Available energy and amino acid digestibility of yellow dent corn fed to growing pigs¹

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ABSTRACT: Two experiments were conducted to determine the DE and ME as well as the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of CP and AA in corn fed to growing pigs. All corn was yellow dent corn collected from different areas in China. In Exp. 1, 60 crossbred barrows (Duroc × Landrace × Yorkshire; 40.7 ± 3.5 kg BW) were randomly allotted to 1 of 10 diets to determine the DE and ME of corns. Diets were formulated to contain 96.8% of 1 of the 10 corn samples and 3.2% of other microingredients. In Exp. 2, 11 crossbred barrows (Duroc × Landrace × Yorkshire; 30.5 ± 2.3 kg) fitted with a T-cannula at the distal ileum were assigned to a 6 × 11 Youden square design with 6 periods and 11 diets. Diets included a N-free diet based on cornstarch and sucrose and 10 test diets formulated with 96.6% 1 of the 10 corns as the sole source of AA. Chromic oxide (0.3%) was added to each diet as an indigestible marker for calculating the AA digestibility. On a DM basis, the starch, ether extract (EE), CP, NDF, and ADF contents of corns averaged 74.05% (69.98 to 78.59%), 3.83% (2.04 to 4.73%), 9.63% (7.74 to 10.43%), 10.80% (10.27 to 11.46%), and 2.27% (2.03 to 2.57%), respectively. The CV of EE, CP, and ADF was 22.59, 8.22, and

8.21%, respectively. The DE and ME of corns averaged 4,087 and 3,981 kcal/kg, respectively, and ranged from 3,999 to 4,161 kcal/kg and from 3,898 to 4,067 kcal/kg, respectively. The DE and ME values were positively correlated ($P < 0.05$) with the EE content. Optimal prediction equations of ME were $ME = 940.35 + (0.72 \times DE) + (21.88 \times EE)$ ($R^2 = 0.94$) or $ME = 1,051.50 + (0.82 \times DE) - (282.05 \times \text{ash})$ ($R^2 = 0.99$). In Exp. 2, significant differences ($P < 0.05$) were observed in the SID of Arg, His, Phe, Ala, Pro, Cys, and Tyr. The SID of Lys (average 73.79%), Met (average 87.32%), and Thr (average 80.06%) ranged from 61.45 to 78.47%, from 74.09 to 90.91%, and from 79.19 to 85.79%, respectively. The standardized ileal digestible Met was positively correlated ($P < 0.01$) with the Met and CP contents. The obtained prediction equations were standardized ileal digestible Met = $31.34 + (3.43 \times CP) + (116.04 \times \text{Met})$ and standardized ileal digestible Met = $104.92 + (294.71 \times \text{Met}) - (7.03 \times \text{NDF})$. In conclusion, sources had an effect on the energy values and ileal digestibility of most AA in corn. The ME can be predicted by the DE combined with either the EE or ash content. The AA concentrations and SID of AA in corn varied largely.

Key words: amino acid digestibility, energy content, growing pigs, yellow dent corn

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INTRODUCTION

Corn is the world's highest yielding crop and the most common grain used in pig's diets, with a global production of more than 1,000 million t (Statista, 2018), and can contribute up to 90% of

starch, 60% of energy, and 30% of protein in pig's diets (Dado, 1999). According to the classification systems of the United States and China, corn is mainly classified by some physical properties, such as bulk weight and 1,000-kernel weight (Li et al., 2014b). However, it had been reported that the bulk weight and 1,000-kernel weight were not associated with the energy content (DM basis) of corn (Li et al., 2014b). Indeed, the energy value (DM basis) of corn is significantly correlated with its chemical composition (Li et al., 2014b; Smith et al., 2015). Many factors, especially differences in corn variety and origin, can lead to large variations in the chemical composition of corn (Snow et al., 2004; Kil et al., 2014; Li et al., 2014a; Mariscal-Landín et al., 2014). Because corn accounts for a large proportion of pig's diets, even small variations in the nutrient compositions of corn may lead to dramatic changes in dietary nutrient compositions (Gehring et al., 2013; Malumba et al., 2014). Therefore, accurate evaluation of corn can contribute to precise formulation and low feed costs (Stein et al., 2016; Wang et al., 2018). However, previous evaluation studies mostly focused on some special corn varieties and generally measured only 1 sample and notably lack comprehensive evaluation of the AA digestibility in yellow dent corn (Bohlke et al., 2005; Muley et al., 2007; O'Quinn et al., 2000; Mariscal-Landín et al., 2014; Xu et al., 2016). Therefore, the objectives of this study were to determine the energy content and digestibility of CP and AA in 10 yellow dent corns fed to growing pigs and then to establish prediction equations for DE, ME, and digestible AA based on the chemical compositions of corn.

MATERIALS AND METHODS

The experimental protocols, including animal care and use, were approved by the Institutional Animal Care and Use Committee of China Agricultural University (Beijing, P.R. China). Two experiments were conducted at the Swine Nutrition Research Center of the National Feed Engineering Technology Research Center (Chengde, P.R. China) and the Metabolism Laboratory of the Ministry of Agriculture Feed Industry Center (China Agricultural University). Ten corn samples were collected from main production areas of China (Table 1). Jilin, Liaoning, and Tianjin provinces are spring corn-growing areas, where seeds are planted from the end of April to May. HeBei, Shandong and Henan provinces are summer corn-growing areas, where seeds are planted in mid-June.

Table 1. Sources and variety of yellow dent corns used in the 2 experiments

Corn number	Sources within China
1	Changling, Jilin
2	Liaocheng, Shandong
3	Guanxian, Shandong
4	Xinxiang, Henan
5	Taian, Liaoning
6	Donggang, Liaoning
7	Tanghe, Hebei
8	Haihe, Tianjin
9	Qianan, Jilin
10	Liaoyuan, Jilin

Table 2. Composition of experimental diets in Exp. 1 and 2 (as-fed basis)

Ingredient, %	Exp. 1	Exp. 2	
	Corn diets	Corn diets	N-free diet
Corn	96.80	96.60	—
Cornstarch	—	—	73.35
Soybean oil	—	—	3.00
Sucrose	—	—	15.00
Acetate cellulose ¹	—	—	4.00
Dicalcium phosphate	1.70	1.50	3.00
Limestone	0.70	0.80	—
Chromic oxide	—	0.30	0.30
Salt	0.30	0.30	0.45
Potassium carbonate	—	—	0.30
Magnesium oxide	—	—	0.10
Mineral and vitamin premix ²	0.50	0.50	0.50

¹Made by Chemical Reagents Company (Beijing, P.R. China).

