DMI) reported in previous experiments using N-free diets (Pedersen and Boisen, 2002). The AID values for each AA were corrected by the average basal endogenous loss that was obtained for that AA (Table 5). Proline was the AA with the greatest concentration and greatest variation in basal $IAA_{end.}$

The SID value of CP, Arg, Lys, and Asp in S-DDGS and in SC-DDGS were not different from the values for C-DDGS (Table 5). The SID of His (71.9%), Leu (77.3%), Met (76.5%), and Glu (76.5%) were less ($P < 0.01$) in S-DDGS than in any sample of C-DDGS (79.3, 86.0, 82.8, 83.8%; respectively) or SC-DDGS (75.1, 81.0, 80.1, 79.9; respectively). The SID of Phe, Ala, and Cys were not different between S-DDGS and SC-DDGS. The SID of Trp in S-DDGS (72.0%) was greater ($P < 0.01$) than the SID of Trp in C-DDGS (64.9%), but there was no difference between C-DDGS and SC-DDGS (60.9%).

Values for SID of AA were different ($P < 0.01$) among C-DDGS sources. Source 5 had the least ($P < 0.01$) SID values for CP and all AA except Ile, Val, Asp, and Gly,

Table 4. Apparent ileal CP and AA digestibility (%) of 10 sources of distillers dried grains with solubles[1]

			Corn DDGS[4]											Contrast, *P*-value		
Item	S[2]	SC[3]	C1	C2	C3	C4	C5	C6	C7	C8	Mean	SEM	*P*-value	S vs. C	SC vs. C	S vs. SC
CP	64.5	63.2	70.9	68.5	66.7	63.9	57.6	59.2	62.7	61.7	63.9	1.65	<0.01	0.69	0.64	0.51
Indispensable AA																
Arg	69.8	73.8	78.2	76.4	76.1	73.0	67.1	69.1	74.1	71.0	73.1	1.58	<0.01	0.01	0.55	0.01
His	68.6	72.2	80.6	80.5	79.3	76.7	73.2	72.3	73.9	73.3	76.2	1.23	<0.01	<0.01	<0.01	0.02
Ile	71.6	69.9	77.7	78.0	74.8	74.5	68.4	67.7	70.3	70.7	72.8	1.22	<0.01	0.35	0.02	0.27
Leu	76.0	79.5	87.1	87.8	86.0	84.0	81.2	81.3	83.7	83.2	84.3	0.88	<0.01	<0.01	<0.01	<0.01
Lys	59.3	57.2	64.6	60.2	61.3	61.7	51.9	52.1	56.8	52.9	57.7	1.94	<0.01	0.37	0.78	0.37
Met	74.9	78.7	83.7	85.5	83.7	82.2	77.2	77.4	80.9	78.7	81.2	0.95	<0.01	<0.01	0.01	<0.01
Phe	74.0	75.1	82.4	82.5	80.3	79.0	74.3	74.8	78.0	77.8	78.6	1.07	<0.01	<0.01	<0.01	0.42
Thr	63.7	60.4	69.1	68.8	66.0	64.6	56.7	56.8	62.8	62.9	63.5	1.59	<0.01	0.90	0.05	0.11
Trp	67.2	55.8	63.0	64.5	58.1	58.7	48.2	48.7	56.3	59.2	57.1	1.91	<0.01	<0.01	0.51	<0.01
Val	70.7	68.8	77.1	77.8	74.3	72.9	67.9	67.2	70.4	70.6	72.3	1.27	<0.01	0.21	0.01	0.26
Dispensable AA																
Ala	71.8	72.7	79.0	79.1	77.4	75.5	70.1	71.3	75.2	73.4	75.1	1.22	<0.01	<0.01	0.03	0.51
Asp	64.9	61.3	68.8	69.9	65.7	65.7	57.6	56.2	62.5	62.3	63.6	1.69	<0.01	0.42	0.13	0.08
Cys	63.2	65.5	74.6	76.7	75.0	68.7	68.6	67.1	65.9	64.6	70.2	1.46	<0.01	<0.01	<0.01	0.22
Glu	74.6	77.8	84.3	85.0	83.3	81.5	77.8	79.0	81.1	79.5	81.4	1.00	<0.01	<0.01	<0.01	0.02
Gly	41.3	39.7	44.7	42.6	41.8	35.8	25.5	25.7	38.4	34.6	36.1	3.54	<0.01	0.08	0.21	0.67
Ser	68.0	69.2	76.8	76.7	74.6	72.0	66.4	66.2	71.5	71.2	71.9	1.40	<0.01	<0.01	0.03	0.46
Pro	35.4	38.5	33.8	24.8	30.6	9.2	−3.5	7.2	30.1	11.6	18.0	6.61	<0.01	<0.01	<0.01	0.60
Indispensable	74.0	73.3	79.4	79.3	77.2	75.6	70.5	70.5	71.6	72.0	74.0	73.28	<0.01	<0.01	<0.01	0.79
Dispensable	64.5	60.5	69.0	67.9	67.2	61.9	55.4	56.9	63.9	64.3	64.5	60.45	<0.01	0.51	0.37	0.85
Total	68.7	66.2	73.7	73.0	71.8	68.1	62.3	63.1	67.3	67.8	68.7	66.21	<0.01	0.41	0.64	0.79

