Effect of High Available Phosphorus Corn and Elevated Fat and Protein Corn on Nutrient Digestibility and Excretion in Finishing Pigs

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Introduction

Typical corn and soybean meal diets fed to pigs in the US are known to contain as much as 80% of their phosphorus content in a form that is unavailable to the pig (NRC, 1998). Therefore, the phosphorus nutrient requirement has historically been met by inorganic phosphorus supplementation in the diet, often in excess of dietary requirements. Excess dietary phosphorus is excreted in the feces and urine of the pig. This can lead to increased nutrient accumulation in the environment as manure is utilized as a nutrient source for crop production. There have been several dietary manipulations studied in an attempt to achieve greater nutrient digestibility by the pig and prevent excess nutrient excretion. One attempt at reducing phosphorus excretion has been genetically selecting corn to contain less phytic acid phosphorus. Two mutant corn genes, Lpa-1 and Lpa-2, have been identified and used to create corn varieties reported to contain 66% and 33% reductions in phytic acid phosphorus, respectively (Raboy and Gerbasi, 1996). These corn varieties have been reported to increase the bioavialability of phosphorus to the pig approximately 54% (Spencer et al., 1998). Similar genetic selections have been made to increase the protein and energy content of corn. Recently, an elevated fat and protein corn has been developed and has been combined with the low phytic acid gene to create an elevated fat and protein corn with high available phosphorus content.

The objective of this study was to determine the nutrient digestibility of four genetically enhanced corns when fed to finishing pigs.

Materials and Methods

Experimental design. Twelve crossbred barrows (initial body weight = 210 lb) were used in two replicates for a total of 24 collections (6 pigs/trt), and housed in metabolism stalls for the total collection of feces and urine. Pigs were adapted to their dietary treatment and the metabolism stalls for five days followed by a three-day total collection. Pigs were fed approximately 5 lb/d (3 × maintenance requirement; NRC, 1998) in two equal feedings (0600 and 1600 h) and had ad libitum access to water. Feed refusal was measured daily.

Dietary treatments. Pigs were blocked by weight and ancestry and assigned to one of four dietary treatments (Table 1) including: 1) high available phosphorus corn hybrid 1 diet (HAP1), 2) high available phosphorus corn hybrid 2 diet (HAP2), 3) elevated fat and protein corn diet (EFP), and 4) elevated fat and protein, high available phosphorus corn diet (EFP-HAP1). Diets were formulated to provide 0.53% digestible lysine and 0.30% total phosphorus and balanced to meet or exceed NRC (1998) requirements for all other nutrients.

Sample analysis. Feces and urine were analyzed for dry matter (DM), ash, total nitrogen (N), ammonium nitrogen, total phosphorus, water-soluble phosphorus (WSP), potassium (K), fecal pH and fecal volatile fatty acids (VFA). Diets were analyzed for dry matter (DM), ash, total nitrogen (N), total phosphorus and water-soluble phosphorus (WSP).

Blood samples were collected from all pigs by jugular venipuncture prior to being started on treatment diets and at the completion of the trial. Serum phosphorus concentration and serum urea nitrogen (SUN) were determined using colorimetric procedures.

Statistical analysis. Data were analyzed using ANOVA analysis in the GLM procedure of SAS (2000; SAS Inst. Inc., Cary, NC) and treatment means were separated using the probability of difference at $P < .05$. Additional contrasts were performed to compare the HAP1 and HAP2 diets, the HAP1 and EFP diets, and the EFP and EFP-HAP1 diets.

Results

There were no differences in pig initial and final body weights among dietary treatments (Table 2). Dry matter intake was not different among treatments and averaged 4.07 lb/d. Total fecal dry matter excreted was not different among treatments and averaged 0.467 lb/d. Dry matter digestibility was similar among treatments. Fecal pH tended to be higher ($P < 0.07$) for pigs fed the HAP1 diet compared to the EFP treatment. Total wet feces, urine and total manure excreted were not affected by dietary treatment (Table 2).