²Premix provided the following per kilogram of complete diet for growing pigs: 5,512 IU vitamin A, 2,200 IU vitamin D₃, 30 IU vitamin E, 2.2 mg vitamin K₃, 27.6 mg vitamin B₁₂, 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.

Experiment 1: Energy Measurements

Animals, diets, and experimental design. Sixty crossbred barrows (Duroc × Landrace × Yorkshire) with an initial BW of 40.7 ± 3.5 kg were allotted to 1 of 10 diets in a completely randomized design with 6 barrows per treatment. Diets included 96.8% of 1 of the corn samples as the only source of energy (Table 2). Vitamins and minerals were supplemented to meet or exceed the requirements recommended by the NRC (2012). Pigs were individually housed in stainless-steel metabolism crates (1.4 by 0.7 by 0.6 m) located in an environmentally controlled room in which the temperature was kept at 22 ± 2 °C.

Pigs were adapted to the environment for 7 d and were fed a complete diet before the experiment.

Pigs were weighed at the beginning of the experiment and fed daily at 4% of their initial individual BW. Daily feed allowances were provided to pigs in 2 equal-sized meals at 0730 and 1630 h in mash form. The experiment lasted a total of 12 d, with 7 d of diet adaptation followed by 5 d of total collection of feces and urine. Water was provided ad libitum through a nipple drinker.

Sample collection. During the collection period, feed refusals and spillage were collected twice daily and subsequently dried and weighed. Feces from each pig were collected as quickly as possible and were immediately stored in plastic bags at -20°C . At the end of collection, the 5 d of collected feces from each pig were thawed, weighed, and thoroughly mixed. About 1,000 g of subsamples were dried in a forced-draft oven at 65°C for 72 h. Subsamples were stored at -20°C for further chemical analysis. Urine was collected into buckets containing 50 mL of 6 N HCl. The volume of collected urine was measured daily, and 10% of the daily collected urine was stored at -20°C . At the end of collection, urine samples were thawed, pooled, and thoroughly mixed within each pig and a subsample of 50 mL was saved for further chemical analysis.

Chemical analysis. Samples including diets and dried feces were ground through a 1-mm screen before chemical analysis. Corns and diets were analyzed for DM (method 930.15; AOAC, 2006), CP (method 984.13; AOAC, 2006), ether extract (EE; Thiex et al., 2003), ash (method 942.05; AOAC, 2006), Ca (method 968.08; AOAC, 2006), and P (method 946.06; AOAC, 2006). The NDF and ADF were determined using fiber analyzer (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. The GE in the corns, diets, feces, and urine samples was determined using an isoperibol calorimeter (Parr 6300 Calorimeter; Parr Instrument Co., Moline, IL) using benzoic acid as a standard. All chemical analyses were performed in duplicate.

Experiment 2: Amino Acid Digestibility

Animals, diets, and experimental design. The experiment was conducted to determine the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of 10 yellow dent corns from different areas of China. All corn samples were the

same as used in Exp. 1. A total of 11 crossbred barrows (Duroc $\times$ Landrace $\times$ Yorkshire; 30.5 ± 2.3 kg) were fitted with a T-cannula at the distal ileum according to the method described by Stein et al. (1998). After 20 d of recovery, those barrows were assigned to a 6×11 Youden square design with 6 periods and 11 diets. Diets included a N-free diet mainly based on cornstarch and sucrose and 10 test diets formulated with 96.6% 1 of the 10 corns as the sole source of AA. Chromic oxide (0.3%) was added to each diet as an indigestible marker for calculating the AA digestibility. Vitamins and minerals were supplemented to meet the nutrient requirement for growing pigs (NRC, 2012). The metabolism crates and environment were similar to those used in Exp. 1. Pigs were weighed at the beginning of each period and fed at a daily level of 4% of the initial BW of each pig. Daily diets were provided to pigs in 2 equal-sized mash meals at 0730 and 1630 h. Water was available through a nipple drinker provided in the crates.

Sample collection. Each period lasted a total of 9 d, with 7 d of diet adaptation followed by 2 d of digesta collection. The daily digesta collection lasted for 9 h and was based on the method described by Stein et al. (1998). On day 8 and 9, a plastic bag was attached to the barrel of the cannula. Digesta was collected every 30 min or whenever the plastic bags were filled with digesta. Collected digesta was subsequently 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, P.R. China) for further chemical analysis.

Chemical analyses. Corns, diets, and lyophilized digesta were ground through a 1-mm screen before the analysis of AA. Corns, diets, and digesta were hydrolyzed using 6 N HCl at 110°C for 24 h. The 15 AA were analyzed using an amino acid analyzer (model L-8900; Hitachi High-Technologies Corp., Tokyo, Japan). Methionine and Cys were determined as methionine sulfone and cysteic acid after cold performic acid oxidation overnight and hydrolyzing using 7.5 N HCl at 110°C for 24 h (Llames and Fontaine, 1994; Commission Directive, 1998) using an amino acid analyzer (model L-8800; Hitachi High-Technologies Corp.). Tryptophan was measured after LiOH hydrolysis for 22 h at 110°C (Commission Directive, 2000) using HPLC (Agilent 1200 Series; Agilent Technologies, Inc., Santa Clara, CA). The Cr in the diet and digesta

was analyzed using a polarized Zeeman Atomic Absorption Spectrometer (model Z2000; Hitachi High-Technologies Corp.) after nitric acid–perchloric acid wet ash sample preparation. All analyses were conducted in duplicate.

Calculations

In Exp. 1, the apparent total tract digestibility (ATTD; %) of GE and the DE and ME of the diets and corns were calculated using the methods described by Adeola (2001) as follows:

$$DE_d = (GE_i - GE_f) / F_i,$$

$$DE_{dc} = DE_d / 0.968,$$

$$DE_f = [DE_d - (100\% - X\%) \times DE_{dc}] / X\%,$$

$$ME_d = (GE_i - GE_f - GE_u) / F_i,$$

$$ME_{dc} = ME_d / 0.968,$$

$$ME_f = [ME_d - (100\% - X\%) \times ME_{dc}] / X\%, \text{ and}$$

$$ATTD = (GE_i - GE_f) / GE_i,$$

in which DE_d and ME_d are the DE and ME values, respectively, of each diet (kcal/kg of DM); GE_i was calculated as the product of the GE content (kcal of DM) of the diet and the actual feed intake (F_i ; kg of DM) over the 5-d collection period; GE_f and GE_u are the GE content (kcal of DM) in feces and urine, respectively, of each pig corresponding to the 5-d collection period; DE_{dc} and ME_{dc} are the adjusted DE and ME, respectively, in the basal diet (kcal/kg of DM); 0.968 is the percentage of the corns that supplied energy in the diet; DE_f and ME_f are the DE and ME values, respectively, in each corn sample (kcal/kg of DM); and $X\%$ is the percentage of energy supplied by corns in the basal diet.

