Effect of inclusion level of corn germ meal on the digestible and metabolizable energy and evaluation of ileal AA digestibility of corn germ meal fed to growing pigs[1]

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ABSTRACT: Two experiments were conducted to investigate the effect of inclusion level of corn germ meal (**CGM**) on the DE and ME values of CGM and to evaluate the ileal AA digestibility of CGM fed to growing pigs. In Exp. 1, 42 barrows (63.8 ± 2.1 kg BW) were allotted to seven diets in a completely randomized design with six replicates per diet. Diets included a corn–soybean meal (**SBM**) diet and six additional diets containing 4.85%, 9.70%, 19.40%, 29.10%, 38.80%, or 48.50% CGM. Pigs were fed twice daily, at 0730 and 1630 hours, at a level of 4% of BW, and feces and urine were collected for 5 d. The apparent total tract digestibility (**ATTD**) of DM, OM, CP, acid-hydrolyzed ether extract, and the DE and ME in diets linearly decreased ($P < 0.01$) as dietary CGM increased. Inclusion level of CGM had no effect on the DE and ME values of CGM. On a DM basis, the concentration of DE and ME varied from 3,396 to 3,747 kcal/kg and 3,107 to 3,502 kcal/kg, respectively. In Exp. 2, 11 crossbred barrows (30.4 ± 2.9 kg BW) with a T-cannula in the distal ileum were allotted to an 11 × 6 Youden square design with 11 diets and 6 period, which included an N-free diet and 10 CGM test diets. Chromic oxide (0.3%) was included in all diets as an indigestible marker. Pigs were fed daily at 4% of BW during each period, which consisted of 5 d of diet adaptation followed by 2 d of digesta collection. The apparent ileal digestibility (**AID**) of Ile, Thr, and Ala and the standardized ileal digestibility (**SID**) of CP and Ile varied ($P < 0.01$) among the 10 CGM. The AID of CP and all AA except Pro and Tyr, and the SID of all AA except Pro were the greatest ($P < 0.05$) in sample 7. The AID and SID of CP averaged 40.47% and 64.75%, respectively, and varied from 32.30% to 54.87% and from 57.48% to 72.15%, respectively. The average SID of Lys, Met, Thr, and Trp was 65.61%, 76.15%, 65.29%, and 60.17%, respectively, with a SEM of 4.49, 2.40, 5.95, and 6.82, respectively. The average SID of Pro was 101.76%, with an SEM of 17.26. Increasing dietary CGM decreased the ATTD of nutrients, the DE and ME values of diets but CGM. The AID and SID of AA in CGM are low but source dependent, and CGM may be fed to pigs as an protein-rich feedstuff.

Key words: AA digestibility, apparent total tract digestibility, corn germ meal, digestible energy, growing pigs, inclusion level

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INTRODUCTION

Corn germ meal (**CGM**), one of the coproducts from the corn wet milling industry, contains about 22.6% CP and fiber equivalent to corn distillers dried grains with solubles (NRC, 2012; Stein et al., 2016). The concentrations of Lys and Trp in CGM are low and cannot meet the requirements for pigs when included in a pig diet as the main source of protein. The standardized ileal digestibility (**SID**) of most AA in CGM is relatively lower than that of corn (Liu et al., 2014). Cellulose and arabinoxylans are two primary fiber components of both corn coproducts and

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CGM (Jaworski et al., 2015), and the apparent total tract digestibility (**ATTD**) of dietary fiber is <50% (Urriola et al., 2010). The poor quality of CP and its high fiber means that up to 30% CGM can be used in diets fed to growing and finishing pigs without changing the growth performance of pigs (Lee et al., 2012). Although global production of CGM is relatively small compare with that of other corn-coproducts, CGM is available in many local markets and may be combined with corn, SBM, and crystalline AA to produce a balanced diet that may be more cost effective than a conventional corn–SBM diet. Therefore, evaluating the nutritive value of CGM is important. However, only a limited number of experiments have been conducted with pigs to evaluate CGM and in all experiments, only one inclusion level of CGM in the experimental diet (Almeida et al., 2011; Rojas et al., 2013; Liu et al., 2014). The higher the substitution rate of the evaluated feedstuff, the more accurately DE and ME can be determined in the feedstuff according to the difference method (Kong and Adeola, 2014). However, higher dietary fiber content can affect energy and other nutrient digestibilities in diets and, therefore, for the evaluated feedstuff (Weber et al., 2010; Chen et al., 2014). Therefore, the objective of the current study was to investigate the hypothesis that different inclusion levels of CGM results in different calculated values for DE and ME of CGM. The second hypothesis was that ileal AA digestibility is consistent among different sources of CGM when fed to growing pigs.

MATERIAL AND METHODS

The protocol for all animal procedures was approved by the Institutional Animal Care and Use Committee at China Agricultural University, Beijing, China.

Experiment 1: Effect of Inclusion Level of Corn Germ Meal on Nutrient Digestibility

Experimental design and dietary treatments. Forty-two crossbred barrows (Duroc × Landrace × Large White) with an initial BW of 63.8 ± 2.1 kg were allotted to seven diets in a completely randomized design according to their initial BW, with six pigs per diet. Diets included a corn–SBM basal diet containing 76.0% corn, 21.0% dehulled SBM, 1.1% dicalcium phosphate, 0.9% limestone, 0.3% sodium chloride, 0.5% vitamin–mineral premix, and 0.2% choline chloride, and the six additional diets were formulated by substituting 5%, 10%, 20%, 30%, 40%, or 50% CGM at the expense of the corn and SBM in the basal diet. The final, complete experimental diets contained 4.85%, 9.70%, 19.40%, 29.10%, 38.80%, and 48.50% CGM (Table 1). Vitamins and minerals were supplemented in all diets to meet or exceed the nutrient requirements of growing pigs according to the NRC (2012). Chemical compositions of corn, dehulled SBM, and CGM are presented in Table 2.