[1]Least squares means for 11 pigs and over 8 periods.
[2]Distillers dried grains with solubles produced from sorghum.
[3]Distillers dried grains with solubles produced from a blend of corn and sorghum grains.
[4]Distillers dried grains with solubles produced from corn.

Table 5. Standardized ileal CP and AA digestibility (%) of 10 sources of distillers dried grains with solubles[1]

			C-DDGS[4]											Contrast, *P*-value		
Item	S[2]	SC[3]	1	2	3	4	5	6	7	8	Mean	SEM	*P*-value	S vs. C	SC vs. C	S vs. SC
CP	72.5	72.1	80.0	77.5	76.1	73.6	67.0	68.6	71.2	71.2	73.1	1.65	<0.01	0.68	0.47	0.81
Indispensable AA																
Arg	79.2	81.8	86.2	84.7	84.4	81.9	75.7	77.5	81.6	80.1	81.5	1.59	<0.01	0.05	0.82	0.10
His	71.9	75.1	83.6	83.5	82.4	80.0	76.4	75.5	76.8	76.6	79.3	1.23	<0.01	<0.01	<0.01	0.03
Ile	74.0	72.7	80.9	81.0	78.1	77.9	71.6	71.1	73.3	74.2	76.0	1.22	<0.01	0.11	0.01	0.42
Leu	77.3	81.0	88.8	89.4	87.7	85.8	82.9	83.1	85.3	85.0	86.0	0.88	<0.01	<0.01	<0.01	<0.01
Lys	64.0	60.9	68.7	64.3	65.2	65.8	55.7	55.9	60.3	57.2	61.6	1.94	<0.01	0.19	0.66	0.19
Met	76.5	80.1	85.3	87.1	85.3	84.0	78.9	79.0	82.4	80.5	82.8	0.95	<0.01	<0.01	<0.01	<0.01
Phe	76.9	78.5	86.0	86.1	84.0	83.1	78.1	78.7	81.4	81.7	82.4	1.06	<0.01	<0.01	<0.01	0.27
Thr	70.2	66.8	75.9	75.4	72.7	71.6	63.6	63.6	68.9	69.9	70.2	1.06	<0.01	0.97	0.03	0.10
Trp	72.0	62.4	71.0	72.0	66.1	66.7	56.2	56.6	63.3	67.1	64.9	1.91	<0.01	<0.01	0.20	<0.01
Val	73.6	72.1	80.7	81.3	78.0	76.9	71.5	70.9	73.9	74.4	75.9	1.27	<0.01	0.07	<0.01	0.37
Dispensable AA																
Ala	74.6	76.3	83.0	82.9	81.5	79.8	74.2	75.5	78.9	77.6	79.2	1.22	<0.01	<0.01	0.01	0.24
Asp	69.4	66.3	74.3	75.2	71.1	71.4	63.0	61.7	67.3	67.7	69.0	1.69	<0.01	0.77	0.09	0.13
Cys	67.3	69.1	78.5	80.4	78.8	73.2	72.6	71.1	69.7	68.9	74.2	1.46	<0.01	<0.01	<0.01	0.33
Glu	76.5	79.9	86.7	87.3	85.7	84.0	80.3	81.4	83.2	82.0	83.8	1.00	<0.01	<0.01	<0.01	<0.01
Gly	69.4	66.2	71.5	68.7	68.3	63.9	52.7	52.9	63.2	61.5	62.8	3.54	<0.01	0.03	0.24	0.40
Ser	73.7	74.9	82.6	82.5	80.5	78.3	72.6	72.2	76.9	77.4	77.9	1.40	<0.01	<0.01	0.02	0.46
Pro	78.1	83.6	80.7	71.0	79.2	61.9	46.9	55.2	73.7	64.1	66.6	6.61	<0.01	0.01	<0.01	0.37
Indispensable	74.9	75.5	83.2	83.0	81.1	79.7	74.3	74.4	77.6	77.4	78.8	1.16	<0.01	<0.01	<0.01	0.67
Dispensable	74.5	76.1	81.7	80.2	80.0	75.7	68.5	70.0	76.1	74.0	75.8	2.00	<0.01	0.41	0.82	0.42
Total	74.6	75.8	82.4	81.5	80.5	77.5	71.2	72.0	76.7	75.5	77.2	1.56	<0.01	0.06	0.30	0.50

