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# Calcium, phosphorus, and amino acid digestibility in low-phytate corn, normal corn, and soybean meal by growing pigs[1,2]

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**ABSTRACT:** Nine growing barrows were equipped with a T-cannula in the distal ileum and used to determine apparent ileal (AID) and apparent total-tract digestibility (ATTD) coefficients of Ca and P in low-phytate corn, normal corn, soybean meal, and in diets where soybean meal was mixed with low-phytate corn or normal corn. The AID and the standardized ileal digestibility coefficients (SID) of CP and AA also were determined. The animals (initial BW = 29.3 ± 1 kg) were allotted to a 9 × 9 Latin square with nine diets and nine periods. Three diets contained low-phytate corn, normal corn, and soybean meal as their sole source of CP, AA, Ca, and P, respectively. Three additional diets were identical to these diets except that limestone and monosodium phosphate were added. Two diets contained low-phytate corn or normal corn and soybean meal, limestone, and monosodium phosphate, and the final diet was a N-free diet. The AID and ATTD of Ca were higher ($P < 0.05$) for low-phytate corn than for normal corn (70.0 and 69.1% vs. 47.4 and 49.6%, respectively). The AID and ATTD for Ca in soybean meal (50.9 and 46.7%, respectively) did not differ from values for normal corn but were lower ($P < 0.05$) than for low-phytate corn. The AID and ATTD for P from low-phytate corn (56.5 and 54.5%, respectively) were greater ($P < 0.05$) than from normal corn (28.3 and 28.8%, respectively), whereas soybean meal had intermediate AID and ATTD for P (37.2 and 38.0%, respectively). The AID and ATTD of P increased ($P < 0.05$) when monosodium phosphate was added to normal corn (44.9 and 49.8%, respectively) and soybean meal (49.6 and 46.2%, respectively), but adding monosodium phosphate to low-phytate corn, did not alter either AID (49.7%) or ATTD (50.7%) of P. No differences between AID and ATTD for Ca or P within the same diet were observed. The AID of Arg, Asp, Gly, Ile, Lys, Phe, Thr, and Val were greater ($P < 0.05$) in low-phytate corn than in normal corn. The AID of all AA in soybean meal were greater ($P < 0.05$) than in both types of corn, with the exception of Ala, Cys, Leu, and Met. The SID of Lys, Phe, and Thr were higher ($P < 0.05$) in low-phytate corn than in normal corn. Because low-phytate corn has a higher digestibility of Ca and P, less inorganic Ca and P need to be supplemented to diets containing low-phytate corn than to those containing normal corn, and P excretion may be decreased when low-phytate corn is used in the diet.

Key Words: Amino Acids, Calcium, Digestibility, Low-Phytate Corn, Pigs, Phosphorus

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## Introduction

Much of the P in conventional corn-soybean meal diets is bound in the phytate complex, thereby rendering it indigestible by nonruminants (Cromwell, 1992). This leads to increased P excretion by the animals and potential environmental concerns (Klopfenstein et al., 2002). In recent years, novel low-phytate varieties of several grain species have been developed (Raboy and Gerbasi, 1996; Rasmussen and Hatzack, 1998). The P is more digestible by nonruminants from such grains than from conventional varieties. For example, the P digestibility from low-phytate barley was greater than from normal barley by rats (Poulsen et al., 2001) and by pigs (Veum et al., 2002).

Low-phytate corn is another grain that has been developed. Produced from seed that is homozygous for the *1pa*1 allele, it contains 66% less phytate-bound P than normal corn, but the total P concentration in low-phytate corn is similar to that in normal corn (Raboy and Gerbasi, 1996). Compared with normal corn, low-phytate corn has greater availability of Ca and P by pigs (Spencer et al., 2000; Sands et al., 2001; Veum et al., 2001). Therefore, pigs fed diets containing adequate

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amounts of available P may excrete less P when fed low-phytate corn than when fed normal corn. The digestibility of AA by roosters was similar or greater in low-phytate corn compared with normal corn (Douglas et al., 2000). In growing pigs, apparent total-tract digestibility (**ATTD**) of CP was similar for low-phytate corn and normal corn (Spencer et al., 2000); however, no data have been reported for the apparent (**AID**) or standardized (**SID**) ileal digestibility of CP and AA in low-phytate corn by growing pigs.

The objective of this experiment was to compare the digestibility coefficients in growing pigs for CP, AA, Ca, and P in low-phytate corn with those obtained in normal corn and in soybean meal. A second objective was to compare the AID of Ca and P to the ATTD of Ca and P within diets.