Animals housing, feeding, and samples collection. During the experiment, pigs were individually housed in stainless steel metabolism crates (1.7 × 0.9 × 0.7 m). The crates had adjustable sides to accommodate animal welfare and were located in rooms with the temperature controlled at 20 ± 2.2 °C. Humidity varied from 35% to 63% during the experiment, and the light and dark time was automatically controlled at 12 h each. All pigs had ad libitum access to water via a drinking nipple. All pigs were acclimated to the new environment for 7 d and fed a standard corn–SBM diet before the start of the experiment. Pigs were weighed at the beginning of the experiment. Experimental diets were fed in a meal form, offered to pigs at a level of 4% of initial individual BW, and fed in two equal daily meals at 0730 and 1630 hours. Diet refusals were collected and weighed daily.

The experiment lasted a total of 12 d, including 7 d of experimental diet adaptation followed by 5 d of feces and urine collection beginning at 1600 hours on d 7 and ending at 1600 hours on d 12. During the collection period, an adjustable tray was placed under each metabolism crate, which permitted separate collection of feces and urine. Fresh feces were stored at −18 °C immediately after collection. Urine was collected in buckets containing 50 mL of 6 N HCl located under each crate. The volume of collected urine was measured daily, and 20% was stored at −20 °C. At the end of collection, the collected feces of 5 d from each pig were weighed, dissolved, and then thoroughly homogenized. A subsample was dried in a forced-air oven at 65 °C for 72 h. Urine was thawed, mixed, and subsampled. Before chemical analysis, dried feces were ground through a 1-mm screen. Urine samples (4 mL) were dried in the oven at 65 °C for 8 h with quantitative filter paper in crucibles.

Sample analysis and calculations. Samples were analyzed for GE using an adiabatic oxygen bomb calorimeter (Parr 6300 Calorimeter; Parr Instrument Company, Moline, IL). Other analyses included DM (method 930.15; AOAC, 2006), CP (method

Table 1. Ingredient and analyzed chemical composition of diets used in Exp. 1 (%, as-fed basis)

	Inclusion level of corn germ meal in diet						
Item	0.00	4.85	9.70	19.40	29.10	38.80	48.50
Corn	76.00	72.20	68.40	60.80	53.20	45.60	38.00
Dehulled soybean meal	21.00	19.95	18.90	16.80	14.70	12.60	10.50
Corn germ meal	0.00	4.85	9.70	19.40	29.10	38.80	48.50
Dicalcium phosphate	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Limestone	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Sodium chloride	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin–mineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Choline chloride	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Analyzed composition							
DM	87.40	87.82	88.02	88.28	88.82	89.22	89.56
Ash	4.40	4.39	4.29	4.31	4.25	4.15	4.40
CP	15.93	16.33	16.68	16.33	17.11	17.61	17.85
AEE[2]	2.98	3.27	3.33	3.69	4.04	4.55	4.86
NDF	11.23	11.78	14.12	17.44	20.80	22.57	28.18
ADF	3.06	3.34	3.86	4.77	5.61	6.48	8.08
Starch	44.71	43.68	42.06	34.58	34.92	30.70	27.48
GE, kcal/kg	3,783	3,824	3,857	3,910	3,965	4,005	4,046

[1]Premix provided the following per kilogram of complete diet for growing pigs: 5,512 IU vitamin A, 2,200 IU vitamin D_3, 30 IU vitamin E, 2.2 mg vitamin K_3, 27.6 mg vitamin B_{12}, 4.0 mg riboflavin, 14.0 mg pantothenic acid, 30.0 mg niacin, 400.0 mg choline chloride, 0.7 mg folic acid, 1.5 mg thiamine, 3.0 mg pyridoxine, 44.0 μg biotin, 40.0 mg Mn, 75.0 mg Fe, 75.0 mg Zn, 100.0 mg Cu, 0.3 mg I, and 0.3 mg Se.

[2]AEE = acid-hydrolyzed ether extract.

Table 2. Analyzed chemical composition of corn, dehulled soybean meal, and corn germ meal used in Exp. 1 (%, as-fed basis)

Item	Corn	Dehulled soybean meal	Corn germ meal
DM	87.62	88.05	92.04
CP	8.32	45.94	21.15
EE[1]	3.04	2.05	5.56
AEE[2]	3.29	2.60	7.06
NDF	10.34	11.52	45.03
ADF	2.73	6.26	11.33
TDF[3]	8.50	16.73	48.52
IDF[4]	7.90	15.28	37.64
SDF[5]	0.60	1.45	10.88
Ash	1.13	6.05	2.66
Starch	63.46	2.02	13.31
GE, kcal/kg	3,737	4,139	4,476

[1]EE = ether extract.

[2]AEE = acid-hydrolyzed ether extract.

[3]TDF = total dietary fiber.

[4]IDF = insoluble dietary fiber.

[5]SDF = soluble dietary fiber.

984.13; AOAC, 2006), ether extract (**EE**; Thiex et al., 2003), acid-hydrolyzed ether extract (**AEE**; method 954.02; AOAC, 2006), ash (method 942.05; AOAC, 2006), Ca (method 968.08; AOAC, 2006), and P (method 946.06; AOAC, 2006). Total starch was determined using method 7613.01 of the American Association of Cereal Chemists (1976) using a commercial starch assay kit (STA20; Sigma-Aldrich Corporation, St. Louis, MO). Total dietary fiber and insoluble dietary fiber were also determined (method 985.29; AOAC, 2006). The concentration of soluble dietary fiber (**SDF**) was calculated as the difference between total dietary fiber and insoluble dietary fiber. Neutral detergent fiber and ADF were determined using filter bags and fiber analyzer equipment (ANKOM Technology, Macedon, NY) following a modification of the procedures 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. All chemical analyses were conducted in duplicate.

