JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Energy and nutrient digestibility in NutriDense corn and other cereal grains fed to growing pigs

C. Pedersen, M. G. Boersma and H. H. Stein

J Anim Sci 2007.85:2473-2483.
doi: 10.2527/jas.2006-620 originally published online Apr 12, 2007;

Energy and nutrient digestibility in NutriDense corn and other cereal grains fed to growing pigs[1,2,3]

C. Pedersen,[4] M. G. Boersma,[5] and H. H. Stein[6,7]

Department of Animal and Range Sciences, South Dakota State University, Brookings 57007

ABSTRACT: Two experiments were conducted to measure the energy and nutrient digestibilities in NutriDense corn and other cereal grains. An additional objective was to evaluate the effect of balancing diets with AA on the values measured for DE and ME of corn varieties. In Exp. 1, 6 growing pigs were fitted with a T-cannula in the distal ileum and allotted to a 6 × 6 Latin square design to measure apparent ileal digestibility (AID) and standardized ileal digestibility (SID) values for CP and AA in NutriDense corn, yellow dent corn, barley, wheat, and sorghum. Diets based on each of the 5 cereal grains were formulated, along with a N-free diet. Results of this experiment showed that the AID for most indispensable AA were greater ($P < 0.05$) in NutriDense corn and wheat than in the other cereal grains. The SID for Lys in NutriDense corn (77.6%) was greater ($P < 0.05$) than in yellow dent corn (68.5%), and sorghum (56.9%), but not different from wheat (75.1%) and barley (71.7%). The SID for Arg and Met in NutriDense corn also were greater ($P < 0.05$) than in yellow dent corn (88.1 and 87.2% vs. 84.5 and 82.8%, respectively). For the remaining indispensable AA, no differences in SID between NutriDense corn and yellow dent corn were observed. For all AA, the lowest values ($P < 0.05$) for AID and SID were obtained for sorghum. If calculated as grams of standardized ileal digestible AA per kilogram of DM, concentrations of all indispensable AA in NutriDense corn were greater ($P < 0.05$) than in yellow dent corn, but barley and wheat had greater concentrations of most AA than yellow dent corn and NutriDense corn. In Exp. 2, 12 growing barrows were placed in metabolism cages, and the DE and ME of NutriDense corn and yellow dent corn were measured. Both grains were used in diets without or with crystalline AA supplementation. Each diet was fed to 6 pigs in a 2-period, changeover design. The DE and the ME in NutriDense corn (4,004 and 3,922 kcal/kg of DM, respectively) were greater ($P < 0.01$) than in yellow dent corn (3,878 and 3,799 kcal/kg of DM, respectively). Values for DE and ME were not affected by the addition of crystalline AA to the diets. It is concluded that NutriDense corn has a greater value than yellow dent corn in diet formulations due to increased concentrations of digestible, indispensable AA and energy. However, barley and wheat have greater concentrations, whereas sorghum has lower concentrations, of many digestible AA than NutriDense corn.

Key words: amino acid, cereal grain, digestibility, energy, NutriDense corn, pig

J. Anim. Sci. 2007. 85:2473–2483
doi:10.2527/jas.2006-620

INTRODUCTION

Cereal grains such as corn, barley, wheat, and sorghum supply the majority of the energy in diets fed to swine in most countries around the world. In the United States, yellow dent corn is by far the most dominant source of these grains. Although the concentrations of digestible nutrients in yellow dent corn and other cereal grains have been measured and published, new varieties of corn are constantly being developed.

One such new variety is NutriDense corn, which was bred to have increased concentrations of ether extract, energy, and AA compared with yellow dent corn. To accurately establish the feeding value of NutriDense

[1]Publication No. 3531 from the South Dakota Agric. Exp. Stn. Journal Series.

[2]NutriDense corn is a registered trade name by ExSeed Genetics LLC, Research Triangle Park, NC.

[3]Financial support from ExSeed Genetics LLC, Research Triangle Park, NC, is greatly appreciated.

[4]Current address: Danisco Animal Nutrition, Marlborough, Wiltshire, UK.

[5]Current address: Pipestone County Extension Office, Pipestone, MN.

[6]Current address: University of Illinois, Department of Animal Sciences, West Gregory Dr., Urbana 61801.

[7]Corresponding author: hstein@uiuc.edu

Received September 10, 2006.

Accepted April 4, 2007.

Table 1. Analyzed energy and nutrient composition of NutriDense corn, yellow dent corn, barley, wheat, and sorghum (as-fed basis)

Item	NutriDense[1] corn	Yellow dent corn[1]	Barley[2]	Wheat[3]	Sorghum[4]
DM, %	86.00	86.36	86.24	85.75	85.07
CP, %	9.09	8.10	12.92	12.44	9.79
ADF, %	2.33	1.84	5.96	2.94	3.83
NDF, %	6.30	6.08	16.1	14.2	7.32
P, %	0.24	0.22	0.39	0.38	0.24
Ca, %	0.01	0.01	0.11	0.04	0.01
Ether extract, %	4.46	3.72	1.84	1.97	2.89
GE, kcal/kg	3,931	3,885	3,855	3,830	3,848
Indispensable AA, %					
Arg	0.40	0.37	0.66	0.57	0.32
His	0.24	0.22	0.29	0.29	0.23
Ile	0.31	0.28	0.44	0.43	0.37
Leu	1.09	0.95	0.87	0.83	1.25
Lys	0.26	0.25	0.49	0.36	0.20
Met	0.21	0.16	0.21	0.21	0.18
Phe	0.41	0.38	0.64	0.53	0.47
Thr	0.28	0.27	0.42	0.33	0.29
Trp	0.07	0.06	0.11	0.16	0.07
Val	0.41	0.31	0.63	0.55	0.48
Dispensable AA, %					
Ala	0.65	0.58	0.53	0.44	0.86
Asp	0.56	0.55	0.78	0.62	0.60
Cys	0.20	0.17	0.24	0.27	0.18
Glu	1.61	1.45	2.86	3.57	1.92
Gly	0.33	0.30	0.53	0.50	0.29
Pro	0.74	0.67	1.24	1.14	0.77
Ser	0.34	0.33	0.46	0.48	0.37
Tyr	0.20	0.19	0.31	0.27	0.25

[1]*Zea mays* L.
[2]*Hordeum* L.
[3]*Triticum* L.
[4]*Sorghum bicolor*.

corn, it is necessary to measure the contents of DE and digestible nutrients in this ingredient and compare these values to other cereal grains.

The objectives of the current experiments were to test the hypothesis that NutriDense corn has an improved digestibility of AA compared with other cereal grains and that NutriDense corn has a greater concentration of digestible and metabolizable energy than yellow dent corn. A second objective was to determine if the concentration of AA in the test diets has an effect on the values for DE and ME that are measured.