**Table 1.** Analyzed nutrient composition of normal corn, low-phytate corn, and soybean meal (%, as-fed basis)

| Nutrient | Low-phytate corn | Normal corn | Soybean meal |
|---|---|---|---|
| Ca | 0.01 | 0.01 | 0.42 |
| P | 0.23 | 0.24 | 0.60 |
| CP | 9.25 | 9.46 | 47.71 |
| Indispensable AA | | | |
| Arginine | 0.40 | 0.39 | 3.22 |
| Histidine | 0.24 | 0.24 | 1.13 |
| Isoleucine | 0.26 | 0.27 | 1.92 |
| Leucine | 0.90 | 0.94 | 3.36 |
| Lysine | 0.24 | 0.25 | 2.91 |
| Methionine | 0.22 | 0.20 | 0.76 |
| Phenylalanine | 0.37 | 0.38 | 1.56 |
| Threonine | 0.25 | 0.24 | 2.08 |
| Valine | 0.37 | 0.38 | 1.92 |
| Dispensable AA | | | |
| Alanine | 0.57 | 0.58 | 5.20 |
| Aspartic acid | 0.52 | 0.52 | 5.20 |
| Cysteine | 0.14 | 0.13 | 0.52 |
| Glutamic acid | 1.47 | 1.46 | 8.51 |
| Glycine | 0.31 | 0.31 | 1.93 |
| Proline | 0.72 | 0.70 | 2.38 |
| Serine | 0.41 | 0.41 | 2.69 |
| Tyrosine | 0.32 | 0.32 | 1.58 |

## Materials and Methods

### *Animals, Housing, and Experimental Design*

Nine barrows (initial BW = 29.3 ± 1.0 kg; final BW = 94.1 ± 2.78) originating from mating Duroc × Pietrain × Large White boars to Yorkshire × Landrace × Duroc sows were surgically equipped with T-cannulas in the distal ileum using procedures adapted from Stein et al. (1998). After surgery, pigs were housed individually in 1.2 × 1.8 m pens. Room temperature was maintained at 22°C. Animal care procedures were approved by the South Dakota State University Animal Care and Use Committee (No. 00-A037). A 9 × 9 Latin square design was used, with nine periods, nine animals, and nine diets. Each experimental period lasted 9 d.

### *Diets and Feeding*

Low-phytate corn and normal corn were obtained from Pioneer Hi-Bred Int. Inc. (Johnston, IA), and dehulled soybean meal was obtained from a commercial source. Before feed mixing, the low-phytate corn and the normal corn were ground to pass a 0.3175-cm screen. The mill had a negative air-assist system to minimize contamination. The nutrient composition of the two corns and soybean meal are shown in Table 1.

The nine diets were prepared (Table 2) and assigned randomly to animals within the Latin square. Two diets were formulated with low-phytate corn and normal corn being the sole source of CP, AA, Ca, and P. Two additional diets were similar to these diets, with the exception that inorganic Ca in the form of limestone and inorganic P in the form of monosodium phosphate were included in the diets to meet requirements for Ca and available P (NRC, 1998). One diet was formulated with soybean meal being the sole source of CP, AA, Ca, and P, whereas another diet was based on soybean meal, limestone, and monosodium phosphate. Two mixed corn-soybean meal diets also were formulated based on either low-phytate corn or normal corn. Limestone and monosodium phosphate were included in these diets to meet requirements for 20- to 50-kg pigs (NRC, 1998) for Ca and available P. The final diet was a N-free diet used to estimate basal endogenous losses of CP and AA. Cellulose (Solka floc, Fiber Sales and Development Corp., Urbana, OH) was included in the diets based on soybean meal and the N-free diet to increase the total concentration of crude fiber. Dextrose and soybean oil were included in all diets at levels of 5 and 3% (as-fed basis), respectively, to enhance palatability. Chromic oxide (0.25%) was included in all diets as an inert marker; vitamins, salt, and trace minerals were included at levels that met or exceeded requirements for 20- to 50-kg pigs (NRC, 1998). All diets that contained monosodium phosphate were formulated to contain 0.20% available P. The relative availability of P in normal corn, soybean meal, and monosodium phosphate were assumed to be 14, 33, and 100%, respectively (NRC, 1998), whereas the relative availability of P in low-phytate corn was assumed to be 62% (Spencer et al., 2000). The nutrient composition of the diets is shown in Table 3.