In Exp. 2, the AID and SID of AA and CP were calculated as described by Stein et al. (2007) using the following equation:

$$AID = [1 - (AA_d/AA_f) \times (Cr_f/Cr_d)] \times 100\%,$$

in which AA_d and Cr_d are the concentrations of AA and Cr, respectively, in the ileal digesta (g/kg of DM) and AA_f and Cr_f are the concentrations of AA and Cr, respectively, in the corn diets (g/kg of DM). The same equation was used to calculate the AID of CP.

The endogenous loss of N for each AA was measured from pigs fed the N-free diet according to 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 are the concentrations of AA and Cr, respectively, in the ileal digesta from the pigs fed the N-free diet. The Cr_f represents the concentration of Cr in the N-free diet. The same equation was used to calculate the endogenous loss of CP.

The average IAA_{end} for the 6 pigs fed the N-free diet was used to calculate the SID of AA in all diets. The SID was calculated using the following equation:

$$SID = [AID + (IAA_{end}/AA_f) \times 100\%].$$

Statistical Analyses

Data in Exp. 1 were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The normality of the data was verified using the UNIVARIATE procedure of SAS, and no outliers were identified. Individual pig was treated as the experimental unit. PROC CORR of SAS was used to determine the relationship between energy content and chemical composition. Prediction equations for DE and ME in the corn samples were developed using PROC REG of SAS. The R^2 , Mallows' root mean square error (RMSE), Mallows' statistic ($C(p)$), and Akaike information criterion (AIC) were used as the selection criteria for the best fit equations. Equations with the greatest R^2 and the least RMSE were chosen as the best fit.

Data in Exp. 2 were analyzed by ANOVA using the MIXED procedure of SAS. Diet was treated as the only fixed effect and period as a random effect. The individual pig was treated as the experiment unit. Mean values were calculated using the LSMEANS model of SAS. The significant differences between treatments were tested using Tukey's multiple range test, and an alpha level of $P < 0.05$ was set as the criterion for statistical significance. The relationship between energy content and chemical composition was determined using PROC CORR of SAS. Prediction equations for SID of AA in the corn samples were developed using PROC REG of SAS. The R^2 , Mallows' RMSE, $C(p)$, and AIC were used as the selection criteria for the best fit equations. Equations with the greatest R^2 and the least RMSE were proposed to be the best fit.

RESULTS

Chemical Composition of Corns

The chemical compositions of the 10 corns are presented in Table 3. The CV was greater than 10%

for EE, Ca, and P. On a DM basis, the concentration of starch, CP, EE, NDF, ADF, ash, Ca, and P in the corns averaged 74.05% (69.98 to 78.59%), 9.63% (7.74 to 10.43%), 3.80% (2.04 to 4.73%), 10.80% (10.27 to 11.46%), 2.27% (2.03 to 2.57%), 1.57% (1.51 to 1.74%), 0.02% (0.01 to 0.03%), and 0.28% (0.20 to 0.38%), respectively. The averaged GE was 4,417 kcal/kg, with a range from 4,373 to 4,504 kcal/kg.

The AA concentrations of the 10 corns are presented in Table 4. The CV of Leu and Met was greater than 10% among the indispensable AA. The CV of Pro and Tyr was 14.10 and 19.14%, respectively, among the dispensable AA. The concentrations of Lys, Met, and Thr ranged from 0.26 to 0.30%, from 0.15 to 0.23%, and from 0.30 to 0.37%, respectively, with averages of 0.28, 0.20, and 0.34%, respectively. The chemical composition and AA composition of the 10 corn diets, corresponding to the 10 corn samples, are presented in Tables 5 and 6, respectively.

Energy Values and the Apparent Total Tract Digestibility of GE in Corns

The DE content in corn samples 5, 7, and 9 was greater ($P < 0.05$) than that in corn sample 6 (Table 7) but not different from that in the other corns. Sample 9 had a greater concentration of ME ($P < 0.05$) than corn samples 3 or 6 but was not different from the other corns. The average DE and ME in the 10 corn samples were 4,087 and 3,981 kcal/kg, respectively, and ranged from 3,999 to 4,161 kcal/kg of DM and from 3,898 to 4,067 kcal/kg of DM, respectively. The ATTD of GE in corn

samples 7, 8, and 9 was comparable and was greater than that in samples 1, 3, 4, and 6. No significant differences were observed in the ME to DE ratio, with an average of 97.41%.

Correlation Analysis and Prediction Equations of DE and ME

As shown in Table 8, the EE content was positively correlated with DE ($r = 0.74$, $P < 0.05$) and ME ($r = 0.84$, $P < 0.01$) of corns. In addition, the ash content was negatively correlated with both the ME and EE contents ($r = -0.66$, $P < 0.05$ and $r = -0.73$, $P < 0.05$, respectively). The ADF was negatively correlated with the GE of corn ($r = -0.72$, $P < 0.05$). The equation with the greatest R^2 and least RMSE was considered the optimal model (Table 9). Accordingly, the optimal prediction equations were $DE = 3,898 + (49.59 \times ME)$ ($R^2 = 0.54$) and $ME = 940.35 + (0.72 \times DE) + (21.88 \times EE)$ ($R^2 = 0.94$; Eq. [4] in Table 9) and $ME = 1,051.50 + (0.82 \times DE) - (282.05 \times \text{ash})$ ($R^2 = 0.99$; Eq. [5] in Table 9), respectively.

The Apparent Ileal Digestibility and Standardized Ileal Digestibility of CP and AA

The AID and SID of CP and AA in the 10 corn samples are presented in Tables 10 and 11, respectively. The AID and SID of CP averaged 69.51 and 90.94%, respectively, and were not significantly different among the 10 corn samples. For indispensable AA, the AID and SID of Arg, His, and Phe significantly varied among the 10 corn samples ($P < 0.05$). The AID of Lys, Met, and Thr ranged

Table 3. Analyzed chemical composition of 10 corn samples (% of DM)