MATERIALS AND METHODS

Protocols for the experiments were reviewed and approved by the Institutional Animal Care and Use Committee at South Dakota State University.

Two experiments were conducted. In both experiments, pigs originating from the matings of SP-1 boars to Line 13 females (Ausgene Intl. Inc., Gridley, IL) were used. The cereal grains that were used were supplied by ExSeed Genetics LLC, Research Triangle Park, NC. NutriDense corn (*Zea mays* L.), yellow dent corn (*Zea mays* L.), barley (*Hordeum* L.), wheat (*Triticum* L.), and sorghum (*Sorghum bicolor*) were used in Exp. 1, whereas only NutriDense corn and yellow dent corn were used in Exp. 2. All grains were ground using a hammer mill with a 3-mm screen. The same batch of NutriDense corn and yellow dent corn was used in both experiments.

Experiment 1

Experiment 1 was conducted with the objective of measuring the apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of CP and AA in NutriDense corn, yellow dent corn, wheat, barley, and sorghum (Table 1). Six growing barrows (average initial BW 76.2 ± 5.6 kg) were surgically fitted with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998). After the surgery, the pigs were housed individually in an environmentally controlled room. Each pen (1.2 × 1.8 m) had fully slatted, metal flooring and solid concrete sidings. A feeder and a nipple drinker were installed in each pen. The room temperature was maintained at 22°C.

Pigs were allotted to a 6 × 6 Latin square design with 6 periods. Each experimental period lasted 7 d. Five diets were formulated on the basis of each of the cereal grains, with the grain being the only ingredient contrib-

Table 2. Ingredient composition (%, as-fed basis) of experimental diets, Exp. 1

Ingredient	NutriDense corn	Yellow dent corn	Barley	Wheat	Sorghum	N-free
NutriDense corn	97.6	—	—	—	—	—
Yellow dent corn	—	97.6	—	—	—	—
Barley	—	—	97.6	—	—	—
Wheat	—	—	—	97.6	—	—
Sorghum	—	—	—	—	97.6	—
Cornstarch	—	—	—	—	—	70.3
Sugar	—	—	—	—	—	20.0
Soybean oil	—	—	—	—	—	3.0
Solka floc[1]	—	—	—	—	—	3.0
Limestone	0.9	0.9	0.9	0.9	0.9	0.4
Monocalcium phosphate	0.6	0.6	0.6	0.6	0.6	1.9
Magnesium oxide	—	—	—	—	—	0.1
Potassium carbonate	—	—	—	—	—	0.4
Chromic oxide	0.3	0.3	0.3	0.3	0.3	0.3
Salt	0.4	0.4	0.4	0.4	0.4	0.4
Vitamin premix[2]	0.05	0.05	0.05	0.05	0.05	0.05
Micro mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15

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

[2]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as vitamin A acetate; vitamin D_3, 1,648 IU as D-activated animal sterol; vitamin E, 55 IU as alpha tocopherol acetate; vitamin K_3, 4.4 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 3.3 mg as thiamine mononitrate; riboflavin, 9.9 mg; pyridoxine, 3.3 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; and biotin, 0.17 mg.

[3]Provided the following quantities of minerals per kilogram of complete diet: Cu, 16 mg as copper sulfate; Fe, 165 mg as iron sulfate; I, 0.36 mg as potassium iodate; Mn, 44 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 165 mg as zinc oxide.

uting CP and AA to each diet (Tables 2 and 3). A N-free diet also was formulated to estimate the basal endogenous losses of CP and AA. Vitamins and minerals were included in all diets to meet or exceed the current requirement estimates for growing pigs (NRC, 1998). All diets contained 0.3% chromic oxide as an indigestible marker.

Pig BW were recorded at the beginning of each period, and the estimated maintenance energy requirement (i.e., 106 kcal of ME per kg of $BW^{0.75}$; NRC, 1998) was calculated for each pig. During the following period, pigs were fed their respective diets at a level of 3 times the estimated energy requirement for maintenance. The daily allotment of feed was divided into 2 equal meals that were provided at 0800 and 1700. Water was available at all times.

The initial 5 d of each period was considered an adaptation period to the diet. During this period, 50 g of an AA mixture (Table 4) was provided at each feeding in addition to the allotted quantity of the experimental diet. These AA were added to reduce the effects of feeding diets that did not meet the requirements of the pigs. The crystalline AA in the AA mixture were assumed to be 100% digestible and not to influence the digestibility values that were measured in the experiment.

Ileal digesta were collected on d 6 and 7. Caps were removed from the cannulas, and a 225-mL plastic bag was attached to the cannula barrel using an auto-locking cable tie. Digesta flowing into the bag were collected, and the bags were removed when they were filled with digesta, or at least once every 30 min, and stored at –20°C. At the completion of an experimental period, pigs were deprived of feed overnight, and the following morning a new experimental diet was offered.

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a subsample was taken for chemical analysis. Samples of each diet and of each of the cereal grains were collected at the time of diet mixing. Digesta samples were lyophilized, and all samples were ground through a 1-mm screen before chemical analysis. All samples were analyzed for DM (procedure 4.1.06, AOAC, 2000) and CP (Thiex et al., 2002). All cereal grains and diets were analyzed for Ca (procedure 4.8.03, AOAC, 2000), ADF, NDF (procedure 4.6.03, AOAC, 2000), and ether extract (Thiex et al., 2003). Diets and feed ingredients were digested in perchloric acid (procedure 2.3.01, AOAC, 2000), and the concentration of P was determined on a UV-visible spectrophotometer (Model 2LV-2101 PC, Shimedzu Scientific Instruments, Colombia, MD) using a wavelength of 650 nm (procedure 3.4.11, AOAC, 2000). The accuracy of this procedure was verified using National Institute of Standards and Technology (US Department of Commerce) reference standard 1570a (standard reference material). The GE in feed ingredients and diets were determined using bomb calorimetry (Parr Instrument 1563, Moline IL), and chromium was analyzed in diet and digesta samples according to the method of Fenton and Fenton (1979). Amino acid concentrations in ingredients, diets, and digesta samples were quantified on a Beckman 6300 Amino Acid Analyzer (Beckman Instruments Corp., Palo Alto, CA) us-

Table 3. Analyzed energy and nutrient composition (as-fed basis) of diets, Exp. 1