Pigs were fed three times their daily energy requirement for maintenance (i.e., 106 kcal ME/kg $BW^{0.75}$; NRC, 1998), with equal amounts of feed provided at 0800 and 2000. Water was available to each pig at all times throughout the experiment.

### *Data Recording and Sample Collection*

The initial 6 d of each experimental period were considered an adaptation period to the diet. At the same time each morning on d 7 and 8, fecal samples were collected by grab sampling and immediately frozen. Il-

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

| Ingredient | Diet[a]: Added Ca and P: | LPC − | NC − | LPC + | NC + | SBM − | SBM + | LPC-SBM + | NC-SBM + | N-free + |
|---|---|---|---|---|---|---|---|---|---|---|
| Low-phytate corn | | 90.95 | — | 89.79 | — | — | — | 65.30 | — | — |
| Normal corn | | — | 90.95 | — | 89.52 | — | — | — | 65.09 | — |
| Soybean meal | | — | — | — | — | 37.65 | 37.65 | 24.50 | 24.50 | — |
| Limestone | | — | — | 1.08 | 1.08 | — | 1.0 | 1.07 | 1.07 | 1.35 |
| Monosodium phosphate | | — | — | 0.16 | 0.70 | — | 0.48 | 0.16 | 0.56 | 0.80 |
| Solka floc | | — | — | — | — | 2.0 | 2.0 | — | — | 3.0 |
| Dextrose | | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Soybean oil | | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Chromic oxide | | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Salt | | 0.40 | 0.40 | 0.32 | 0.05 | 0.40 | 0.16 | 0.32 | 0.13 | 0.40 |
| Vitamin premix[b] | | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Trace mineral premix[c] | | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Cornstarch | | — | — | — | — | 51.30 | 50.06 | — | — | 85.80 |

[a]LPC = low-phytate corn; NC = normal corn; SBM = soybean meal.
[b]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,000 IU; vitamin $D_3$, 1,000 IU; vitamin E, 88 IU; vitamin K, 4.4 mg; thiamin, 3.0 mg; riboflavin, 10 mg; pyridoxine, 4.0 mg; vitamin $B_{12}$, 0.050 mg; D-pantothenic acid, 26.4 mg; niacin, 50 mg; folic acid, 3.0 mg; biotin, 0.4 mg; and choline, 250 mg.
[c]Provided the following quantities of minerals per kilogram of complete diet: Cu, 25 mg as copper sulfate; Fe, 120 mg as iron sulfate; I, 0.30 mg as potassium iodate; Mn, 25 mg as manganese sulfate; Se, 0.30 mg as sodium selenite; and Zn, 125 mg as zinc oxide.

eal digesta were collected for 12 h on d 8 and 9 as described by Stein et al. (1999). Briefly, a plastic bag was attached to the cannula barrel, and digesta flowing into the bag were collected. Bags were removed whenever they were filled with digesta, or at least every 30 min, and immediately frozen at −20°C to prevent microbial degradation of digesta proteins. At the conclusion of each experimental period, the animals were deprived of feed overnight; the following morning, the next diet in the Latin square sequence was fed. A sample of

