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Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs[1]

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ABSTRACT: An experiment was conducted to measure DE and ME and the apparent total tract digestibility (ATTD) of energy, N, and P in distillers dried grains with solubles (DDGS) fed to growing pigs. Ten sources of DDGS were obtained from ethanol plants in South Dakota and Minnesota, and 11 diets were formulated. One diet was based on corn (96.8%), limestone, salt, vitamins, and microminerals. Ten additional diets were formulated by mixing the corn diet and each of the 10 sources of DDGS in a 1:1 ratio. Eleven growing pigs (initial BW of 29.3 ± 0.42 kg) were allotted to an 11 × 11 Latin square design, with 11 periods and 11 pigs. Each of the 11 diets was fed to each pig during 1 period. Pigs were placed in metabolism cages that allowed for the total, but separate, collection of feces and urine. Samples were analyzed for GE, N, and P and energy and N balances, and the ATTD of GE, N, and P were calculated for each diet. By subtracting the contribution from the corn diet to the DDGS-containing diets, the energy and N balances and the ATTD for GE, N, and P for each source of DDGS were calculated. Results of the experiment showed that the DE and ME differed ($P < 0.001$) among the 10 sources of DDGS (3,947 to 4,593 kcal of DE/kg of DM and 3,674 to 4,336 kcal of ME/kg of DM). The average DE and ME in DDGS were 4,140 and 3,897 kcal/kg of DM, respectively. These values were not different from the DE and ME in corn (4,088 and 3,989 kcal/kg of DM, respectively). Based on the analyzed GE and nutrient composition of DDGS and the calculated values for DE and ME, prediction equations for DE and ME were developed. These equations showed that DE and ME in DDGS may be predicted from the concentration of ash, ether extract, ADF, and GE. The retention of N from DDGS was greater ($P < 0.001$) than from corn, but when calculated on a percentage basis, the N retention did not differ between DDGS and corn. The ATTD of P in DDGS was 59.1% on average for the 10 samples. This value was greater ($P < 0.001$) than the ATTD of P in corn (19.3%). It is concluded that the DE and ME in DDGS is not different from the DE and ME in corn. However, if DDGS is included in diets fed to growing swine, a greater portion of the organic P will be digested and absorbed, thus reducing the need for adding inorganic P to the diets.

Key words: digestibility, distillers dried grain with solubles, energy, phosphorus, pig, prediction equation

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INTRODUCTION

With the rapid increase in ethanol production, the quantities of distillers dried grains with solubles (**DDGS**) that are available for inclusion in diets fed to swine are increasing (Lumpkins et al., 2004). The DE and ME in DDGS have been estimated at 3,441 and 3,032 kcal/kg of DM, respectively (NRC, 1998). However, based on the chemical composition of many samples, values for DE and ME in DDGS of approximately 3,990 and 3,750 kcal/kg of DM, respectively, have been calculated (Spiehs et al., 2002). In experiments by Hastad et al. (2004) and Stein et al. (2005), ME values of approximately 3,900 and 3,400 kcal/kg of DM, respectively, were measured. Therefore, there is evidence that DE and ME in DDGS are greater than the values currently suggested by the NRC (1998). However, the data from Spiehs et al. (2002) and from Stein et al. (2005) also indicate that there may be some variation in the DE and ME among samples of DDGS, but no experiments have been conducted to estimate this variation.

The relative availability of P in corn is 14% (NRC, 1998), because most of the P in corn is bound in the

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phytate complex. However, the relative availability of P in DDGS produced from corn has been reported to be 77% (NRC, 1998), and the apparent total tract digestibility (**ATTD**) of P in 4 samples of DDGS has been reported at 55% (Stein et al., 2005). The reason why the P in DDGS seems to be more digestible than in corn has not been elucidated, but because of the importance of P in the nutrition of pigs and in the manure management of swine farms, it is important that accurate values for the ATTD of P in DDGS are available.

The objective of the current experiment was to test the hypothesis that the DE and ME in DDGS produced from modern ethanol plants are greater than the values suggested by the NRC (1998) and that the DE and ME in DDGS may be predicted from the chemical composition of DDGS. A second objective was to test the hypothesis that the ATTD for P in DDGS is greater than that of corn.

MATERIALS AND METHODS

Diets, Animals, and Experimental Design

Ten samples of DDGS from 10 ethanol plants were collected and used in the experiment (Table 1). Nine of the samples were from ethanol plants in South Dakota, and 1 sample was from a plant in Minnesota. Eleven diets were formulated (Tables 2 and 3). One diet was based on corn (96.8%), limestone, salt, vitamins, and microminerals. The remaining 10 diets were formulated by mixing the corn diet and each of the 10 samples of DDGS in a 1:1 ratio.

The South Dakota State University Animal Care and Use Committee reviewed and approved the protocol for the experiment. Eleven growing barrows (initial BW of 29.3 ± 0.42 kg) originating from the matings of SP-1 boars to line 13 sows (Ausgene International Inc., Gridley, IL) were placed in metabolism cages that allowed for the total, but separate, collection of urine and feces. Pigs were randomly allotted to an 11 × 11 Latin square design with 11 pigs and 11 periods. Each experimental period was 14 d.

Feeding and Sample Collections

Each of the 11 experimental diets was fed to 1 pig in each period in such a way that a pig never received the same diet in more than 1 period. The daily amount of feed provided per pig was calculated as 2.5 times the energy requirement for maintenance (i.e., 106 kcal of ME/kg of $BW^{0.75}$; NRC, 1998). The ME was calculated at 3,307 and 3,064 kcal/kg (as-fed basis) for the corn diet and the corn-DDGS diets, respectively (NRC, 1998). The daily feed allotments were divided into 2 equal meals and fed at 0800 and 1700. Water was available at all times.