Item	NutriDense corn	Yellow dent corn	Barley	Wheat	Sorghum	N-free
DM, %	86.28	86.45	86.79	86.07	85.15	90.94
CP, %	8.90	7.99	12.44	12.41	9.50	0.24
ADF, %	1.90	2.12	7.42	2.69	4.10	2.08
NDF, %	6.29	5.83	17.6	9.01	5.65	2.20
P, %	0.30	0.34	0.46	0.48	0.36	0.30
Ca, %	0.39	0.42	0.51	0.40	0.40	0.44
Ether extract, %	4.64	3.61	1.76	1.79	2.53	2.56
GE, kcal/kg	3,886	3,808	3,788	3,744	3,746	3,784
Indispensable AA, %						
Arg	0.41	0.33	0.62	0.57	0.32	0.01
His	0.24	0.21	0.27	0.29	0.22	0.01
Ile	0.30	0.26	0.42	0.40	0.36	0.01
Leu	1.06	0.92	0.80	0.82	1.27	0.03
Lys	0.26	0.23	0.48	0.35	0.18	0.01
Met	0.21	0.15	0.19	0.20	0.16	—
Phe	0.41	0.36	0.56	0.53	0.47	0.01
Thr	0.29	0.25	0.39	0.34	30	0.01
Trp	0.06	0.06	0.14	0.16	0.05	—
Val	0.41	0.35	0.60	0.52	0.45	0.01
Dispensable AA, %						
Ala	0.65	0.56	0.51	0.44	0.88	0.02
Asp	0.55	0.51	0.76	0.62	0.59	0.02
Cys	0.20	0.16	0.23	0.28	0.18	—
Glu	1.66	1.44	2.55	3.59	2.02	0.06
Gly	0.34	0.28	0.51	0.50	0.28	0.01
Pro	0.73	0.63	1.09	1.14	0.78	0.01
Ser	0.35	0.33	0.43	0.52	0.41	0.01
Tyr	0.24	0.22	0.30	0.27	0.31	—

ing ninhydrin for postcolumn derivatization and norleucine as the internal standard. Samples were hydrolyzed for 24 h at 110°C with 6 *N* HCl before analysis. Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation before hydrolysis. Tryptophan was determined after hydrolysis with NaOH for 22 h at 110°C.

Apparent ileal digestibilities of AA in the samples obtained from feeding the 5 cereal-containing diets were calculated. Because the cereal grain was the only feed ingredient contributing AA in each of these diets, the AID also represent the digestibilities of AA in each of the grains. Equation [1] was used for these calculations:

$$AID = \{1 - [(AAd/AAf) \times (Crf/Crd)]\} \times 100\%, \quad [1]$$

where AID is the apparent ileal digestibility of an AA (%), AAd is the concentration of that AA in the ileal digesta DM, AAf is the AA concentration of that AA in the feed DM, Crf is the chromium concentration in the feed DM, and Crd is the chromium concentration in the ileal digesta DM. The AID for CP was also calculated using this equation.

The basal ileal endogenous loss ($\mathbf{IAA_{end}}$) of each AA was determined using Eq. [2], based on the flow obtained after feeding the N-free diet:

$$IAA_{end} = [AAd \times (Crf/Crd)], \quad [2]$$

where IAA_{end} is the basal endogenous loss of an AA (mg per kg of DMI). The basal endogenous loss of CP was determined using the same equation.

By correcting the AID for the IAA_{end} of each AA, standardized ileal AA digestibilities were calculated using Eq. [3]:

$$SID = AID + [(IAA_{end}/AAf) \times 100\%], \quad [3]$$

where SID is the standardized ileal digestibility of an AA (%).

Table 4. Composition (as-fed basis) of the AA mixture used in Exp. 1[1,2]

AA	Inclusion, %
L-Gly	58.0
L-Lys·HCl	16.3
DL-Met	3.8
L-Thr	6.2
L-Trp	2.2
L-Ile	4.7
L-Val	4.8
L-His	1.1
L-Phe	2.9

[1]All AA were purchased from Ajinomoto AminoScience LLC, Raleigh, NC.
[2]The AA mixture was fed to the pigs used in Exp. 1 in the amount of 50 g per d for the initial 5 d of each period.

Table 5. Composition (as-fed basis) of the experimental diets, Exp. 2

Item	NutriDense corn		Yellow dent corn	
	–[1]	+	–	+
NutriDense corn	99.40	97.40	–	–
Yellow dent corn	–	–	99.40	97.40
Salt	0.40	0.40	0.40	0.40
Vitamin premix[2]	0.05	0.05	0.05	0.05
Micro mineral premix[3]	0.15	0.15	0.15	0.15
L-Lys·HCl	–	0.78	–	0.78
DL-Met	–	0.16	–	0.16
L-Thr	–	0.26	–	0.26
L-Trp	–	0.10	–	0.10
L-Ile	–	0.20	–	0.20
L-Val	–	0.22	–	0.22
L-Phe	–	0.22	–	0.22
L-His	–	0.06	–	0.06

[1]The minus and plus sign indicate without or with the addition of crystalline AA, respectively.

[2]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as vitamin A acetate; vitamin D_3, 1,648 IU as D-activated animal sterol; vitamin E, 55 IU as alpha tocopherol acetate; vitamin K_3, 4.4 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 3.3 mg as thiamine mononitrate; riboflavin, 9.9 mg; pyridoxine, 3.3 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; and biotin, 0.17 mg.

[3]Provided the following quantities of minerals per kg of complete diet: Cu, 16 mg as copper sulfate; Fe, 165 mg as iron sulfate; I, 0.36 mg as potassium iodate; Mn, 44 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 165 mg as zinc oxide.

Table 6. Analyzed energy and nutrient composition (as-fed basis) of the experimental diets, Exp. 2

Item	NutriDense corn		Yellow dent corn	
	–[1]	+	–	+
DM, %	86.1	85.9	86.5	86.7
CP, %	8.79	10.28	7.88	9.40
Ether extract, %	4.39	4.20	3.29	3.25
GE, kcal/kg	3,922	3,946	3,859	3,825
P, %	0.22	0.21	0.22	0.22
Indispensable AA, %				
Arg	0.42	0.45	0.38	0.36
His	0.24	0.28	0.22	0.25
Ile	0.30	0.51	0.26	0.43
Leu	1.10	1.02	0.95	0.97
Lys	0.26	1.02	0.25	0.87
Met	0.20	0.35	0.14	0.28
Phe	0.43	0.66	0.39	0.60
Thr	0.30	0.59	0.28	0.48
Trp	0.07	0.17	0.07	0.15
Val	0.41	0.66	0.37	0.55
Dispensable AA, %				
Ala	0.65	0.63	0.58	0.58
Asp	0.57	0.57	0.56	0.55
Cys	0.21	0.22	0.18	0.18
Glu	1.60	1.53	1.41	1.43
Gly	0.33	0.34	0.29	0.29
Pro	0.82	0.77	0.70	0.72
Ser	0.38	0.38	0.35	0.35
Tyr	0.29	0.29	0.26	0.27
All AA	8.69	10.55	7.75	9.41

[1]The minus and plus sign indicate without or with the addition of crystalline AA, respectively.