Calculations. In Exp. 1, the digestibility and metabolizability of diet components were calculated according to the following equations (Kong and Adeola, 2014): digestibility (%) = $[(C_{input} - C_{output})/C_{input}] \times 100$ and metabolizability (%) = $[(C_{input} - C_{output} - C_{urine})/C_{input}] \times 100$, in which C_{input}, C_{output}, and C_{urine} are the amount of component ingested and voided via the feces and the amount of component voided via the urine, respectively.

The digestibility of each component in the test ingredient was determined using the total collection method and was calculated according to the following equation described by Kong and Adeola (2014): $D_{ti} = [D_{td} - (D_{bd} \times P_{bd})]/P_{ti}$, in which D_{bd}, D_{td}, and D_{ti} are the digestibility (%) of the component in the basal diet, test diet, and test ingredient, respectively, and P_{bd} and P_{ti} are the proportional contribution of the component by the basal diet and the test ingredient to the test diet, respectively.

By definition, DE and ME values are calculated by multiplying the concentration of GE in the diet or ingredient and the digestibility (or metabolizability) of GE in the diet or ingredient.

Experiment 2: AA Digestibility

Experimental design and dietary treatments. This experiment was conducted to evaluate the apparent ileal digestibility (**AID**) and SID of AA in CGM. Origins of the 10 test CGM samples are presented in Table 3. Eleven crossbred barrows (30.4 ± 2.9 kg BW) fitted with a T-cannula in the distal ileum according to the method of Stein et al. (1998) were individually housed in stainless steel metabolism crates (1.7 × 0.9 × 0.7 m) located in a temperature-controlled room (22.0 ± 2.3 °C) and allotted to 11 × 6 as indicated in abstract. Pigs were weighed at the beginning of each period. All pigs were fed at a daily level of 4% of BW. Equal meals were provided to pigs at 0730 and 1630 hours each day. The 11 experimental diets included an N-free diet and 10 CGM test diets (Table 4). The N-free diet was used to determine the basal ileal endogenous N losses. The test diets contained 40% of 1 of the 10 CGM as the only source of dietary N. Chromic oxide (0.3%) was included in all diets as an indigestible marker. Vitamins and minerals were supplemented in all diets to meet or exceed the estimated nutrient requirements for growing pigs (NRC, 2012). The CP and AA compositions of the experimental diets are shown in Table 5.

Experimental procedures. After 7 d of recovery from surgery, pigs were fed 1 of the 11 diets for six 7-d periods, which consisted of a 5-d diet acclimation followed by 2 d of digesta collection. The collection lasted for 9 h daily beginning at 0800 hours according to the procedures described by Stein et al. (1998). On days 6 and 7, a plastic bag was attached to the barrel of the cannula, removed whenever it was filled with digesta, and then stored at −20 °C. At the end of the experiment, digesta samples were thawed, mixed by pig and period, subsampled, and lyophilized in a vacuum freeze dryer (Tofflon Freezing Drying Systems, Minhang District, Shanghai, China).

Table 3. Sources of corn germ meal used in Exp. 2

Number	Sources in China
1	Xiwang, Shandong
2	Liangyou, Shandong
3	Aobang, Hebei
4	Zhonghe, Henan
5	Zhengwang, Henan
6	Sanxing, Shandong
7	Guangyuan, Shandong
8	Xuxin, Hebei
9	Jindouzi, Hebei
10	Derui, Neimeng

Analytical methods. Before analysis, samples of CGM, diets, and digesta were ground through a 1-mm screen and thoroughly mixed. Analyses of the AA content of all CGM samples as well as the diets and digesta were conducted according to Li et al. (2015). For all AA but Met, Cys, and Trp, samples were hydrolyzed with 6 N HCl at 110 °C for 24 h and then analyzed using an AA analyzer (Hitachi L-8900; Hitachi Ltd., Tokyo, Japan). The sulfur AA (Met and Cys) were subjected to cold performic acid oxidation overnight and hydrolyzed with 7.5 N HCl at 110 °C for 24 h before being measured using an AA analyzer (Hitachi L-8900). Tryptophan was analyzed by hydrolyzing the sample with LiOH for 22 h at a constant temperature of 110 °C and then analyzing the sample using HPLC (Agilent 1200 Series; Agilent Technologies Inc., Santa Clara, CA). Analysis of Cr in diets and digesta was conducted using a polarized Zeeman Atomic Absorption Spectrometer (Hitachi Z2000; Hitachi Ltd., Tokyo, Japan) after nitric acid–perchloric acid wet ash sample preparation. All analyses were conducted in duplicate.

Calculations. In Exp. 2, the AID and SID of AA were calculated using the following equation (Stein et al., 2007): $AID = [1 - (AA_d/AA_f) \times (Cr_f/Cr_d)] \times 100\%$, in which AA_d and Cr_d are the concentrations of AA and Cr in the ileal digesta (g/kg of DM) and AA_f and Cr_f are the concentrations of AA and Cr in the test diets (g/kg of DM). The AID of CP was calculated using the same equation.

The endogenous loss of N for each AA was measured from pigs fed the N-free diet based on the following equation: $IAA_{end} = [AA_d \times (Cr_f/Cr_d)]$, in which IAA_{end} is the basal endogenous loss of an AA (g/kg of DMI) and AA_d and Cr_d represent the concentrations of AA and Cr in the ileal digesta of the pigs fed the N-free diet. The concentration of Cr in the N-free diet is represented by Cr_f. The basal endogenous loss of CP was determined using the same equation.

The average IAA_{end} of the six pigs fed the N-free diet was used to calculate the SID of AA in all diets. Standardized ileal digestibility was then calculated using the following equation: SID = [AID + (IAA_{end}/AA_f) × 100%].