Nitrogen intake was lower ($P < 0.05$) for pigs fed the HAP2 diet compared to all other treatments (Table 3). Nitrogen digestibility was similar among corn hybrids at 82.8%, 79.5%, 83.3%, and 80.0% for the HAP1, HAP2, EFP, and EFP-HAP1 treatments, respectively. Fecal nitrogen excreted (lb/d) was not affected by dietary treatment; however, nitrogen excretion as a percent of total fecal DM was 23% lower ($P < 0.05$) for the EFP treatment compared to the EFP-HAP1 and HAP2 treatments. In contrast, urinary nitrogen expressed as g/d was 31% and 41% lower ($P < 0.05$) for the EFP-HAP1 treatment compared to the EFP and HAP1 treatments, respectively, resulting in a trend ($P < 0.10$) for lower total nitrogen excretion from pigs fed the EFP-HAP1 treatment compared to the HAP1 treatment. The greater nitrogen utilization from EFP-HAP1 fed pigs is also evident when compared to pigs fed the HAP2 corn hybrid diets. Nitrogen retained and nitrogen retained as a percentage of nitrogen absorbed was increased ($P < 0.05$) for pigs fed the EFP-HAP1 treatment compared to the HAP2 treatment. Pigs fed the EFP-HAP1 treatment also tended ($P < 0.10$) to have increased nitrogen retained as a percent of intake compared to pigs fed HAP2 diet.

Urinary ammonium nitrogen was reduced ($P < 0.05$) approximately 30% from pigs fed the EFP and EFP-HAP1 treatments compared to the HAP1 treatment (Table 3). Fecal ammonium concentrations and total ammonium excreted were not different among dietary treatments. Serum urea nitrogen was 23% lower ($P < 0.05$) for pigs fed the EFP-HAP1 corn diet compared to pigs fed the EFP diet (Table 3).

Phosphorus intake was greater ($P < 0.05$) for pigs fed the HAP1 treatment (7.35 g/d) compared to the HAP2 (5.96 g/d) and EFP-HAP1 (5.78 g/d) treatments (Table 4). Fecal phosphorus was reduced 41% ($P < 0.05$) with the EFP-HAP1 treatment as compared to the EFP treatment. When fecal phosphorus is expressed as a percentage of total fecal DM, pigs fed the EFP treatment had 44%, 34%, and 52% greater ($P < 0.05$) fecal phosphorus than the HAP1, HAP2, and EFP-HAP1 treatments, respectively. In addition, EFP-HAP1 had 28% lower ($P < 0.05$) fecal phosphorus as a percent of DM than pigs fed the HAP2 corn hybrid. Urine phosphorus (g/d) was 85%, 74%, and 57% lower for the HAP2, EFP, and EFP-HAP1 treatments, respectively, compared to the HAP1 treatment. Total phosphorus excreted was 38% greater ($P < 0.02$) for pigs fed the EFP treatment compared to the EFP-HAP1 treatment. Phosphorus digestibility was increased ($P < 0.05$) 45% and 42% for pigs fed the HAP1 and EFP-HAP1 diets, respectively, compared to pigs fed the EFP treatment. Phosphorus absorbed was increased ($P < 0.05$) 52% when the HAP1 treatment was compared to the EFP treatment, and phosphorus absorbed tended ($P < 0.07$) to be lower in pigs fed the HAP2 diet compared to pigs fed the HAP1 diet. Pigs fed the HAP1 diet had 49% greater ($P < 0.04$) phosphorus retention when compared to the EFP diet. The lower digestibility for the EFP treatment is reflected in the tendency for lower phosphorus retention as a percent of intake for the EFP diet compared to the EFP-HAP1 ($P < 0.06$) diet and compared to the HAP1 ($P < 0.08$) diet. Phosphorus retained as a percent of absorbed was approximately 7% lower ($P < 0.05$) for pigs fed the HAP1 diet compared to the HAP2 diet. Serum phosphorus concentrations were not affected by dietary treatment (Table 4).

Fecal WSP was 44% and 42 % lower ($P < 0.05$) for the HAP2 and EFP-HAP1 treatments, respectively, compared to the EFP treatment (Table 4). When reported as a percentage of fecal DM, fecal WSP was reduced ($P < 0.05$) by all other treatments compared to the EFP treatment. Total WSP excretion was reduced ($P < 0.05$) 60%, 29% and 41% when the HAP2, EFP and EFP-HAP1 diets were compared to the HAP1 diet, respectively.