**Table 3.** Analyzed nutrient composition of diets (%, as-fed basis)

| Item | Diet[a]: Added Ca and P: | LPC − | NC − | LPC[b] + | NC[b] + | SBM − | SBM[b] + | LPC-SBM + | NC-SBM + | N-free[b] + |
|---|---|---|---|---|---|---|---|---|---|---|
| Nutrient | | | | | | | | | | |
| DM | | 90.53 | 89.68 | 89.04 | 88.89 | 91.62 | 91.81 | 89.73 | 90.00 | 92.96 |
| Ca | | 0.01 | 0.01 | 0.46 | 0.44 | 0.23 | 0.60 | 0.56 | 0.54 | 0.48 |
| P | | 0.27 | 0.26 | 0.32 | 0.52 | 0.27 | 0.43 | 0.41 | 0.51 | 0.20 |
| CP | | 8.95 | 8.67 | 8.31 | 8.96 | 19.67 | 19.07 | 22.70 | 21.14 | 0.21 |
| Indispensable AA | | | | | | | | | | |
| Arginine | | 0.44 | 0.40 | — | — | 1.42 | — | 1.21 | 1.20 | — |
| Histidine | | 0.25 | 0.23 | — | — | 0.52 | — | 0.51 | 0.50 | — |
| Isoleucine | | 0.29 | 0.27 | — | — | 0.89 | — | 0.77 | 0.77 | — |
| Leucine | | 0.96 | 0.96 | — | — | 1.56 | — | 1.69 | 1.66 | — |
| Lysine | | 0.28 | 0.26 | — | — | 1.29 | — | 1.01 | 0.99 | — |
| Methionine | | 0.22 | 0.23 | — | — | 0.34 | — | 0.37 | 0.36 | — |
| Phenylalanine | | 0.41 | 0.40 | — | — | 1.01 | — | 0.92 | 0.91 | — |
| Threonine | | 0.26 | 0.25 | — | — | 0.60 | — | 0.63 | 0.61 | — |
| Valine | | 0.43 | 0.39 | — | — | 0.95 | — | 0.90 | 0.90 | — |
| Dispensable AA | | | | | | | | | | |
| Alanine | | 0.61 | 0.59 | — | — | 0.87 | — | 0.98 | 0.97 | — |
| Aspartic acid | | 0.57 | 0.56 | — | — | 2.30 | — | 1.85 | 1.81 | — |
| Cysteine | | 0.15 | 0.15 | — | — | 0.22 | — | 0.25 | 0.24 | — |
| Glutamic acid | | 1.54 | 1.50 | — | — | 3.74 | — | 3.42 | 3.36 | — |
| Glycine | | 0.34 | 0.32 | — | — | 0.86 | — | 0.78 | 0.77 | — |
| Proline | | 0.74 | 0.70 | — | — | 1.01 | — | 1.10 | 1.07 | — |
| Serine | | 0.45 | 0.45 | — | — | 1.19 | — | 1.06 | 1.01 | — |
| Tyrosine | | 0.34 | 0.34 | — | — | 0.71 | — | 0.69 | 0.68 | — |

[a]LPC = low-phytate corn; NC = normal corn; SBM = soybean meal.
[b]These diets were not analyzed for AA.

each feed ingredient and each diet was collected at the time the diets were mixed.

*Chemical Analyses*

At the conclusion of the experiment, fecal and ileal samples were thawed, pooled within animal and diet, and a subsample was retained for chemical analyses. Fecal and digesta samples were lyophilized, and dried samples were finely ground before chemical analyses.

The concentration of CP was determined in low-phytate corn, normal corn, soybean meal, in all diets, and in digesta samples from pigs fed the diets that contained no monosodium phosphate, as well as in the two corn-soybean meal-based diets, using a Kjeldahl apparatus (AOAC, 1998). The concentrations of AA were analyzed in low-phytate corn, normal corn, soybean meal, all diets (except the corn-monosodium phosphate diets, the soybean meal-monosodium phosphate diet, and the N-free diet), and in the ileal samples that also were used for CP analysis. A Chrom-tech HPLC AA analyzer (Thermo Separation Products, San Jose, CA), using ninhydrin for postcolumn derivatization and nor-leucine as the internal standard, was used for AA analysis (AOAC, 1998). Before analysis, samples were hydrolyzed with 6 *N* HCL for 24 h at 110°C. Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis. Tryptophan concentrations were not determined. The Cr concentration in diets, digesta, and fecal samples was determined according to the procedure of Fenton and Fenton (1979). After wet acid digestion with nitric and perchloric acids (2:1), Ca and P concentrations of feed ingredients, diets, digesta, and fecal samples were measured. The Ca concentrations were determined with an atomic absorption spectrophotometer (model 5000, Perkin-Elmer, Norwalk, CT). The P determination was accomplished on a UV-visible scanning spectrophotometer (model UV-2101 PC, Shimadzu Corp., Kyoto, Japan) at 650 nm (AOAC, 2000; Method 3.4.11). Accuracy of the procedure was verified using National Institute of Standards and Technology (U.S. Department of Commerce) Reference Standard 1570a.

*Calculations and Statistical Analyses*

The AID of Ca and P were calculated for all diets, with the exception of the N-free diet. The ATTD of Ca and P were calculated for all diets, except for the corn-soybean meal diets and the N-free diet. The AID and the ATTD of Ca in diets that contained no monosodium phosphate were calculated using the difference method (Adeola, 2001) because of the low concentrations of Ca in these diets. The direct method (Adeola, 2001) was used for all other calculations.