The initial 7 d of each period was an adaptation period to the diet. In the morning meals on d 8 and 13, 0.5% ferric oxide was mixed into the diet. Fecal collections were initiated as the ferric oxide appeared in the feces after d 8 and ceased when the marker appeared in the feces for the first time after d 13, as described by Adeola (2001). During the collection period, fecal materials were collected twice daily and stored at −20°C. Urine collections were initiated in the morning of d 8 and ceased in the morning of d 13. Urine was collected into urine buckets that were placed under the metabolism cages. The buckets were emptied morning and afternoon, and 50 mL of 6 *N* sulfuric acid was added to the buckets every time they were emptied, as previously described (Stein et al., 2004). The collected urine was weighed, and 20% was stored at −20°C. After the experiment, all urine samples were thawed and mixed within animal and diet, and a subsample was collected for chemical analysis. Fecal samples were dried in a forced-air oven at 60°C, ground, and thoroughly mixed before a subsample was collected for analysis.

Sample Analysis

All analyses were conducted in duplicate samples, and the analyses were repeated if the results of the duplicates differed by more than 5%. Samples of corn, DDGS, diets, and feces were analyzed for DM (procedure 4.1.06; AOAC, 2000), GE via bomb calorimetry (Parr Instruments, Moline, IL), and Kjeldahl N (Thiex et al., 2002). Urine samples were lyophilized and analyzed for GE via bomb calorimetry. All samples of DDGS were analyzed for ash (procedure 4.1.10; AOAC, 2000). Diets, feed ingredients, and fecal samples were digested in perchloric acid (procedure 2.3.01; AOAC, 2000), and P was determined on a UV-vis spectrophotometer (Model UV-2101 PC; Shimadzu Scientific Instruments, Columbia, MD) at 650 nm (procedure 3.4.11; AOAC, 2000). Accuracy of the procedure was verified using National Institute of Standards and Technology (US Department of Commerce) reference standard 1570a (standard reference material).

Samples of corn, DDGS, and diets were analyzed for ether extract (Thiex et al., 2003), ADF, NDF (procedure 4.6.03; AOAC, 2000), and Ca (procedure 4.8.03; AOAC, 2000). To help characterize the sources of DDGS used in the experiment, AA were analyzed in corn, DDGS samples, and diets on a Thermo Quest HPLC (Thermo Separation Products, Inc., San Jose, CA), using ninhydrin for postcolumn derivatization and nor-Leu as the internal standard. Before analysis, the samples were hydrolyzed with 6 *N* HCl for 24 h at 110°C (procedure 4.1.11, alternative 3; AOAC, 2000). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (procedure 4.1.11, alternative 1; AOAC, 2000). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (procedure 988.15; AOAC, 1995). The concentration of starch in corn and in the DDGS samples was analyzed using an enzymatic procedure (Xiong et al., 1990). Subjective color scores of all DDGS samples were obtained according to NPCC (1999) using a Mi-

Table 1. Analyzed composition of the corn and 10 sources of distillers dried grains with solubles (DDGS), and measured color of DDGS (as-fed basis)

		DDGS source									
Item	Corn	1	2	3	4	5	6	7	8	9	10
DM, %	86.7	89.7	86.7	87.3	87.0	88.0	87.9	86.9	86.8	89.7	86.2
CP, %	7.2	32.4	29.9	29.7	25.9	27.4	27.7	27.9	26.3	27.4	28.0
Starch, %	57.1	6.9	12.7	4.1	8.4	6.8	5.2	6.0	5.3	11.6	4.9
Ether extract, %	2.9	8.6	8.7	10.8	12.4	10.3	10.4	9.7	11.4	8.6	11.2
ADF, %	2.3	12.0	8.6	11.0	8.6	11.7	10.0	10.5	10.1	8.9	10.1
NDF, %	6.7	26.6	20.0	24.4	23.2	25.7	24.3	22.8	24.1	26.6	24.2
Ash, %	0.94	2.98	4.16	3.94	4.07	4.12	3.79	3.97	4.14	3.76	3.36
Ca, %	0.02	0.02	0.15	0.04	0.28	0.02	0.03	0.03	0.02	0.03	0.04
P, %	0.20	0.51	0.60	0.58	0.52	0.54	0.53	0.74	0.69	0.69	0.69
GE, kcal/kg	3,898	4,782	4,571	4,771	4,780	4,817	4,755	4,685	4,851	4,777	4,820
Indispensable AA, %											
Arg	0.37	1.50	1.33	1.37	1.12	1.32	1.19	1.22	1.19	1.19	1.29
His	0.22	0.89	0.73	0.80	0.66	0.79	0.72	0.72	0.73	0.76	0.77
Ile	0.26	1.27	1.05	1.21	0.96	1.10	1.04	1.05	1.05	1.03	1.14
Leu	0.87	4.33	3.32	3.66	3.08	3.66	3.34	3.43	3.40	3.39	3.73
Lys	0.23	1.04	0.86	0.91	0.64	0.82	0.75	0.75	0.78	0.75	0.76
Met	0.19	0.80	0.65	0.73	0.65	0.72	0.65	0.65	0.67	0.63	0.64
Phe	0.35	1.68	1.36	1.46	1.25	1.44	1.33	1.36	1.35	1.31	1.46
Thr	0.24	1.12	0.92	1.00	0.85	0.97	0.90	0.91	0.92	0.95	0.97
Trp	0.04	0.23	0.19	0.21	0.16	0.21	0.17	0.17	0.18	0.17	0.18
Val	0.36	1.70	1.38	1.51	1.28	1.49	1.39	1.41	1.41	1.37	1.50
Dispensable AA, %											
Ala	0.53	2.57	2.00	2.23	1.88	2.20	2.05	2.10	2.06	2.06	2.20
Asp	0.57	2.36	2.04	2.05	1.83	2.06	1.94	1.96	2.00	1.91	2.04
Cys	0.13	0.43	0.35	0.41	0.36	0.41	0.37	0.36	0.37	0.39	0.38
Glu	1.36	6.45	5.20	5.55	4.65	5.49	5.17	5.28	5.18	5.31	5.56
Gly	0.30	1.26	1.10	1.20	1.04	1.15	1.11	1.13	1.13	1.11	1.35
Pro	0.64	2.71	2.19	2.41	2.04	2.38	2.25	2.25	2.32	2.50	2.44
Ser	0.40	1.66	1.39	1.51	1.30	1.53	1.37	1.38	1.38	1.38	1.43
Tyr	0.30	1.40	1.13	1.22	1.05	1.21	1.12	1.16	1.16	1.13	1.22
Color[1]											
L*	—	67.12	58.12	56.43	63.31	61.66	45.09	40.13	58.37	54.45	57.77
a*	—	7.10	7.31	8.87	11.07	7.97	9.03	10.56	11.42	11.30	10.30
b*	—	45.55	31.02	40.60	46.33	41.43	28.69	26.52	43.00	43.20	41.75

