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Energy, phosphorus, and amino acid digestibility of high-protein distillers dried grains and corn germ fed to growing pigs[1]

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ABSTRACT: Three experiments were conducted to measure energy, P, and AA digestibility in 2 novel co-products from the ethanol industry [i.e., high-protein distillers dried grains (HP DDG) and corn germ]. These products are produced by dehulling and degerming corn before it enters the fermentation process. Experiment 1 was an energy balance experiment conducted to measure DE and ME in HP DDG, corn germ, and corn. Six growing pigs (initial BW, 48.9 ± 1.99 kg) were placed in metabolism cages and fed diets based on corn, corn and HP DDG, or corn and corn germ. Pigs were allotted to a replicated, 3 × 3 Latin square design. The DE and ME in corn (4,056 and 3,972 kcal/kg of DM, respectively) did not differ from the DE and ME in corn germ (3,979 and 3,866 kcal/kg of DM, respectively). However, HP DDG contained more ($P < 0.05$) energy (4,763 kcal of DE/kg of DM and 4,476 kcal of ME/kg of DM) than corn or corn germ. Experiment 2 was conducted to measure apparent total tract digestibility (ATTD) and true total tract digestibility of P in HP DDG and corn germ. Thirty growing pigs (initial BW, 33.2 ± 7.18 kg) were placed in metabolism cages and fed a diet based on HP DDG or corn germ. A P-free diet was used to measure endogenous P losses. Pigs were assigned to treatments in a randomized complete block design, with 10 replications per treatment. The ATTD and the retention of P were calculated for the diets containing HP DDG and corn germ, and the endogenous loss of P was estimated from pigs fed the P-free diet. The ATTD was lower ($P < 0.05$) in corn germ (28.6%) than in the HP DDG (59.6%). The retention of P was also lower ($P < 0.05$) in pigs fed corn germ (26.7%) than in pigs fed HP DDG (58.9%). The endogenous loss of P was estimated to be 211 ± 39 mg per kg of DMI. The true total tract digestibility of P for HP DDG and corn germ was calculated to be 69.3 and 33.7%, respectively. In Exp. 3, apparent ileal digestibility and standardized ileal digestibility values of CP and AA in HP DDG and corn germ were measured using 6 growing pigs (initial BW, 78.2 ± 11.4 kg) allotted to a replicated, 3 × 3 Latin square design. The apparent ileal digestibility for CP and all AA except Arg and Pro, and the standardized ileal digestibility for CP and all AA except Arg, Lys, Gly, and Pro were greater ($P < 0.05$) in HP DDG than in corn germ. It was concluded that HP DDG has a greater digestibility of energy, P, and most AA than corn germ.

Key words: amino acid, corn germ, digestibility, energy, high-protein distillers dried grain, pig

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INTRODUCTION

There has been a rapid increase in ethanol production in recent years, which in turn has led to an increase in the production of distillers dried grains with solubles (**DDGS**). In 2006, there were 143 ethanol plants in production or under construction in the United States, and 9 million metric tons of DDGS were produced in 2005 (Renewable Fuels Association, 2006). As a result of the increase in DDGS production, the quantity of DDGS used in swine diets has increased.

The Broin Companies (Sioux Falls, SD) have introduced a novel biorefining ethanol technology called BFrac. This new process dehulls and degerms the corn before it enters the fermentation process. The distillers dried grains (**DDG**) that are produced as a result of this process are not mixed with the solubles, as is the case when DDGS are produced. The solubles are added to the corn hulls and marketed to the ruminant feed industry, and the DDG are dried separately. The DDG contains more protein and less fat, ADF, NDF, and P than DDGS and are called high-protein distillers dried grains (**HP DDG**). The reason for the changed composi-

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Table 1. Analyzed nutrient composition of the dietary ingredients (as-fed basis)

Item	Corn[1]	HP DDG[2]	Corn germ[2]
	Ingredient		
Ingredient			
DM, %	88.00	92.40	92.20
CP, %	7.20	41.10	14.00
Starch, %	55.70	11.20	23.60
Crude fat, %	3.30	3.70	17.60
ADF, %	2.50	8.70	5.60
NDF, %	9.0	16.40	20.40
Ash, %	3.30	3.20	3.30
Ca, %	—	0.01	0.03
P, %	—	0.37	1.09
GE, kcal/kg	3,890	4,989	4,919
Indispensable AA, %			
Arg	—	1.54	1.08
His	—	1.14	0.41
Ile	—	1.75	0.45
Leu	—	5.89	1.06
Lys	—	1.23	0.79
Met	—	0.83	0.25
Phe	—	2.29	0.57
Thr	—	1.52	0.51
Trp	—	0.21	0.12
Val	—	2.11	0.71
Dispensable AA, %			
Ala	—	3.17	0.91
Asp	—	2.54	1.05
Cys	—	0.78	0.29
Glu	—	7.11	1.83
Gly	—	1.38	0.76
Pro	—	3.68	0.92
Ser	—	1.85	0.56
Tyr	—	1.91	0.41

[1]AA, Ca, and P were not analyzed in corn.
[2]HP DDG = high-protein distillers dried grains. Both HP DDG and corn germ were from The Broin Companies (Sioux Falls, SD).