The basal endogenous flow of CP and AA to the distal ileum was calculated as the CP and AA flow obtained from pigs fed the N-free diet. The AID and SID of CP and AA were determined for low-phytate corn, normal corn, soybean meal, and the two corn-soybean meal diets. For all calculations, previously published equations were used (Stein et al., 2001).

Data were analyzed statistically using MIXED procedure of SAS (Littell et al., 1996). Individual pigs were the experimental units. An ANOVA was conducted with diet as the fixed effect and pig and period as random effects. Least squares means were calculated, and differences were determined using the PDIFF option in SAS. This procedure was used for comparisons of Ca, P, CP, and AA digestibility coefficients among diets. Interactions between ingredients and Ca and P supplementation also were analyzed for AID and ATTD of Ca and P. When comparing AID of Ca and P to ATTD of Ca and P within diets, a Student's *t*-test was used. A *P*-value of ≤0.05 was considered significant.

## Results

All animals remained healthy throughout the experiment and readily consumed their diets without leaving orts. The pigs gained weight throughout the experiment, and they did not lose weight during any of the periods.

*Digestibility of Ca and P*

The digestibility coefficients for Ca and P are shown in Table 4. Pig and period had no effect on Ca and P digestibility, which was true for the AID as well as the ATTD for Ca and P, regardless of the diet being fed.

The AID and the ATTD of Ca were greater ($P < 0.05$) in low-phytate corn than in normal corn (70.0 and 69.1% vs. 47.4 and 49.6%, respectively). The addition of limestone to the diets did not affect the AID (70.0 vs. 63.4%) or the ATTD (69.1 vs. 63.2%) of Ca in low-phytate corn. Likewise, there was no effect of the addition of limestone on the AID or ATTD of Ca in normal corn (47.4% and 49.6 vs. 43.0 and 46.0%). No interaction between corn source and AID or ATTD of Ca was detected. The AID and ATTD for Ca in soybean meal did not differ from the AID and ATTD in the soybean meal—monosodium diet (50.9 and 46.7% vs. 57.2 and 50.1%, respectively). The AID and ATTD of Ca in low-phytate corn were greater ($P < 0.05$) than in soybean meal; however, the AID and ATTD of Ca in normal corn and soybean meal did not differ. The AID of Ca did not differ in the low-phytate corn-soybean meal and the normal corn-soybean meal diets (55.0 and 51.0%, respectively). There were no differences between AID and ATTD of Ca within any of the diets.

The AID and the ATTD of P in low-phytate corn were greater ($P < 0.05$) than in normal corn (56.5 and 54.5% vs. 28.3 and 28.8%). All diets that contained monosodium phosphate had similar AID and ATTD for P; all of these diets were formulated to contain identical concentrations of available P. The AID and the ATTD of P in soybean meal (37.2 and 38%, respectively) were greater ($P < 0.05$) than in normal corn (28.3 and 28.8%,

**Table 4.** Apparent ileal (AID) and apparent total tract (ATTD) digestibility coefficients (%) of Ca and P in low-phytate corn, normal corn, soybean meal, and corn-soybean meal diets[a]

| Item | Diet[b]: Added Ca and P: | LPC – | NC – | LPC + | NC + | SBM – | SBM + | LPC-SBM + | NC-SBM + | SEM |
|---|---|---|---|---|---|---|---|---|---|---|
| Ca digestibility[c] | | | | | | | | | | |
| AID | | 70.0[v] | 47.4[wx] | 63.4[vy] | 43.0[w] | 50.9[wz] | 57.2[yz] | 55.0[xyz] | 51.0[wz] | 4.87 |
| ATTD | | 69.1[w] | 49.6[xy] | 63.2[wx] | 46.0[yz] | 46.7[yz] | 50.1[xz] | — | — | 7.63 |
| P digestibility[c] | | | | | | | | | | |
| AID | | 56.5[w] | 28.3[x] | 49.7[wy] | 44.9[y] | 37.2[z] | 49.6[wy] | 47.9[wy] | 49.8[wy] | 3.66 |
| ATTD | | 54.5[w] | 28.8[x] | 50.7[wz] | 49.8[wz] | 38.0[y] | 46.2[z] | — | — | 3.40 |

[a]Values represent means of nine pigs per treatment.
[b]LPC = low-phytate corn; NC = normal corn; SBM = soybean meal.
[c]No differences between AID and ATTD for either Ca or for P.
[v,w,x,y,z]Means within a row that do not have a common superscript differ, $P < 0.05$.

respectively), but less ($P < 0.05$) than in low-phytate corn (56.5 and 54.5%, respectively). An interaction between ingredient and P supplementation was detected ($P < 0.05$). The AID and the ATTD of P in normal corn and soybean meal increased ($P < 0.05$) when monosodium phosphate was added, but this was not the case for low-phytate corn. The AID for the low-phytate corn-soybean meal and the normal corn-soybean meal diets (47.9 and 49.8% respectively) did not differ; however, both values were greater $P < 0.05$) than the AID for normal corn and soybean meal but not different from any of the other diets. There were no differences between AID and ATTD of P within any of the diets.