[1]Lightness (L*) values: 0 = dark, 100 = light; redness (a*) values: –60 = green, +60 = red; yellowness (b*) values: –60 = blue, +60 = yellow.

nolta Chroma Meter CR-310 (Minolta Corp., Ramsey, NJ) at D_{65} illuminant to measure lightness (**L***), redness (**a***), and yellowness (**b***) color values.

Calculations

After chemical analysis, the energy lost in feces and urine was calculated for each diet, and the DE and ME in each of the 11 diets were calculated. By subtracting the DE and ME contributed by the corn diet to the corn-DDGS diets, the DE and ME contributed by each source of DDGS were calculated by difference (Adeola, 2001). The N balance for each diet and for each of the 10 sources of DDGS was also calculated (Adeola, 2001). The ATTD (%) of energy, N, and P in each diet was calculated using the following equation:

$$\text{ATTD} = [(\text{Ni} - \text{Nf})/\text{Ni}] \times 100\%,$$

where Ni = the total intake of energy (kcal), N (g), or P (g) from d 8 to 13 and Nf = the total fecal output of energy (kcal), N (g), or P (g) originating from the feed fed from d 8 to 13. The ATTD for energy, N, and P in each source of DDGS was subsequently calculated by subtracting the contribution of energy, N, and P from the corn diet to the corn-DDGS diets.

Statistical Analysis

Data were analyzed using PROC MIXED (Littell et al., 1996; SAS Inst. Inc., Cary, NC). Homogeneity of the data was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to analyze data for outliers; however, no outliers were identified. Data obtained for the diets containing the 10 sources of DDGS were compared using an ANOVA. The source of DDGS and period were the fixed effects, and pig was considered a random effect. The LSMEANS procedure was used to calculate mean values, and the PDIFF option was used to separate means. The values for corn were compared with the values for the corn-DDGS diets using a contrast statement. Values for each source of DDGS were compared using a similar approach. The values for L*, a*, and b* and

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

Ingredient	Corn	Corn-DDGS
Corn	96.80	48.40
DDGS[1]	—	50.00
Limestone	2.20	1.10
Salt	0.60	0.30
Micromineral premix[2]	0.30	0.15
Vitamins premix[3]	0.10	0.05
Total	100.00	100.00

[1]DDGS = distillers dried grains with solubles.
[2]Provided the following quantities of microminerals per kilogram of complete diet in the corn diet and half of these amounts in the DDGS diets: Cu, 19 mg as copper sulfate; Fe, 198 mg as iron sulfate; I, 0.43 mg as potassium iodate; Mn, 53 mg as manganese sulfate; Se, 0.36 mg as sodium selenite; and Zn, 198 mg as zinc oxide.
[3]Provided the following quantities of vitamins per kilogram of complete diet in the corn diet and half of these amounts in the DDGS diets: vitamin A, 21,980 IU as vitamin A acetate; vitamin D_3, 3,296 IU as D-activated animal sterol; vitamin E, 110 IU as α-tocopherol acetate; vitamin K_3, 8.8 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 6.6 mg as thiamine mononitrate; riboflavin, 18.8 mg; pyridoxine, 6.6 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.088 mg; D-pantothenic acid, 66 mg as calcium pantothenate; niacin, 110 mg; folic acid, 2.2 mg; and biotin, 0.34 mg.

the DE and ME in DDGS were correlated using PROC CORR of SAS. Linear and quadratic effects of period on values for DE and ME (kcal/kg of DM) in corn and DDGS were analyzed using contrast statements. The pig was the experimental unit for all analyses, and an α value of 0.05 was used to assess differences among means.

Prediction equations for DE and ME in DDGS were developed using PROC REG of SAS. In the first model, the analyzed values (DM basis) for CP, ash, ether extract, starch, ADF, NDF, and GE were regressed on the measured DE and ME for the 10 sources of DDGS. In subsequent models, the variable with the greatest P-value was removed using a manual stepwise procedure to create reduced models containing fewer variables. The stepwise removal of variables continued until all variables in the model were significant.

RESULTS

The concentration of CP in the 10 samples of DDGS differed from 25.9 to 32.4% (as-fed basis), and the concentration of GE differed from 4,571 to 4,820 kcal/kg (Table 1). The concentration of starch was low in all samples but differed from 4.1 to 11.4%, and the concentration of ether extract differed from 8.6 to 12.4%. The concentration of Ca was low (<0.3%) in all samples, and the concentration of P differed from 0.51 to 0.74%. The color score for the DDGS samples also differed among samples. In general, the scores for L* were in good agreement with the scores for b*, whereas the a* values were different.

