RESEARCHREPORT

ENVIRONMENT

Title: Genetically Modified Corn and Soybean Meal and Microbial Phytase as Means of Reducing Phosphorus Excretion by Swine **- NPB# 99-068**

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Abstract

Four studies were conducted with growing pigs to assess recent technologies including the use of microbial phytase in swine diets and the feeding of genetically enhanced corn and soybean meal containing reduced amounts of indigestible phytate phosphorus (P) and greater amounts of inorganic P. The genetically modified corn contained the mutant *lpa1* gene and the soybean meal was from genetically modified soybeans that were low in phytate and oligosaccharides. The phytate P content of the genetically enhanced corn and soybean meal was approximately half of that present in the near-isogenic corn and near-isogenic soybean meal.

The studies provided clear evidence that the P in low-phytate corn and low-phytate soybean meal is three to four times as bioavailable to pigs than the P in conventional corn and soybean meal, which results in lower amounts of supplemental P needed in diets. Phytase addition to the diet tended to improve growth and bone mineralization to a greater degree in diets containing normal corn than in those containing low phytate corn. Phytase added to normal corn-soybean meal diets resulted in a 35% reduction in P excretion. The combination of phytase and low-phytate corn resulted in a 51% reduction in P excretion. Feeding a combination of low-phytate corn and low-phytate soybean meal with no added inorganic P resulted in optimal performance and bone traits. In addition, pigs fed this diet excreted 53% less P in their manure, compared with pigs fed conventional corn and soybean meal. When used in combination with microbial phytase, the reduction in P excretion would be even greater. The use of these genetically enhanced feedstuffs will enhance the environmental aspects associated with application of swine manure to cropland.

Introduction

One of the major concerns in the swine industry is the excessive nitrogen (N) and phosphorus (P) excreted in pig manure. Recent estimates indicate that over 460 thousand tons of P are excreted annually by swine, enough to fertilize over half of the land used to grow corn in the Corn Belt. In swine manure, P is excessive relative to N, which means that it is often added to cropland in amounts greater than the amount used by plants. When this is the case, the excess P accumulates in soil. High-P soil can erode into surface waters (streams, rivers, and lakes) causing pollution problems. In fact, P is considered by some to be more of a potential environmental pollutant than N or other mineral elements.

Environmental legislation now limits animal production in some areas according to the amounts of N and P that are produced by the animals. These restrictions are especially important for concentrated swine operations that have a limited land base upon which to dispose of their manure. The P excreted by animals in their manure is generally the nutrient that limits production and/or expansion.

The major reason for the P problem is due to the unusually high P content of pig manure relative to that of most other animals. This is due to the fact that the P in cereal grains and oilseed meals is mainly in the form of phytic acid (or phytate), an organic complex that is not utilized by pigs due to a lack of phytase enzyme in their digestive tract. As a result, swine diets are generally supplemented with relatively large amounts of inorganic P (mono- or dicalcium phosphate) in order to meet the P needs of pigs. The large quantities of undigested phytate P coupled with the relatively large amounts of inorganic P in the diet result in excess amounts of P excreted in the manure.

Microbial phytase is now commercially available as a supplement for swine feeds. This enzyme degrades a portion of the phytate P and it allows for the feeding of diets with reduced levels of inorganic P supplementation. In turn, from 20 to 30% less P is excreted in the manure. However, microbial phytase degrades only a portion of the phytic acid in corn, and its activity diminishes when feeds are pelleted.

Recently, mutant genes have been identified that substantially reduce the amount of phytate P in corn without affecting the total P in the kernel. As a result, the inorganic P content of the kernel in more than doubled. The mutant *lpa1* gene, which blocks phytate synthesis, has recently been incorporated into hybrid corn. In initial studies with low-phytate corn at the University of Kentucky, we found that the P was three to four times more bioavailable to pigs than the P in conventional hybrid corn. This means that less supplemental P is needed in the diet to maximize growth and bone traits in pigs when this type of corn is fed; consequently, less P is excreted in the manure.

Even when low-phytate corn is fed to pigs, there is still a considerable amount of phytate P in the diet that is contributed by the soybean meal. Incorporation of phytase enzyme should further improve the utilization of P and reduce the excretion of P, but this has not yet been investigated. In addition, low-phytic acid soybeans will soon be commercially available; and, when combined with low-phytate corn, the use of this type of soybean meal may reduce P excretion even further. These new technologies could have a powerful impact on environmental issues related to P excretion.

Objectives

1. To assess the effects of phytase supplementation in corn-soybean meal diets containing normal or low-phytate corn on performance, bone traits, and P excretion of swine.

2. To determine the bioavailability of P in low-phytate soybean meal, and to assess the effects of low-phytate corn and low-phytate soybean meal in corn-soybean meal diets on performance, bone traits, and P excretion of swine.

Procedures

Objective 1 - Efficacy of phytase in diets containing normal and low-phytate corn.