### *Digestibility of CP and AA*

For all calculations, pig and period had no effect on the AID and the SID of CP and AA. The AID of CP and AA for the low-phytate corn, normal corn, soybean meal, and the corn-soybean meal diets are shown in Table 5.

The AID of Arg, Ile, Lys, Phe, Thr, Val, Asp, and Gly were greater ($P < 0.05$) in low-phytate corn than in normal corn. Soybean meal had higher ($P < 0.05$) AID of CP, all indispensable AA except Leu and Met, and all dispensable AA, except Ala and Cys compared with low-phytate corn and normal corn. The AID in the two corn-soybean meal diets were similar for CP and all AA.

The basal endogenous losses of CP and AA were calculated based on collections of digesta from pigs fed the N-free diet. These values were used to correct the AID for basal endogenous losses to calculate SID (Table 6). The SID of Lys, Phe, and Thr were greater ($P < 0.05$) for low-phytate corn than for normal corn, but for all other AA and for CP, there were no differences between the two corns. The SID of Arg, His, and Lys were gretater ($P < 0.05$) in soybean meal than in low-phytate corn and normal corn. The SID of Ile, Thr, and Asp in soybean meal did not differ from those of low-phytate corn, but they were greater ($P < 0.05$) than in normal corn. The SID of Leu and Ala were greater ($P < 0.05$) in low-phytate corn than in soybean meal; however, for CP and for the remaining AA, no differences in SID between soybean meal, low-phytate corn, and normal corn were observed. The two corn-soybean meal diets had similar SID of all AA regardless of the type of corn used in the diet.

## Discussion

### *Digestibility of Ca and P*

In the present experiment, the digestibility coefficients by growing pigs of Ca in low-phytate corn and normal corn were measured in diets in which either low-phytate corn or normal corn was the sole source of Ca. To the best of our knowledge, such a comparison has not been reported previously. Presumably, Ca digestibility was greater in low-phytate corn than in normal corn because less Ca was bound in the phytate complex in low-phytate corn than in normal corn; therefore, more Ca was absorbed from low-phytate corn than from normal corn. The fact that the digestibility coefficients of Ca in normal corn and soybean meal were similar indicates that similar proportions of Ca were bound in the phytate complex in these two feed ingredients.

The digestibility coefficients of Ca in the two corn-soybean meal diets are similar to the values reported by Spencer et al. (2000) and Veum et al. (2001). In contrast, the values obtained in the current experiment were less than the digestibility coefficients of Ca in corn-soybean meal-based diets reported by Sands et al. (2001). In the Sands et al. (2001) experiment, greater concentrations of inorganic Ca were included in the experimental diets than in the diets used in the present experiment, which may be the reason for this difference.

Because there was no difference between AID and ATTD for Ca in any of the diets, the present data indicate that there is no net absorption or net excretion of Ca in the large intestine. This observation agrees with previous published data (Partridge, 1978). Based on these findings, there seems to be no advantage of mea-

**Table 5.** Apparent ileal digestibility coefficients (%) of CP and AA in low-phytate corn, normal corn, soybean meal, and corn-soybean meal diets[a]