The values for SID were multiplied by the AA concentration (DM basis) for all cereal grains to calculate the quantities of standardized ileal digestible AA in each grain.

Data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC). An ANOVA was conducted, with diet as the main effect and pig and period as random effects. Means were separated using the LSMeans statement and the PDIFF option of SAS. Pig was considered the experimental unit, and an alpha value of 0.05 was used to assess differences among means.

Experiment 2

Experiment 2 was conducted with the objective of measuring the digestibility of energy and ether extract in NutriDense corn and yellow dent corn. A second objective was to compare digestibility values obtained for diets that were deficient in AA with those obtained for diets that were adequate in AA.

The NutriDense corn and the yellow dent corn used in these experiments were from the same batches as those used in Exp. 1. Two diets were formulated (Tables 5 and 6) using NutriDense corn or yellow dent corn (99.4%) and salt, vitamins, and microminerals. Two additional diets were also formulated using NutriDense corn or yellow dent corn (97.4%), salt, vitamins, and microminerals, but crystalline AA were supplied to these diets in quantities that were needed to formulate diets that were adequate in indispensable AA (NRC, 1998). The 2 sources of corn were the sole providers of ether extract in all diets and, with the exception of the crystalline AA, the corn sources were also the sole providers of energy in the diets.

Twelve growing barrows (average initial BW 37.7 ± 2.9 kg) were allotted to a 2-period, balanced, changeover design, with 12 animals and 4 diets (Gill and Magee, 1976). Pigs were placed in metabolism cages equipped with a feeder and a nipple drinker. The cages had expanded metal floorings, a screen below the floors for collection of fecal materials, and a stainless-steel funnel tray below the screens for collection of urine.

The quantity of feed provided per pig daily was calculated as 2.5 times the estimated requirement for maintenance energy (i.e., 106 kcal of ME per kg of $BW^{0.75}$; NRC, 1998) and was divided into 2 equal meals that were fed at 0800 and 1700. Water was available at all times. Each experimental period lasted 14 d. The initial 7 d of each period was considered an adaptation period to the diet. A marker (0.1% ferric oxide) was included in the meals that were fed in the morning of d 8 and in the morning of d 13. Fecal collections were initiated the first time after d 8 that the marker appeared in the feces and ceased the first time after d 13 that the marker appeared in the feces. All fecal samples were stored at –20°C. Urine collections were initiated on the morning of d 8 and ceased on the morning of d 13. A preservative of 6 *N* sulfuric acid was added to the urine collection buckets, which were covered with cheesecloth. Buckets were emptied twice daily after the total volume of urine had been recorded and a 20% subsample had been collected. The subsample was stored at –20°C.

At the conclusion of the experiment, urine 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 at 60°C, finely ground, mixed, and subsampled. Fecal, urine, and feed samples were analyzed for DM, Kjeldahl N, and GE, and the diets were also analyzed for AA. Diets and fecal samples were also analyzed for ether extract. The procedures outlined for Exp. 1 were used in all analyses.

Values for DE and ME in each diet were calculated. By correcting these values for the nonenergy-containing ingredients in the diets, the energy concentrations in the feed ingredients were calculated on an as-fed and on a DM basis, as previously outlined (Stein et al., 2004). It was assumed that the energy contributed by the crystalline AA that were included in 2 of the diets was completely digestible and that this energy was 100% retained by the pigs and did not contribute to the energy that was lost in the feces or the urine.

The retention of N (**Nr**) for each pig and period was calculated using Eq. [4]:

$$Nr = \{[Ni - (Nf + Nu)]/Ni\} \times 100\%, \quad [4]$$

where Nr is the retention (%) of N, Ni is the intake (g) of N from d 8 to 13, Nf is the fecal output (g) of N from d 8 to 13, and Nu is the urinary output (g) of N from d 8 to d 13.

The apparent total tract digestibility (**ATTD**) for energy, ether extract, and N was calculated using Eq. [5]:

$$ATTD = [(Fi - Ff)/Fi] \times 100\%, \quad [5]$$

where ATTD is the apparent total tract digestibility of energy, ether extract, or N (%); Fi is the total intake of energy (kcal), ether extract (g), or N (g) from d 8 to 13; and Ff is the total fecal output of energy (kcal), ether extract (g), or N (g) originating from the feed that was fed from d 8 to 13.

Data were analyzed as a 2 × 2 factorial design, with 2 corn varieties (NutriDense and yellow dent corn) and 2 levels of crystalline AA (none or adequate), using the MIXED procedure of SAS. The interaction between corn variety and AA level was also included in the model, but the interaction was not significant for any of the variables tested and therefore was omitted in the final analysis and only main effects are presented. Means were separated using the LSMeans procedure and the PDIFF option of SAS. Pig was the experimental unit for all calculations, and an alpha level of 0.05 was used to assess significance between means.

RESULTS

Experiment 1

All pigs easily consumed their diets throughout the experiment without leaving orts in the feeders. The analyzed CP and AA composition of yellow dent corn, wheat, and sorghum (Table 1) agree with previously published values (NRC, 1998), but the analyzed concentration of CP and AA in barley was greater than values published by NRC (1998).

The AID for CP and AA in the 5 cereal grains are presented in Table 7. The AID for CP in NutriDense corn (73.6%) was greater ($P < 0.05$) than in sorghum (58.8%) but not different from yellow dent corn, barley, and wheat (69.1, 70.9, and 78.5%, respectively). The AID for CP in wheat also was greater ($P < 0.05$) than in yellow dent corn, barley, and sorghum. For the indispensable AA, the mean AID was greater ($P < 0.05$) in NutriDense corn (79.3%) and wheat (79.4%) than in yellow dent corn (74.2%), barley (71.8%), and sorghum (62.3%) and was lower ($P < 0.05$) for sorghum than for all the other grain sources. The AID for Arg, Ile, Lys, Met, Thr, and Val also were greater ($P < 0.05$) in NutriDense corn than in yellow dent corn. The AID for Trp was greater ($P < 0.05$) in wheat compared with NutriDense corn, but for all other indispensable AA, no differences between NutriDense corn and wheat were observed. Barley had lower ($P < 0.05$) AID for all indispensable AA except Lys, Thr, Trp, and Val compared with NutriDense corn, but compared with yellow dent corn, only the AID for Leu was lower ($P < 0.05$) in barley. The AID for all indispensable AA in wheat except Lys, Trp, and Val were greater ($P < 0.05$) than in barley, and with the exception of Leu and Met, wheat also had greater AID for all indispensable AA compared with yellow dent corn. The AID for Thr was not different among sorghum, yellow dent corn, and barley, but for all other indispensable AA, sorghum had values for AID that were lower ($P < 0.05$) than in the other cereal grains.