[1]Least squares means for 11 pigs and over 8 periods. Standardized ileal digestibility values were calculated using the following basal endogenous CP and AA losses (g/kg of DMI): CP, 18.6; Arg, 0.72; His, 0.16; Ile, 0.23; Leu, 0.39; Lys, 0.24; Met, 0.06; Phe, 0.36; Thr, 0.50; Trp, 0.13; Val, 0.35; Ala, 0.58; Asp, 0.71; Cys, 0.14; Glu, 0.81; Gly, 2.11; Pro, 7.73; and Ser, 0.57.
[2]Distillers dried grains with solubles produced from sorghum.
[3]Distillers dried grains with solubles produced from a blend of corn and sorghum grains.
[4]Distillers dried grains with solubles produced from corn.

Table 6. Prediction of digestible AA concentration from analyzed composition in 8 sources of corn-based distillers dried grains with solubles

Item	a	b	r^2	RMSE[1]	*P*-value	r^2 SBM[2]
CP	−0.97	0.76	0.64	1.32	<0.01	NA[3]
Arg	−0.25	1.00	0.88	0.04	<0.01	NA
His	−0.11	0.91	0.71	0.03	<0.01	NA
Ile	0.11	0.66	0.85	0.04	<0.01	NA
Leu	0.79	0.63	0.82	0.13	<0.01	NA
Lys	0.06	0.55	0.66	0.04	<0.01	0.96
Met	<0.01	0.82	0.75	0.02	<0.01	0.98
Phe	0.18	0.70	0.84	0.05	<0.01	NA
Thr	−0.03	0.72	0.39	0.05	<0.05	0.90
Trp	0.03	0.76	0.84	0.02	<0.01	0.89
Val	0.13	0.67	0.72	0.06	<0.01	NA

[1]RMSE = root mean square error.
[2]Calculated from van Kempen et al. (2002). SBM = soybean meal.
[3]NA = not available.

which were less in source 6. Source 1 had the greatest ($P < 0.01$) SID values for CP and all AA. Lysine was the indispensable AA with the greatest variation in SID (12.9 percentage units).

Predictions of Digestible AA from Total AA Concentrations in C-DDGS

The prediction of the concentration of digestible Lys from the total concentration of Lys was poorer than for other AA. The r^2 for the prediction of the concentration of digestible Arg, (0.88), Ile (0.85), Leu (0.82), Phe (0.84), and Trp (0.84) were greater than the r^2 for the prediction of digestible CP (0.64), His (0.71), Lys (0.66), Met (0.75), and Thr (0.39; Table 6).