| Item Diet[b]: | LPC | NC | SBM | LPC-SBM | NC-SBM | SEM |
|---|---|---|---|---|---|---|
| CP | 68.2[y] | 64.5[y] | 78.6[z] | 78.0[z] | 78.8[z] | 2.00 |
| Indispensable AA | | | | | | |
| Arginine | 79.6[w] | 75.1[x] | 92.1[y] | 88.4[z] | 88.8[z] | 1.28 |
| Histidine | 78.4[x] | 76.6[x] | 87.9[y] | 83.5[z] | 84.5[z] | 1.08 |
| Isoleucine | 71.2[w] | 67.9[x] | 83.2[y] | 78.0[z] | 79.5[z] | 1.49 |
| Leucine | 84.5[y] | 83.3[yz] | 84.2[y] | 81.8[z] | 83.0[yz] | 0.99 |
| Lysine | 65.5[w] | 57.4[x] | 86.7[y] | 81.4[z] | 82.2[yz] | 2.38 |
| Methionine | 79.7 | 79.5 | 80.8 | 77.8 | 78.1 | 1.70 |
| Phenylalanine | 80.8[x] | 77.8[y] | 85.1[z] | 81.5[x] | 82.5[xz] | 1.38 |
| Threonine | 61.8[w] | 57.0[x] | 76.8[y] | 70.5[z] | 71.9[z] | 1.91 |
| Valine | 67.4[w] | 61.6[x] | 75.3[y] | 70.8[wz] | 73.4[yz] | 1.97 |
| Dispensable AA | | | | | | |
| Alanine | 76.9[w] | 74.1[wy] | 75.6[wz] | 73.2[xyz] | 76.2[wz] | 1.55 |
| Aspartic acid | 69.2[w] | 65.8[x] | 83.4[y] | 78.3[z] | 79.4[z] | 1.45 |
| Cysteine | 75.1 | 75.2 | 75.1 | 73.2 | 74.2 | 2.02 |
| Glutamic acid | 81.6[wx] | 80.6[w] | 86.4[y] | 83.6[xz] | 84.6[yz] | 1.13 |
| Glycine | 44.7[x] | 34.9[y] | 68.5[z] | 62.6[z] | 64.4[z] | 3.73 |
| Proline | 32.4[y] | 28.1[y] | 68.5[z] | 61.1[z] | 63.3[z] | 9.97 |
| Serine | 71.5[x] | 69.0[x] | 81.6[y] | 75.8[z] | 76.9[z] | 1.57 |
| Tyrosine | 79.8[xy] | 77.9[y] | 84.4[z] | 80.5[x] | 82.0[xz] | 1.17 |

[a]Values represent means of nine pigs per treatment.
[b]LPC = low-phytate corn; NC = normal corn; SBM = soybean meal.
[w,x,y,z]Means within a row that do not have a common superscript differ, $P < 0.05$.

**Table 6.** Standardized ileal digestibility coefficients (%) of CP and AA in low-phytate corn, normal corn, soybean meal, and corn-soybean meal diets[a,b]

| Item Diet[c]: | LPC | NC | SBM | LPC-SBM | NC-SBM | SEM |
|---|---|---|---|---|---|---|
| CP | 87.9 | 84.8 | 87.5 | 85.8 | 87.1 | 1.98 |
| Indispensable AA | | | | | | |
| Arginine | 92.9[xy] | 90.0[x] | 96.2[z] | 93.2[yz] | 93.7[yz] | 1.49 |
| Histidine | 85.9[wx] | 84.6[w] | 91.5[y] | 87.2[xz] | 88.3[z] | 1.07 |
| Isoleucine | 86.0[yz] | 83.4[y] | 88.00[z] | 83.5[y] | 85.0[yz] | 1.48 |
| Leucine | 89.9[x] | 88.7[xy] | 87.5[y] | 84.9[z] | 86.2[yz] | 0.98 |
| Lysine | 81.3[x] | 74.4[y] | 90.2[z] | 85.8[xz] | 86.8[z] | 2.49 |
| Methionine | 87.7[y] | 87.3[y] | 86.1[yz] | 82.6[z] | 83.1[z] | 1.79 |
| Phenylalanine | 88.5[x] | 85.7[yz] | 88.2[xy] | 84.9[z] | 86.0[xyz] | 1.37 |
| Threonine | 80.5[xz] | 76.2[y] | 83.6[z] | 78.2[xy] | 79.9[xyz] | 1.90 |
| Valine | 85.4[y] | 81.4[yz] | 83.4[yz] | 79.4[z] | 81.9[yz] | 2.07 |
| Dispensable AA | | | | | | |
| Alanine | 88.2[x] | 85.6[xz] | 83.4[yz] | 80.2[y] | 83.2[yz] | 1.57 |
| Aspartic acid | 85.3[xy] | 82.2[x] | 87.3[yz] | 83.2[x] | 84.5[xz] | 1.51 |
| Cysteine | 85.2[y] | 85.7[y] | 82.2[yz] | 79.4[z] | 80.7[z] | 2.05 |
| Glutamic acid | 89.17[yz] | 88.36[yz] | 89.45[y] | 87.01[z] | 88.06[yz] | 1.14 |
| Glycine | 88.6[x] | 82.2[x] | 85.8[x] | 81.8[x] | 83.7[x] | 3.67 |
| Proline | 106.6[x] | 105.6[x] | 122.7[x] | 110.6[x] | 114.3[x] | 9.98 |
| Serine | 87.5[y] | 84.7[yz] | 87.6[y] | 82.5[z] | 84.0[z] | 1.54 |
| Tyrosine | 88.7[y] | 87.1[yz] | 88.8[y] | 84.9[z] | 86.6[yz] | 1.17 |