Table 2. Composition of diets (as-fed basis), Exp. 1

Item	Corn	HP DDG	Corn germ
	Diet		
Ingredient, %			
Corn	97.60	50.00	50.00
HP DDG[1]	—	47.70	—
Corn germ[1]	—	—	47.80
Dicalcium phosphate	1.00	0.65	—
Limestone	0.80	1.05	1.60
Salt	0.40	0.40	0.40
Vitamin premix[2]	0.05	0.05	0.05
Micromineral premix[3]	0.15	0.15	0.15
Energy and CP, analyzed			
GE, kcal/kg	3,798	4,347	4,305
CP, %	7.10	24.10	9.70

[1]HP DDG = high-protein distillers dried grains. Both HP DDG and corn germ were from The Broin Companies (Sioux Falls, SD).
[2]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as retinyl 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 bisulfite; thiamin, 3.3 mg as thiamine mononitrate; riboflavin, 9.4 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.
[3]Provided the following quantities of microminerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; and Zn, 99 mg as zinc oxide.

tion of HP DDG compared with DDGS is that much of the fiber is removed during dehulling, whereas the fat and P largely remain with the germ fraction. In addition, the concentration of fat and P is greater in solubles than in DDG, so DDGS would be expected to contain more fat and P than DDG.

The last coproduct of the BFrac technology is corn germ. This product has a greater concentration of CP, fat, ADF, NDF, and P than corn and is a potential feed ingredient for swine (Table 1). However, no data are available on the digestibility of energy and nutrients in HP DDG and corn germ.

Therefore, the objective of these experiments was to measure digestibility values for energy, CP, P, and AA in HP DDG and corn germ that were fed to growing pigs.

MATERIALS AND METHODS

General

The Institutional Animal Care and Use Committee at South Dakota State University reviewed and approved the experiments. Three experiments were conducted. Pigs used in the experiments were the offspring of SP-1 boars and Line 13 sows (Ausgene Intl. Inc., Gridley, IL).

Exp. 1

Experiment 1 was designed to measure DE and ME and N digestibility of HP DDG and corn germ in growing pigs. Six growing barrows (initial BW, 48.9 ± 1.99 kg) were placed in metabolism cages and allotted to a replicated, 3 × 3 Latin square design, with 3 periods and 3 pigs per square. A feeder and a nipple drinker were installed in each cage.

Three corn-based diets were prepared (Table 2). The first contained 97.6% (as-fed basis) corn. The second diet contained 50.0% corn and 47.7% HP DDG, and the third diet contained 50.0% corn and 47.8% corn germ. Vitamins and minerals were included in all diets to meet or exceed the estimated nutrient requirements for growing pigs (NRC, 1998).

Feed was supplied to the pigs at a daily level of 2.5 times the estimated maintenance requirement for energy (i.e., 106 kcal of ME/kg of $BW^{0.75}$; NRC, 1998). The ME was calculated to be 3,338, 3,494, and 3,710 kcal of ME per kg (as-fed basis) in the corn diet, HP DDG diet, and corn germ diet, respectively, based on the NRC (1998) values for ME in corn and the ME values in HP DDG and corn germ from the supplier of these products. The daily allotment of feed was divided into 2 equal meals and was fed at 0800 and 1700. Each pig was fed each of the 3 diets during one experimental period. Water was available at all times.

Pigs were weighed at the beginning of each period and the amount of feed supplied each day was recorded. The pigs were allowed a 5-d adaptation period to their assigned diet. Chromic oxide (0.5%) and ferric oxide (0.5%) were added to the diet in the morning meals on d 6 and 11, respectively. Fecal collections commenced when chromic oxide first appeared in the feces after d 6 and collection ceased when ferric oxide appeared in the feces after d 11 as previously described (Adeola, 2001). Feces were collected twice daily and stored at −20°C until the end of the period. Urine collection was initiated on d 6 at 1700 and ceased on d 11 at 1700. Urine buckets were placed under the metabolism cages, which allowed for total collection. The buckets were emptied in the morning and afternoon and a preservative of 50 mL of 6 *N* sulfuric acid was added to each bucket when they were emptied. All collected urine samples were weighed and a 20% subsample was collected and stored at −20°C. At the end of the experiment, urine and fecal samples were thawed and mixed within animal and diet, and a subsample was taken for chemical analysis. Fecal samples were dried in a forced-air oven and ground before the subsample was collected.

All samples were analyzed in duplicate. Fecal samples, diets, and feed ingredients were analyzed for DM (procedure 930.15; AOAC, 2005). Fecal samples, urine, diets, and feed ingredients were analyzed for Kjeldahl N (Thiex et al., 2002) and for GE by bomb calorimetry (Parr Instruments, Moline, IL). The energy that was excreted in the feces and in the feces and urine, respectively, were subtracted from the intake of GE to calculate the DE and ME for each diet (Adeola, 2001). The DE and ME in the corn diet was then divided by 0.976 to calculate the DE and ME in corn. By subtracting the contribution of corn to the HP DDG and the corn germ diets from the energy that was measured in each of these diets, the concentrations of DE and ME in HP DDG and corn were calculated by using the difference procedure (Adeola, 2001). By further correcting these values for DM in corn, HP DDG, and corn germ (85.95, 92.43, and 92.24%, respectively), the DE and ME in the ingredient DM were calculated. The digestibility of N for each diet and each feed ingredient was calculated using a similar approach.

Data were analyzed by ANOVA using the PROC MIXED procedure (Littell et al., 1996; SAS Inst. Inc., Cary, NC). Homogeneity of the variance was verified using the UNIVARIATE procedure of SAS. The residual vs. predicted plot procedure was used to check for outliers in the data. An ANOVA was conducted, with diet as the main effect and period as the random effect. Treatment means were separated by using the LSMEANS statement and the PDIFF option of PROC MIXED. Pig was the experimental unit and an alpha level of 0.05 was used to assess significance among means.