Statistical analyses. All the data were checked for normality, and outliers were identified using the UNIVARIATE procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). Then, both data sets were analyzed using the GLM procedure of SAS, with pig treated as the experimental unit. In Exp. 1, the statistical model included the inclusion level of CGM as the only fixed effect. Polynomial contrast was also conducted using the CONTRAST statement to determine linear and quadratic effects of inclusion levels, and contrast coefficients were generated using the IML procedure of SAS. In Exp. 2, the statistical model included the CGM sample as the only fixed effect, one-way ANOVA was used to separate treatment means calculated using the LSMEANS statement, and Tukey's multiple range test was used for post hoc comparison. Statistical significance was assumed at $P < 0.05$.

Table 4. The ingredient composition of the experimental diets in Exp. 2 (%, as-fed basis)

Item	Corn germ meal diets	N-free diet
Corn	—	—
Dehulled soybean meal	—	—
Corn germ meal	40.0	—
Corn starch	40.0	73.35
Soybean oil	2.0	3.0
Sucrose	15.0	15.0
Acetate cellulose[1]	—	4.0
Dicalcium phosphate	1.5	2.5
Limestone	0.4	0.5
Sodium chloride	0.3	0.45
Chromic oxide	0.3	0.3
Potassium carbonate	—	0.3
Magnesium oxide	—	0.1
Vitamin–mineral premix[2]	0.5	0.5

[1]Made by Chemical Reagents Company (Beijing, China).

[2]Premix provided the following per kilogram of complete diet for growing pigs: 5,512 IU vitamin A, 2,200 IU vitamin D_3, 30 IU vitamin E, 2.2 mg vitamin K_3, 27.6 mg vitamin B_{12}, 4.0 mg riboflavin, 14.0 mg pantothenic acid, 30.0 mg niacin, 400.0 mg choline chloride, 0.7 mg folic acid, 1.5 mg thiamine, 3.0 mg pyridoxine, 44.0 µg biotin, 40.0 mg Mn, 75.0 mg Fe, 75.0 mg Zn, 100.0 mg Cu, 0.3 mg I, and 0.3 mg Se.

RESULTS

Chemical Composition of Corn Germ Meal and Diets in Exps. 1 and 2

Table 2 shows the chemical composition of the corn, dehulled SBM, and CGM, and Table 1 shows the analyzed composition of the experimental diets used in Exp. 1. The concentrations of EE, AEE, SDF, and GE in CGM used in Exp. 1 were higher than the highest concentrations of EE, AEE, SDF (Table 2), and GE in the 10 CGM samples used in Exp. 2 (Table 6), but each of the other chemical components

Table 5. Analyzed CP and AA composition of diet in Exp. 2 (%, as-fed basis)

	Corn germ meal number										
Item	1	2	3	4	5	6	7	8	9	10	N-free diet
CP	7.66	7.86	7.32	7.97	9.75	7.55	7.38	8.22	7.19	7.91	0.36
Indispensable AA											
Arg	0.38	0.49	0.40	0.40	0.45	0.43	0.41	0.47	0.32	0.44	0.01
His	0.23	0.26	0.23	0.22	0.30	0.24	0.23	0.24	0.21	0.25	0.01
Ile	0.27	0.29	0.27	0.27	0.32	0.26	0.26	0.27	0.22	0.26	0.01
Leu	0.71	0.78	0.71	0.72	0.90	0.71	0.71	0.70	0.65	0.69	0.04
Lys	0.32	0.36	0.30	0.29	0.33	0.31	0.30	0.30	0.22	0.33	0.01
Met	0.12	0.11	0.10	0.11	0.14	0.11	0.11	0.12	0.09	0.12	0.00
Phe	0.31	0.36	0.33	0.32	0.35	0.32	0.32	0.33	0.26	0.32	0.03
Thr	0.31	0.33	0.29	0.31	0.38	0.30	0.29	0.30	0.26	0.30	0.01
Trp	0.07	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.05	0.08	0.00
Val	0.44	0.55	0.49	0.52	0.63	0.51	0.51	0.54	0.47	0.54	0.01
Dispensable AA											
Ala	0.51	0.53	0.47	0.51	0.71	0.47	0.48	0.48	0.48	0.47	0.02
Asp	0.52	0.57	0.49	0.50	0.57	0.47	0.48	0.51	0.40	0.51	0.02
Cys	0.23	0.21	0.22	0.21	0.26	0.21	0.21	0.23	0.22	0.22	0.11
Glu	1.19	1.21	1.05	1.06	1.39	1.06	1.04	1.10	0.97	1.11	0.04
Gly	0.39	0.43	0.38	0.39	0.46	0.37	0.37	0.38	0.32	0.38	0.01
Pro	0.51	0.55	0.49	0.52	0.76	0.55	0.52	0.49	0.57	0.52	0.02
Ser	0.34	0.36	0.31	0.32	0.38	0.31	0.31	0.33	0.26	0.33	0.01
Tyr	0.17	0.15	0.11	0.13	0.13	0.15	0.12	0.14	0.13	0.11	0.02

Table 6. Analyzed chemical composition of corn germ meal in Exp. 2 (%, as-fed basis)

	Corn germ meal number											
Item	1	2	3	4	5	6	7	8	9	10	Mean	CV
DM	91.27	92.46	92.29	92.26	93.09	91.72	90.87	89.94	92.10	91.11	91.92	0.74
CP	18.27	18.77	19.64	19.26	22.73	18.09	17.23	19.35	16.97	18.71	20.75	8.67
EE[1]	1.35	2.62	0.72	0.59	0.92	1.61	2.15	1.05	0.32	1.60	1.90	87.08
AEE[2]	2.40	3.70	2.22	1.68	2.00	3.04	3.44	2.52	1.75	2.92	3.29	52.23
NDF	47.29	45.78	44.93	47.98	37.88	50.71	49.69	52.42	43.67	50.48	50.44	8.88
ADF	13.34	12.42	12.64	13.14	10.10	13.41	14.49	15.51	17.40	12.92	14.28	14.96
TDF[3]	53.36	49.21	43.83	48.47	44.09	53.21	50.00	48.24	50.00	54.31	53.97	7.76
IDF[4]	44.25	39.61	42.71	44.24	37.33	45.60	44.12	43.42	48.61	46.96	46.91	9.25
SDF[5]	9.11	9.60	1.12	4.23	6.75	7.61	5.88	4.81	1.39	7.35	7.05	53.12
Ash	1.69	4.35	2.20	2.48	4.98	1.51	2.64	2.30	4.59	1.42	3.10	45.67
Starch	14.42	16.48	16.71	17.43	12.38	13.93	15.35	17.41	9.88	15.95	15.87	15.89
Ca	0.03	0.15	0.04	0.05	0.10	0.04	0.07	0.05	0.21	0.04	0.09	75.48
P	0.33	0.43	0.39	0.42	0.71	0.31	0.31	0.44	0.34	0.33	0.45	30.73
GE, kcal/kg	4,223	4,235	4,149	4,211	4,209	4,295	4,046	4,244	4,158	4,292	4,206	1.75