Table 3. Analyzed nutrient composition of the experimental diets (as-fed basis)

		Corn-DDGS[1] diets using DDGS source									
Item	Corn	1	2	3	4	5	6	7	8	9	10
DM, %	87.5	88.8	87.7	87.8	88.7	87.9	88.7	88.1	88.3	88.6	87.9
CP, %	6.9	18.5	16.1	17.3	15.4	17.4	16.8	16.4	16.8	16.5	17.1
Ether extract, %	2.8	6.3	6.5	7.1	7.8	6.9	7.0	6.9	7.4	6.3	7.3
ADF, %	2.2	8.6	5.3	7.4	6.2	7.4	6.8	6.4	5.8	5.5	5.7
NDF, %	6.7	17.9	11.4	16.8	15.4	16.0	15.4	14.3	15.7	16.2	15.4
Ca, %	0.84	0.39	0.53	0.42	0.54	0.47	0.52	0.44	0.44	0.42	0.45
P, %	0.19	0.39	0.43	0.47	0.42	0.47	0.46	0.42	0.48	0.39	0.47
GE, kcal/kg	3,795	4,223	4,158	4,263	4,297	4,249	4,271	4,257	4,324	4,249	4,286
Indispensable AA, %											
Arg	0.36	0.99	0.83	0.88	0.80	0.80	0.78	0.83	0.83	0.80	0.86
His	0.22	0.59	0.47	0.53	0.47	0.52	0.48	0.49	0.50	0.50	0.52
Ile	0.27	0.81	0.64	0.72	0.64	0.69	0.65	0.68	0.69	0.66	0.72
Leu	0.95	2.67	2.06	2.36	2.07	2.32	2.17	2.23	2.25	2.19	2.37
Lys	0.22	0.67	0.53	0.59	0.48	0.55	0.50	0.50	0.52	0.51	0.53
Met	0.19	0.51	0.43	0.48	0.43	0.46	0.46	0.44	0.45	0.44	0.44
Phe	0.37	1.07	0.85	0.95	0.84	0.92	0.87	0.89	0.90	0.87	0.95
Thr	0.24	0.71	0.57	0.64	0.57	0.63	0.60	0.60	0.62	0.62	0.63
Trp	0.05	0.14	0.13	0.14	0.12	0.13	0.11	0.11	0.12	0.12	0.13
Val	0.36	1.07	0.85	0.96	0.87	0.93	0.87	0.92	0.92	0.86	0.95
Dispensable AA, %											
Ala	0.57	1.61	1.25	1.45	1.27	1.41	1.34	1.36	1.37	1.36	1.43
Asp	0.56	1.50	1.28	1.42	1.31	1.39	1.33	1.27	1.29	1.24	1.35
Cys	0.13	0.29	0.25	0.28	0.26	0.27	0.26	0.25	0.25	0.26	0.25
Glu	1.44	3.98	3.17	3.59	3.15	3.53	3.35	3.43	3.47	3.39	3.57
Gly	0.29	0.80	0.67	0.76	0.70	0.74	0.72	0.73	0.75	0.73	0.75
Pro	0.67	1.62	1.34	1.52	1.38	1.55	1.43	1.40	1.50	1.60	1.58
Ser	0.40	1.09	0.93	1.00	0.89	0.97	0.97	0.93	0.94	0.92	0.98
Tyr	0.32	0.91	0.73	0.81	0.72	0.78	0.75	0.76	0.77	0.76	0.80

[1]DDGS = distillers dried grains with solubles.

There were no differences in the GE intake among the diets containing DDGS, but as expected, the GE intake for pigs fed the corn diet was lower ($P \leq 0.001$) than for pigs fed the DDGS diets (Table 4). The fecal excretion of GE differed ($P \leq 0.001$) from 895 kcal of GE/kg for pigs fed the diet containing DDGS from source 10 to 1,322 kcal of GE/kg for pigs fed the diet containing DDGS from source 7. The urinary excretion of energy was lowest ($P \leq 0.01$) in pigs fed the diet containing DDGS from source 4 and greatest in pigs fed DDGS from source 7. Pigs fed all the DDGS-containing diets excreted more ($P \leq 0.001$) energy in the feces and in the urine than did pigs fed the corn diet. The diet containing DDGS from source 10 contained 3,694 kcal of DE and 3,543 kcal of ME per kg, which was more ($P \leq 0.001$) than the DE and ME in any of the other DDGS-containing diets, except the diet containing DDGS source 8. In contrast, the diets containing DDGS from sources 2, 5, and 7 contained less ($P \leq 0.001$) DE and ME than the diets containing DDGS from sources 4, 8, 9, and 10. The DE in the DDGS-containing diets was greater ($P \leq 0.01$) than the DE in the corn diet, but there was no difference in ME between the corn diet and DDGS-containing diets.

The N intake, the fecal N output, and the urinary N output differed ($P \leq 0.01$) among the DDGS-containing diets, but the intake of N, the fecal excretion of N, and the urinary excretion of N were lower ($P \leq 0.001$) for pigs fed the corn diet than for pigs fed all the DDGS-containing diets. The quantities of N absorbed by pigs fed the DDGS-containing diets also differed ($P \leq 0.01$) among sources, but pigs fed the corn diet absorbed less ($P < 0.001$) N than pigs fed all the DDGS-containing diets. The retention of N was similar among pigs fed all the DDGS-containing diets. However, when calculated as a percentage of N intake, the retention of N was lower ($P \leq 0.05$) in pigs fed diets containing DDGS from source 7 than from pigs fed diets containing DDGS from sources 3, 4, 8, 9, and 10. The total N retention was greater ($P \leq 0.001$) for pigs fed all the DDGS-containing diets than for pigs fed the corn diet, but as a percentage of N intake, the retention of N was similar for pigs fed the corn diet and pigs fed the DDGS-containing diets.