Table 3. Composition of diets (as-fed basis), Exp. 2

Item	Diet		
	HP DDG	Corn germ	P-free
Ingredient, %			
HP DDG[1]	60.00	—	—
Corn germ[1]	—	42.50	—
Sugar	15.00	15.00	20.00
Soybean oil	3.00	—	4.00
Gelatin[2]	—	10.00	20.00
Solka floc[3]	—	—	4.00
Limestone	1.20	1.55	0.80
L-Lys·HCl	0.24	0.06	—
DL-Met	—	0.02	0.27
L-Thr	—	0.10	0.08
L-Trp	0.01	—	0.14
L-His	—	—	0.08
L-Ile	—	—	0.16
L-Val	—	—	0.05
Salt	0.40	0.40	0.40
Vitamin premix[4]	0.05	0.05	0.05
Micromineral premix[5]	0.15	0.15	0.15
Potassium carbonate	—	—	0.40
Magnesium oxide	—	—	0.10
Cornstarch	19.95	30.17	49.32
Nutrient, analyzed			
Ca, %	0.38	0.44	0.26
P, %	0.23	0.50	—

[1]HP DDG = high-protein distillers dried grains. Both HP DDG and corn germ were from The Broin Companies (Sioux Falls, SD).
[2]Gelita Gelatine US Inc. (Sioux City, IA).
[3]Fiber Sales and Development Corp. (Urbana, OH).
[4]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as retinyl 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 bisulfite; thiamine, 3.3 mg as thiamine mononitrate; riboflavin, 9.4 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.
[5]Provided the following quantities of microminerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; and Zn, 99 mg as zinc oxide.

Exp. 2

Experiment 2 was designed to measure apparent (**ATTD**) and true (**TTTD**) total tract digestibility values for P, ATTD for Ca, and Ca and P balances in pigs fed diets based on HP DDG and corn germ. Thirty growing barrows (initial BW, 33.2 ± 7.18 kg) were placed in metabolism cages in a randomized complete block design with 3 diets and 10 pigs per diet. The metabolism cages were similar to those used in Exp. 1.

Three diets were prepared (Table 3). The first diet contained HP DDG at a concentration of 60% (as-fed basis), whereas the second diet contained corn germ in the amount of 42.5% (as-fed basis). Corn germ and HP DDG were the only P-containing ingredients in these diets. The last diet, a P-free diet, was used to estimate basal endogenous losses of P (Petersen and Stein, 2006). Vitamins and microminerals were included in all diets to meet or exceed estimated nutrient requirements for growing pigs (NRC, 1998). Limestone was included at a concentration of 1.20% in the HP DGG diet, 1.55% in the corn germ diet, and 0.80% in the P-free diet. Soybean oil was added to the HP DDG diet (3.00%) and to the P-free diet (4.00%), but because of the high fat concentration in corn germ, no oil was added to the corn germ diet. Sugar was added at 15.00% in the HP DDG and corn germ diets and 20.00% in the P-free diet to increase palatability. A pork gelatin with a bloom of 100 (Gelita Gelatine US Inc., Sioux City, IA) was added to the corn germ diet and to the P-free diet at 10.00 and 20.00%, respectively, to increase the concentration of AA. Crystalline AA were used as needed to ensure that all diets met current AA requirement estimates (NRC, 1998). Solka floc, a synthetic source of fiber (Fiber Sales and Development Corp., Urbana, OH), was included in the P-free diet (4.00%) to increase the concentration of crude fiber. The ingredients in the P-free diet contained no K and Mg; therefore, these minerals were supplied in the form of potassium carbonate (0.40%) and magnesium oxide (0.10%), respectively.

Feed was supplied to the pigs at a daily level of 2.5 times the estimated maintenance requirement for energy. The ME was calculated to be 3,654, 3,491, and 3,452 kcal of ME per kg (as-fed basis) in the HP DDG diet, corn germ diet, and P-free diet, respectively. The daily allotment of feed was divided into 2 equal meals and fed at 0800 and 1700 each day. Water was available at all times through a nipple drinker.

Diets were fed for 14 d, with the initial 7 d being an adaptation period, and fecal matter and urine were collected during the following 5 d as described for Exp. 1. All samples were stored, dried, and processed as described for Exp. 1. All samples were analyzed in duplicate. Fecal samples, diets, and feed ingredients were analyzed for DM (procedure 930.15; AOAC, 2005). Concentrations of Ca were determined in fecal matter, urine, diets, and feed ingredients using an atomic absorption spectrophotometer (procedure 4.8.03; AOAC, 2000), and P was determined in these samples using a spectrophotometer (procedure 3.4.11; AOAC, 2000). The ATTD, retention, endogenous losses, and TTTD of P were calculated as outlined previously (Petersen and Stein, 2006).

Data were analyzed as explained for Exp. 1, but 2 models were used. In the first model, all means except data for P digestibility, P absorption, and P retention were compared among all 3 diets. In the second model, means for P digestibility, P absorption, and P retention were compared between HP DDG and corn germ.