[1]EE = ether extract.

[2]AEE = acid-hydrolyzed ether extract.

[3]TDF = total dietary fiber.

[4]IDF = insoluble dietary fiber.

[5]SDF = soluble dietary fiber.

of the CGM used in Exp. 1 was within the range of values observed among the 10 sources of CGM in Exp. 2. On an as-fed basis, the concentration of AEE and EE varied from 1.68% to 3.70% and from 0.32% to 2.62%, respectively, with an average of 3.29% and 1.90%, respectively. The average concentration of NDF in the 10 CGM samples was 50.44%. The concentration of ADF, SDF, starch, ash, Ca, and P averaged 14.28% (10.10% to 17.40%), 7.05% (1.12% to 9.60%), 15.87% (9.88% to 17.43%), 3.10% (1.42% to 4.98%), 0.09% (0.03% to 0.21%), and 0.45% (0.31% to 0.71%), respectively. Table 7 indicates that the concentrations of AA in the 10 CGM samples greatly varied. The CV for each AA ranged from 6.34% to 19.20% and was >10% for the proximate composition of AEE, EE, ADF, SDF, starch, ash, Ca, and P. The least CV was obtained for Phe. In contrast, the greatest CV was obtained for Trp. Concentrations of Lys, Met, Thr, and Trp ranged from 0.65% to 1.01%, from 0.29% to 0.39%, from 0.70% to 0.96%, and from 0.10% to 0.20%, respectively, with averages of 0.87%, 0.36%, 0.82%, and 0.16%, respectively. The analyzed CP and AA compositions of diets in Exp. 2 are presented in Table 5.

Effect of Inclusion Level on the Apparent Total Tract Digestibility of Nutrients and DE or ME Value of Corn Germ Meal

The ATTD of DM, OM, CP, AEE, and the concentration of DE and ME in the diet linearly decreased as dietary CGM increased ($P < 0.01$; Table 8). The CGM inclusion level had no effect on the DE or ME value of CGM, and the concentration of DE and ME varied from 3,396 to 3,747 kcal/kg and from 3,107 to 3,502 kcal/kg (on a DM basis), respectively (Table 9).

Digestibility of CP and AA in Corn Germ Meal

The AID and SID of CP and AA in the 10 tested CGM samples are shown in Tables 10 and11, respectively. The AID of Ile, Thr, and Ala varied ($P < 0.01$) among the 10 CGM samples. The SID of CP and Ile varied ($P < 0.01$) among the 10 CGM samples. Overall, the AID of CP and all AA except Pro and Tyr and the SID of all AA except Pro were greatest ($P < 0.05$) in sample 7. Sample 1 had the least ($P < 0.05$) AID and SID of Arg, His, Leu, Thr, and Val. The AID and SID of CP averaged 40.47% and 64.75%, respectively, and varied ($P < 0.01$) from 32.30% to 54.87% and from 57.48% to 72.15%, respectively. An average AID of 57.40%, 72.87%, 41.03%, and 33.77% was observed for Lys, Met, Thr, and Trp, respectively, with an SEM of 4.32%, 2.41%, 5.02%, and 7.21%, respectively. The average SID of Lys, Met, Thr, and Trp was 65.61%, 76.15%, 65.29%, and 60.17%, respectively, with an SEM of 4.49%, 2.40%, 5.95%, and 6.82%, respectively. In addition, the average SID of Arg and Leu in the 10 CGM samples was ($P < 0.05$) >80%, and the average SID of Pro was 101.76%, with an SEM of 17.26%.

Table 7. Analyzed AA composition of corn germ meal in Exp. 2 (%, as-fed basis)

	Corn germ meal number											
Item	1	2	3	4	5	6	7	8	9	10	Mean	CV
Indispensable AA												
Arg	1.12	1.17	1.30	1.03	1.21	1.13	1.04	1.22	0.80	1.22	1.12	12.51
His	0.69	0.68	0.73	0.63	0.83	0.71	0.66	0.68	0.63	0.74	0.70	8.37
Ile	0.69	0.68	0.73	0.67	0.81	0.69	0.64	0.81	0.58	0.70	0.70	9.91
Leu	1.78	1.71	1.80	1.71	2.14	1.78	1.69	1.97	1.60	1.73	1.79	8.73
Lys	0.87	0.89	0.87	0.80	0.90	0.88	0.80	1.01	0.65	0.99	0.87	11.78
Met	0.39	0.34	0.36	0.37	0.39	0.37	0.32	0.38	0.29	0.39	0.36	9.16
Phe	0.98	0.99	1.06	0.97	1.03	0.97	0.94	0.90	0.85	1.02	0.97	6.34
Thr	0.81	0.78	0.83	0.80	0.96	0.82	0.77	0.89	0.70	0.81	0.82	8.49
Trp	0.17	0.15	0.19	0.15	0.17	0.17	0.14	0.20	0.10	0.20	0.16	19.20
Val	1.15	1.15	1.23	1.15	1.38	1.15	1.09	1.31	1.00	1.20	1.18	9.16
Dispensable AA												
Ala	1.40	1.37	1.47	1.54	1.96	1.36	1.35	1.57	1.43	1.44	1.49	12.02
Asp	1.32	1.33	1.43	1.32	1.47	1.30	1.24	1.54	1.09	1.39	1.34	9.47
Cys	0.41	0.37	0.38	0.39	0.51	0.42	0.38	0.42	0.41	0.40	0.41	9.85
Glu	2.63	2.65	2.87	2.56	3.27	2.64	2.51	3.53	2.42	2.75	2.78	12.66
Gly	1.05	1.03	1.13	1.05	1.23	1.04	0.99	1.19	0.91	1.08	1.07	8.84
Pro	1.30	1.22	1.25	1.23	1.86	1.32	1.21	1.44	1.38	1.26	1.35	14.44
Ser	0.88	0.89	0.96	0.87	0.99	0.87	0.84	1.00	0.74	0.91	0.90	8.70
Tyr	0.41	0.41	0.46	0.36	0.50	0.42	0.38	0.43	0.27	0.38	0.40	14.86