Items	DM	Starch	CP	Ether extract	NDF	ADF	Ash	Ca	P	GE, kcal/kg
Corn number ¹										
1	87.03	69.98	7.74	4.16	10.46	2.42	1.52	0.01	0.20	4,435
2	87.31	78.59	10.21	3.47	10.55	2.44	1.52	0.03	0.21	4,374
3	86.85	74.02	10.43	2.04	10.78	2.20	1.74	0.02	0.38	4,444
4	87.38	72.01	10.14	3.58	10.27	2.03	1.61	0.02	0.23	4,458
5	86.76	76.97	9.76	4.73	10.53	2.05	1.54	0.01	0.21	4,504
6	87.62	75.44	8.87	2.74	11.42	2.11	1.57	0.01	0.35	4,441
7	87.05	72.75	9.88	4.22	10.67	2.33	1.53	0.03	0.37	4,382
8	87.02	73.57	9.85	4.08	11.46	2.57	1.52	0.02	0.31	4,373
9	86.85	75.90	9.43	4.51	10.79	2.13	1.51	0.01	0.33	4,389
10	87.01	71.29	9.95	4.52	11.09	2.37	1.59	0.01	0.26	4,373
Minimum	86.76	69.98	7.74	2.04	10.27	2.03	1.51	0.01	0.20	4,373
Maximum	87.62	78.59	10.43	4.73	11.46	2.57	1.74	0.03	0.38	4,504
Mean	87.09	74.05	9.63	3.80	10.80	2.27	1.57	0.02	0.28	4,417
CV	0.31	3.62	8.22	22.59	3.73	8.21	4.49	48.36	25.50	1.03

¹Sources of corns are described in Table 1.

Table 4. Analyzed AA composition of 10 corn samples (% of DM)

	Corn number ¹										Minimum	Maximum	Mean	CV
Items	1	2	3	4	5	6	7	8	9	10				
Indispensable AA														
Arg	0.44	0.46	0.45	0.47	0.46	0.42	0.45	0.40	0.43	0.44	0.40	0.47	0.44	4.61
His	0.24	0.31	0.31	0.33	0.30	0.26	0.28	0.29	0.30	0.28	0.24	0.33	0.29	9.13
Ile	0.25	0.30	0.31	0.31	0.31	0.26	0.29	0.30	0.29	0.31	0.25	0.31	0.29	7.08
Leu	0.94	1.43	1.47	1.32	1.28	1.06	1.23	1.30	1.31	1.26	0.94	1.47	1.26	12.52
Lys	0.26	0.27	0.29	0.30	0.30	0.27	0.30	0.28	0.28	0.29	0.26	0.30	0.28	4.35
Met	0.15	0.19	0.20	0.19	0.20	0.21	0.20	0.23	0.20	0.21	0.15	0.23	0.20	10.09
Phe	0.37	0.47	0.50	0.40	0.46	0.41	0.43	0.46	0.46	0.47	0.37	0.50	0.44	8.90
Thr	0.30	0.36	0.37	0.34	0.35	0.32	0.34	0.34	0.35	0.33	0.30	0.37	0.34	5.65
Val	0.48	0.56	0.55	0.51	0.48	0.45	0.45	0.47	0.46	0.44	0.44	0.56	0.49	9.04
Dispensable AA														
Ala	0.44	0.57	0.58	0.57	0.54	0.49	0.53	0.55	0.54	0.55	0.44	0.58	0.54	8.05
Asp	0.57	0.65	0.68	0.63	0.63	0.58	0.63	0.63	0.63	0.63	0.57	0.68	0.63	4.85
Cys	0.20	0.24	0.23	0.25	0.23	0.22	0.23	0.25	0.24	0.23	0.20	0.25	0.23	7.30
Glu	1.34	1.78	1.77	1.74	1.64	1.45	1.55	1.65	1.65	1.67	1.34	1.78	1.62	8.61
Gly	0.31	0.36	0.36	0.35	0.36	0.33	0.34	0.33	0.35	0.33	0.31	0.36	0.34	4.46
Pro	0.76	0.96	1.06	0.89	0.69	0.67	0.84	0.91	0.89	0.82	0.67	1.06	0.85	14.10
Ser	0.37	0.46	0.46	0.45	0.44	0.40	0.41	0.43	0.43	0.43	0.37	0.46	0.43	6.57
Tyr	0.16	0.38	0.38	0.32	0.33	0.31	0.36	0.33	0.32	0.32	0.16	0.38	0.32	19.14

¹Sources of corns are described in Table 1.

Table 5. Analyzed chemical composition of the 10 corn diets in Exp. 1 (% , as-fed basis)

Diet number ¹	DM	Starch	CP	Ether extract	NDF	ADF	Ash	Ca	P	GE, kcal/kg
1	89.77	59.19	6.55	3.52	8.84	2.05	3.39	0.55	0.47	3,738
2	89.53	66.69	8.66	2.94	8.95	2.07	3.43	0.62	0.48	3,774
3	89.81	62.49	8.81	1.72	9.10	1.86	3.90	0.50	0.59	3,779
4	89.45	61.15	8.61	3.04	8.72	1.72	3.63	0.55	0.47	3,791
5	88.88	64.92	8.23	3.99	8.88	2.00	3.47	0.57	0.46	3,800
6	89.67	64.23	7.55	2.33	9.72	1.80	3.55	0.59	0.57	3,755
7	90.06	61.56	8.36	3.57	9.03	1.97	3.43	0.53	0.58	3,800
8	89.97	62.23	8.33	3.45	9.69	2.18	3.40	0.60	0.54	3,779
9	89.36	64.08	7.96	3.81	9.11	2.12	3.38	0.61	0.56	3,788
10	89.56	60.29	8.42	3.82	9.38	2.01	3.56	0.62	0.50	3,791

¹Sources of corns are described in Table 1.

from 49.76 to 66.73%, from 68.63 to 86.40%, and from 54.72 to 70.58%, respectively. The SID of Lys, Met, and Thr ranged from 61.45 to 78.47% (average 73.79%), from 74.09 to 90.91% (average 87.32%), and from 70.19 to 85.79% (average 80.06%), respectively. The AID and SID of Ala, Cys, Pro, and Tyr significantly varied among the 10 corn samples ($P < 0.05$).

Correlation Analysis and Prediction Equations of Standardized Ileal Digestible AA

As shown in Table 12, the standardized ileal digestible CP and standardized ileal digestible Lys were positively correlated with standardized ileal digestible Thr ($r = 0.82$, $P < 0.01$ and

$r = 0.91$, $P < 0.01$, respectively). The standardized ileal digestible Met was positively correlated with Met ($r = 0.76$, $P < 0.01$), CP ($r = 0.79$, $P < 0.01$), standardized ileal digestible Val ($r = 0.70$, $P < 0.05$), and Thr ($r = 0.73$, $P < 0.05$). The standardized ileal digestible Thr was positively correlated with standardized ileal digestible Val ($r = 0.77$, $P < 0.01$). As shown in Table 13, CP was the only predictor of standardized ileal digestible Lys. Crude protein was the only predictor of standardized ileal digestible Lys but had a low R^2 of 0.45. The CP was the first predictor of standardized ileal digestible Met ($R^2 = 0.62$, $P < 0.01$). When the Met was included in the equation, the accuracy of the equation was improved ($R^2 = 0.76$, $P < 0.01$). Methionine can