Exp. 3

Experiment 3 was designed to measure apparent (**AID**) and standardized (**SID**) ileal digestibility values for AA in HP DDG and corn germ by growing pigs. Six growing barrows (initial BW, 78.2 ± 11.4 kg) were equipped with a T-cannula in the distal ileum according to procedures adapted from Stein et al. (1998). Pigs were placed in a replicated 3 × 3 Latin square design with 3 periods and 3 pigs per square. Pigs were allowed a 2-wk recovery period following the surgery before the experiment was initiated. During that period, a standard corn- and soybean meal-based grower diet (18% CP) was provided. Pigs were housed individually in 1.2 × 1.8-m pens in an environmentally controlled building (22°C). A feeder and a nipple drinker were installed in each pen.

Table 4. Ingredient composition of diets (as-fed basis), Exp. 3

	Diet		
Ingredient, %	HP DDG	Corn germ	N-free
HP DDG[1]	50.00	—	—
Corn germ[1]	—	50.00	—
Sugar	35.00	35.00	20.00
Soybean oil	3.00	3.00	3.00
Solka floc[2]	—	—	3.00
Chromic oxide	0.40	0.40	0.40
Dicalcium phosphate	1.65	—	2.75
Limestone	0.75	1.85	0.20
Salt	0.40	0.40	0.40
Vitamin premix[3]	0.05	0.05	0.05
Micromineral premix[4]	0.15	0.15	0.15
Potassium carbonate	—	—	0.40
Magnesium oxide	—	—	0.10
Cornstarch	8.60	9.15	69.55

[1]HP DDG = high-protein distillers dried grains. Both HP DDG and corn germ were from The Broin Companies (Sioux Falls, SD).

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

[3]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as retinyl 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 bisulfite; thiamin, 3.3 mg as thiamine mononitrate; riboflavin, 9.4 mg; pyridoxine, 3.3 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; and biotin, 0.17 mg.

[4]Provided the following quantities of microminerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; and Zn, 99 mg as zinc oxide.

Three diets were prepared (Tables 4 and 5). The first diet contained HP DDG at a concentration of 50% (as-fed basis), whereas the second diet contained corn germ in the amount of 50% (as-fed basis). Corn germ and HP DDG were the only AA-containing ingredients in these diets. The last diet was an N-free diet used to estimate basal endogenous losses of CP and AA. Soybean oil was included in all diets at 3%. Sugar was included at 35% in the HP DDG and corn germ diets and at 20% in the N-free diet to increase palatability. Chromic oxide (0.4%) was included in all diets as an indigestible marker. Solka floc was included in the N-free diet (3%) to increase the concentration of crude fiber. The feed ingredients that were included in the N-free diet contained no K and Mg; therefore, these minerals were supplied in the form of potassium carbonate and magnesium oxide, respectively. Vitamins and microminerals were included in all diets to meet or exceed estimated nutrient requirements for growing pigs (NRC, 1998).

Table 5. Analyzed nutrient composition of diets (as-fed basis), Exp. 3

	Diet		
Item	HP DDG[1]	Corn germ	N-Free
DM, %	94.90	95.30	92.40
CP, %	20.60	6.91	0.28
Indispensable AA, %			
Arg	0.74	0.51	—
His	0.55	0.20	—
Ile	0.83	0.22	—
Leu	2.88	0.53	0.01
Lys	0.61	0.37	0.01
Met	0.39	0.11	—
Phe	1.10	0.28	0.01
Thr	0.76	0.26	—
Trp	0.10	0.07	<0.04
Val	1.01	0.35	0.01
Dispensable AA, %			
Ala	1.58	0.45	0.01
Asp	1.29	0.53	0.01
Cys	0.38	0.14	—
Glu	3.71	0.95	0.02
Gly	0.68	0.37	—
Pro	1.81	0.43	0.01
Ser	0.90	0.28	—
Tyr	0.85	0.20	—

[1]HP DDG = high-protein distillers dried grains.

Feed was supplied to the pigs at a daily level of 3 times the estimated maintenance requirement for energy. The ME was calculated to be 3,534, 3,775, and 3,751 kcal of ME per kg (as-fed basis) in the HP DDG diet, the corn germ diet, and the N-free diet, respectively. The daily allotment of feed was divided into 2 equal meals and fed at 0800 and 1700 each day. Water was available at all times through a nipple drinker.

Pigs were weighed at the beginning of each period and the amount of feed supplied each day was recorded. Each experimental period lasted 7 d. The initial 5 d of each period were an adaptation period to the diet, whereas the remaining 2 d were used for digesta collections in 9-h periods as described by Stein et al. (1999). Briefly, a 225-mL plastic bag was attached to the cannula barrel by using a cable tie, and digesta that flowed into the bag were collected. Bags were removed whenever they were filled with digesta, or at least once every 30 min. They were then stored at −20°C to prevent bacterial degradation of AA in the digesta.

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a subsample was taken for chemical analysis. All digesta samples were lyophilized and finely ground before chemical analysis. All samples were analyzed in duplicate. Dry matter was analyzed in samples of digesta, diets, and feed ingredients (procedure 930.15; AOAC, 2005). Amino acids were analyzed in HP DDG, corn germ, all diets, and ileal samples on a Beckman 6300 Amino Acid Analyzer (Beckman Instruments Corp., Palo Alto, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6 *N* HCl for 24 h at 110°C (procedure 994.12; AOAC, 2005). Methionine and Cys were determined as methionine sulfone and cysteic acid after cold perfomic acid oxidation before hydrolysis (procedure 994.12, alternative 3; AOAC, 2005). Tryptophan was determined after hydrolysis with NaOH for 22 h at 110°C (procedure 988.15, alternative 1; AOAC, 2005). The Cr concentrations in digesta and diets were determined according to the procedure of Fenton and Fenton (1979).

