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Bioavailability of Phosphorus in Meat and Bone Meal for Swine

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Calcium and phosphorus are the most abundant mineral elements in the body. Aside from protein and amino acids these nutrients become the next most referenced in compounding diets and evaluating ingredients. Both Ca and P are classified as macrominerals that are required in the diets at concentrations that exceed 100 ppm. Throughout life Ca and P are continuously deposited and reabsorbed from bone. Their accumulation is interdependent and one element will not accumulate without the other. Thus animal diets are formulated on specific Ca:P ratios.

Cereal grains are essentially devoid of Ca and although relatively abundant in total P the form is not available to nonruminant animals. Oilseed sourced proteins are similarly extremely poor sources of Ca and P. It is necessary to provide both Ca and P from mineral sources or feed ingredients with available sources to meet nutrient requirements. Based on total ingredient costs, P is the most expensive mineral added to swine diets. Animal byproduct ingredients namely meat and bone meal historically have provided excellent and inexpensive sources of both Ca and P nutrients. Dicalcium and monocalcium phosphate and defluorinated rock phosphate has become a primary source of these inorganic elements. These sources vary in bioavailability but the calcium phosphates are considered to be highly available. The phosphorus in defluorinated rock phosphate is generally less available and creates concern for its total fluorine content.

The relatively recent availability of exogenous phytase has made it possible to utilize a higher portion of the phytic phosphorus in plant sources. The inclusion of microbial phytase which releases some of the bound phosphorus does reduce the amount of inorganic phosphorus that must be added to meet the animals requirement as well as reducing the excretion of unavailable sources. The magnitude of the response to microbial phytase has been shown to be influenced by a number of factors including source, source of P, dietary level, amount of phytase added, its distribution and stability within the feed and the ratio of C to P. Thus the use of phytase in carefully controlled university animal feeding studies as well as under practical field use conditions have shown mixed results.

Similarly a controversy among environmental researchers exists relative to the total amount of soluble P excreted in manure when comparing phytase-containing diets to that of inorganic sources. Research has demonstrated that total P is reduced in the manure of animals fed phytase added to the diet but results in a higher level of soluble P in the manure. The allegation is that soluble P results in substantially more P in runoff water when manure is applied to the soil and actually producing more harm to the ecosystem.

Calcium and phosphorus nutrient levels are most important in formulating animal diets. Excesses and deficiencies as well as an imbalance between the two nutrients create inefficiencies and health concerns. The following research provides current documentation that meat and bone meal contains highly available sources of phosphorus as well as calcium and protein for growing-finishing swine. Dr. Cromwell has been a leader in defining the nutrient requirements for swine during his career as a most highly respected researcher and teacher.

FPRF Comments by Gary G. Pearl, D.V.M.

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Bioavailability of phosphorus in meat and bone meal for swine[1,2]