Potassium excretion and digestibility were not affected by dietary treatment and are reported in Table 5.

Total fecal VFA concentrations were 23% and 26% lower ($P < 0.05$) for the EFP treatment compared to the EFP-HAP1 and HAP2 treatments, respectively (Table 6). Acetate was reduced ($P < 0.05$) for the EFP treatment compared to all other treatments, and butyrate tended ($P < 0.10$) to be lower for the EFP treatment compared to the EFP-HAP1 treatment. Pigs fed the EFP and HAP1 treatments had lower ($P < 0.05$) propionate concentration than the EFP-HAP1 treatment. Isobutyrate concentration was reduced 37% ($P < 0.05$) by the EFP diet compared to the HAP2 diet.

Discussion

Nitrogen digestibility was not affected by dietary treatment in this experiment. Although fecal nitrogen excretion as a percent of total fecal DM excretion was increased for pigs on the EFP-HAP1 treatment, the urinary excretion of nitrogen from these pigs was reduced 34% and resulted in a trend toward lower total nitrogen excretion when pigs were fed this trait-stacked corn hybrid. This may be a result of the combination of the genetic modification to reduce the phytic acid content allowing for hydrolysis of bound amino acids and the greater protein content of the corn allowing for greater nitrogen uptake by the animal. The difference in nitrogen absorption from pigs fed the HAP2 treatment compared to the HAP1 treatment is likely a result of the lower nitrogen intake for those pigs. The reduction in urinary ammonium nitrogen in pigs fed the EFP and EFP-HAP1 treatments are likely the result of the elevated protein content more ideally meeting the amino acid requirements of the pig to allow for greater protein synthesis and utilization of the amino acids.

Fecal phosphorus excretion was reduced when the EFP-HAP1 treatment was compared to the EFP treatment, indicating the increased availability of phosphorus with the high available phosphorus genetic manipulation. The greater urinary phosphorus excretion observed in the HAP1 treatment may be a result of the greater phosphorus intake from that treatment and the greater availability of phosphorus in that diet. Phosphorus digestibility was different between the two HAP varieties, which may be attributed to the difference in genetic modification between these two varieties. The greater phosphorus retention from pigs fed the HAP1 diet compared to the EFP diet is likely a result of the greater phosphorus digestibility in the HAP1 diet. Water soluble phosphorus differences between the HAP varieties are also an indication of the difference in phosphorus availability between these two genetic lines.

Potassium digestibility was not different among treatments. Potassium excreted was numerically lower for the HAP2 corn treatment than the HAP1 treatment and this is reflected in the retention values. This again may be a result of differences in the genetics of these two corn varieties.

The increased production of acetate and propionate with the EFP-HAP1 treatment compared to the EFP treatment may be a result of the difference in the availability of nutrients for utilization between these two genetic lines.

Implications

Elevated fat and protein corn contained nutrient profiles that more closely met the amino acid requirements of the pigs in this study, reducing urinary nitrogen excretion. The HAP corn varieties presented differences in nitrogen and phosphorus absorption as well as overall excretion patterns and indicated the importance of quantifying the differences in nutrient availabilities between corn hybrids. This study suggests that feeding genetically enhanced corn types to pigs can be beneficial in reducing nutrient excretion. It is important, however, to account for the increased availability of specific nutrients in the enhanced corn variety to avoid exceeding the nutrient requirement of the pigs, which encourages greater nutrient excretion.

References

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Table 1. Ingredient composition of treatment diets[a]