Two experiments were conducted using a low-phytate corn (LP-corn) containing the mutant *lpa1* gene and a near-isogenic normal corn (N-corn). The *lpa1* mutant gene in LP-corn restricts the synthesis of phytate P in the kernel, leaving more of the P in a non-phytate (mostly inorganic) form. The corns were provided to us for research studies by Optimum Quality Grains (now DuPont Specialty Grains), Johnston, IA.

The composition of the two corn types is shown in Table 1. The LP-corn was lower in phytate P (.10 vs .20%) and higher in inorganic P (.18 vs .05%) than N- corn, but the total P concentrations in the two corns were similar (.28 vs .25%). All other components of the two corns were similar. Previous studies at our station demonstrated that approximately 75% of the P in LP-corn is bioavailable compared with approximately 20% in N-corn. This indicates that the bioavailable P (total P x percent bioavailability) was .22% in LP-corn and .06% in N-corn.

Experiment 1 was conducted to determine if supplemental phytase to corn-soybean meal diets containing LP-corn would improve the utilization of P by swine as has been shown with conventional corn-soybean meal diets. Crossbred (Hampshire x Landrace-Yorkshire) pigs initially averaging 39 lb were used in the study. Diets consisted of a low-P (.22%) dextrose-soybean meal basal diet or the basal with .16% added P from monosodium phosphate (MSP), N-corn, or LP-corn. The P sources (MSP, N-corn, LP-corn) were added at the expense of dextrose. Four additional diets were the same except that phytase (Natuphos; BASF, Mount Olive, NJ) was added to supply 600 phytase units/kg of diet. In Diet 6, the level of supplemental P was slightly less (.34 vs .38% total P) due to the anticipated beneficial effects of phytase, and in order for the bone data to be linear (an important prerequisite in determining phosphorus bioavailability). The composition of the diets is shown in Table 2.

Pigs were penned individually in 4 x 4 ft. pens in an environmentally controlled room. There were with five replications per treatment. Pigs consumed their diets from self-feeders on an ad libitum basis. At the end of 34 days (average weight, 97 lb), all pigs were killed and the femurs and 2nd and 5th metacarpals and metatarsals were collected.

Bone strength was measured with an Instron machine. The bones were then ashed in a muffle furnace. Bone strength and ash were regressed on P intake and slope-ratio procedures were used to determine the effects of corn type (N-corn vs LP-corn) and the impact of adding phytase to these corns on the bioavailability of P. Bioavailability of P is expressed relative to the MSP standard, which is considered 100% bioavailable.

Experiment 2 was conducted to determine the efficacy of supplemental phytase as a means of further reducing P excretion. Diets containing N-corn were formulated to contain .55 (adequate) or .45% (slightly deficient) total P (Table 3). Diets containing LP-corn were formulated to contain .45 (adequate) or .35% (slightly deficient) total P. The bioavailable P was .29 (adequate) or .19% (slightly deficient) in both types of diets. Two additional diets consisted of the low P diets supplemented with phytase. Diets were fed to six replicates of two pigs (41 pounds initial weight) per pen for 42 days. At the end of the study (average weight, 105 lb), all pigs were killed and bones were taken for strength and ash determinations. Excretion of P was also determined, using chromic oxide as an indigestible indicator.

Objective 2 - Assessment of normal and low-phytate corn and normal and low-phytate soybean meal

Two experiments were conducted to assess the bioavailability of P in a low-phytate, soybean meal (LP-SBM) and a near-isogenic normal soybean meal (N-SBM) and to assess N- and LP-corn in combination with N- and LP-SBM. The LP-SBM was also low in oligosaccharides (indigestible carbohydrates). The soybean meals were provided by Optimum Quality Grains (DuPont Specialty Grains), Johnston, IA.

The composition of the two soybean meals is shown in Table 1. The LP-SBM contained .77% P compared with .70% P for the N-SBM. The LP-SBM contained less phytate P (.22 vs .48%) and more inorganic P (.55 vs .22%) than the N-SBM. The LP-SBM was also lower in two of the major oligosaccharides, raffinose (.55 vs .91%) and stachyose (.53 vs 5.20%), and higher in sucrose (12.32 vs 7.22%), the carbohydrate precursor of these oligosaccharides. Other components were relatively similar for the two soybean meals.

Experiment 3 was conducted to determine the relative bioavailability of the P in LP-SBM. Pigs were fed a low P basal diet (similar to that used in Exp. 1) or the basal diet with .08 or .16% added P in which the P was supplied by MSP, N-SBM, or LP-SBM. The three sources of P (MSP, N-SBM, LP-SBM) were substituted for dextrose-cornstarch. Chromic oxide was added to all diets at the end of the study to determine P digestibility. The composition of the diets is shown in Table 4.

Each of the seven diets were fed on an ad libitum basis to five crossbred pigs individually penned in 1.5 x 4 ft. pens for 38 days. The pigs initially averaging 30 lb. At the end of the test (average weight, 88 lb), the pigs were killed and bones were collected and processed as previously described. The data were subjected to slope-ratio analysis for determination of bioavailability of P in the two soybean meals.