Table 8. Effect of inclusion level of corn germ meal on the apparent total tract digestibility (%) of nutrients, DE, and ME values in diets in Exp. 1

	Inclusion level of corn germ meal in diet								*P*-value	
Item	0.00	4.85	9.70	19.40	29.10	38.80	48.50	SEM	Linear	Quadratic
DM	91.08	89.43	89.04	86.70	86.00	83.87	82.10	0.69	<0.01	0.81
OM	92.86	91.19	90.76	88.36	87.66	85.45	83.84	0.64	<0.01	0.66
CP	91.76	89.69	89.41	86.94	84.59	83.29	83.06	0.85	<0.01	0.05
AEE[1]	61.26	61.41	58.51	54.82	51.87	54.28	49.16	1.63	<0.01	0.34
NDF	72.75	67.83	69.21	69.16	74.50	70.58	73.95	2.09	0.15	0.43
ADF	70.35	66.14	67.57	65.69	70.53	68.72	73.14	2.14	0.11	0.10
As-fed basis, kcal/kg										
DE	3,449	3,415	3,422	3,360	3,366	3,308	3,286	30.24	<0.01	0.93
ME	3,393	3,374	3,377	3,313	3,293	3,224	3,195	33.31	<0.01	0.76
DM basis, kcal/kg										
DE	3,946	3,889	3,888	3,806	3,789	3,707	3,669	33.99	<0.01	0.82
ME	3,882	3,842	3,737	3,753	3,708	3,613	3,568	37.42	<0.01	0.86

[1]AEE = acid-hydrolyzed ether extract.

DISCUSSION

Corn germ meal is a coproduct of the wet milling industry, where processed corn grain is cleaned and steeped and then the corn germ is extracted for food-grade corn oil, resulting in CGM for animal feed (Archer Daniels Midland, 2008). Therefore, CGM has a relatively high concentration of fiber and a relatively low concentration of fat. Some studies have evaluated the concentration of DE or ME in CGM (Anderson et al., 2012; Rojas et al., 2013; Liu et al., 2014), but only two studies (Almeida et al., 2011; Liu et al., 2014) and one review (Stein et al., 2016) were performed on the ileal AA digestibility in CGM fed to pigs. The average concentration of CP in the 10 tested CGM samples in Exp. 2 was in agreement with reported values (Weber et al., 2010; Anderson et al., 2012), but less than those values (Almeida et al., 2011; NRC, 2012; Rojas et al., 2013; Jaworski et al., 2015). Other chemical compositions such as AEE, EE, SDF, ash, Ca, P, and AA greatly varied among the 10 CGM samples. The 11 CGM samples used in the

Table 9. Effect of inclusion level of corn germ meal on the DE and ME value in corn germ meal in Exp. 1

	Inclusion level of corn germ meal in diet							*P*-value	
Item	4.85	9.70	19.40	29.10	38.80	48.50	SEM	Linear	Quadratic
As-fed basis, kcal/kg									
DE	3,448	3,361	3,126	3,269	3,190	3,249	145	0.33	0.29
ME	2,860	3,223	3,086	3,155	3,062	3,117	140	0.58	0.44
DM basis, kcal/kg									
DE	3,747	3,652	3,396	3,551	3,467	3,531	157	0.33	0.29
ME	3,107	3,502	3,353	3,427	3,327	3,387	152	0.58	0.44

Table 10. Apparent ileal digestibility (%) of AA in corn germ meal fed to growing pigs in Exp. 2