[a]Basal endogenous losses that were used to estimate SID were calculated from the flow of CP and AA to the distal ileum after feeding the N-free diet. These losses were determined as follows (g/kg of DMI): CP, 17.7; Arg, 0.59; His, 0.19; Ile, 0.43; Leu, 0.52; Lys, 0.45; Met, 0.18; Phe, 0.32; Thr, 0.49; Val, 0.77; Ala, 0.68; Asp, 0.92; Cys, 0.16; Glu, 1.16; Gly, 1.49; Pro, 5.46; Ser, 0.71; Tyr, 0.31.
[b]Values represent means of nine pigs per treatment.
[c]LPC = Low-phytate corn; NC = normal corn; SBM = soybean meal.
[w,x,y,z]Means within a row that do no have a common superscript differ, $P < 0.05$.

suring Ca digestibility coefficients at the distal ileum rather than using ATTD.

The digestibility coefficient of P in low-phytate corn was approximately twice that of normal corn. This result reflects less P binding in the phytate complex for low-phytate corn than for normal corn. The ATTD of P in the two corn-soybean meal diets used in this experiment are similar to the values reported by Spencer et al. (2000) and Veum et al. (2001). The ATTD of P in low-phytate corn measured in the current experiment also is similar to the values obtained using an in vitro procedure (Spencer et al., 2000; Veum et al., 2001). Likewise, the digestibility of P in soybean meal determined in the current experiment is similar to reported values (NRC, 1998), but the ATTD of P in normal corn measured in this experiment was greater than previously reported values (NRC, 1998; Spencer et al., 2000; Veum et al., 2001). The reason for this difference is unknown, but it may indicate that different varieties of normal corn may differ in the amount of P that is bound in the phytate complex.

Partridge (1978) concluded that there is no net absorption or net excretion of P in the large intestine in pigs, and Ajakaiye et al. (2003) and Sulabo (2003) recently provided data to support this hypothesis. The data from the current experiment confirm these findings.

### *Digestibility of CP and AA*

Previous research has indicated that AA are bound in the phytate complex (Biehl and Baker, 1996). Because less phytate is present in low-phytate corn than in normal corn, an increased digestibility of AA in low-phytate corn might be expected. Previously, it was reported that the SID by roosters were greater in low-phytate corn than in normal corn for some, but not all AA (Douglas et al., 2000). Our data indicate that this also is the case in pigs. This observation may suggest that fewer AA are bound in the phytate complex in low-phytate corn than in normal corn. Compared with normal corn, low-phytate corn had greater SID for Lys, Phe, and Thr; however, when each corn was supplemented with soybean meal, no differences in the SID of AA were found between the low-phytate corn-soybean meal and the normal corn-soybean meal diets. This observation suggests that the differences in digestibility coefficients of AA between the low-phytate corn and normal corn are too small to markedly affect the digestibility coefficients of AA in a corn-soybean meal-based diet, for which the majority of the AA is provided by soybean meal.

The AID and the SID of most AA in soybean meal and normal corn were within the range of values previously reported for these two ingredients (NRC, 1998; Rademacher et al., 2001). The current experiment also confirmed that the SID of a few AA (Leu, Met, Cys) are similar between soybean meal and normal corn, which agrees with previous work (Jondreville et al., 1995; NRC, 1998).

In conclusion, the digestibility of Ca, P, and certain AA is greater in low-phytate corn than in normal corn. Hence, less P from inorganic sources needs to be supplemented to diets formulated with low-phytate corn than with normal corn. As a consequence, less P will be excreted from animals when they are fed low-phytate corn rather than normal corn, provided that diets are formulated to contain similar amounts of digestible P. Both ileal digestibility coefficients and total-tract digestibility coefficients may be used to predict the digestibility of Ca and P by growing pigs. Low-phytate corn also has greater SID for Lys, Phe, and Thr than normal corn.

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