Experiment 4 assessed combinations of N- and LP-corn supplemented with N- and LP-SBM with three levels of inorganic P additions for growing pigs. Diets 1, 2, and 3 consisted of the combination of N-corn and N-SBM with .20, .10, or 0% added P (Table 5). The highest level of P addition was sufficient to meet the total and available P requirement (NRC, 1998) for growing pigs, while the other two levels were moderately and severely deficient. Diets 4-6 consisted of N-corn and LP-SBM with the same levels of added inorganic P as in Diets 1-3. Diets 7-9 consisted of LP-corn and LP-SBM with the same levels of supplemental P as in the other diets.

Each diet was fed on an ad libitum basis to eight crossbred pigs individually penned in 4 x 4 ft. pens in an environmentally controlled room for 36 days. The pigs averaged 48 lb and 108 lb at the beginning and end of the experiment. During the final week of the experiment, chromic oxide was added to all diets and feces were collected for determination of P digestibility and excretion. At termination, all pigs were killed and bones were collected and processed as previously described.

Results

Objective 1 - Efficacy of phytase in diets containing normal and low-phytate corn.

Experiment 1. Pigs fed LP-corn without phytase gained faster and had stronger bones than those fed N-corn without phytase (Table 6). Added phytase improved performance and bone strength to a greater degree in pigs fed N-corn than in those fed LP-corn. The bioavailability of P in the LP-corn was 3.5 times that of P in the N-corn (76 vs 19%, averaged over diets without and with phytase). The estimates of P bioavailability in the two corns was not affected by the addition of phytase suggesting that the action of phytase may have been more on the phytate in the soybean meal in the diets rather than on the phytate in the corn.

***Experiment 2*.** Performance and bone strength were reduced when the P deficient diets were fed (Table 7). Phytase addition improved performance and bone traits to levels that approached or exceeded those of pigs fed the adequate P diets. The level of P in the feces was reduced by feeding LP-corn and by including microbial phytase in the diet. Compared with pigs fed the N-corn-soybean meal diet containing adequate P (Diet 1), fecal P was reduced by 23% when phytase was included, and it was reduced by 35% when LP-corn was fed instead of N-corn. Fecal P was reduced by 51% when both phytase and LP-corn were fed in combination to pigs.

Objective 2 - Assessment of normal and low-phytate corn and normal and low-phytate soybean meal.

***Experiment 3*.** Growth rate, feed efficiency, and bone traits were improved when P was added to the diet in the form of MSP or additional soybean meal; however, the improvements were greater when LP-SBM was fed, compared with N-SBM (Table 8). More of the P from the LP-SBM was digested than that of the N-SBM. Based on slope-ratio of bone traits, the bioavailability of P in N-SBM was 19% and in LP-SBM was 49%, a 2.5-fold difference in the two soybean meals.

***Experiment 4*.** Rate and efficiency of gain was markedly decreased when the level of supplemental P was reduced in the N-corn and N-SBM conventional diet (Table 9). A slight reduction in performance and bone traits occurred when no inorganic P was included in the N-corn, LP-SBM diet, but performance was optimal when pigs were fed the combination of LP-corn and LP-SBM with no supplemental inorganic P. The P digestibility was higher in pigs fed the LP-corn, LP-SBM diets resulting in a lower concentration of P in the feces and a marked reduction in P excretion. In fact, pigs fed the genetically modified corn and genetically modified soybean meal diet with no supplemental P excreted 53% less P in their manure compared with pigs fed the diets containing conventional corn and soybean meal.

Summary and Implications

New technologies including the use of microbial phytase in swine diets and the development of corn and soybean meal with reduced amounts of indigestible phytate phosphorus (P) and greater bioavailability of P hold great promise for the swine industry. These studies provide clear evidence that the P in low-phytate corn and low-phytate soybean meal is several times more bioavailable to pigs than the P in conventional corn and soybean meal. The use of this genetically enhanced grain and oilseed meal results in less than half as much P excreted in the manure. When used in combination with microbial phytase, the reduction in P excretion would be even greater. The use of these genetically enhanced feedstuffs will greatly enhance the environment aspects associated with application of swine manure to cropland.

Table 1. Composition of Normal and Low Phytate Corn and Normal and Low Phytate, Low Oligosaccharide Dehulled Soybean Meal[a]

	Low Phytate Soybean Meal	Normal Corn	Low Phytate CornSoybean	Normal Meal
Promimate components, %				
Dry matter			95.8	95.8
Crude protein	8.50	8.50	53.6	55.3
Crude fat	2.50	2.74	.94	.57
Minerals, %				
Phytate P	.20	.10	.48	.22
Non-phytate (inorganic) P	.05	.18	.22	.55
Total P	.25	.28	.70	.77
Ca	.01	.01	.35	.36
Sucrose and oligosaccharides, %				
Sucrose			7.22	12.32
Stachyose			5.20	.53
Raffinose			.91	.55
Galactinol			.17	.00
Total oligosaccharides			6.28	1.08
Amino acids, %				
Lysine	.23	.24	3.03	3.18
Methionine	.15	.15	.80	.83
Cystine.17	.19	.79	.80	
Methionine+Cystine	.32	.33	1.59	1.63
Threonine	.28	.28	1.97	2.01
Tryptophan	.05	.05	.72	.76
Isoleucine	.29	.27	2.42	2.52
Valine	.40	.40	2.56	2.68

[a]DuPont Specialty Grains (Formerly Optimum Quality Grains), Johnston, IA.