DISCUSSION

Chemical Composition of DDGS Sources

Differences in chemical composition among S-DDGS, SC-DDGS, and C-DDGS were expected based on the composition of the original grains that were used to produce ethanol (NRC, 1998). Values for CP and crude fat in the C-DDGS sources were similar to the values reported by Spiehs et al. (2002) and Goodson and Fontaine (2004). However, NDF and ADF values were less than those reported by Spiehs et al. (2002). The fact that S-DDGS contains a greater concentration of Trp than C-DDGS may be an advantage because Trp may become limiting in diets containing low amounts of soybean meal.

Apparent and Standardized Ileal AA Digestibility in DDGS

The differences in chemical composition between sorghum and corn grains are also in agreement with differences in the digestibility of AA between these grains. The AID and SID of AA in sorghum is less than in corn (Jondreville et al., 2001; Pedersen et al., 2007). Corn contains smaller quantities of ADF, NDF, and antinutritional factors than sorghum grain (Lin et al., 1987; Mariscal-Landin et al., 2004). Corn also contains more oil than sorghum, which may contribute to an increase in the digestibility of AA (Cervantes-Pahm and Stein, 2008). These differences in nutrient composition may explain the greater digestibility of AA in C-DDGS than in S-DDGS.

In the present experiment, the SID of Lys in S-DDGS, SC-DDGS, and in C-DDGS were not different, whereas the SID values of most other AA except Ile, Thr, Trp, Val, Asp, Gly, and Pro were less in S-DDGS than in C-DDGS. Relatively large variations in SID values for Lys among different sources of C-DDGS have been reported (Fastinger and Mahan, 2006; Stein et al., 2006; Pahm et al., 2008). The variation in SID of Lys among C-DDGS sources is attributed to heat damage of AA. If DDGS samples are heat damaged, the Lys:CP ratio will be reduced (Stein, 2007). However, the Lys:CP ratio for the 8 sources of C-DDGS that were used in this experiment was within a relatively narrow range and all values except 1 were greater than the value of 2.80 that is considered the minimum for C-DDGS included in diets fed to pigs (Stein, 2007). This observation indicates that at least 7 of the 8 sources of DDGS used in this experiment were not severely heat damaged. The acceptable Lys:CP ratio is different for each feed ingredient, and the reduced Lys:CP ratio in S-DDGS than in C-DDGS cannot be used to conclude that the S-DDGS that was used in this experiment was heat damaged. Based on the fact that the SID for Lys in S-DDGS was not different from the SID for Lys in the 8 sources of C-DDGS used in this experiment, it may be concluded that the S-DDGS was not heat damaged.

Predictions of Digestible AA from Total AA Concentration in C-DDGS

The r^2 for the prediction of the concentration of digestible Arg, (0.88), Ile (0.85), Leu (0.82), Phe (0.84), and Trp (0.84) were greater than the r^2 for the prediction of digestible CP (0.64), His (0.71), Lys (0.66), Met (0.75), and Thr (0.39). This observation differs from that reported by van Kempen et al. (2002) for soybean meal, where the amount of digestible CP and AA could be predicted from its total concentration ($r^2 = 0.96$ for Lys, 0.98 for Met, 0.90 for Thr, and 0.89 for Trp).

A poorer correlation between the concentration of total AA and digestible AA is expected in heat-treated proteins than in non-heat-treated proteins because the decrease in digestibility and AA concentration due to heat damage is not linear (van Barneveld et al., 1994). A portion of the heat-damaged Lys can also revert into free Lys during analytical acid hydrolysis, but that portion of Lys is not digestible (Moughan and Rutherfurd, 1996). The relationship between total and digestible Lys will, therefore, change as samples become heat damaged.

In conclusion, the digestibility of CP and Lys in S-DDGS and SC-DDGS is similar to values obtained for C-DDGS, but many of the remaining AA are less digestible in S-DDGS and SC-DDGS than in C-DDGS. The concentration and digestibility of AA in C-DDGS varies among ethanol plants, which impedes the prediction of the concentration of digestible AA from the concentration of total AA.

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