Table 6. Analyzed CP and AA composition of experimental diets in Exp. 2 (%; as-fed basis)

Items	Corn diet number ¹										N-free diet
	1	2	3	4	5	6	7	8	9	10	
CP	6.55	8.66	8.79	8.61	8.21	7.54	8.36	8.33	7.95	8.41	0.84
Indispensable AA											
Arg	0.37	0.39	0.38	0.40	0.39	0.36	0.38	0.34	0.36	0.37	0.01
His	0.20	0.26	0.26	0.28	0.25	0.22	0.23	0.24	0.25	0.23	0.02
Ile	0.21	0.25	0.26	0.26	0.26	0.22	0.24	0.25	0.24	0.26	0.01
Leu	0.79	1.21	1.24	1.11	1.07	0.90	1.03	1.09	1.10	1.06	0.05
Lys	0.22	0.23	0.24	0.25	0.25	0.23	0.25	0.23	0.23	0.24	0.01
Met	0.13	0.16	0.16	0.16	0.16	0.17	0.16	0.19	0.16	0.17	0.00
Phe	0.31	0.40	0.42	0.34	0.39	0.35	0.36	0.39	0.39	0.40	0.02
Thr	0.25	0.30	0.31	0.29	0.29	0.27	0.29	0.29	0.29	0.28	0.02
Val	0.41	0.47	0.46	0.43	0.41	0.38	0.38	0.40	0.39	0.37	0.02
Dispensable AA											
Ala	0.37	0.48	0.48	0.48	0.45	0.42	0.44	0.46	0.45	0.46	0.03
Asp	0.48	0.55	0.57	0.53	0.53	0.49	0.53	0.53	0.53	0.53	0.02
Cys	0.16	0.20	0.19	0.21	0.19	0.18	0.19	0.21	0.20	0.19	0.00
Glu	1.13	1.50	1.49	1.47	1.37	1.23	1.30	1.39	1.38	1.40	0.06
Gly	0.26	0.30	0.30	0.30	0.30	0.28	0.29	0.28	0.29	0.28	0.02
Pro	0.64	0.81	0.89	0.75	0.58	0.57	0.71	0.76	0.74	0.69	0.03
Ser	0.31	0.39	0.39	0.38	0.37	0.34	0.35	0.36	0.36	0.36	0.02
Tyr	0.14	0.32	0.32	0.27	0.28	0.26	0.30	0.28	0.27	0.27	0.01

¹Sources of corns are described in Table 1.

Table 7. Energy content (kcal/kg of DM) and the apparent total tract digestibility (ATTD; %) of GE in corn fed to growing pigs (Exp. 1)¹

Diet number ²	DE	ME	ATTD of GE	ME:DE ratio
1	4,049 ^{ab}	3,956 ^{ab}	91.29 ^{bc}	97.72
2	4,045 ^{ab}	3,954 ^{ab}	92.48 ^{abc}	97.73
3	4,051 ^{ab}	3,898 ^b	91.17 ^{bc}	96.17
4	4,037 ^{ab}	3,940 ^{ab}	90.55 ^c	97.62
5	4,158 ^a	4,039 ^{ab}	92.31 ^{abc}	97.15
6	3,999 ^b	3,909 ^b	90.06 ^c	97.75
7	4,141 ^a	4,038 ^{ab}	94.51 ^a	97.52
8	4,130 ^{ab}	4,028 ^{ab}	93.32 ^a	97.53
9	4,161 ^a	4,067 ^a	94.80 ^a	97.75
10	4,099 ^{ab}	3,982 ^{ab}	93.72 ^{ab}	97.15
Mean	4,087	3,981	92.42	97.41
SEM	30.02	37.13	0.67	0.49
<i>P</i> -value	<0.01	0.02	<0.01	0.45

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

¹Data are means of 6 observations per treatment.

²Sources of corns are described in Table 1.

also be used as a single predictor in the standardized ileal digestible Met prediction equation ($R^2 = 0.58$, $P < 0.01$). Similarly, the accuracy of the equation was improved ($R^2 = 0.72$, $P < 0.01$) when NDF was included in the prediction equation. On a DM basis, the optimal models to predict standardized ileal digestible Met were standardized ileal digestible Met = $31.34 + (3.43 \times \text{CP}) + (116.04 \times \text{Met})$ ($R^2 = 0.76$) and standardized

ileal digestible Met = $104.92 + (294.71 \times \text{Met}) - (7.03 \times \text{NDF})$ ($R^2 = 0.72$).

DISCUSSION

Chemical Composition of Corns

The chemical composition of corn is affected by many factors such as origin, variety, growing

Table 8. Correlation coefficients between chemical compositions and energy values of the 10 corn samples (Exp. 1)

Item	DE	ME	GE	Starch	CP	Ether extract	NDF	ADF	Ash
DE	1.00								
ME	0.94**	1.00							
GE	-0.18	-0.27	1.00						
Starch	0.12	0.14	0.06	1.00					
CP	0.20	0.03	-0.15	0.36	1.00				
Ether extract	0.74*	0.84**	-0.17	-0.12	-0.20	1.00			
NDF	0.00	0.01	-0.38	0.05	-0.03	-0.15	1.00		
ADF	0.07	0.12	-0.72*	-0.22	-0.10	0.15	0.32	1.00	
Ash	-0.40	-0.66*	0.32	-0.17	0.43	-0.73*	-0.03	-0.33	1.00

* $P < 0.05$; ** $P < 0.01$.

Table 9. Regression equations to estimate DE and ME in corns (Exp. 1)

Corn number	Regression equation ¹	Statistics ²				
		R^2	RMSE	AIC	C(p)	P-value
1	DE = 3,898 + (49.59 × EE)	0.54	41.57	76.31	2.00	0.02
2	ME = 3,761.30 + (57.77 × EE)	0.71	33.79	72.17	1.00	<0.01
3	ME = 46.21 + (0.96 × DE)	0.89	20.49	62.16	6.38	<0.01
4	ME = 940.35 + (0.72 × DE) + (21.88 × EE)	0.94	16.47	58.46	3.00	<0.01
5	ME = 1,051.50 + (0.82 × DE) - (282.05 × ash)	0.99	7.67	43.17	1.24	<0.01

¹Regression equations were developed using stepwise regression analyses. The unit of energy value is as kilocalories per kilogram of DM, and the ether extract (EE) and ash contents are reported as percent of DM.