The AID for Cys was greater ($P < 0.05$) in NutriDense corn than in yellow dent corn, but for all other dispensable AA, no differences between NutriDense corn and yellow dent corn were observed. NutriDense corn also had a greater ($P < 0.05$) AID for Ala, but a lower ($P < 0.05$) AID for Glu, Gly, Pro, and Ser compared with wheat. The AID for Ala, Asp, Cys, and Ser were greater in NutriDense corn than in barley, and compared with sorghum, the AID for all dispensable AA were greater ($P < 0.05$) in NutriDense corn. For the mean of the dispensable AA and for the mean of all AA, the AID in NutriDense corn, yellow dent corn, and barley were not different, but lower ($P < 0.05$) than in wheat and greater ($P < 0.05$) than in sorghum.

The SID for CP was lower ($P < 0.05$) in sorghum compared with the other grains, but there was no difference among NutriDense corn, yellow dent corn, and wheat (Table 8). The SID for Arg, Lys, and Met were greater ($P < 0.05$) in NutriDense corn compared with yellow dent corn, but for the remaining indispensable AA and for the mean of all indispensable AA, no differences in SID between the 2 corns were observed. The SID for Trp in NutriDense corn was lower ($P < 0.05$) than in wheat, but for all other indispensable AA and

Table 7. Apparent ileal digestibility (%) by growing pigs of CP and AA in NutriDense corn, yellow dent corn, barley, wheat, and sorghum, Exp. 1[1,2]

Item	NutriDense corn	Yellow dent corn	Barley	Wheat	Sorghum	SEM	*P*-value
CP	73.6^{yz}	69.1^{y}	70.9^{y}	78.5^{z}	58.8^{x}	2.01	0.001
Indispensable AA							
Arg	79.8^{z}	74.2^{y}	74.8^{y}	81.7^{z}	59.6^{x}	1.58	0.001
His	81.5^{zw}	77.5^{yz}	73.5^{y}	82.4^{w}	60.4^{x}	1.77	0.001
Ile	77.4^{z}	71.9^{y}	72.0^{y}	79.9^{z}	62.0^{x}	1.96	0.002
Leu	84.6^{z}	82.4^{z}	73.7^{y}	82.6^{z}	68.1^{x}	1.93	0.001
Lys	70.2^{z}	60.1^{y}	67.7^{yz}	69.5^{z}	46.3^{x}	2.82	0.03
Met	85.0^{w}	79.7^{yz}	75.9^{y}	83.6^{zw}	66.3^{x}	1.62	0.001
Phe	81.2^{zw}	76.9^{yz}	75.1^{y}	83.1^{w}	64.7^{x}	1.92	0.001
Thr	69.4^{yz}	60.5^{x}	62.1^{xy}	70.7^{z}	54.6^{x}	2.80	0.02
Trp	64.5^{yz}	58.7^{y}	74.6^{zw}	82.1^{w}	43.7^{x}	3.73	0.001
Val	75.7^{z}	68.5^{y}	69.2^{yz}	75.6^{z}	58.6^{x}	2.24	0.006
Mean	79.3^{z}	74.2^{y}	71.8^{y}	79.4^{z}	62.3^{x}	1.88	0.001
Dispensable AA							
Ala	80.1^{y}	75.4^{y}	63.5^{x}	68.6^{x}	65.3^{x}	2.44	0.001
Asp	74.9^{z}	69.8^{yz}	65.1^{xy}	71.0^{yz}	59.3^{x}	2.30	0.004
Cys	77.5^{z}	71.4^{y}	69.8^{y}	82.4^{z}	58.4^{x}	1.94	0.001
Glu	46.8^{y}	37.3^{y}	49.7^{y}	64.5^{z}	18.6^{x}	5.23	0.006
Gly	84.5^{y}	81.6^{y}	81.8^{y}	90.5^{z}	68.9^{x}	1.58	0.001
Pro	41.5^{yz}	36.6^{y}	63.2^{zw}	76.6^{w}	9.8^{x}	1.94	0.004
Ser	77.7^{z}	74.1^{yz}	69.5^{xy}	82.8^{w}	66.6^{x}	1.81	0.001
Tyr	76.1^{yz}	72.4^{yz}	70.6^{y}	77.3^{z}	63.6^{x}	2.04	0.009
Mean	72.1^{y}	68.1^{y}	71.0^{y}	82.0^{z}	55.6^{x}	2.44	0.002
All AA	75.2^{y}	70.7^{y}	71.5^{y}	81.0^{z}	58.3^{x}	1.94	0.001

[w–z]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data are means of 6 observations per treatment.

[2]Apparent ileal digestibilities were calculated as {1 − [(CP or AA in digesta/CP or AA in feed) × (chromium in feed/chromium in digesta)]} × 100%.

for the mean of the indispensable AA, no differences in SID between NutriDense corn and wheat were observed. The SID for Ile, Lys, and Trp were not different in NutriDense corn and barley, but for all other indispensable AA and for the mean of all indispensable AA, the SID in NutriDense corn were greater ($P < 0.05$) than in barley. The SID for all indispensable AA except Lys and Trp and the mean of all indispensable AA in barley were lower ($P < 0.05$) than in wheat, but with the exception of Leu and Met, there were no differences in SID between barley and yellow dent corn. The SID for all indispensable AA except Ile and Trp and the SID for the mean of all indispensable AA also were similar in yellow dent corn and wheat. For sorghum, the SID for all indispensable AA and the mean of all indispensable AA were lower ($P < 0.05$) than in the other cereal grains.

There were no differences in the SID for any of the dispensable AA between NutriDense corn and yellow dent corn. The SID for Ala in NutriDense corn was greater ($P < 0.05$) than in wheat, but for all other dispensable AA except Pro and for the mean SID of the dispensable AA, no differences between NutriDense corn and wheat were observed. However, with the exception of Glu, Gly, Pro, and Tyr, the SID for all dispensable AA were greater ($P < 0.05$) in NutriDense corn than in barley. The SID for Ala, Asp, and Ser were greater ($P < 0.05$) in yellow dent corn than in barley, but for the remaining dispensable AA and for the mean of the dispensable AA, no differences between yellow dent corn and barley were observed. The SID for Cys, Glu, Gly, Ser, and the mean of all dispensable AA were greater ($P < 0.05$) in wheat than in yellow dent corn, but this was not the case for Ala, Asp, Pro, and Tyr. The SID of the mean of the dispensable AA and of all dispensable AA except Ala and Pro also were greater ($P < 0.05$) in wheat than in barley. With the exception of Asp and Ser in barley, the SID for all dispensable AA and the mean of all dispensable AA were greater in NutriDense corn, yellow dent corn, barley, and wheat compared with sorghum.