The ATTD for GE, N, and P for pigs fed the DDGS-containing diets differed ($P \leq 0.001$) among DDGS sources (Table 5). The ATTD for GE in pigs fed all the diets containing DDGS was lower ($P \leq 0.001$) than for pigs fed the corn diet. In contrast, the ATTD for P was lower ($P \leq 0.001$) for pigs fed the corn diet compared with pigs fed the DDGS-containing diets, whereas the ATTD for N was not different between pigs fed the corn diet and the DDGS-containing diets.

The intake of GE from DDGS did not differ among sources (Table 6), but as expected, it was much greater ($P < 0.001$) for corn than for DDGS. The excretion of GE in feces and of GE and N in urine also differed ($P \leq 0.001$) among the 10 sources of DDGS, but invariably, the excretions were greater from DDGS than from corn ($P \leq 0.001$). The DE and ME differed ($P \leq 0.001$) among

Table 4. Daily energy and N balances for pigs fed the experimental diets (as-fed basis)[1]

		Corn-DDGS[2] diets using DDGS source										DDGS[3]		DDGS-corn[4]	
Item	Corn	1	2	3	4	5	6	7	8	9	10	SEM	P-value	SEM	P-value
GE intake, kcal	5,232	6,828	6,687	6,736	6,502	6,790	6,524	7,321	6,623	6,185	6,447	526	0.50	469	0.001
N intake, g	15.3	47.7^{v}	41.3^{xyz}	43.7^{vyz}	37.2^{x}	44.4^{vz}	41.0^{xyz}	44.9^{vz}	41.2^{xyz}	38.5^{xy}	41.3^{xyz}	3.16	0.01	2.75	0.001
GE in feces, kcal	504	$1,161^{yz}$	$1,162^{yz}$	$1,180^{yz}$	$1,135^{y}$	$1,270^{z}$	$1,189^{yz}$	$1,322^{z}$	$1,051^{xy}$	955^{x}	895^{x}	91	0.001	79.5	0.001
N in feces, g	2.8	6.9^{yz}	6.9^{yz}	7.1^{vyz}	6.7^{xyz}	7.6^{vz}	8.1^{v}	9.5^{w}	7.3^{yzv}	6.2^{xy}	5.6^{x}	0.56	0.001	0.50	0.001
GE in urine, kcal	111	243^{yz}	250^{yz}	231^{yz}	156^{x}	264^{yz}	217^{y}	274^{z}	231^{yz}	238^{yz}	229^{yz}	25.7	0.003	21.8	0.001
N in urine, g	7.3	24.6^{v}	21.7^{yzv}	21.1^{vyz}	14.0^{x}	23.1^{vz}	19.9^{yz}	22.8^{vyz}	19.3^{yz}	19.0^{y}	19.9^{yz}	2.02	0.001	1.70	0.001
DE of the diet, kcal/kg	3,431	$3,485^{xy}$	$3,439^{x}$	$3,505^{xy}$	$3,540^{yz}$	$3,453^{x}$	$3,489^{xy}$	$3,462^{x}$	$3,633^{vw}$	$3,596^{vz}$	$3,694^{w}$	33	0.001	30	0.008
ME of the diet, kcal/kg	3,347	$3,336^{x}$	$3,286^{x}$	$3,361^{xy}$	$3,430^{yz}$	$3,292^{x}$	$3,347^{x}$	$3,301^{x}$	$3,482^{zv}$	$3,435^{yz}$	$3,543^{v}$	36	0.001	32	0.38
N absorbed, g	12.5	40.8^{z}	34.4^{xy}	36.5^{y}	30.5^{x}	36.8^{yz}	33.0^{xy}	35.4^{y}	33.9^{xy}	32.2^{xy}	35.7^{y}	2.74	0.006	2.38	0.001
N retained, g	5.2	16.2	12.8	15.5	16.5	13.7	13.1	12.6	14.6	13.3	15.8	1.77	0.55	1.28	0.001
N retention, %	32.5	33.9^{xyz}	31.7^{xy}	35.8^{yz}	42.3^{z}	31.4^{xy}	31.5^{xy}	26.4^{x}	35.8^{yz}	35.1^{yz}	38.2^{yz}	3.1	0.05	2.2	0.61

$^{v–z}$Values within a row and DDGS source lacking a common superscript letter are different ($P < 0.05$).

[1]n = 11.

[2]DDGS = distillers dried grains with solubles.

[3]Comparison of the 10 diets containing DDGS.

[4]Values for the corn diet vs. all DDGS-containing diets.

Table 5. Apparent total tract digestibility (ATTD) of GE, N, and P in the experimental diets[1]

		Corn-DDGS[2] diets using DDGS source										DDGS[3]		DDGS-corn[4]	
Item, %	Corn	1	2	3	4	5	6	7	8	9	10	SEM	*P*-value	SEM	*P*-value
ATTD of GE	90.4	82.5[xy]	82.7[xy]	82.2[x]	82.4[xy]	81.3[x]	81.7[x]	81.3[x]	84.0[yz]	84.6[vz]	86.2[v]	0.77	0.001	0.68	0.001
ATTD of N	81.5	85.0[uw]	83.5[vwz]	83.5[vwz]	81.8[yz]	82.8[vz]	80.4[y]	78.0[x]	82.2[vyz]	83.7[vw]	86.4[u]	0.83	0.001	0.80	0.22
ATTD of P	19.3	50.7[yz]	48.5[xyz]	52.5[z]	52.7[z]	46.5[xy]	51.1[yz]	44.3[x]	52.8[z]	50.5[yz]	58.6[v]	2.49	0.001	2.45	0.001

[u–z]Values within a row and DDGS source lacking a common superscript letter are different ($P < 0.05$).
[1]n = 11.
[2]DDGS = distillers dried grain with solubles.
[3]Comparison of the 10 diets containing DDGS.
[4]Values for the corn diet vs. all DDGS-containing diets.

the 10 sources of DDGS and ranged from 3,947 to 4,593 and from 4,336 to 4,163 kcal/kg of DM, respectively. The DE and ME for corn (4,088 and 3,989 kcal/kg of DM, respectively) were not different from the DE and ME values obtained for DDGS.