Ingredient, %	HAP1	HAP2	EFP	EFP-HAP1
HAP corn hybrid 1	93.34	--	--	--
HAP corn hybrid 2	--	93.34	--	--
EFP corn	--	--	93.42	--
EFP-HAP1 corn	--	--	--	93.42
Soy concentrate	5.00	5.00	5.00	5.00
Limestone	0.85	0.85	0.85	0.85
Salt	0.25	0.25	0.25	0.25
Vit. Premix[b]	0.25	0.25	0.25	0.25
TM Premix[c]	0.20	0.20	0.20	0.20
Lysine-HCl	0.11	0.11	0.03	0.03
Calculated Composition				
Crude protein, %	10.94	10.94	12.53	12.53
Calcium, %	0.35	0.35	0.35	0.35
Phosphorus, %	0.30	0.30	0.30	0.30
Available Phosphorus, %	0.17	0.17	0.04	0.17
Digestable amino acids				
Lysine, %	0.53	0.53	0.53	0.53
Threonine, %	0.40	0.40	0.48	0.48
Methionine + Cysteine, %	0.43	0.43	0.54	0.54
Tryptophan, %	0.097	0.097	0.106	0.106
Isoleucine, %	0.41	0.41	0.50	0.50
Analyzed composition				
Crude protein, %	11.03	9.54	10.37	10.77
Total Phosphorus, %	0.35	0.30	0.33	0.27
Total Potassium, %	0.52	0.54	0.55	0.53

[a]HAP1 = High available phosphorus corn hybrid 1; HAP2 = High available phosphorus corn hybrid 2; EFP = Elevated fat and protein corn; EFP-HAP1 = Elevated fat and protein, high available phosphorus corn.

[b]Vitamins per lb of diet: 2570 IU A, 275 IU D, 20 IU E, 0.9 mg Menadione, 15.9 mg B12, 3.22 mg Riboflavin, 9.98 mg Pantothenic Acid, 15 mg Niacin.

[c]Provides per lb of diet: 67 ppm Zn, 67 ppm Fe, 8.16 ppm Manganese, 6.12 ppm Cu, 0.24 ppm I, 0.14 ppm Se.

Table 2. Pig initial and ending weights and the effect of high available phosphorus corn and elevated fat and protein corn hybrids on dry matter (DM) digestibility

Diet[a]	HAP1	HAP2	EFP	EFP-HAP1	SE	Contrasts[b], P < 1	2	3
Average initial wt., lb	213	214	214	213	4.04	0.89	0.94	0.93
Average final wt., lb	219	220	220	219	3.66	0.77	0.84	0.82
Intake, lb/d as-is	4.64	4.39	4.38	4.65	0.281	0.55	0.54	0.48
Diet, % DM	91.63	89.59	90.03	89.12	--	--	--	--
DM intake, lb/d	4.26	3.93	3.94	4.14	0.253	0.40	0.42	0.56
Feces, lb/d as-is	1.26	1.20	1.16	1.35	0.187	0.85	0.72	0.46
Feces, % DM	38.40	35.83	40.64	36.81	0.021	0.41	0.47	0.20
Total feces DM excreted, lb/d	0.469	0.424	0.481	0.494	0.069	0.67	0.90	0.89
DM digestibility, %	88.46	89.06	87.97	88.04	1.66	0.81	0.84	0.97
Feces, pH	6.23[e]	6.19[de]	5.99[d]	6.02[de]	0.083	0.74	0.07	0.80
Urine, gal/d	0.850	0.797	0.826	0.771	0.162	0.83	0.92	0.80
Total manure excreted, lb/d as-is	8.33	7.86	8.05	7.78	1.40	0.82	0.90	0.89

[a] HAP1 = high available phosphorus corn hybrid 1; HAP2 = high available phosphorus corn hybrid 2; EFP = elevated fat and protein corn; EFP-HAP1 = elevated fat and protein, high available phosphorus corn.
[b] Treatment contrasts: 1 = HAP1 vs. HAP2; 2 = HAP1 vs. EFP; 3 = EFP vs. EFP-HAP1.
[de] Different superscripts within a row indicate significance at $P < 0.10$.

Table 3. The effect of high available phosphorus corn and elevated fat and protein corn hybrids on nitrogen digestibility and NH_4-N excretion