Table 2. Composition of Diets (%) - Experiment 1

Diet:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Source of P:	**Basal**	**MSP**	**N-Corn**	**LP-Corn**	**Basal**	**MSP**	**N-Corn**	**LP-Corn**
Added P, %:	**.00**	**.16**	**.16**	**.16**	**.00**	**.12**	**.16**	**.16**
Total P, %:	**.22**	**.38**	**.38**	**.38**	**.22**	**.34**	**.38**	**.38**
Phytase (600 units/kg):	**-**	**-**	**-**	**-**	**+**	**+**	**+**	**+**
Soybean meal, dehulled	32.63	32.63	32.63	32.63	32.63	32.63	32.63	32.63
Dextrose	49.63	48.70	.07	4.87	49.55	48.74		4.80
Starch	14.00	13.73	.02	1.38	13.98	13.75		1.35
Normal corn			63.54				63.54	
Low phytate corn				57.38				57.38
Natuphos-600					.10	.10	.10	.10
Corn oil	1.00	1.50	1.00	1.00	1.00	1.50	1.00	1.00
Amino acids[a]	.20	.20	.20	.20	.20	.20	.20	.20
Monosodium phosphate		.70				.54		
Ground limestone	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
Salt, iodized	.50	.50	.50	.50	.50	.50	.50	.50
Premixes, antibiotic[b]	.46	.46	.46	.46	.46	.46	.46	.46
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis								
Crude protein, %	15.8	15.8	21.2	20.7	15.8	15.8	21.2	20.7
Lysine, %	1.00	1.00	1.15	1.15	1.00	1.00	1.15	1.15
Calcium, %	.70	.70	.70	.70	.70	.70	.70	.70
Phosphorus, %	.22	.38	.38	.38	.22	.34	.38	.38
ME, Mcal/lb	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53

[a]DL-methionine at .15% and L-threonine at .05%.
[b]Vitamins and trace minerals added to meet or exceed NRC (1998) requirements. Carbadox added at 50 g/ton.

Table 3. Composition of Diets (%) - Summary of Experiment 2

Diet:	**1**	**2**	**3**	**4**	**5**	**6**
	N-Corn			**LP-Corn**		
Total P, %:	**.55**	**.45**	**.45**	**.45**	**.35**	**.35**
Available P, %:	**.29**	**.19**	**.19**	**.29**	**.19**	**.19**
Phytase (600 units.kg):	**-**	**-**	**+**	**-**	**-**	**+**
Normal corn	76.35	76.54	76.44			
Low phytate corn				76.59	76.79	76.69
Soybean meal, dehulled	19.87	19.87	19.87	19.87	19.87	19.87
Natuphos-600			.10			.10
Lysine HCl	.19	.19	.19	.19	.19	.19
Corn oil	1.00	1.00	1.00	1.00	1.00	1.00
Dicalcium phosphate	1.20	.66	.66	.54		
Ground limestone	.64	.99	.99	1.06	1.40	1.40
Salt, iodized	.35	.35	.35	.35	.35	.35
Premixes, antibiotic	.40	.40	.40	.40	.40	.40
Chromic oxide[a]	+	+	+	+	+	+
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis						
Crude protein, %	16.2	16.2	16.2	16.2	16.2	16.2
Lysine, %	.95	.95	.95	.95	.95	.95
Calcium, %	.60	.60	.60	.60	.60	.60
Phosphorus, %	.55	.45	.45	.45	.35	.35
Available phosphorus, %	.29	.19	.19	.29	.19	.19
ME, Mcal/lb	1.53	1.53	1.53	1.53	1.53	1.53

[a]Chromic oxide added as an indigestible marker at the end of the study to determine phosphorus digestion and excretion.
[b]Vitamins and trace minerals added to meet or exceed NRC (1998) requirements. Carbadox added at 50 g/ton.