Values for AID, endogenous losses, and SID for CP and AA in the diets containing HP DDG or corn germ were calculated as described by Stein et al. (2007). These values also represented the digestibility for HP DDG and corn germ, respectively. Data were analyzed as outlined for Exp. 1.

RESULTS

Energy Digestibility

There was no difference in the GE intake among pigs fed the experimental diets (Table 6). The fecal excretion of energy did not differ between pigs fed the corn and the HP DDG diets (533 and 682 kcal, respectively), but pigs fed the corn germ diet (1,109 kcal) had a greater ($P < 0.01$) fecal excretion of energy. Pigs fed the corn and corn germ diets did not differ in excretion of energy in the urine; however, pigs fed the HP DDG diet had a greater ($P < 0.01$) excretion of energy than those fed the other diets. Consequently, DE and ME were greater ($P < 0.01$) in the HP DDG diet compared with the corn or the corn germ diet. The ATTD for GE did not differ between the corn and the HP DDG diets (89.6 and 88.4%, respectively); however, the corn germ diet had a lower ($P < 0.01$) ATTD for GE (81.2%) than the other 2 diets.

Nitrogen intake and urinary excretion of N did not differ between pigs fed the corn (18.7 and 7.6 g, respectively) and the corn germ (23.9 and 8.2 g, respectively) diets. However, pigs fed the HP DDG diet had a greater ($P < 0.001$) N intake and urinary excretion of N than pigs fed the other 2 diets (57.7 and 23.3 g, respectively). Pigs fed the HP DDG and corn germ diets did not differ in fecal excretion of N; however, pigs fed the corn diet had a lower ($P < 0.05$) fecal excretion of N compared with pigs fed the other 2 diets. The ATTD for N did not differ between the corn and the corn germ diets, but these values were greater ($P < 0.001$) for the HP DDG diet than for the other diets.

Pigs fed corn germ had a greater ($P < 0.01$) fecal excretion of energy (836 kcal) compared with the fecal excretion of energy from pigs fed corn (546 kcal) or HP DDG (409 kcal) when the values for each ingredient were calculated by difference (Table 7). Pigs fed corn and corn germ did not differ in urinary excretion of energy; however, pigs fed HP DDG had a greater ($P < 0.05$) excretion of energy in the urine than pigs fed the other ingredients (92, 73, and 173 kcal, respectively).

Table 6. Daily energy and nitrogen balance of experimental diets (as-fed basis; Exp. 1)[1]

Item	Diet			SEM	*P*-value
	Corn	HP DDG[2]	Corn germ		
GE intake, kcal	5,391	5,789	5,915	492.28	0.551
GE in feces, kcal	532.5^{x}	681.7^{x}	1,108.9^{y}	57.08	<0.001
GE in urine, kcal	89.7^{x}	219.3^{y}	118.7^{x}	24.10	0.004
DE in diet, kcal/kg	3,402^{x}	3,843^{y}	3,497^{x}	32.79	<0.001
ME in diet, kcal/kg	3,332^{x}	3,680^{y}	3,411^{x}	39.93	<0.001
Apparent total tract digestibility of GE, %	89.6^{y}	88.4^{y}	81.2^{x}	0.82	<0.001
N intake, g	18.7^{x}	57.7^{y}	23.9^{x}	3.09	<0.001
N in feces, g	3.0^{x}	5.5^{y}	4.3^{y}	0.46	0.002
N in urine, g	7.6^{x}	23.3^{y}	8.2^{x}	2.48	<0.001
Apparent total tract digestibility of N, %	82.7^{x}	90.6^{y}	81.9^{x}	1.73	0.005

^{x,y}Values within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data represent means of 6 observations per treatment.
[2]HP DDG = high-protein distillers dried grains.

The DE and ME did not differ between corn and corn germ, but HP DDG had greater ($P < 0.01$) values for DE and ME than the other ingredients (4,056, 3,979, and 4,763 kcal DE/kg of DM; 3,972, 3,866, and 4,476 kcal ME/kg of DM for corn, corn germ, and HP DDG, respectively). The ATTD for GE was lower ($P < 0.01$) in corn germ (74.6%) than in corn (89.6%) and HP DDG (88.2%).

Nitrogen intake and urinary excretion of N from corn (19.2 and 7.8 g, respectively) and corn germ (14.3 and 4.3 g, respectively) were not different, but N intake and urinary losses from HP DDG (48.1 and 19.5 g, respectively) were greater ($P < 0.01$) than from the other ingredients. There was no difference in fecal N excretion among pigs fed the 3 experimental diets (3.1, 4.0, and 2.8 g for pigs fed corn, HP DDG, and corn germ, respectively). Pigs fed HP DDG had greater ($P < 0.01$) ATTD of N (92.0%) than pigs fed corn (82.7%) or corn germ (80.3%).

Phosphorus Digestibility

Feed intake did not differ between pigs fed the HP DDG (825 g) and the P-free (900 g) diets, but intake of the corn germ diet (671 g) was lower ($P < 0.05$) than for the other diets (Table 8). Pigs fed the HP DDG and corn germ diets did not differ in Ca intake; however, pigs fed the P-free diet had a lower ($P < 0.05$) intake of Ca than pigs fed the other 2 diets (3.38, 3.37, and 2.58 g, respectively). Phosphorus intake was lower ($P < 0.01$) for pigs fed the HP DDG diet compared with pigs fed the corn germ diet (2.09 vs. 3.82 g).