²RMSE = root mean square error; AIC = Akaike information criterion; C(p) = Mallows' statistic.

environment, and drying method (Li et al., 2014b). The corn used in the current study was yellow dent corn from different corn-producing areas. Different areas have different natural conditions such as soil, rain, and sunlight. Differences in growth environment affect the physical characteristics and chemical composition of corns (Li et al., 2014a). The average values of CP, EE, NDF, Ca, and P were close to those reported by the NRC (2012). The wide variations in the EE content were consistent with results from Li et al. (2014b), who reported that the CV of EE content in corns was 14.79%. Similar results were reported by Jeong et al. (2015), who reported that CV of EE and NDF in corns was 10.89 and 8.71%, respectively. In the current study, the CV of starch and NDF was less than 4%. Li et al. (2014b) observed that the CV of starch and NDF was 4.56 and 8.35%, respectively, which indicated that corn from the same variety had relatively stable starch and NDF content but that its EE content greatly varied. The starch content ranged from 69.98 to 78.59% with a CV of 3.62%. Because corn contains high starch, low fiber, and antinutritional factors (Cowieson et al., 2005), it can be used as a main energy source in feed.

In general, the data measured in the current study is consistent with that reported by the NRC (2012). The concentrations of Met, Val, Leu, and His greatly

varied, which indicated that growing environment is one of the major sources of variation in AA of corns (Kil et al., 2014). Based on ideal protein formulation for pigs (NRC, 2012), corn protein was considered to have poor nutritional value (Cowieson, 2005). Lysine and Met are the first and second limiting AA, respectively, for pig production. However, concentrations of Lys and Met in corn were lower than in grains such as wheat, polished rice, and oats (Stein et al., 2016). The low Met concentration in corn was close to that in barley, sorghum, and rye (Almeida et al., 2011; Cervantes-Pahm et al., 2014; Pan et al., 2017). The lowest AA in corn is Trp (average 0.06%), and it is not listed for reasons of detection error. In addition, Cys in corn was second lowest. The concentrations of Trp, Met, and Cys in SBM were generally first, second, and third lowest, respectively, among all AA (Li et al., 2015b). This might lead to AA imbalance in corn-soybean meal based diets. Accordingly, the addition of Lys, Trp, Met, and Cys in corn-SBM-based diets fed to pigs should be taken seriously.

Energy Values and the Apparent Total Tract Digestibility of GE in Corns

The average DE and ME contents of corns measured in the current study were 4,087 and 3,981

Table 10. Apparent ileal digestibility (%) of AA in corn fed to growing pigs (Exp. 2)¹

Item	Corn diet number ²										Mean	SEM	P-value
	1	2	3	4	5	6	7	8	9	10			
CP	63.72	74.25	70.25	67.02	72.73	65.43	60.4	73.55	74.83	72.92	69.51	1.52	0.13
Indispensable AA													
Arg	79.45 ^{ab}	82.85 ^{ab}	82.65 ^{ab}	84.32 ^a	85.29 ^a	77.56 ^{ab}	72.02 ^b	81.15 ^{ab}	83.45 ^{ab}	81.16 ^{ab}	80.99	1.17	0.04
His	62.04 ^b	74.13 ^a	81.22 ^a	83.36 ^a	84.01 ^a	79.43 ^a	74.24 ^a	82.28 ^a	84.76 ^a	82.60 ^a	78.81	2.11	0.01
Ile	68.32	77.33	72.27	71.45	76.44	72.04	63.46	74.77	76.1	76.55	72.87	1.32	0.07
Leu	81.72	88.78	87.63	86.25	87.43	84.66	82.14	87.91	89.12	87.12	86.28	0.79	0.04
Lys	62.17	66.25	61.52	61.09	66.73	59.95	49.76	61.15	63.34	64.74	61.67	1.44	0.40
Met	68.63	86.40	84.98	83.84	86.22	83.52	78.07	86.29	84.68	85.65	82.83	0.80	0.17
Phe	81.69 ^{abc}	87.82 ^a	81.79 ^{abc}	78.11 ^{ab}	83.94 ^{ab}	81.17 ^{abc}	75.07 ^c	83.88 ^{ab}	86.24 ^{ab}	86.91 ^{ab}	82.66	1.20	0.01
Thr	59.35	70.03	63.28	58.67	70.58	64.8	54.72	68.29	69.41	65.00	64.41	1.63	0.21
Val	68.04	77.68	72.68	73.56	78.25	76.36	67.94	79.52	76.03	69.78	73.98	1.29	0.05
Dispensable AA													
Ala	63.58 ^b	73.16 ^{ab}	70.83 ^{ab}	66.65 ^b	81.09 ^a	79.11 ^a	72.41 ^{ab}	81.60 ^a	83.43 ^a	82.88 ^a	75.47	2.24	0.01
Asp	70.18	75.95	70.88	66.15	75.36	71.4	63.65	74.90	75.99	74.38	71.88	1.29	0.14
Cys	64.24 ^b	79.29 ^a	73.40 ^{ab}	73.96 ^{ab}	76.28 ^a	72.12 ^{ab}	65.13 ^b	80.00 ^a	80.6 ^a	77.85 ^a	74.29	1.75	0.01
Glu	81.25	85.79	82.96	79.82	85.26	82.85	78.16	85.76	87.07	86.74	83.57	5.26	0.08
Gly	44.63	63.56	45.55	46.17	58.24	50.35	40.09	52.27	61.48	39.73	50.21	2.57	0.10
Pro	70.41 ^{ab}	78.28 ^{ab}	71.69 ^{ab}	56.00 ^b	77.88 ^{ab}	61.91 ^{ab}	72.4 ^{ab}	81.69 ^a	85.48 ^a	66.07 ^{ab}	72.18	2.74	0.01
Ser	68.68	78.75	75.55	74.18	78.65	73.74	66.09	78.52	79.63	76.32	75.01	1.37	0.07
Tyr	76.95 ^c	90.54 ^b	92.74 ^a	84.84 ^{ab}	91.01 ^a	91.3 ^a	89.62 ^a	92.63 ^a	85.64 ^{ab}	79.02 ^{bc}	87.43	1.71	0.01

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

¹Data are means of 6 observations per treatment.

²Sources of corns are described in Table 1.