Table 4. Composition of Diets (%) - Experiment 3

Diet:	1	2	3	4	5	6	7
Source of P:	**Basal**	**MSP**		**N-SBM**		**LP-SBM**	
Added P, %:	**-**	**.08**	**.16**	**.08**	**.16**	**.08**	**.16**
Total P, %:	**.31**	**.39**	**.47**	**.39**	**.47**	**.39**	**.47**
Normal corn	48.17	48.17	48.17	48.17	48.17	48.17	48.17
Soybean meal (non-experimental)	25.60	25.60	25.60	25.60	25.60	25.60	25.60
Dextrose	17.19	16.73	16.26	8.60	.02	9.47	1.79
Starch	4.85	4.72	4.59	2.42	.01	2.67	.50
Normal soybean meal				11.43	22.86		
Low phytate soybean meal						10.26	20.51
Corn oil	1.32	1.55	1.80	1.00	.68	1.04	.74
Amino acids[a]	.33	.33	.33	.33	.33	.33	.33
Monosodium phosphate		.36	.71				
Ground limestone	1.61	1.61	1.61	1.52	1.41	1.53	1.43
Salt, iodized	.50	.50	.50	.50	.50	.50	.50
Premixes, antibiotic[b]	.43	.43	.43	.43	.43	.43	.43
Chromic oxide[c]	+	+	+	+	+	+	+
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis							
Crude protein, %	16.5	16.5	16.5	22.6	28.7	22.1	27.8
Lysine, %	1.05	1.05	1.05	1.39	1.74	1.37	1.70
Calcium %	.70	.70	.70	.70	.70	.70	.70
Phosphorus, %	.31	.39	.47	.39	.47	.39	.47
ME, Mcal/kg	1.54	1.54	1.54	1.54	1.54	1.54	1.54

[a]DL-methionine at .15% and L-threonine at .05%.
[b]Vitamins and trace minerals added to meet or exceed NRC (1998) requirements. Carbadox added at 50 g/ton.
[c]Chromic oxide added an an indigestible marker at the end of the study to determine phosphorus digestibility

Table 5. Composition of Diets (%) - Experiment 4

Diet	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Corn:		**Normal**			**Normal**				**Low Phytate**
Soybean meal:		**Normal**			**Low Phytate**			**Low**	
Phytate									
Added P, %:	**.20**	**.10**	**.00**	**.20**	**.10**	**.00**	**.20**	**.10**	**.00**
Total P, %:	**.55**	**.45**	**.35**	**.57**	**.47**	**.37**	**.59**	**.49**	**.39**
Nonphytate P, %	**.29**	**.19**	**.09**	**.37**	**.27**	**.17**	**.46**	**.36**	**.26**
Bioavailable P, %:	**.27**	**.17**	**.07**	**.33**	**.23**	**.13**	**.44**	**.34**	**.24**
Normal corn	72.14	72.23	72.53	72.19	72.38	72.58			
Low phytate corn							72.19	72.38	72.58
Normal soybean meal	24.20	24.20	24.20						
Low phytate soybean meal				24.20	24.20	24.20	24.20	24.20	24.20
Lysine HCl	.05	.05	.05						
Corn oil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dicalcium phosphate	1.05	.54		1.08	.54		1.08	.54	
Ground limestone	.78	1.13	1.47	.78	1.13	1.47	.78	1.13	1.47
Salt, iodized	.35	.35	.35	.35	.35	.35	.35	.35	.35
Premixes, antibiotic[a]	.40	.40	.40	.40	.40	.40	.40	.40	.40
Chromic oxide[b]	+	+	+	+	+	+	+	+	+
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis									
Crude protein, %	19.1	19.1	19.1	19.3	19.3	19.3	19.3	19.3	19.3
Lysine, %	.95	.95	.95	.95	.95	.95	.95	.95	.95
Calcium, %	.65	.65	.65	.65	.65	.65	.65	.65	.65
Phosphorus, %	.55	.45	.35	.57	.47	.37	.59	.49	.39
Available P, %	.27	.17	.07	.33	.23	.13	.44	.34	.24
ME, Mcal/kg	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53

[a]Vitamins and trace minerals added to meet or exceed NRC (1998) requirements. Carbadox added at 50 g/ton.

[b]Chromic oxide added an an indigestible marker at the end of the study to determine phosphorus digestibility and excretion.

Table 6. Summary of Experiment 1[a]

Diet:	1	2	3	4	5	6	7	8	
Source of P:	**Basal**	**MSP**	**N-Corn**	**LP-Corn**	**Basal**	**MSP**	**N-Corn**	**LP-Corn**	
Added P, %:	**.00**	**.16**	**.16**	**.16**	**.00**	**.12**	**.16**	**.16**	
Total P, %:	**.22**	**.38**	**.38**	**.38**	**.22**	**.34**	**.38**	**.38**	
Phytase (600 units/kg):	**-**	**-**	**-**	**-**	**+**	**+**	**+**	**+**	**CV**
Performance data									
Daily gain, lb[cefg]	1.43	1.94	1.56	1.85	1.70	1.87	1.72	1.84	10.1
Daily feed, lb[c]	3.33	4.05	3.28	3.58	3.62	4.03	3.51	3.57	9.8
Feed:gain[cde]	2.34	2.08	2.12	1.94	2.15	2.16	2.04	1.95	7.2
Bone strength and ash									
Femur strength, kg[cefgi]	99	234	120	209	147	241	176	230	18.6
MM[b] strength, kg[cefghi]	30	68	36	54	47	71	51	67	13.2
Mean relative strength	100	233	121	197	154	241	174	228	
MC[b] ash, %[cefgi]	41.4	49.2	43.0	47.7	46.1	49.1	45.8	48.6	3.8
MC[b] ash, g[cefghi]	1.81	3.04	2.07	2.61	2.33	3.16	2.42	3.04	8.9
Bioavailability of P, %[gi]		100	22	79		100	16	73	39.4