The quantity of N that was absorbed differed ($P \leq 0.01$) from 23.0 to 34.1 g among the 10 sources of DDGS, but there were no differences among sources in the amount of N that was retained in the pigs (Table 6). However, greater quantities of N were absorbed and retained from DDGS than from corn ($P \leq 0.001$), but the percentage of N retained was not different between corn and DDGS.

The greatest ($P \leq 0.001$) ATTD for GE (82.8%) was calculated for DDGS source 10 (Table 7). This value was greater than the ATTD for all other sources of DDGS except source 9 (80.0%). The ATTD for GE in the remaining sources ranged from 73.9 to 79.0%. However, the ATTD for GE in corn (90.4%) was greater ($P \leq 0.001$) than for all sources of DDGS. The ATTD for N also differed ($P < 0.001$) among the 10 sources of DDGS, but it was not different from the ATTD for N in corn. For P, the ATTD in DDGS differed ($P \leq 0.001$) from 50.1% to 68.3%, but the ATTD for P in all sources of DDGS was greater ($P \leq 0.001$) than in corn (19.3%).

The correlations between DE and ME and the a* color were 0.43 and 0.44, respectively, but the correlations with both L* and b* values were less than 0.2 (data not shown). There were no quadratic effects of period on the DE or ME for corn or DDGS (data not shown). However, values for DE and ME of DDGS tended to increase with period (linear effect, $P = 0.09$ and 0.10, respectively), but this was not the case for corn.

Prediction equations for DE and ME in DDGS are presented in Table 8. For DE, 4 models were developed that all had r^2 values between 0.96 and 0.99 ($P \leq 0.05$). The most reduced model included ash, ether extract, ADF, and GE. This model had an r^2 of 0.96 ($P \leq 0.001$). For ME, 5 different models were developed. These models had r^2 values between 0.94 and 0.99 ($P \leq 0.05$). The most reduced model had an r^2 of 0.94 ($P \leq 0.0001$) and included ash, ADF, and GE.

DISCUSSION

The variation in DM, CP, and ether extract in the 10 sources of DDGS agree with the values reported by Spiehs et al. (2002), but the values for ADF and NDF that were measured in the present experiment are lower and the values for ether extract are greater than the values published by the NRC (1998). The concentration of P in the DDGS used in the current experiment also was lower than previously published values (NRC, 1998; Spiehs et al., 2002; Stein et al., 2006). However, the concentration of AA in the 10 samples of DDGS differed but generally agreed with recently published values (Stein et al., 2006). The reason for the variability in the chemical composition of DDGS among samples may be that the corn that was used by the different ethanol plants may have differed in chemical composition according to variety, geographic location, fertilization, and growing conditions, as has been shown for barley and wheat (Fairbairn et al., 1999; Zijlstra et al., 1999; van Barneveld, 1999). In addition, the differences in starch concentration among samples of DDGS indicated that not all sources had been fermented to the same degree, which also explains some of the variability in chemical composition.

The DE and ME in corn that were measured in the current experiment agree with published values (NRC, 1998). The average DE for the 10 samples of DDGS that was calculated in the present experiment was 4,140 kcal/kg of DM, and the average ME was 3,897 kcal/kg of DM. These values are 20 and 29% greater than the current NRC values of 3,441 and 3,032 kcal/kg of DM, respectively. However, the values obtained in the current experiment are in agreement with the values for DE and ME (3,990 and 3,750 kcal/kg of DM, respectively) that were calculated based on the chemical composition of DDGS (Spiehs et al., 2002). Likewise, Hastad et al. (2004) reported that DDGS contains 3,900 kcal of ME/kg of DM. The reason why greater values for DE and ME in DDGS have been reported in recent years compared with NRC (1998) values may be that modern ethanol plants use production processes that differ from the processes used in the past (Spiehs et al., 2002; Lumpkins et al., 2004). The lower concentrations of ADF and NDF and the greater concentration of ether extract in the DDGS samples used in the current experiment compared with values published by the NRC (1998) may also have contributed to the greater DE and ME values. Based on the data from the current experiment and the data reported by Spiehs et al.

Table 6. Daily energy and N balances in the corn and 10 sources of distillers dried grains with solubles (DDGS; as-fed basis)[1]