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ABSTRACT: Meat and bone meal (MBM), when supplemented with tryptophan, is an excellent protein source for pigs. It is also a rich source of Ca and P, but some research has suggested that the bioavailability of P is variable. Experiment 1 further examined the bioavailability of P in MBM. The MBM was obtained directly from a plant and was processed to pass through a 10-mesh screen. It contained 50.7% CP, 2.26% lysine, 10.0% Ca, and 5.0% P (air-dry basis). Individually penned pigs ($n = 35$; 17 kg initial BW) were fed (ad libitum basis) a low-P, corn–soybean meal–basal diet (0.95% lysine, 0.70% Ca, 0.34% P; as-fed basis) or the basal with graded levels of added P (0.067, 0.133, 0.200%) from monosodium phosphate (MSP) or MBM for 40 d. The Ca level was 0.70% in all diets. Diets were fortified with salt, vitamins, and trace minerals. At termination, the third and fourth metacarpals and metatarsals and femurs were removed from all pigs. Growth rate and feed:gain improved linearly ($P < 0.01$) with P addition, regardless of source, whereas ADFI was unaffected ($P = 0.20$). Bone strength and ash increased linearly ($P < 0.01$) with increasing level of P from either source. The main effect of P source (MSP vs. MBM) was not significant, except for the greater femur strength ($P < 0.05$) in the pigs fed the MSP-supplemented diets. Femur and metacarpal/metatarsal strength and metacarpals ash (grams) were regressed on grams of added P consumed for each P source, with the basal included in both regressions. Based on slope ratios (MSP considered as 100%), the relative bioavailability of P in MBM averaged 87% when the regression lines were forced through a common intercept and 95% when unforced. In Exp. 2, 100 pigs were fed fortified corn-soybean meal or corn–soybean meal–MBM diets from 45 to 110 kg BW to evaluate MBM as the sole source of supplemental P. The MBM (54% CP, 2.3% lysine, 9.2% Ca, 4.4% P; air-dry basis) was substituted for corn and soybean meal on a lysine basis, and crystalline lysine was added to all diets at 0.15%. Tryptophan was included in diets containing MBM. Treatments were arranged in a 2 × 2 factorial with P source (dicalcium phosphate or MBM) and P level as the two factors. The two levels of P and Ca were at the NRC requirement or the NRC level plus 0.10% additional P and Ca. Performance, carcass traits, and bone strength were not affected by source of P and Ca, but bone strength was greater ($P < 0.01$) at the higher P and Ca level. These results indicate that the bioavailability of P in MBM, relative to that in MSP, is high (approximately 91%) for growing pigs, and MBM can serve as the sole source of supplemental P and Ca for finishing pigs.

Key Words: Meat and Bone Meal, Phosphorus, Pigs

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Introduction

Rendered animal by-products, such as meat and bone meal (MBM), contain relatively high levels of protein, Ca, P, and B vitamins and are commonly included in swine and poultry diets. Early research with pigs indicated that growth performance was decreased with increasing levels of MBM in diets (Peo and Hudman, 1962; Evans and Leibholz, 1979); however, subsequent studies showed that the decrease in performance associated with inclusion of high levels of MBM could be prevented with the inclusion of 0.03% tryptophan for every 10% addition of MBM to the diet (Cromwell et al., 1991).

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Table 2. Composition of diets (as-fed basis, %) in Exp. 1

	Basal	MSP[a]			MBM[a]		
Item Added P, %:	0.00	0.067	0.133	0.200	0.067	0.133	0.200
Ground corn	70.38	70.38	70.37	70.39	70.38	70.38	70.38
Dehulled soybean meal	21.99	21.99	21.99	21.99	21.99	21.99	21.99
Cornstarch	4.00	3.45	2.89	2.32	2.78	1.54	0.25
Corn oil	1.00	1.25	1.52	1.78	1.22	1.45	1.71
Monosodium phosphate	—	0.297	0.595	0.893	—	—	—
Meat and bone meal	—	—	—	—	1.33	2.67	4.00
Ground calcitic limestone	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Calcium carbonate[b]	0.98	0.98	0.98	0.98	0.64	0.31	—
Iodized salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin-trace mineral premix[c]	0.17	0.17	0.17	0.17	0.17	0.17	0.17
L-Lysine·HCl	0.13	0.13	0.13	0.13	0.13	0.13	0.13
L-Tryptophan	—	—	—	—	0.005	0.010	0.015
Antibiotic[d]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Calculated analysis[e]							
CP, %	16.4	16.4	16.4	16.4	17.1	17.8	18.4
Lysine, %	0.95	0.95	0.95	0.95	0.98	1.02	1.05
Ca, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70
P, %	0.34	0.40	0.47	0.54	0.41	0.47	0.54
ME, Mcal/kg	3.365	3.365	3.365	3.365	3.365	3.365	3.365

[a] MSP = monosodium phosphate; MBM = meat and bone meal.

[b] Technical grade.