[a]Five individually-penned pigs per treatment, 39 to 97 lb body weight; 34-day test. MSP is monosodium phosphate, N-corn is normal corn, and LP-corn is low phytate corn.
[b]MM=average of the third and fourth metacarpal and metatarsal; MC=metacarpal.
[c]Diet 1 vs 2 (*P*<.05).
[d]Diet 1 vs 3 (*P*<.05).
[e]Diet 1 vs 4 (*P*<.05).
[f]Diet 1 vs 5 (*P*<.05).
[g]Diet 3 vs 4 (*P*<.05).
[h]Diet 4 vs 8 (*P*<.05).
[i]Diet 7 vs 8 (*P*<.05).

Table 7. Summary of Experiment 2[a]

Diet:	1	2	3	4	5	6	
	N-Corn			LP-Corn			
Total P, %:	**.55**	**.45**	**.45**	**.45**	**.35**	**.35**	
Available P, %[bc]:	**.29**	**.19**	**.19**	**.29**	**.19**	**.19**	
Phytase (600 units/kg):	**-**	**-**	**+**	**-**	**-**	**+**	**CV**
Performance data							
Daily gain, lb[deh]	1.78	1.52	1.54	1.79	1.62	1.84	4.6
Daily feed, lb[h]	3.67	3.69	3.49	3.67	3.55	3.93	6.2
Feed/gain[fg]	2.06	2.43	2.28	2.05	2.19	2.15	4.8
Bone strength							
Femur, kg[efgh]	272	231	265	282	232	283	8.3
Metatarsal-metacarpal, kg[efg]	73	61	66	73	58	73	8.1
Mean relative strength	100	84	94	102	82	102	
Bone ash							
Metacarpal, g[gh]	3.27	3.05	3.23	3.51	3.00	3.72	7.0
Metacarpal, %[dh]	52.8	49.8	53.0	52.3	50.6	53.6	4.5
Fecal phosphorus							
P concentration in feces							
% of dry matter[degh]	2.79	2.31	2.18	1.92	1.57	1.14	9.7
P excreted, g/d[dh]	6.80	5.95	5.24	4.43	3.75	3.34	11.4
Reduction in P excretion, %	--	13	**23**	**35**	45	**51**	

[a]Six pens of two pigs per pen per treatment, 41 to 105 lb body weight, 42-day test.
[b]Diets 2, 3, 5, and 6 had no supplemental P.
[c]Based on the following bioavailabiliities of P: normal corn, 20%; low-phytate corn, 75%; soybean meal, 25%, dicalcium phosphate, 100%.
[d]Diets 1, 2, 3 vs 4, 5, 6 (P<.05).
[e]Diet 1 vs 2, 3 (P<.05).
[f]Diet 2 vs 3 (P<.05).
[g]Diet 4 vs 5, 6 (P<.05).
[h]Diet 5 vs 6 (P<.05).

Table 8. Summary of Experiment 3[a]

Diet:	1	2	3	4	5	6	7	
Source of P:	**Basal**	**MSP**		**N-SBM**		**LP-SBM**		
Added P, %:	**-**	**.08**	**.16**	**.08**	**.16**	**.08**	**.16**	
Total P, %:	**.31**	**.39**	**.47**	**.39**	**.47**	**.39**	**.47**	**CV**
Performance data								
Daily gain, lb[defgij]	1.25	1.70	1.88	1.40	1.37	1.58	1.62	6.9
Daily feed, lb[def]	2.85	3.27	3.56	2.63	2.44	3.02	2.75	11.2
Feed:gain[fhi]	2.28	1.92	1.90	1.89	1.78	1.91	1.71	7.9
Bone strength								
Femur, kg[defi]	67	165	240	78	91	110	138	19.4
MM[b], kg[defi]	19	30	44	20	20	25	25	15.7
Mean relative strength	100	202	297	112	122	148	167	
Bone ash								
Metacarpal, g[defhij]	1.40	2.00	2.58	1.63	1.61	1.81	1.95	6.4
Metacarpal, %[defgi]	44.3	49.3	51.4	44.4	44.4	46.7	49.0	2.6
Phosphorus bioavailability, %[ce]			100		19		49	19.6
Phosphorus digested								
Percent of intake[defgi]	17	34	39	23	19	24	28	20.7
Absolute, g/d[defi]	.70	1.99	2.91	1.06	.98	1.25	1.65	20.9

[a]Five individually penned pig per treatment, 30 to 88 lb body weight, 38-day test. N-SBM is normal soybean meal, LP-SBM is low-oligosaccharide, low phytate soybean meal.