		DDGS source										DDGS[2]		DDGS-corn[3]	
Item	Corn	1	2	3	4	5	6	7	8	9	10	SEM	*P*-value	SEM	*P*-value
GE intake, kcal	5,232	4,151	3,978	4,096	3,640	4,143	4,055	4,551	3,824	3,792	4,050	537	0.72	482	0.001
N intake, g	15.3	39.7^{z}	33.3^{y}	36.1^{y}	28.1^{x}	36.7^{yz}	34.4^{y}	36.4^{yz}	32.5^{xy}	32.4^{xy}	35.1^{y}	3.08	0.006	2.64	0.001
GE in feces, kcal	504	901^{vyz}	906^{vyz}	918^{vwyz}	846^{xyz}	1,031^{vw}	953^{vwz}	1,069^{w}	760^{xy}	739^{x}	690^{x}	87.8	0.001	76.5	0.001
N in feces, g	2.8	5.6^{yz}	5.4^{xyz}	5.7^{yz}	5.1^{xy}	6.4^{vz}	6.9^{v}	8.1^{w}	5.6^{yz}	5.0^{xy}	4.5^{x}	0.55	0.001	0.48	0.001
GE in urine, kcal	111	179	180	200	159	211	182	172	174	186	136	25	0.28	16.4	0.02
N in urine, g	7.4	19.1^{vz}	17.4^{vyz}	20.0^{v}	7.4^{x}	18.7^{vyz}	14.0^{yz}	17.8^{vyz}	13.6^{y}	14.6^{yz}	15.9^{vyz}	2.48	0.001	2.04	0.001
DE, kcal/kg as-is	3,544	3,539^{xy}	3,446^{x}	3,579^{xy}	3,650^{yz}	3,476^{x}	3,547^{xy}	3,492^{x}	3,834^{vw}	3,760^{vz}	3,957^{w}	64	0.001	57.3	0.25
DE, kcal/kg of DM	4,088	3,950^{x}	3,970^{x}	4,103^{xy}	4,188^{y}	3,947^{x}	4,035^{xy}	3,995^{x}	4,413^{z}	4,205^{y}	4,593^{v}	74	0.001	65	0.79
ME, kcal/kg as-is	3,458	3,326^{x}	3,226^{x}	3,375^{xy}	3,513^{yz}	3,237^{x}	3,347^{x}	3,255^{x}	3,617^{vz}	3,523^{yz}	3,738^{v}	72	0.001	63	0.59
ME, kcal/kg of DM	3,989	3,712^{x}	3,716^{x}	3,868^{xyz}	4,034^{vz}	3,674^{x}	3,807^{xy}	3,719^{x}	4,163^{vw}	3,941^{yz}	4,336^{w}	83	0.001	72	0.18
N absorbed, g	12.5	34.1^{z}	27.9^{y}	30.3^{yz}	23.0^{x}	30.3^{yz}	27.6^{xy}	28.3^{y}	26.9^{xy}	27.3^{xy}	30.6^{yz}	2.69	0.003	2.29	0.001
N retained, g	5.1	14.9	10.5	10.3	15.6	11.7	13.5	10.6	13.4	12.8	14.6	2.37	0.49	1.77	0.001
N retention, %	31.7	38.8	33.4	28.0	52.1	33.5	40.6	27.3	40.3	40.0	41.6	7.2	0.19	5.4	0.44

$^{v–z}$Values within a row and DDGS source lacking a common superscript letter are different ($P < 0.05$).
[1]n = 11.
[2]Comparison of the 10 diets containing DDGS.
[3]Values for the corn diet vs. all DDGS-containing diets.

(2002), it is concluded that the DE and ME in DDGS are not different from the DE and ME in corn. Therefore, if DDGS is included in diets fed to growing pigs at the expense of corn, the DE and ME of the diet will not change.

The difference between DE and ME in corn was 99 kcal/kg of DM, but the average difference between DE and ME in DDGS was 243 kcal/kg of DM. The reason for this difference is most likely that the pigs fed the DDGS-containing diets excreted significantly more N in the urine than pigs fed the corn diet. It has been demonstrated that the best predictor of the ME:DE ratio in a feed ingredient is the CP concentration of the ingredient (Noblet and Perez, 1993). With greater CP concentrations in DDGS than in corn, it was expected that more N would be excreted in the urine, which would decrease the ME:DE ratio. It also was reported that the digestibility of indispensable AA, and Lys in particular, in samples of DDGS may vary (Fastinger and Mahan, 2006; Stein et al., 2006). This may create AA imbalances, which would also be expected to contribute to differences in the urinary excretion of N and thus to differences in the ME:DE ratio.

More N was retained from DDGS than from corn because of the greater CP concentration in DDGS than in corn. However, when calculated on a percentage basis, the N retention from corn was similar to the N retention from DDGS. The reason for this observation is most likely that the AA profile in DDGS is similar to the profile in corn, and Lys is the first limiting AA in both ingredients.

The values obtained for the ATTD of P in DDGS were between 50.1 and 68.3%, with an average of 59.1%. Previously, the relative availability of P in DDGS has been reported at 77 and 85%, respectively (NRC, 1998; Fent et al., 2004). The ATTD of P may be estimated from the relative availability by multiplying availability values by 0.9 (Jongbloed, 1987). This would give ATTD values of 0.69 and 0.76% for the data reported by NRC (1998) and Fent et al. (2004), respectively. It is not known why lower values were obtained in the present experiment, but the value of 59.1% for ATTD of P in DDGS agrees with Stein et al. (2005), who reported an average ATTD of P in 4 sources of DDGS of 55%. The ATTD of P in corn was 19%. This value is greater than the 14% relative availability of P that has been published (NRC, 1998). However, the ATTD of P in corn was recently reported at 28% (Bohlke et al., 2005). Therefore, it appears that there is some variation among sources of corn in the digestibility of P. The reason for the greater ATTD of P in DDGS compared with corn may be that some of the bonds that bind P to the phytate complex in corn have been hydrolyzed during the fermentation process in the ethanol plants. This would make more P available for absorption and result in greater values for the ATTD of P in DDGS compared with corn. As a consequence, the utilization of organic P is increased, and the need for supplemental

Table 7. Apparent total tract digestibility (ATTD) of GE, N, and P in the corn and 10 sources of distillers dried grain with solubles (DDGS)[1]

		DDGS source										DDGS[2]		DDGS-corn[3]	
Item (%)	Corn	1	2	3	4	5	6	7	8	9	10	SEM	*P*-value	SEM	*P*-value
ATTD of GE	90.4	76.1[xy]	76.2[xy]	75.6[x]	76.1[xy]	73.9[x]	74.7[x]	74.0[x]	79.0[yz]	80.0[vz]	82.8[v]	1.36	0.001	1.17	0.001
ATTD of N	81.5	85.6[vw]	84.0[vz]	84.0[zv]	81.8[yz]	83.1[z]	80.2[y]	77.1[x]	82.3[yz]	84.4[v]	87.5[w]	1.05	0.001	0.97	0.23
ATTD of P	19.3	59.1[yz]	55.6[xyz]	59.8[yz]	62.4[vz]	52.7[xy]	60.0[yz]	50.1[x]	61.3[vz]	61.4[vz]	68.3[v]	3.35	0.001	2.97	0.001

[v–z]Values within a row and DDGS source lacking a common superscript letter are different ($P < 0.05$).
[1]n = 11.
[2]Comparison of the 10 diets containing DDGS.
[3]Values for the corn diet vs. all DDGS-containing diets.

inorganic P is reduced if DDGS is included in formulations at the expense of corn.