						Contrasts[g], P <		
Diet[f]	**HAP1**	**HAP2**	**EFP**	**EFP-HAP1**	**SE**	**1**	**2**	**3**
Nitrogen								
Intake, g/d[h]	37.16[a]	30.37[b]	35.59[a]	36.35[a]	1.56	0.008	0.52	0.73
Feces, g/d	6.25	6.15	6.01	7.23	1.09	0.95	0.89	0.42
Feces, % DM excreted	2.79[ab]	3.20[b]	2.47[a]	3.21[b]	0.202	0.19	0.31	0.02
Urine, g/d	17.14[a]	13.47[ab]	14.74[a]	10.05[b]	1.56	0.12	0.32	0.02
Total N excreted, g/d	23.39[e]	19.62[de]	20.75[de]	17.28[d]	2.07	0.23	0.41	0.24
N, % digested	82.80	79.47	83.26	80.05	3.18	0.48	0.93	0.47
Absorbed, g/d	30.91[a]	24.22[b]	29.58[a]	29.12[ab]	1.82	0.02	0.64	0.86
Retained, g/d	13.77[ab]	10.75[b]	14.84[ab]	19.07[a]	2.59	0.44	0.79	0.25
Retained, % intake	36.75[de]	33.76[e]	41.45[de]	52.28[d]	7.04	0.77	0.67	0.28
Retained, % absorbed	43.90[ab]	41.04[b]	49.53[ab]	65.00[a]	7.40	0.80	0.62	0.15
NH_4-N								
Feces, g/d	1.23	1.33	1.23	1.50	.204	0.73	1.00	0.34
Urine, g/d	1.86[a]	1.67[ab]	1.31[b]	1.33[b]	.172	0.48	0.05	0.96
Total NH_4-N excreted, g/d	3.08	3.00	2.54	2.82	.273	0.85	0.20	0.45
SUN, mg/dL[i]	11.93[ab]	11.96[ab]	13.39[a]	10.26[b]	.845	0.98	0.26	0.02

[ab] Differing superscripts within a row indicate significance at $P < 0.05$.
[de] Differing superscripts within a row indicate significance at $P < 0.10$.
[f] HAP1 = high available phosphorus corn hybrid 1; HAP2 = high available phosphorus corn hybrid 2; EFP = elevated fat and protein corn; EFP-HAP1 = elevated fat and protein, high available phosphorus corn.
[g] Treatment contrasts: 1 = HAP1 vs. HAP2; 2 = HAP1 vs. EFP; 3 = EFP vs. EFP-HAP1.
[h] Intakes calculated using actual feed intakes and analyzed N values.
[i] SUN = serum urea nitrogen.

Table 4. The effect of high available phosphorus corn and elevated fat and protein corn hybrids on phosphorus digestibility

						Contrasts[g], P <		
Diet[f]	**HAP1**	**HAP2**	**EFP**	**EFP-HAP1**	**SE**	**1**	**2**	**3**
Phosphorus								
Intake, g/d[h]	7.35[a]	5.96[b]	6.50[ab]	5.78[b]	0.424	0.04	0.20	0.22
Feces, g/d	3.11[ab]	3.31[ab]	4.47[a]	2.63[b]	0.536	0.80	0.11	0.02
Feces, % DM excreted	1.47[bc]	1.73[b]	2.62[a]	1.24[c]	0.133	0.21	0.001	0.0001
Urine, g/d	0.501[b]	0.074[a]	0.132[a]	0.216[a]	0.069	0.0006	0.003	0.39
Total P excreted, g/d	3.61[ab]	3.38[ab]	4.60[a]	2.84[b]	0.516	0.77	0.22	0.02
P digestibility, %	57.42[a]	43.30[ab]	31.41[b]	53.88[a]	7.62	0.22	0.04	0.05
Absorbed, g/d	4.25[a]	2.66[ab]	2.04[b]	3.13[ab]	0.565	0.07	0.02	0.18
Retained, g/d	3.74[b]	2.58[ab]	1.91[a]	2.91[ab]	0.552	0.17	0.04	0.20
Retained, % intake	50.57[e]	41.88[de]	29.17[d]	50.20[e]	7.45	0.44	0.08	0.06
Retained, % absorbed	88.24[a]	95.52[b]	92.86[ab]	93.54[ab]	2.23	0.04	0.19	0.83
WSP[i]								
Feces, g/d	0.294[ab]	0.244[b]	0.439[a]	0.254[b]	0.055	0.54	0.08	0.03
Feces, % DM excreted	0.142[b]	0.130[b]	0.196[a]	0.116[b]	0.010	0.43	0.002	0.0001
Total WSP (feces and urine), g/d	0.793[b]	0.318[c]	.565[a]	0.470[ac]	0.065	0.0001	0.03	0.28
Serum P, mg/dL	7.66	7.05	6.97	7.33	.394	0.32	0.27	0.54