Calcium in the feces and P in the urine did not differ between pigs fed the HP DDG and the P-free diets, but pigs fed the corn germ diet had greater losses ($P < 0.05$) compared with pigs fed the other diets. Fecal excretion of P was lower ($P < 0.01$) from pigs fed the HP DDG diet compared with pigs fed the corn germ diet (0.82 vs. 2.74 g), but pigs fed the P-free diet had the lowest

Table 7. Daily energy and N balance of corn, high-protein distillers dried grains (HP DDG), and corn germ (as-fed basis), Exp. 1[1]

Item	Ingredient			SEM	*P*-value
	Corn	HP DDG	Corn germ		
GE intake, kcal	5,523^{y}	3,027^{x}	3,154^{x}	590.85	<0.001
GE in feces, kcal	545.6^{x}	408.9^{x}	836.1^{y}	59.12	<0.001
GE in urine, kcal	91.9^{x}	173.4^{y}	72.8^{x}	21.97	0.013
DE of ingredient, kcal/kg	3,486^{x}	4,403^{y}	3,670^{x}	62.30	<0.001
DE, ingredient, kcal/kg of DM	4,056^{x}	4,763^{y}	3,979^{x}	68.31	<0.001
ME, ingredient, kcal/kg	3,414^{x}	4,137^{y}	3,566^{x}	69.82	<0.001
ME, ingredient, kcal/kg, DM	3,972^{x}	4,476^{y}	3,866^{x}	76.93	<0.001
Apparent total tract digestibility of GE, %	89.6^{y}	88.2^{y}	74.6^{x}	1.32	<0.001
N intake, g	19.2^{x}	48.1^{y}	14.3^{x}	3.11	<0.001
N in feces, g	3.1	4.0	2.8	0.46	0.115
N in urine, g	7.8^{x}	19.5^{y}	4.3^{x}	2.48	0.002
Apparent total tract digestibility of N, %	82.7^{x}	92.0^{y}	80.3^{x}	1.86	<0.001

^{x,y}Values within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data represent means of 6 observations per treatment.

Table 8. Daily balance and apparent total tract digestibility (ATTD) of P and Ca and true total tract digestibility (TTTD) of P in high-protein distillers dried grains (HP DDG) and corn germ (Exp. 2)[1]

	Diet				
Item	HP DDG	Corn germ	P-free	SEM	*P*-value
Feed intake, g of DM	824.89[y]	671.16[x]	899.55[y]	49.652	0.012
P intake, g	2.09[x]	3.82[y]	—	0.107	<0.001
P in feces, g	0.82[y]	2.74[z]	0.19[x]	0.099	<0.001
P in urine, g	0.02[x]	0.07[y]	0.01[x]	0.015	0.018
P absorption, g	1.27	1.09	—	0.106	0.231
P retention, g	1.26	1.02	—	0.106	0.126
ATTD of P, %	59.63[y]	28.60[x]	—	2.628	<0.001
TTTD of P,[2] %	69.32[y]	33.72[x]	—	2.515	<0.001
P retention, %	58.91[y]	26.71[x]	—	2.624	<0.001
Ca intake, g	3.38[y]	3.37[y]	2.58[x]	0.169	0.003
Ca in feces, g	0.83[x]	2.19[y]	0.59[x]	0.146	<0.001
Ca in urine, g	0.77[y]	0.21[x]	1.55[z]	0.095	<0.001
Ca absorption, g	2.55[y]	1.18[x]	1.99[y]	0.210	<0.001
Ca retention, g	1.78[y]	0.97[x]	0.43[x]	0.226	<0.001
Ca retention, %	52.60[y]	28.92[x]	14.15[x]	7.126	0.003
ATTD of Ca, %	74.96[y]	35.19[x]	75.83[y]	5.108	<0.001

[x–z]Values within a row lacking a common superscript letter are different ($P < 0.05$).
[1]Data represent means of 10 observations per treatment.
[2]Values were calculated by correcting ATTD for the basal endogenous loss (211 mg per kg of DMI) that was calculated for pigs fed the P-free diet.

($P < 0.01$) excretion of P (0.19 g). Calcium excretion in urine differed ($P < 0.01$) among treatments (0.77, 0.21, and 1.55 g for pigs fed HP DDG, corn germ, and the P-free diet, respectively).

Pigs fed the corn germ diet had a lower ($P < 0.01$) ATTD of Ca (35.19%) compared with the ATTD of Ca from pigs fed the HP DDG (74.96%) or the P-free diet (75.83%). The ATTD and TTTD of P were greater ($P < 0.01$) in the HP DDG diet (59.63 and 69.32%, respectively) than in the corn germ diet (28.60 and 33.72%, respectively). The basal endogenous loss of P was estimated from pigs fed the P-free diet at 211 ± 39 mg per kg of DMI.

The absorption of Ca was lower ($P < 0.05$) in pigs fed the corn germ diet (1.18 g) than in pigs fed the HP DDG (2.55 g) or the P-free (1.99 g) diets. The retention of Ca was greater ($P < 0.05$) for pigs fed the HP DDG diet (1.78 g) than for pigs fed the corn germ (0.97 g) or the P-free (0.43 g) diets. When Ca retention was calculated to be a percentage of Ca intake, pigs fed the HP DDG diet had a greater ($P < 0.05$) retention (52.60%) than pigs fed the corn germ (28.92%) or the P-free (14.15%) diets.