	Corn germ meal number												
Item	1	2	3	4	5	6	7	8	9	10	Mean	SEM	*P*-value
CP	33.52^{b}	47.97^{ab}	32.30^{b}	40.49^{ab}	44.96^{ab}	33.37^{b}	54.87^{a}	34.36^{b}	41.91^{ab}	40.95^{ab}	40.47	4.41	0.01
Indispensable AA													
Arg	69.56	84.09	73.11	75.95	79.70	75.71	84.42	78.43	73.32	77.02	77.13	3.35	0.07
His	63.81^{b}	77.92^{ab}	67.00^{ab}	66.79^{ab}	69.61^{ab}	66.93^{ab}	78.59^{a}	69.30^{ab}	67.66^{ab}	69.44^{ab}	69.71	3.03	0.02
Ile	54.71^{ab}	66.38^{ab}	59.81^{ab}	59.72^{ab}	69.27^{a}	56.19^{ab}	70.21^{a}	54.96^{ab}	55.56^{ab}	50.03^{b}	59.68	3.58	<0.01
Leu	65.35	77.92	69.95	71.79	79.87	66.78	79.86	69.86	72.18	66.69	72.03	3.11	0.01
Lys	53.55	68.06	57.57	54.69	60.81	53.17	68.12	53.06	51.34	53.48	57.40	4.32	0.04
Met	73.89	75.25	69.72	71.54	76.20	70.97	79.17	72.06	68.58	71.34	72.87	2.41	0.08
Phe	60.20	70.83	63.84	68.68	72.73	62.61	77.20	68.57	64.54	62.84	67.20	3.59	0.08
Thr	29.08^{b}	47.51^{ab}	33.10^{ab}	42.32^{ab}	52.30^{ab}	42.42^{ab}	55.96^{a}	34.23^{ab}	34.84^{ab}	38.51^{ab}	41.03	5.02	<0.01
Trp	27.26	48.02	30.80	26.68	27.54	25.81	51.84	29.30	30.48	40.00	33.77	7.21	0.08
Val	53.66^{b}	69.75^{ab}	57.65^{b}	64.48^{ab}	70.66^{ab}	60.54^{ab}	75.88^{a}	64.24^{ab}	65.81^{ab}	64.06^{ab}	64.67	3.90	0.02
Dispensable AA													
Ala	57.16^{abc}	62.38^{abc}	52.55^{bc}	58.65^{abc}	67.38^{abc}	53.94^{abc}	68.29^{a}	50.99^{c}	58.40^{abc}	58.63^{abc}	59.13	3.35	<0.01
Asp	40.13^{ab}	55.98^{ab}	36.87^{b}	43.19^{ab}	52.54^{ab}	39.93^{ab}	58.89^{a}	39.29^{ab}	38.95^{ab}	38.91^{ab}	44.47	4.69	0.01
Cys	47.17	51.61	44.54	49.72	54.71	45.38	62.50	49.58	54.51	51.52	51.12	3.95	0.08
Glu	60.04^{ab}	70.07^{ab}	56.24^{b}	61.43^{ab}	62.35^{ab}	60.33^{ab}	71.82^{a}	57.53^{ab}	58.07^{ab}	55.84^{b}	61.37	3.35	0.01
Gly	10.27	34.04	21.33	20.34	30.57	28.40	37.72	17.44	28.76	26.24	25.51	7.52	0.30
Pro	18.13	36.97	30.29	48.06	47.13	26.79	45.59	13.79	37.79	28.72	33.33	9.19	0.16
Ser	45.05	60.87	44.31	48.20	57.90	45.53	63.49	47.00	45.05	46.60	50.40	4.49	0.01
Tyr	56.33	58.04	38.83	41.19	41.96	48.80	56.68	48.17	48.22	46.46	48.47	4.95	0.05

$^{a–c}$Means within a row with different superscripts differ ($P < 0.05$).

current two experiments were obtained from different manufacturing factories with different processing procedures (Shi et al., 2018), which may be the main reason for the chemical variations among the 11 CGM. For example, during processing of the CGM, a liquid corn extract is produced when the soluble portion of the corn kernel is removed during the steeping process (Archer Daniels Midland, 2008) and is sometimes added back to the CGM product, which may have contributed to the large variation among the 11 CGM samples. In addition to the processing procedures, the hybrids, growing region, storage duration, and drying method of the corn grain used for manufacturing CGM are likely related to the differences in proximate and AA compositions among the 11 CGM samples (de Lima et al., 2012; Li et al., 2014a,b; Liu et al., 2014; Zhang et al., 2016).

In general, CGM contains about 22.6% CP (Stein et al., 2016), much greater than corn grain, which makes CGM possible as an alternative to corn in pig diets. However, the high content and low digestibility of fiber in CGM limits its usage in complete diets for pigs. The average concentration of 50.44% NDF in the 10 tested CGM samples was in good agreement with that of 49.3% NDF reported by Stein et al. (2016). Some studies evaluated the concentration of DE or ME in CGM, but to our knowledge, all these studies focused on only one substitution rate of CGM in the evaluation diet (Anderson et al., 2012; Rojas et al., 2013; Liu et al., 2014). The current work was the first research investigating the effect of dietary CGM on nutrient digestibility and the DE or ME values of CGM fed to pigs. The decreasing ATTD of CP in diets as dietary CGM increased was in agreement

Table 11. Standardized ileal digestibility (%) of AA in corn germ meal fed to growing pigs in Exp. 2

Item	Corn germ meal number										Mean	SEM	*P*-value
	1	2	3	4	5	6	7	8	9	10			
CP	58.32[b]	72.15[ab]	58.26[b]	64.35[ab]	64.45[ab]	58.56[b]	80.63[a]	57.48[b]	68.33[ab]	64.99[ab]	64.75	4.41	<0.01
Indispensable AA													
Arg	81.20	93.20	84.21	87.08	89.68	86.19	95.32	88.01	87.45	87.09	87.94	3.35	0.20
His	72.87[b]	85.80[ab]	75.85[ab]	76.31[ab]	79.87[ab]	75.31[ab]	87.49[a]	77.78[ab]	77.35[ab]	77.52[ab]	78.62	2.90	0.02
Ile	66.96[ab]	77.75[ab]	72.35[ab]	72.30[ab]	79.65[a]	69.04[ab]	83.10[a]	67.48[ab]	70.54[ab]	62.86[b]	72.20	3.58	<0.01
Leu	74.08[b]	85.91[ab]	78.74[ab]	80.44[ab]	86.81[ab]	75.54[ab]	88.63[a]	78.80[ab]	81.83[ab]	75.72[ab]	80.65	3.11	0.01
Lys	61.72	75.92	66.23	63.55	68.66	61.51	76.89	61.83	58.42	61.38	65.61	4.49	0.06
Met	76.98	78.44	73.45	74.97	78.76	74.32	82.38	74.99	72.78	74.40	76.15	2.40	0.15
Phe	75.10	80.16	74.26	79.26	82.45	73.31	87.87	78.73	77.78	73.34	78.23	3.59	0.13
Thr	51.74[b]	72.46[ab]	56.92[ab]	62.63[ab]	73.95[ab]	62.60[ab]	83.79[a]	61.83[ab]	66.53[ab]	60.40[ab]	65.29	5.95	0.02
Trp	51.74	76.58	59.13	54.34	49.40	52.32	79.77	52.03	61.48	64.90	60.17	6.82	0.02
Val	66.18[b]	79.74[ab]	68.82[ab]	74.95[ab]	79.36[ab]	71.17[ab]	86.56[a]	74.39[ab]	77.45[ab]	74.15[ab]	75.28	3.90	0.04
Dispensable AA													
Ala	71.24[ab]	76.06[ab]	67.76[ab]	72.89[ab]	80.40[a]	69.34[ab]	83.26[a]	66.10[ab]	73.54[ab]	61.57[b]	71.92	4.20	0.01
Asp	57.31[ab]	71.71[ab]	54.89[b]	60.96[ab]	68.13[ab]	58.76[ab]	77.53[a]	56.87[ab]	61.07[ab]	56.44[ab]	62.37	4.69	0.01
Cys	65.55	75.18	67.30	69.75	73.72	69.34	86.64	71.68	77.48	68.72	72.54	4.52	0.07
Glu	69.66[ab]	79.59[ab]	67.17[b]	72.25[ab]	70.64[ab]	71.17[ab]	82.85[a]	67.99[ab]	69.96[ab]	66.16[b]	71.74	3.35	0.01
Gly	55.70	84.26	63.83	70.00	71.18	52.43	96.40	58.55	75.75	64.02	69.21	11.20	0.18
Pro	107.38	112.04	104.82	105.38	90.36	71.42	111.93	96.37	117.52	100.38	101.76	17.26	0.82
Ser	64.44	78.74	65.36	68.38	75.10	66.60	84.63	66.81	69.75	66.34	70.62	4.49	0.03
Tyr	69.80	73.57	60.46	59.38	59.11	64.28	75.96	58.79	65.68	58.90	64.59	5.36	0.17