[b]Average of the third and fourth metacarpal and metatarsal.

[c]Based on slope-ratio analysis. Mean of femur bone strength, MM bone strength, and metacarpal ash in grams regressed on grams of added P intake with the basal included in each regression. The bioavailability of P for these three traits were, respectively: N-SBM: 20, 8, and 28%; LP-SBM: 54, 31, and 62%.

[d]Monosodium phosphate vs soybean meal (*P*<.05).

[e]Normal vs low phytate soybean meal (*P*<.05).

[f]Linear effect of P within Diets 1, 2, and 3 (*P*<.05).

[g]Quadratic effect of P within Diets 1, 2, and 3 (*P*<.05).

[h]Linear effect of P within Diets 1, 4, and 5 (*P*<.05).

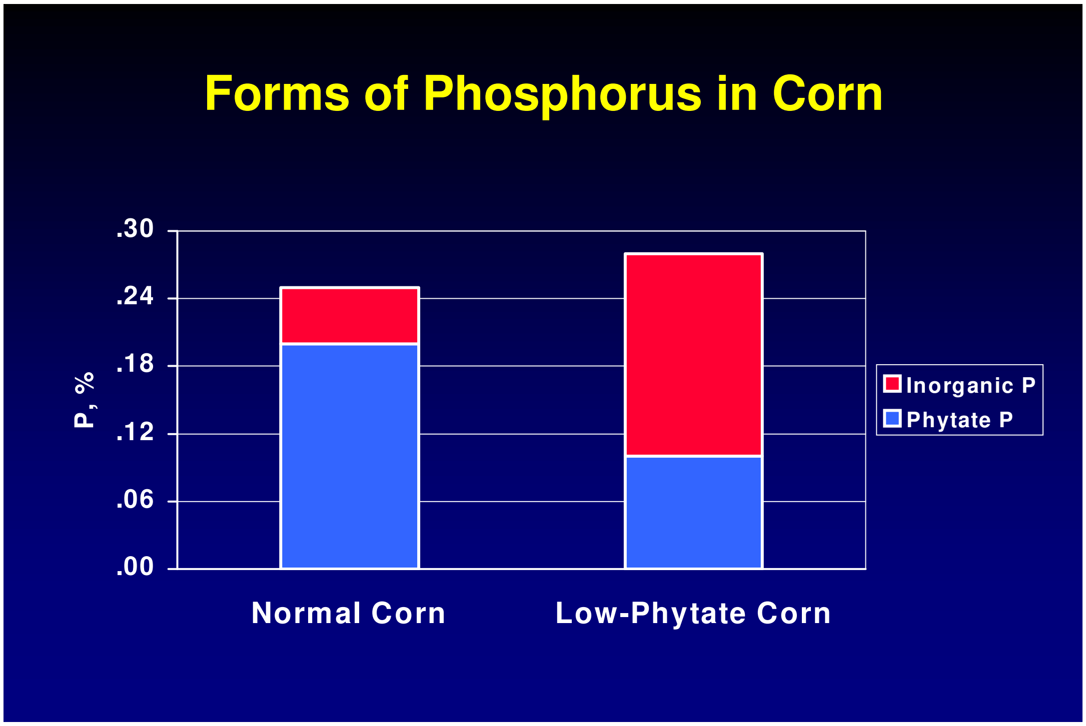
[i]Linear effect of P within Diets 1, 6, and 7 (*P*<.05).

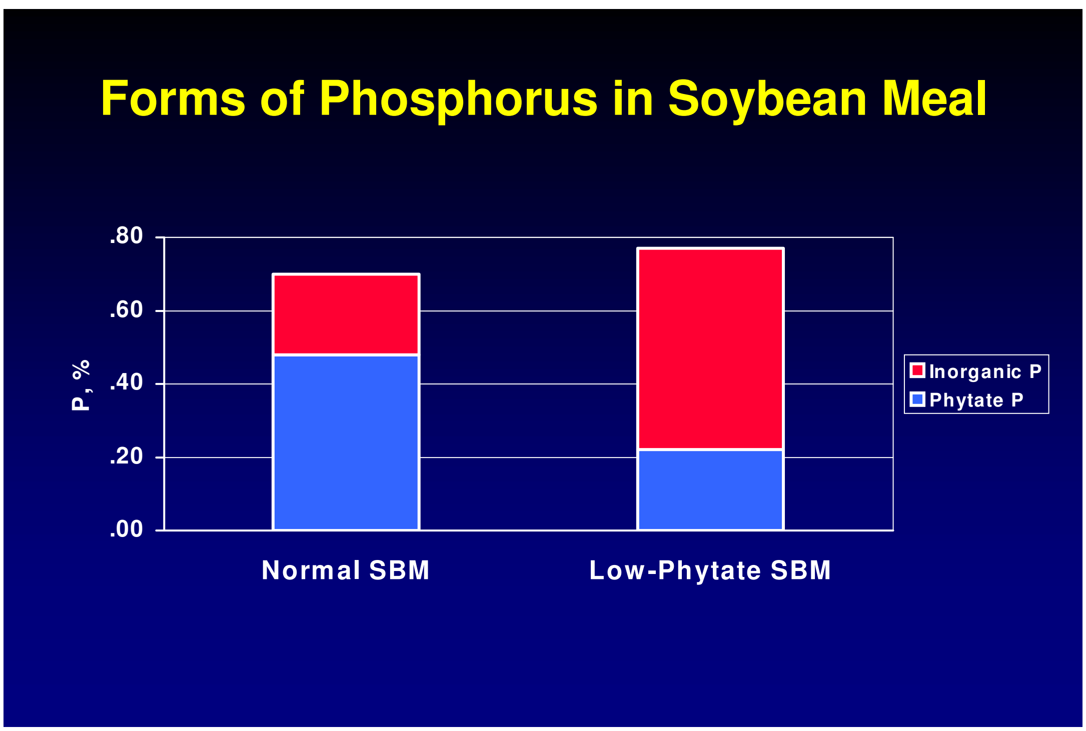
[j]Quadratic effect of P within Diets 1, 6, and 7 (*P*<.05).