Table 11. Standardized ileal digestibility (%) of AA in corn fed to growing pigs (Exp. 2)¹

Item	Corn diet number ²										Mean	Minimum	Maximum	SEM	P-value
	1	2	3	4	5	6	7	8	9	10					
CP	90.20	94.14	90.12	87.23	93.65	88.43	81.2	94.37	96.53	93.56	90.94	81.2	96.53	1.36	0.39
Indispensable AA															
Arg	87.61 ^{ab}	90.58 ^{ab}	90.71 ^{ab}	91.84 ^{ab}	92.98 ^a	86.01 ^{ab}	80.18 ^b	90.27 ^{ab}	91.83 ^{ab}	89.42 ^{ab}	89.14	86.01	92.98	1.14	0.05
His	69.12 ^b	79.63 ^a	86.82 ^a	88.53 ^a	89.66 ^a	85.87 ^a	80.46 ^a	88.32 ^a	90.52 ^a	88.81 ^a	84.77	69.12	90.52	2.00	0.01
Ile	75.58	83.35	78.05	77.28	82.3	78.83	69.81	81.00	82.30	82.38	79.09	69.81	83.35	0.67	0.11
Leu	86.52	91.87	90.67	89.62	90.92	88.84	85.83	91.38	92.54	90.66	89.89	85.83	91.87	4.86	0.15
Lys	75.11	78.47	73.37	72.75	78.11	72.60	61.45	73.71	75.77	76.60	73.79	61.45	78.47	1.45	0.39
Met	74.09	90.91	89.59	88.4	90.58	87.84	82.6	90.16	89.24	89.82	87.32	74.09	90.91	1.58	0.25
Phe	88.32 ^{ab}	92.95 ^a	86.67 ^{ab}	84.20 ^{ab}	89.16 ^{ab}	87.01 ^b	80.86 ^{ab}	89.14 ^{ab}	91.50 ^a	92.05 ^a	88.19	80.86	92.95	1.12	0.01
Thr	77.62	84.73	77.83	73.98	85.79	81.26	70.19	83.82	84.62	80.80	80.06	70.19	85.79	1.55	0.29
Val	73.97	82.81	77.95	79.24	84.06	82.77	74.39	85.60	82.25	76.33	79.94	73.97	85.60	1.25	0.06
Dispensable AA															
Ala	72.46 ^b	80.09 ^{ab}	77.71 ^{ab}	71.55 ^b	88.41 ^a	87.04 ^a	79.99 ^{ab}	88.90 ^a	90.71 ^a	90.09 ^a	82.70	71.55	90.71	2.19	0.01
Asp	80.92	85.37	80.07	75.90	85.17	81.98	73.49	84.81	85.74	84.25	81.77	73.49	85.74	1.28	0.15
Cys	76.40 ^{bc}	88.66 ^a	83.20 ^{abc}	83.08 ^{abc}	86.10 ^{abc}	82.32 ^{abc}	75.33 ^c	89.02 ^a	90.08 ^a	87.78 ^{ab}	84.20	75.33	90.08	1.56	0.01
Glu	86.24	89.56	86.75	83.65	89.36	87.46	82.53	89.32	91.15	90.78	87.68	82.53	91.15	0.89	0.11
Gly	75.77	90.23	72.64	72.82	84.40	78.57	67.75	81.00	89.24	68.49	78.09	67.75	90.23	2.43	0.15
Pro	81.53 ^{ab}	87.01 ^{ab}	79.69 ^{ab}	65.44 ^b	90.04 ^{ab}	74.35 ^{ab}	82.47 ^{ab}	91.10 ^a	95.08 ^a	76.33 ^{ab}	82.30	65.44	95.08	2.69	0.01
Ser	80.08	87.99	84.69	83.56	88.26	84.29	76.35	88.42	89.46	86.26	84.94	80.08	89.46	1.25	0.15
Tyr	83.81 ^b	93.26 ^a	95.84 ^a	88.46 ^{ab}	94.44 ^a	95.12 ^a	92.94 ^a	96.20 ^a	89.25 ^{ab}	82.73 ^b	91.21	82.73	96.20	1.49	0.01

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

¹Data are means of 6 observations per treatment.

²Sources of corns are described in Table 1.

Table 12. Correlation coefficients between chemical characteristics and standardized ileal digestible AA in corn (Exp. 2; DM basis)¹

Item ²	SID CP	SID Lys	SID Met	SID Thr	SID Val	Lys	Met	Thr	Val	CP	EE ²	NDF	ADF	Ash
SID CP	1.00													
SID Lys	0.87**	1.00												
SID Met	0.45	0.35	1.00											
SID Thr	0.91**	0.82**	0.52	1.00										
SID Val	0.59	0.47	0.70*	0.77**	1.00									
Lys	-0.33	-0.35	0.39	-0.35	-0.07	1.00								
Met	0.18	-0.10	0.76**	0.28	0.58	0.37	1.00							
Thr	0.22	0.10	0.73*	0.21	0.38	0.47	0.41	1.00						
Val	0.12	0.31	0.22	0.07	0.12	-0.07	-0.26	0.60	1.00					
CP	0.03	-0.05	0.79**	0.00	0.26	0.67*	0.59	0.86**	0.41	1.00				
EE	0.25	0.09	-0.14	0.19	-0.01	0.17	-0.05	-0.28	-0.56	-0.20	1.00			
NDF	0.21	-0.04	0.30	0.33	0.38	-0.25	0.73*	-0.14	-0.46	-0.03	-0.15	1.00		
ADF	0.15	-0.03	-0.23	0.07	-0.11	-0.44	0.04	-0.18	0.01	-0.10	0.15	0.32	1.00	
Ash	-0.20	-0.04	0.24	-0.30	-0.23	0.33	0.09	0.40	0.43	0.43	-0.73*	-0.03	-0.33	1.00

¹SID CP, Lys, Met, Thr, and Val = standardized ileal digestible CP, Lys, Met, Thr, and Val, respectively.

²EE = ether extract.

* $P < 0.05$; ** $P < 0.01$.

Table 13. Regression equations to predict the standardized ileal digestible AA in corns (Exp. 2)¹

Number	Regression equations	Statistics ²				
		R^2	RMSE	AIC	C(p)	P-value
1	Standardized ileal digestible Lys = $0.17 + (0.01 \times \text{CP})$	0.45	0.01	-88.06	2.00	0.03
2	Standardized ileal digestible Met = $37.39 + (5.19 \times \text{CP})$	0.62	3.41	26.32	2.36	<0.01
3	Standardized ileal digestible Met = $31.34 + (3.43 \times \text{CP}) + (116.04 \times \text{Met})$	0.76	2.93	23.92	1.39	<0.01
4	Standardized ileal digestible Met = $48.87 + (194.22 \times \text{Met})$	0.58	3.60	27.38	8.02	<0.01
5	Standardized ileal digestible Met = $104.92 + (294.71 \times \text{Met}) - (7.03 \times \text{NDF})$	0.72	3.16	25.42	5.43	<0.01

¹The CP, Lys, Met, and NDF content was analyzed as % of DM.