The concentrations of standardized ileal digestible CP and all indispensable AA were greater ($P < 0.05$) in NutriDense corn than in yellow dent corn and with the exception of Ile, Leu, Phe, and Val, these concentrations were greater ($P < 0.05$) than in sorghum (Table 9). However, with the exception of Leu and Met, greater ($P < 0.05$) concentrations of standardized ileal digestible CP and indispensable AA were present in wheat and barley than in NutriDense corn. For the dispensable AA, NutriDense corn had greater concentrations of standardized ileal digestible Ala, Cys, Glu, and Tyr than yellow dent corn ($P < 0.05$), but with the exception of Ala and Cys, the standardized ileal digestible concentration of all dispensable AA was lower ($P < 0.05$) in NutriDense corn than in barley and wheat.

Table 8. Standardized ileal digestibility (%) of CP and AA in NutriDense corn, yellow dent corn, barley, wheat, and sorghum by growing pigs, Exp. 1[1,2]

Item	NutriDense corn	Yellow dent corn	Barley	Wheat	Sorghum	SEM	*P*-value
CP	83.3[yz]	79.9[yz]	77.9[y]	85.6[z]	66.8[x]	2.11	0.001
Indispensable AA							
Arg	88.1[w]	84.5[yz]	81.2[y]	87.7[zw]	70.1[x]	1.64	0.001
His	85.4[z]	82.0[yz]	77.1[y]	85.7[z]	64.7[x]	1.88	0.001
Ile	82.5[yz]	77.8[y]	75.6[y]	83.7[z]	66.2[x]	2.04	0.001
Leu	87.0[z]	85.2[z]	77.0[y]	85.7[z]	70.1[x]	2.00	0.001
Lys	77.6[z]	68.5[y]	71.7[yz]	75.1[yz]	56.9[x]	2.69	0.001
Met	87.2[w]	82.8[z]	78.4[y]	86.0[zw]	69.3[x]	1.71	0.001
Phe	85.3[z]	81.6[yz]	78.1[y]	86.2[z]	68.2[x]	2.02	0.001
Thr	79.2[z]	71.8[yz]	69.6[xy]	79.1[z]	63.9[x]	2.99	0.003
Trp	75.6[y]	69.8[y]	79.2[yz]	86.3[z]	56.8[x]	3.69	0.001
Val	82.1[z]	76.0[yz]	73.6[y]	80.7[z]	64.3[x]	2.34	0.001
Mean	84.4[z]	80.1[yz]	75.9[y]	83.8[z]	67.2[x]	1.98	0.001
Dispensable AA							
Ala	85.1[w]	81.2[zw]	69.8[xy]	76.0[yz]	69.0[x]	2.54	0.001
Asp	82.2[y]	77.6[y]	70.6[x]	77.5[y]	66.0[x]	2.38	0.001
Cys	82.3[zw]	77.4[yz]	74.1[y]	85.8[w]	63.7[x]	2.04	0.001
Glu	75.0[yz]	71.6[y]	70.9[y]	83.8[z]	52.4[x]	5.65	0.001
Gly	87.6[yz]	85.2[y]	83.8[y]	92.0[z]	71.4[x]	1.66	0.001
Pro	85.1[y]	87.2[yz]	98.7[yz]	104.7[z]	50.0[x]	12.95	0.001
Ser	84.6[yz]	81.4[y]	75.3[x]	87.5[z]	72.4[x]	1.99	0.001
Tyr	80.2[yz]	76.9[yz]	74.1[y]	81.0[z]	66.7[x]	2.17	0.001
Mean	84.4[yz]	82.1[y]	80.9[y]	90.0[z]	66.1[x]	2.63	0.001
All AA	84.4[yz]	81.3[y]	78.8[y]	87.8[z]	66.6[x]	2.10	0.001

[w–z]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data are least squares means of 6 observations per treatment.

[2]Standardized ileal digestibility values were calculated by correcting the values for apparent ileal digestibility for the basal ileal endogenous losses. Basal ileal endogenous losses were determined as (g/kg of DMI): CP, 9.14; Arg, 0.36; His, 0.10; Ile, 0.16; Leu, 0.27; Lys, 0.20; Met, 0.05; Phe, 0.18; Thr, 0.30; Trp, 0.07; Val, 0.28; Ala, 0.34; Asp, 0.42; Cys, 0.10; Glu, 1.01; Gly, 0.54; Pro, 3.35; Ser, 0.25; and Tyr, 0.10.

Experiment 2

The pigs on all treatments consumed their diets without any apparent problems. The ADG for the pigs was not affected by the type of corn, but the addition of crystalline AA increased ($P = 0.001$) the ADG from 498 to 878 g (Table 10). The consumption of GE did not differ between pigs fed the diets based on NutriDense corn and yellow dent corn, but the pigs fed diets containing crystalline AA consumed less GE ($P < 0.05$) than pigs fed the nonsupplemented diets (5,281 vs. 5,481 kcal/d). The daily N intake was greater ($P < 0.05$) for pigs fed NutriDense corn (19.8 g) compared with pigs fed yellow dent corn (18.6 g), and pigs fed the AA-supplemented diets consumed more ($P < 0.01$) N than pigs fed the nonsupplemented diets (20.1 vs. 18.3 g/d).

The quantity of GE and N that were lost in the feces or in the urine was not influenced by the source of grain. However, supplementation with crystalline AA reduced ($P < 0.01$) the excretion of GE and N in the feces and in the urine.

The DE (3,423 kcal/kg) and ME (3,355 kcal/kg) in the diets containing NutriDense corn were greater ($P < 0.05$) than the DE (3,338 kcal/kg) and the ME (3,270 kcal/kg) in the diets containing yellow dent corn. As a consequence, the DE and ME in NutriDense corn (4,004 and 3,922 kcal/kg of DM, respectively) were greater ($P < 0.01$) than the DE and ME in yellow dent corn (3,878 and 3,799 kcal/kg of DM, respectively). The addition of crystalline AA to the diets did not influence the DE and ME values in the 2 sources of corn.

The absorption and retention of N and the biological value of the protein were not influenced by the source of corn. However, the addition of crystalline AA increased ($P < 0.01$) N absorption, N retention, and the biological value of protein in the diets.

The ATTD for N was not affected by the source of corn (Table 11), but was greater ($P < 0.01$) for diets that contained crystalline AA (82.6%) than for diets without crystalline AA (77.3%). The ATTD of ether extract in NutriDense corn was greater ($P < 0.01$) than in yellow dent corn (61.4 vs. 46.2%), but there were no effects of AA supplementation on the ATTD of ether extract. For energy, no effect of grain source on ATTD was observed, but the addition of AA to the diets increased ($P < 0.05$) ATTD (87.6 vs. 86.3%).