The P absorption and P retention in grams per day did not differ between pigs fed the HP DDG and corn germ diets. When P retention was calculated as a percentage of P intake, pigs fed the HP DDG diet had a greater ($P < 0.01$) retention (58.91%) than pigs fed the corn germ diet (26.71%).

AA Digestibility

The AID and SID for CP and AA in HP DDG and corn germ are presented in Table 9. The AID for CP was greater ($P < 0.05$) in HP DDG than in corn germ (72 vs. 33%). The AID for all indispensable AA except Arg were also greater ($P < 0.05$) for HP DDG than for corn germ. For Lys, AID values of 57 and 47% were obtained for HP DDG and corn germ, respectively, but for Met, Thr, and Trp, values of 86 vs. 61, 70 vs. 34, and 71 vs. 53% were obtained for HP DDG and corn germ, respectively. Likewise, the AID values for all dispensable AA except Pro were greater ($P < 0.05$) for HP DDG than for corn germ.

The SID for CP in HP DDG was greater ($P < 0.05$) than in corn germ (80 vs. 56%). The SID values for Arg (83 vs. 83%) and for Lys (64 vs. 58%) were similar for HP DDG and corn germ. However, for Met (88 vs. 68%), Thr (77 vs. 53%), Trp (81 vs. 67%), and all other indispensable AA, SID values were greater ($P < 0.05$) for HP DDG than for corn germ. Likewise, SID values for all dispensable AA except Gly and Pro were greater ($P < 0.05$) for HP DDG than for corn germ.

DISCUSSION

Energy Digestibility

The GE and CP in corn corresponded with published values (Pedersen et al., 2007). These values were lower than in the HP DDG. When corn goes through fermentation, the starch is converted to ethanol, and after fermentation the remaining nutrients (protein, fat, and fiber) are concentrated 3 times in DDGS compared with corn. When corn is dehulled and degermed before fermentation the resulting HP DDG has a greater GE, CP, ADF, and NDF concentration than corn. The greater fat

Table 9. Apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of CP and AA in high-protein distillers dried grains (HP DDG) and corn germ by growing pigs (Exp. 3)[1,2,3]

	Procedure							
	AID, %				SID, %			
	Diet				Diet			
Item	HP DDG	Corn germ	SEM	*P*-value	HP DDG	Corn germ	SEM	*P*-value
CP	72	33	3.2	0.001	80	56	4.1	0.007
Indispensable AA								
Arg	75	73	1.8	0.095	83	83	1.8	0.693
His	78	60	2.0	0.001	81	69	2.1	0.004
Ile	77	44	2.8	0.001	81	57	3.2	0.002
Leu	89	58	1.9	0.001	91	68	2.1	0.001
Lys	57	47	2.9	0.025	64	58	3.0	0.152
Met	86	61	2.3	0.001	88	68	2.5	0.001
Phe	85	53	2.4	0.001	87	64	2.6	0.001
Thr	70	34	4.0	0.001	77	53	4.7	0.010
Trp	71	53	4.4	0.033	81	67	4.1	0.042
Val	76	49	2.3	0.001	80	62	2.7	0.003
Dispensable AA								
Ala	83	53	2.4	0.001	86	64	2.8	0.002
Asp	70	47	3.1	0.002	76	60	3.6	0.018
Cys	78	52	2.4	0.001	82	64	2.7	0.001
Glu	86	63	2.0	0.001	88	72	2.3	0.003
Gly	44	14	6.1	0.001	75	76	10.7	0.924
Pro	46	–34	22.0	0.100	73	84	8.4	0.292
Ser	79	48	1.7	0.001	84	65	2.2	0.001
Tyr	85	46	3.3	0.001	88	59	3.6	0.002

[1]AID, % = {1 − [(CP or AA in digesta DM/CP or AA in feed DM) × (chromium in feed DM/chromium in digesta DM)]} × 100.
[2]SID, % = [AID + (endogenous losses/intake)] × 100. Endogenous losses determined after feeding the N-free diet (g per kg of DMI): CP, 16.6; Arg, 0.61; His, 0.17; Ile, 0.28; Leu, 0.47; Lys, 0.40; Met, 0.07; Phe, 0.29; Thr, 0.47; Trp, 0.10; Val, 0.42; Ala, 0.53; Asp, 0.72; Cys, 0.16; Glu, 0.87; Gly, 2.15; Pro, 5.97; Ser, 0.47; and Tyr, 0.26.
[3]Data are least squares means of 6 observations per treatment.

concentration contributes to the greater DE and ME in HP DDG compared with corn.

When comparing published values for conventional DDGS with values for HP DDG, it appears that HP DDG have a greater energy concentration. Pedersen et al. (2007) reported an average GE of 5,398 kcal/kg of DM in 10 samples of conventional DDGS, which is similar to the GE in HP DDG of 5,399 kcal/kg of DM that was measured in the current experiment. However, the ATTD of GE was 76.8% for conventional DDGS (Pedersen et al., 2007), which is lower than the 88.2% that was measured for HP DDG in the current study. As a consequence, HP DDG has a greater DE and ME (4,763 and 4,476 kcal/kg of DM, respectively) than conventional DDGS (4,140 and 3,897 kcal/kg of DM, respectively). In the production of HP DDG, corn has the hulls removed before fermentation. Therefore, HP DDG contains less ADF and NDF than conventional DDGS, which is likely the reason for the greater energy digestibility in HP DDG than in conventional DDGS.