The lack of good correlations between L*, a*, and b* values and the DE and ME in DDGS suggests that color is not a good predictor of the energy value in DDGS, and the differences in DE and ME among samples of DDGS seem to be caused by factors that do not influence the color of the samples. It has been suggested that the color of DDGS may be negatively correlated with the digestibility of some AA (Cromwell et al., 1993; Fastinger and Mahan, 2006). This observation is believed to be a consequence of overheating of DDGS and subsequent Maillard reactions, because the Maillard reaction does not only reduce the digestibility of some AA, but also causes browning reactions in the product. The current data suggesting that color does not correlate with the concentrations of DE and ME in DDGS indicate that the Maillard reaction does not influence energy digestibility.

It has been suggested that the ability of pigs to digest and metabolize energy increases as pigs become older (Noblet et al., 1994). Older pigs have an increased microbial population in the hindgut that enables them to increase fermentation and thus absorb more energy in the form of short-chained fatty acids. In the current experiment, pigs were fed experimental diets over a 22-wk period to obtain values for DE and ME that are representative of the entire growing period. The tendencies for positive linear effects of period on DE and ME of DDGS indicate that improved fermentation may have taken place as pigs became older. However, there were no effects of period on the DE and ME in corn. The reason for this difference between corn and DDGS is most likely that the main energy-contributing component in corn is starch that is easily digested in the small intestine with a subsequent absorption of glucose. In contrast, DDGS contains greater quantities of nonstarch polysaccharides that are fermented by microbes in the hindgut before animals can utilize the energy in these components by absorbing short-chained fatty acids. The current data indicate that the digestibility of energy in growing pigs is increased with age if the diet contains significant quantities of nonstarch polysaccharides.

The prediction equations for DE and ME showed that if the concentrations of ash, ether extract, ADF, and GE are known in DDGS, then the DE and ME can be calculated with relatively high accuracy. This observation is consistent with findings for barley by Fairbairn et al. (1999), in which a prediction equation with an r^2 of 0.89 for DE was reported if the same 4 variables were used.

In conclusion, results from the current experiment indicate that the DE and ME in DDGS may vary among sources, but they can be predicted from the concentrations of ash, ether extract, ADF, and GE. On average,

Table 8. Prediction equations for DE and ME in dried distillers grain with solubles (DDGS)[1]

Equation	r^2	*P*-value
DE		
$Y = -12{,}766 - (76.90 \times \text{ash}) + (34.92 \times \text{CP}) - (10.88 \times \text{starch}) - (123.69 \times \text{EE}) - (164.36 \times \text{ADF}) + (9.78 \times \text{NDF}) + (3.540 \times \text{GE})$	0.99	0.025
$Y = -12{,}220 - (111.21 \times \text{ash}) + (26.52 \times \text{CP}) - (10.35 \times \text{starch}) - (127.05 \times \text{EE}) - (154.95 \times \text{ADF}) + (3.550 \times \text{GE})$	0.99	0.004
$Y = -12{,}637 - (128.27 \times \text{ash}) + (25.38 \times \text{CP}) - (115.72 \times \text{EE}) - (138.02 \times \text{ADF}) + (3.569 \times \text{GE})$	0.99	0.001
$Y = -9{,}929 - (180.38 \times \text{ash}) - (106.82 \times \text{EE}) - (120.44 \times \text{ADF}) + (3.202 \times \text{GE})$	0.96	0.001
ME		
$Y = -10{,}866 - (108.12 \times \text{ash}) + (37.55 \times \text{CP}) - (8.04 \times \text{starch}) - (71.78 \times \text{EE}) - (164.99 \times \text{ADF}) + (15.91 \times \text{NDF}) + (3.007 \times \text{GE})$	0.99	0.021
$Y = -11{,}128 - (124.99 \times \text{ash}) + (35.76 \times \text{CP}) - (63.40 \times \text{EE}) - (150.92 \times \text{ADF}) + (14.85 \times \text{NDF}) + (3.023 \times \text{GE})$	0.99	0.003
$Y = -10{,}267 - (175.78 \times \text{ash}) + (23.09 \times \text{CP}) - (71.22 \times \text{EE}) - (137.93 \times \text{ADF}) + (3.036 \times \text{GE})$	0.99	0.001
$Y = -7{,}803 - (223.19 \times \text{ash}) - (61.30 \times \text{EE}) - (121.94 \times \text{ADF}) + (2.702 \times \text{GE})$	0.97	0.001
$Y = -4{,}212 - (266.38 \times \text{ash}) - (108.35 \times \text{ADF}) + (1.911 \times \text{GE})$	0.94	0.001

[1]Units for GE are kcal·kg^{-1} of DM; units for nutrients are % of DM. EE = ether extract.

values for DE and ME of 4,140 and 3,897 kcal/kg of DM, respectively, were measured. These values are not different from the values obtained in corn. Therefore, if DDGS replaces corn in diets fed to swine, the energy concentration in the diet will not be affected. The ATTD of P in DDGS was measured at 59.1%. This value is much higher than in corn, and the need for supplemental inorganic phosphate is reduced if DDGS is included in the formula.

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