²RMSE = root mean square error; AIC = Akaike information criterion; C(p) = Mallows' statistic.

kcal/kg DM, respectively, which were close to those reported by [Li et al. \(2014b\)](#), who reported that the average DE and ME of corn was 4,053 and 3,923 kcal/kg DM, respectively. However, the average energy values measured in the current study were greater than those reported (3,878 and 3,799 kcal/kg DM for DE and ME, respectively) by [Stein et al. \(2016\)](#). Particle size of corn is the main cause of the differences. It has been reported that the ME of diets linearly increased as the particle size decreased ([Rojas and Stein, 2015](#)). According to habits of Chinese producers and the weight of pigs, the mean particle size of the corn in the current study was about 450 μm , which was smaller than the value (600 to 700 μm level) recommended for corn fed to growing pigs ([Rojas and Stein, 2015](#); [Nemecek et al., 2016](#)).

Correlation Analysis and Prediction Equations of DE and ME

The difference between the maximum and minimum concentration of DE and ME was 162 and 169 kcal/kg of DM, respectively. The greater

energy values in samples 9 and 5 may be due to their relative greater EE contents of the corn. The current results showed that the EE content was positively correlated with the DE and ME values and predominantly determined the ME values of corn. Similar results were observed in previous studies ([Li et al., 2014b](#); [Chen et al., 2016](#); [Huang et al., 2018](#)). Two reasons lead to this result: one is that the EE content in corns greatly varied and the other reason is that EE is an important energetic substance with the highest energy value (2.25 times greater than the energy of carbohydrate and CP) per kilogram of feed ([Noblet and van Milgen, 2004](#)). For the ME prediction equation, the R^2 was 0.71 when only EE was included in the equation. When the DE and EE or the DE and ash were included in the equations, the accuracy of the equations (Eq. [4] or Eq. [5] in [Table 9](#)) were all improved ($R^2 > 0.90$). [Li et al. \(2014b\)](#) reported that the R^2 of the ME prediction equations of corns were less than 0.50 when the DE was excluded from the equations; however, the R^2 value was improved to greater than 0.79 when the DE was

included in the equations. Similar findings were also observed in prediction equations based on the chemical composition of SBM (Li et al., 2015b); in this report, DE was the indispensable predictor of ME. However, other equations based on ingredients with wide variations of chemical composition showed inconsistent results. Li et al. (2015a), Huang et al. (2018), and Chen et al. (2016) established equations based on chemical composition to predict energy values of corn distillers dried grains with solubles, defatted rice bran, and flaxseed expellers, respectively, fed to growing pigs. When DE was included in the ME prediction equations, energy values of ingredients were well predicted ($R^2 > 0.85$). These ingredients have greater variation in chemical composition and energy values and higher correlations between nutrients and energy values than corn or SBM. Accordingly, the variation in chemical composition largely determines the establishment of the prediction equations.

The Apparent Ileal Digestibility and Standardized Ileal Digestibility of CP and AA

At present, research on AA digestibility is concentrated on some special varieties (O'Quinn et al., 2000; Bohlke et al., 2005). However, yellow dent corn is still the most important feed ingredient compared with the other types of corns for pigs. There was limited data for comprehensive and systematic evaluation of the AID and SID of yellow dent corn. The focus of our research was to evaluate the variation in AA digestibility of yellow dent corn. After comparison, it is found that the relationship between the digestibility of different AA is basically the same regardless of the corn variety (Bohlke et al., 2005; Stein et al., 2016). However, data from different databases or papers are inconsistent. The average AID of CP (69.51%) was similar to that (65.00%) reported by the NRC (2012), whereas the average SID of CP was 13.7% greater than that reported by the NRC (2012). In the current study, the SID of Tyr was the highest, whereas the SID of Lys was the lowest. The SID of Lys reported by the NRC (2012) was also the lowest among all AA, but the SID of Pro was the highest. For indispensable AA, the SID of most AA, with the exception of Ile, Val, and Lys, was greater than that reported by the NRC (2012). For dispensable AA, the SID of most AA, with the exception of Gly, was greater than that reported by the NRC (2012). The differences may be explained by the particle size of corn. Smaller particle size (about 450 μm in the current study) contributes to the binding of enzymes and proteins

(Rojas and Stein, 2015), which improves CP and AA digestibility (Kim et al., 2009). Although no significant differences were observed for the AID and SID of most AA, the range of variation was still very large. Indeed, AA of endogenous origin have a relatively greater contribution to the ileal output of AA in feed ingredients with a low concentration of AA (Cervantes-Pahm et al., 2014). The low concentration of each AA in corns may misrepresent the AID of AA in corns, and therefore, the SID of AA in corns may be more representative of the true digestibility of AA. In the current study, the values for SID of Arg, His, Phe, Ala, Cys, Pro, and Tyr were significantly different. However, Kil et al. (2014) reported that values for SID of all AA were not significantly different among 9 corn samples. The SID of Lys and Met ranged from 61.45 to 78.47% and from 74.09 to 90.91%, respectively. Accordingly, the average values or prediction equations contribute to reduce error.

Correlation Analysis and Prediction Equations of Standardized Ileal Digestible AA

Although corn contains lower protein content than the other protein ingredients, it can provide about 30% of total dietary protein due to its high levels of supplementation in pig's diets (Dado, 1999). There were limited data for the SID of AA in yellow dent corns, and therefore, prediction equations of ileal digestible AA in yellow dent corns have not yet been established. Wide variations in the SID of AA lead to the possibility to predict the standardized ileal digestible AA. In the current study, significant negative correlations between different fiber fractions and digestible AA were not found, which can be explained by the variations and concentrations of NDF or ADF in corn being lower than those in fiber-rich ingredients (Huang et al., 2018). The standardized ileal digestible Met was positively correlated with Met and CP contents. Therefore, Met and CP can be used as 2 optimal predictors to predict the standardized ileal digestible Met. The Met concentration was positively correlated with the standardized ileal digestible Met, and the predicting accuracy was improved when Met combined with CP was included in the predicting equation. Equations with the greatest R^2 and the least RMSE were optimal to predict the standardized ileal digestible Met. Accordingly, the best prediction equation ($R^2 = 0.76$; RMSE = 2.93) was standardized ileal digestible Met = $31.34 + (3.43 \times \text{CP}) + (116.04 \times \text{Met})$.

In conclusion, the relatively high concentration of starch and low concentration of fiber results in corns being main energy sources for using in pig feed. The EE in yellow dent corns widely varied. The DE and ME values of corns were positively correlated with EE content. The SID of Lys, Met, and Thr ranged from 61.45 to 78.74% (average 73.79%), from 74.09 to 90.91% (average 87.32%), and from 79.19 to 85.79% (average 80.06%), respectively. The standardized ileal digestible Met was positively correlated with Met and CP contents. The AA concentrations and SID of AA in corn varied largely. The EE, DE, and ash content were best predictors of the ME of yellow dent corns.

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