High-protein DDG and corn germ have similar GE values (5,399 and 5,335 kcal/kg of DM, respectively); however, HP DDG has a greater ATTD of GE than corn germ. Therefore, DE and ME are greater in HP DDG than in corn germ. The reason for the lower ATTD in corn germ may be that corn germ contains more NDF than HP DDG. However, it is also likely that the fibers in HP DDG are more digestible than in corn germ because they have been fermented.

Corn germ has a greater GE concentration than corn because of the greater concentration of fat. However, corn has a greater ATTD for GE than corn germ; therefore, the DE and ME were not greater in corn germ than in corn. The increased concentration of ADF and NDF in corn germ compared with corn is likely the reason for the lower ATTD for GE in corn germ. It was not the objective of this experiment to measure the ATTD for ADF and NDF. However, based on the data for corn germ, it can be speculated that the fiber in corn germ has a reduced digestibility. Otherwise, corn germ containing 18% fat should have had a greater ATTD for GE.

Phosphorus Digestibility

The values for ATTD of P in HP DDG and corn germ that were measured in this experiment are similar to values measured in poultry (Parsons et al., 2006). The concentration of P in HP DDG and corn germ that was measured in this study also concurs with the values reported by Parsons et al. (2006).

Pedersen et al. (2007) reported an average P concentration of 0.61% in 10 samples of conventional DDGS, which is greater than the 0.37% measured in HP DDG. The reason for the lower concentration of P in HP DDG is most likely that the corn used to produce HP DDG was degermed prior to fermentation. However, HP DDG had a similar ATTD of P (59.6%) compared with conventional DDGS (59.1%). Corn germ contains much of the P in corn, which is the reason for the high concentration (1.09%) of P in corn germ. The P is also less digestible in corn germ than in the HP DDG. Bohlke et al. (2005) reported a value of 28.8% for ATTD of P in corn, which is similar to the value of 28.6% observed for corn germ in the present experiment. Thus, corn germ and corn appear to have similar P digestibility, and HP DDG and conventional DDGS also have similar digestibility values for P. When corn goes through the fermentation process, some of the P in the phytate is hydrolyzed. Therefore, more P is available for absorption in the small intestine of the pig, which is likely the reason why the ATTD for P in HP DDG and conventional DDGS are greater than in unfermented corn and corn germ.

The endogenous losses of P were estimated to be 211 ± 39 mg per kg of DMI. This value is greater than the value of 138 mg per kg of DMI reported by Petersen and Stein (2006). However, in a study by Stein et al. (2006a), the endogenous loss of P was reported at 207 mg per kg of DMI, which is in close agreement with the value obtained in this experiment. The values reported by Petersen and Stein (2006) and by Stein et al. (2006a) were measured using a P-free diet, as was used in this study. Values reported for endogenous losses that were measured using the regression technique have been between 70 mg per kg of DMI (Pettey et al., 2006) and 670 mg per kg of DMI (Shen et al., 2002). Thus, the value for endogenous losses of P obtained in this experiment is within the wide range of previously published values.

Most of the Ca in all diets originated from limestone. However, the ATTD for Ca was much lower for pigs fed corn germ than for pigs fed HP DDG or the P-free diet. The reason for this observation may be that corn germ contained much more phytate than HP DDG. The Ca in the corn germ diet may have been bound to the phytate complex during passage through the intestinal tract of the pig, which in turn reduced the ATTD for Ca in pigs fed this diet. Thus, it seems that the presence of phytate in the diet greatly influences the digestibility of Ca. In contrast, the high ATTD for Ca in the P-free diet indicates that the digestibility of Ca is not influenced by the presence of P in the diet. This observation is in agreement with recent data from Stein et al. (2006a). The high urinary excretion and low retention of Ca in pigs fed the P-free diet is also in agreement with data presented by Stein et al. (2006a). This observation indicates that if there is no P available in the body, then Ca will not be retained because both P and Ca are needed for the synthesis of bone tissue. The absorption of Ca is not influenced by the presence of P in the body, but the absorbed Ca is retained only if there is sufficient P available for bone tissue synthesis.

AA Digestibility

The AID and SID for most AA and CP in HP DDG that were measured in this experiment are greater than the average values reported for conventional DDGS (Stein et al., 2006b). The reason for this observation is most likely that no solubles are added to the HP DDG, as is the case for DDGS. It has been shown that in conventional DDGS, greater AID and SID for AA are obtained if the solubles are not added to the DDG (A. A. Pahm, Univ. Illinois, personal communication). Nevertheless, the values obtained for HP DDG in the present experiment are within the range of values obtained for conventional DDGS (Stein et al., 2006b).

Of all the indispensable AA, the lowest values for AID and SID in HP DDG were obtained for Lys. The reason for this observation may be that the heat applied to the product during dehydration may have damaged some of the Lys. Heat damage has been shown to reduce both the concentration and the digestibility of Lys.

The relatively low values for AID and SID that were measured for corn germ indicate that the protein in the germ fraction is of poor quality. Another possible reason for the low AID and SID in corn germ is the greater concentration of ADF and NDF. It has been demonstrated that greater concentrations of fiber negatively influence AA digestibility (Mosenthin et al., 1994; Lenis et al., 1996).

In conclusion, HP DDG have a greater digestibility of energy and most AA than previously reported for conventional DDGS and corn. The digestibility of P in HP DDG is similar to values previously reported for conventional DDGS, but is greater than in corn. Therefore, HP DDG is expected to have a greater feeding value than conventional DDGS or corn when fed to pigs. Corn germ has a lower energy and AA digestibility than corn or conventional DDGS. However, the DE and ME in corn germ are similar to the DE and ME in corn.

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