DISCUSSION

AA Digestibility

The AID and SID for yellow dent corn, wheat, sorghum, and barley that were measured in this experiment are within the range of previously published val-

Table 9. Concentration of standardized ileal digestible CP and AA (g/kg of DM) in NutriDense corn, yellow dent corn, barley, wheat, and sorghum, Exp. 1[1]

Item	NutriDense corn	Yellow dent corn	Barley	Wheat	Sorghum	SEM	*P*-value
CP	85.9^{y}	74.9^{x}	115.9^{z}	123.7^{w}	76.7^{x}	2.52	0.001
Indispensable AA							
Arg	4.1^{z}	3.6^{y}	6.2^{w}	5.8^{v}	2.6^{x}	0.08	0.001
His	2.4^{z}	2.1^{y}	2.6^{v}	2.9^{w}	1.7^{x}	0.05	0.001
Ile	3.0^{y}	2.5^{x}	3.8^{z}	4.2^{w}	2.9^{y}	0.09	0.001
Leu	11.0^{z}	9.4^{y}	7.7^{x}	8.3^{x}	10.3^{z}	0.26	0.001
Lys	2.3^{z}	2.0^{y}	4.1^{w}	3.1^{v}	1.3^{x}	0.10	0.001
Met	2.1^{z}	1.5^{x}	1.9^{y}	2.1^{z}	1.5^{x}	0.04	0.001
Phe	4.1^{y}	3.6^{x}	5.8^{w}	5.3^{z}	3.8^{xy}	0.11	0.001
Thr	2.6^{y}	2.2^{x}	3.4^{w}	3.0^{z}	2.2^{x}	0.11	0.001
Trp	0.6^{y}	0.5^{x}	1.0^{z}	1.6^{w}	0.5^{x}	0.04	0.001
Val	3.9^{y}	3.3^{x}	5.3^{z}	5.2^{z}	3.6^{xy}	0.13	0.001
Total	36.0^{y}	30.8^{x}	41.6^{z}	41.5^{z}	30.4^{x}	0.91	0.001
Dispensable AA							
Ala	6.4^{z}	5.5^{y}	4.3^{x}	3.9^{w}	7.0^{v}	0.19	0.001
Asp	5.3^{yz}	4.9^{xy}	6.3^{w}	5.6^{z}	4.6^{x}	0.17	0.001
Cys	1.9^{z}	1.5^{y}	2.0^{z}	2.7^{w}	1.3^{x}	0.05	0.001
Glu	16.3^{y}	14.3^{x}	27.6^{z}	38.1^{w}	16.1^{y}	0.39	0.001
Gly	2.9^{y}	2.5^{y}	4.3^{z}	4.9^{w}	1.8^{x}	0.25	0.001
Pro	7.3^{y}	6.8^{y}	13.8^{z}	13.9^{z}	4.5^{x}	1.26	0.001
Ser	3.3^{x}	3.1^{x}	3.9^{y}	4.9^{z}	3.1^{x}	0.09	0.001
Tyr	1.9^{y}	1.7^{x}	2.6^{z}	2.5^{z}	2.0^{y}	0.06	0.001
Total	46.1^{y}	41.1^{x}	65.5^{z}	77.1^{w}	41.4^{x}	1.67	0.001
All AA	70.9^{y}	62.1^{x}	92.9^{z}	102.2^{w}	61.2^{x}	2.00	0.001

$^{v-z}$Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Calculated by multiplying analyzed concentrations of AA by calculated values for standardized ileal digestibilities for each AA in the grains. Data are means of 6 observations per treatment.

ues (NRC, 1998; Stein et al., 2001; Pedersen and Boisen, 2002). The concentration of most AA in NutriDense corn was 5 to 20% greater than in yellow dent corn, and the AID for most AA and the SID for Arg, Lys, and Met were greater in NutriDense corn than in yellow dent corn. The reason for this observation remains to be elucidated, but it is likely that natural differences among varieties of corn exist as has been demonstrated for barley (van Wijk et al., 1998; McCann et al., 2006) and for field peas (Fan and Sauer, 1999). Because of the increased concentration of standardized ileal digestible indispensable AA in NutriDense corn compared with yellow dent corn, less supplemental protein such as soybean meal is needed in diets containing NutriDense

Table 10. Daily energy and N balance in growing pigs fed diets containing NutriDense (ND) or yellow dent (YD) corn without or with AA supplementation, Exp. 2[1]

Item	Corn		Crystalline AA		Pooled SEM	*P*-value	
	ND	YD	–	+		Corn	AA
ADG, g	663	712	498	878	45	0.43	0.001
GE consumed, kcal	5,399	5,363	5,481	5,281	314	0.64	0.02
N intake, g	19.8	18.6	18.3	20.1	1.11	0.01	0.004
GE lost in feces, kcal	703	704	753	654	33	0.96	0.001
GE lost in urine, kcal	94.6	95.6	109	81	15.8	0.91	0.001
N lost in feces, g	3.91	3.73	4.16	3.48	0.225	0.36	0.005
N lost in urine, g	6.91	6.60	9.23	4.28	0.633	0.58	0.001
DE in diet, kcal/kg	3,423	3,338	3,358	3,403	23	0.001	0.30
ME in diet, kcal/kg	3,355	3,270	3,280	3,343	19	0.03	0.08
DE in ingredient, kcal/kg of DM	4,004	3,878	3,914	3,967	27	0.001	0.82
ME in ingredient, kcal/kg of DM	3,922	3,799	3,824	3,897	22	0.001	0.33
N absorbed, g	15.8	14.9	14.2	16.6	1.18	0.07	0.001
N retained, g	9.0	8.3	5.0	12.3	0.75	0.23	0.001
N retention, %	45.2	43.0	27.5	60.3	2.15	0.37	0.001
Biological value,[2] %	56.6	55.6	39.5	72.7	3.23	0.74	0.001

[1]Data are means of 12 observations.

[2]Calculated as (N retained/N absorbed) × 100.

Table 11. Apparent total tract digestibility (%) of N, ether extract, and GE in growing pigs fed diets containing NutriDense (ND) or yellow dent (YD) corn without or with AA supplementation, Exp. 2[1]

	Corn		Crystalline AA			*P*-value	
Item	ND	YD	–	+	Pooled SEM	Corn	AA
N	80.0	79.9	77.3	82.6	1.85	0.94	0.001
Ether extract	61.4	46.2	52.0	55.7	1.58	0.001	0.10
GE	87.0	86.9	86.3	87.6	0.57	0.57	0.02

[1]Data are means of 12 observations.

corn. However, the concentration of digestible AA in barley and wheat was greater than in both sources of corn, although SID for most AA was lower in barley than in NutriDense corn. The reason for this observation is that the concentration of AA in barley was greater than in NutriDense corn and yellow dent corn. Therefore, the lowest amount of supplemental protein will be needed if barley or wheat is used in formulating diets. The lower AID and SID in sorghum compared with corn and wheat is in agreement with published values (Sauer et al., 1977; NRC, 1998). This observation suggests that more supplemental protein is needed in the diets if sorghum is used rather than barley, wheat, or the 2 corn sources.