Table 9. Summary of Experiment 4[a]

Diet:	1	2	3	4	5	6	7	8	9	
Corn:	Normal			Normal			Low Phytate			
Soybean meal:	Normal			Low Phytate			Low Phytate			
Added P, %:	.20	.10	.00	.20	.10	.00	.20	.10	.00	
Total P, %:	.55	.45	.35	.57	.47	.37	.59	.49	.39	
Nonphytate P, %	.29	.19	.09	.37	.27	.17	.46	.36	.26	
Bioavailable P, %:	.27	.17	.07	.33	.23	.13	.44	.34	.24	CV
Performance data										
Daily gain, lb[ce]	1.76	1.66	1.38	1.73	1.69	1.61	1.77	1.76	1.74	8.8
Daily feed, lb	3.92	3.80	3.64	3.74	3.82	3.67	3.99	3.81	3.82	11.0
Feed:gain[ce]	2.22	2.30	2.62	2.16	2.26	2.30	2.24	2.16	2.19	6.4
Bone strength and ash										
Femur strength kg[cdefg]	292	219	157	268	266	187	313	305	292	14.8
MM[b] strength kg[cdefg]	83	61	42	76	75	58	74	84	80	12.6
Mean relative strength	100	74	52	92	90	67	98	102	98	
MC[b] ash, g[cdef]	3.72	3.02	2.49	3.35	3.26	2.85	3.42	3.58	3.41	8.9
MC[b] ash, %[cdeg]	56.5	54.2	51.7	56.3	56.0	53.6	56.5	56.9	56.2	1.5
Digested phosphorus										
Percent of intake[cdef]	29	20	8	38	31	29	52	53	50	23.0
Absolute, g/d[cdefh]	2.79	1.60	.52	3.68	2.54	1.85	5.57	4.48	3.35	24.4
Fecal phosphorus										
P concentration in feces										
% of dry matter[cdefh]	2.54	2.49	2.24	2.57	2.38	2.07	1.82	1.59	1.34	12.5
P excreted, g/d[cdefh]	7.00	6.15	5.34	5.99	5.62	4.32	5.10	4.00	3.34	17.1
Reduction in P excretion, %[i]		12	24	14	20	38	27	43	**53**	

[a]Eight individually-penned pig per treatment, 48 to 108 lb body weight, 36-day test. N-SBM is normal soybean meal, LP-SBM is low-oligosaccharide, low phytate soybean meal.
[b]MM=average of the third and fourth metacarpal and metatarsal; MC=metacarpal.
[c]N-SBM vs LP-SBM diets (Diets 1-3 vs 4-9) (P<.05).
[d]Within LP-SBM diets, N-corn vs LP-corn (Diets 4-6 vs 7-9)(P<.05).
[e]Linear effect of P within N-corn, N-SBM diets (Diets 1-3) (P<.05).
[f]Linear effect of P within N-corn, LP-SBM diets (Diets 4-6) (P<.05).
[g]Quadratic effect of P within N-corn, LP-SBM diets (Diets 4-6) (P<.05).
[h]Linear effect of P within LP-corn, LP-SBM diets (Diets 7-9) (P<.05).
[i]Percent reduction from the positive control diet (Diet 1), which approximates the P requirement (NRC, 1998).


Forms of Phosphorus in Corn
.30
.24
.18
.12
.06
.00
P, %
Inorganic P
Phytate P
Normal Corn
Low-Phytate Corn


Forms of Phosphorus in Soybean Meal
.80
.60
.40
.20
.00
P, %
Inorganic P
Phytate P
Normal SBM
Low-Phytate SBM