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

with several studies reporting that increasing dietary fiber has negative effects on protein digestibility (Dégen et al., 2009; Zhang et al., 2013; Huang et al., 2015). The negative effect of dietary fiber on CP digestibility may be due to increasing endogenous excretion of N and the passage rate of digesta through the entire gastrointestinal tract (Schulze et al., 1994; Le Goff et al., 2002). Part of the reason was that the excretion of NDF-binding N increased in the upper gastrointestinal tract as dietary NDF increased (Schulze et al., 1994; Dégen et al., 2009). The decreased ATTD of AEE observed in this experiment was in agreement with reports that increasing dietary fiber decreased the ATTD of fat because of increased synthesis of microbial fat in diets with high fiber concentration (Dégen et al., 2007; Kil et al., 2010). The inclusion level of CGM did not affect the ATTD of NDF and ADF indicated that the NDF and ADF digestibility of CGM is similar to the digestibility of NDF and ADF in the basal diet, and which was higher than that of 50% for corn coproducts reported by Urriola et al. (2010). Previous reports showed that increasing dietary fiber decreased the ATTD of CP and fat (Dégen et al., 2009; Huang et al., 2015). The combined effects of decreased ATTD of CP and EE (or AEE) contributed to the decreased DE or ME values of the experimental diets. Though affected the ATTD of some nutrients and DE and ME values of diets, the inclusion level of CGM had no effect on the DE or ME value of CGM.

During Exp. 2, all pigs were healthy, so it is likely that the pigs did not affect the results. The average SID of most AA in the 10 CGM samples was less than reported values (Almeida et al., 2011; Stein et al., 2016). The discrepancy in the SID of Trp and Tyr was even >21% and 15%, respectively, between our values and previously published values (Almeida et al., 2011; Stein et al., 2016). Differences are mainly due to differences in processing procedures including addition or not of corn steep liquor back to the CGM product. Although the concentration of AEE in CGM was not very high, it has been reported that addition of fat or oil increased the ileal digestibility of some AA (Li and Sauer, 1994; Albin et al., 2001; Cervantes-Pahm and Stein, 2008) and that low dietary CP led to higher ileal digestibility of AA (He et al., 2016). Therefore, one possible reason for the greatest ileal digestibility of CP and most AA in sample 7 is the combined effect of its relative low concentration of CP and high AEE content compared with the other samples.

The reason for the low AID and SID of CP and AA in the current CGM samples compared with corn grain is most likely because corn germ and corn bran, two main parts of CGM, have less

AID and SID of AA than corn grain (Widmer et al., 2007; NRC, 2012). Corn germ and corn bran have greater concentrations of fiber compared with corn grain, which may have decreased the ileal digestibility of AA in these two components of CGM (Chen et al., 2015). Another reason for the low SID of CP and AA in CGM is most likely due to the high concentration of NDF and ADF, because high fiber can increase the specific endogenous losses of AA (Schulze et al., 1994; Nyachoti et al., 1997; Stein et al., 2007). The specific endogenous losses of AA are not included in the basal endogenous losses of AA determined using the N-free diet. Therefore, increased specific endogenous losses of AA are most likely the main reason for the low SID of CP and AA, because the specific endogenous losses are not included in the calculation of SID (Stein et al., 2007).

The AID of Pro in all CGM samples was very low. In contrast, the average SID of Pro in CGM was very high, >100%. The SID of Pro in CGM was far >62.0% reported by Stein et al. (2016). One reason for the variations in the SID of Pro may be that estimates for the basal endogenous losses of AA and digestibility are often inaccurate when pigs are fed diets containing inadequate indispensable AA (Stein et al., 2007). Another possible reason is that restrictively fed animals have greater basal endogenous losses of Pro compared with animals fully provided with feed (Stein et al., 1999), which can lead to greater SID values according to the calculation for SID of AA (Stein et al., 2007).

CONCLUSIONS

Increasing dietary CGM decreased the ATTD of nutrients, the DE and ME values of diets but CGM. The AID and SID of AA in CGM are low but source dependent, and CGM may be fed to pigs as a protein-rich feedstuff.

Conflict of interest statement. None declared.

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