Energy and Nitrogen Balance and Digestibility

The values for DE and ME in yellow dent corn (3,878 and 3,799 kcal/kg of DM) concur with the values of 3,879 kcal of DE and 3,825 kcal of ME per kg of DM reported by Stein et al. (2004). Likewise, the values obtained in the current experiment agree with the values of 3,961 kcal of DE and 3,843 kcal of ME per kg of DM published by NRC (1998). The greater concentration of GE in NutriDense corn as compared with yellow dent corn was likely caused by the increased concentration of ether extract in this grain. The ATTD for GE was not different between the 2 corns. The difference in GE concentration, therefore, resulted in differences in the concentration of DE and ME between the 2 corns with NutriDense corn containing more DE and ME per kilogram than yellow dent corn. This demonstrates that pigs are able to utilize the increased concentration of energy in NutriDense corn. This observation is in agreement with data indicating that the G:F for growing pigs is improved if NutriDense corn rather than yellow dent corn is included in the diets (Hastad et al., 2005).

The increased ATTD for ether extract in NutriDense corn as compared with yellow dent corn is most likely a result of the greater concentration of ether extract in NutriDense corn. The endogenous losses of ether extract will contribute relatively more to the total fecal output in diets with low concentrations of ether extract compared with diets with higher concentrations of ether extract. This in turn will lead to a lower calculated value for ATTD in diets with a low concentration of ether extract (Just et al., 1980; Just, 1982). To determine if the ether extract in NutriDense corn per se is more digestible than in yellow dent corn, it will be necessary to measure the true rather than the apparent digestibility of ether extract in the 2 varieties of corns.

The direct procedure was used to measure the DE and ME in the 2 corns in the present experiment. This procedure has previously been used to estimate DE and ME in corn (Adeola and Bajjalieh, 1997; Stein et al., 2004). By necessity, experimental diets that are deficient in AA are formulated when this approach is used. In the current experiment, an attempt was made to correct this deficiency by supplementing the experimental diets with crystalline AA. Based on the ADG for the pigs, the data for the N balance, the ATTD for N, and the biological value of the diets, it is clear that diets were more balanced in AA when formulated using this approach. As expected, the diets containing crystalline AA resulted in more protein being retained and, therefore, less excretion of N in the urine. The improved protein balance also resulted in more energy being absorbed from the diets as indicated by a greater ATTD for GE in the AA-supplemented diets compared with the unsupplemented diets. However, the lack of an effect of crystalline AA on values for DE and ME in the 2 grains indicates that the accuracy of measuring DE and ME is not improved by balancing diets with AA.

In conclusion, results from the current research demonstrate that NutriDense corn has a greater concentration of standardized ileal digestible AA and of ether extract compared with yellow dent corn. As a consequence, if NutriDense corn is used in diet formulations rather than yellow dent corn, less supplemental protein is needed to balance the diet. NutriDense corn also contains more digestible and metabolizable energy than yellow dent corn, which is expected to improve feed conversion if NutriDense corn is used. However, wheat and barley contain greater quantities of digestible AA than NutriDense corn and yellow dent corn, whereas the concentration of digestible AA in sorghum is less than in all other cereal grains. Therefore, if diets are formulated based on barley or wheat, lower concentrations of supplemental protein sources are needed than if NutriDense corn, yellow dent corn, or sorghum is used.

LITERATURE CITED

Adeola, O., and N. L. Bajjalieh. 1997. Energy concentration of high-oil corn varieties for pigs. J. Anim. Sci. 75:430–436.

AOAC. 2000. Official Methods of Analysis. 17th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Fan, M. Z., and W. C. Sauer. 1999. Variability of apparent ileal amino acid digestibility in different pea samples for growing-finishing pigs. Can. J. Anim. Sci. 79:467–475.

Fenton, T. W., and M. Fenton. 1979. An improved procedure for the determination of chromic oxide in feed and feces. Can. J. Anim. Sci. 59:631–634.

Gill, J. L., and W. T. Magee. 1976. Balanced two-period changeover designs for several treatments. J. Anim. Sci. 42:775–777.

Hastad, C. W., M. D. Tokach, R. D. Goodband, J. L. Nelssen, S. S. Dritz, J. M. DeRouchey, and C. L. Jones. 2005. Comparison of yellow dent corn and NutriDense corn hybrids in swine diets. J. Anim. Sci. 83:2624–2631.

Just, A. 1982. The net energy value of crude fat for growth in pigs. Livest. Prod. Sci. 9:501–509.

Just, A., J. O. Andersen, and H. Jørgensen. 1980. The influence of diet composition on the apparent digestibility of crude fat and fatty acids at the terminal ileum and overall in pigs. Z. Tierphysiol. Tierernährg. Futtermittelkde. 44:82–92.

McCann, M. E. E., J. D. G. McEvoy, and K. J. McCracken. 2006. Factors affecting digestibility of barley-based diets for growing pigs. Livest. Sci. 102:51–59.

NRC. 1998. Pages 110–123 in Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Pedersen, C., and S. Boisen. 2002. Establishment of tabulated values for standardized ileal digestibility of crude protein and essential amino acids in common feedstuffs for pigs. Acta. Agric. Scand. Sect. Anim. Sci. 52:121–140.

Sauer, W. C., S. C. Stothers, and G. D. Phillips. 1977. Apparent availabilities of amino acids in corn, wheat, and barley for growing pigs. Can. J. Anim. Sci. 57:585–597.

Stein, H. H., G. Benzoni, R. A. Bohlke, and D. N. Peters. 2004. Assessment of the feeding value of South Dakota-grown field peas (*Pisum sativum* L.) for growing pigs. J. Anim. Sci. 82:2568–2578.

Stein, H. H., S. W. Kim, T. T. Nielsen, and R. A. Easter. 2001. Standardized amino acid digestibilities in growing pigs and sows. J. Anim. Sci. 79:2113–2122.

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical Note: A technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436.

Thiex, N. J., S. Anderson, and B. Gildemeister. 2003. Crude fat, diethyl ester extraction, in feed, cereal grain, and forage (Randall/Soxtec/Submersion Method): Collaborative study. J. AOAC Int. 86:888–898.

Thiex, N. J., H. Manson, S. Anderson, and J. A. Persson. 2002. Determination of crude protein in animal feed, forage, grain, and oilseeds by using block digestion with a copper catalyst and steam distillation into boric acid: Collaborative study. J. AOAC Int. 85:309–317.

van Wijk, H. J., P. J. Moughan, S. M. Hodginson, P. P. Jansen, and G. Pearson. 1998. Variation in apparent and true ileal amino acid digestibility in barley using a rat model. Anim. Feed Sci. Technol. 76:9–22.