[abc] Differing superscripts within a row indicate significance at P < 0.05.
[de] Differing superscripts within a row indicate significance at P < 0.10.
[f]HAP1 = high available phosphorus corn hybrid 1; HAP2 = high available phosphorus corn hybrid 2; EFP = elevated fat and protein corn; EFP-HAP1 = elevated fat and protein, high available phosphorus corn.
[g] Treatment contrasts: 1 = HAP1 vs. HAP2; 2 = HAP1 vs. EFP; 3 = EFP vs. EFP-HAP1.
[h] Intakes calculated using actual feed intakes and analyzed P values.
[i] WSP=Water soluble phosphorus.

Table 5. The effect of high available phosphorus corn and elevated fat and protein corn hybrids on potassium digestibility

						Contrasts [b], P <		
Diet[a]	**HAP1**	**HAP2**	**EFP**	**EFP-HAP1**	**SE**	**1**	**2**	**3**
Potassium								
Intake, g/d[c]	10.79	10.71	11.00	11.08	0.742	0.95	0.86	0.93
Feces, g/d	0.427	0.403	0.431	0.442	0.059	0.79	0.97	0.89
Feces, % DM excreted	0.206	0.212	0.209	0.200	0.014	0.82	0.90	0.65
Urine, g/d	4.81	3.83	4.80	4.31	0.564	0.28	0.99	0.51
Total K excreted, g/d	5.24	4.23	5.23	4.76	0.582	0.29	0.99	0.54
K, % digested	95.97	96.16	96.09	95.96	0.537	0.83	0.89	0.85
Absorbed, g/d	10.36	10.31	10.57	10.64	0.732	0.97	0.86	0.94
Retained, g/d	5.55	6.48	5.77	6.32	0.837	0.49	0.87	0.61
Retained, % intake	50.95	59.99	50.81	57.11	5.66	0.32	0.99	0.40
Retained, % absorbed	53.06	62.28	52.82	59.54	5.76	0.32	0.98	0.38

[a] HAP1 = high available phosphorus corn hybrid 1; HAP2 = high available phosphorus corn hybrid 2; EFP = elevated fat and protein corn; EFP-HAP1 = elevated fat and protein, high available phosphorus corn.
[b] Treatment contrasts: 1 = HAP1 vs. HAP2; 2 = HAP1 vs. EFP; 3 = EFP vs. EFP-HAP1.
[c] Intakes calculated using actual feed intakes and analyzed K values.

Table 6. The effect of high available phosphorus corn and elevated fat and protein corn hybrids on fecal volatile fatty acid concentration (VFA)

						Contrasts [g], P <		
Diet[f]	**HAP1**	**HAP2**	**EFP**	**EFP-HAP1**	**SE**	**1**	**2**	**3**
VFA, mmol/L								
Acetate	39.752[b]	39.492[b]	26.473[a]	38.794[b]	3.68	0.96	0.02	0.03
Propionate	17.133[a]	19.524[ab]	16.287[a]	22.845[b]	1.61	0.31	0.72	0.008
Isobutyrate	2.059[ab]	2.435[b]	1.534[a]	1.939[ab]	0.289	0.38	0.22	0.32
Butyrate	9.45[de]	11.64[de]	8.88[d]	13.89[e]	1.79	0.41	0.83	0.06
Isovalerate	2.012	2.491	1.651	1.690	0.368	0.38	0.50	0.94
Valerate	1.501	1.956	1.886	2.165	0.320	0.34	0.42	0.53
Total	71.91[ab]	77.53[b]	56.98[a]	81.33[b]	6.27	0.54	0.12	0.01

[ab]Differing superscripts within a row indicate significance at $P < 0.05$.
[de]Differing superscripts within a row indicate significance at $P < 0.10$.
[f]HAP1 = high available phosphorus corn hybrid 1; HAP2 = high available phosphorus corn hybrid 2; EFP = elevated fat and protein corn; EFP-HAP1 = elevated fat and protein, high available phosphorus corn.
[g]Treatment contrasts: 1 = HAP1 vs. HAP2; 2 = HAP1 vs. EFP; 3 = EFP vs. EFP-HAP1.