[c] Provided the following per kilogram of diet: vitamin A, 6,600 IU (2,204 μg of retinyl acetate); vitamin D_3, 880 IU (22.0 μg of cholecalciferol); vitamin E, 22 IU (22 mg of DL-α-tocopherol acetate); vitamin K (as menadione sodium bisulfite complex), 6.4 mg; riboflavin, 8.8 mg; pantothenic acid, 22 mg; niacin, 44 mg; vitamin B_{12}, 0.022 mg; D-biotin, 0.22 mg; folic acid, 1.1 mg; Zn, 135 mg (ZnO); Fe, 135 mg ($FeSO_4 \cdot H_2O$); Mn, 45 mg (MnO); Cu, 13 mg ($CuSO_4 \cdot 5H_2O$); I, 1.5 mg (CaI_2O_6); and Se, 0.3 mg ($NaSeO_3$).

[d] Mecadox (Phibro Animal Health, Fairfield, NJ) provided 55 mg of carbadox/kg of diet.

[e] Based on referenced analysis of corn and soybean meal (NRC, 1998) and determined analysis of meat and bone meal.

Breaking strength is defined as the peak amount of force, before fracture, applied by a wedge mounted on a pressure-sensitive compression cell at the center of the fresh bone when placed horizontally on two supports spaced 7.0 cm (femurs) or 3.2 cm (metacarpals and metatarsals) apart. The metacarpals were cut in half to remove the marrow. After drying in an oven, they were wrapped in cheesecloth and extracted with fresh petroleum ether three times at 24-h intervals. They were then air-dried at room temperature under a chemical hood for 24 h, dried in an oven overnight, and then ashed in a muffle furnace at 600°C for at least 6 h. Ash weight was recorded and the ash percent in dry, fat-free bone was determined.

Bone strength and ash weight were regressed on the daily quantity of added P consumed by pigs fed the two sources of P. Results from pigs fed the basal diet were used to calculate the regression slope for each P source. A comparison of the two slopes gives the bioavailability of the P in MBM relative to the bioavailability of P in MSP (given a value of 100%). The P bioavailabilities based on the femurs, mean of metacarpals-metatarsals, and ash content in grams of the metacarpals were then averaged to give an overall estimate of the relative bioavailability of P in the MBM. The relative bioavailabilities were calculated both with and without a forced y-intercept.

Experiment 2

One hundred crossbred (Hampshire × Yorkshire-Landrace) pigs initially averaging 45.1 kg BW were used in the study. They were grouped by gender and initial weight and allotted at random to five replications of four dietary treatments from outcome groups of initial weight within gender. Each pen consisted of five pigs with equal gender ratio within replication (i.e., two barrows and three gilts or three barrows and two gilts per pen).

Pigs were housed in an open-front building in 1.2 m × 6.7 m, concrete-floored pens, with approximately half of the pen covered. Pigs were allowed to consume their diets (meal form) and water on an ad libitum basis from wooden, two-hole self-feeders and automatic watering fountains. The pens were cleaned two or three times per week. The pigs were individually weighed, and feed consumption was determined on a pen basis at weekly or biweekly intervals during the experiment. The study was conducted during the summer.

Four dietary treatments, factorially arranged, were fed during two finishing phases (Phase 1 = 45 to 78 kg BW; Phase II = 78 to 110 kg BW; Table 3). Two fortified corn-soybean meal diets used feed-grade dicalcium phosphate (DCP) as the source of supplemental P. Two additional diets used MBM as the source of supplemenfor crude fat based on ether extraction, and for ash in a muffle furnace. After wet ashing, Ca was determined by atomic absorption chromatography, and P was determined by a gravimetric procedure. All methods were based on standard procedures (AOAC, 1995). Amino acids were analyzed with ion exchange chromatography after acid hydrolysis. Methionine and cystine were oxidized to methionine sulfone and cysteic acid by treatment with performic acid before hydrolysis. Tryptophan was analyzed after alkaline hydrolysis. Calcium and AA assays were conducted at the University of Missouri Experiment Station Chemical Laboratories (Columbia) and the other assays were conducted at the University of Kentucky.

Statistical Analyses

The data were analyzed as a randomized complete block design (Steel and Torrie, 1980) using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC). The statistical model included the effects of replication, diet, and replication × diet (error). Preplanned treatment comparisons in Exp. 1 were as follows: basal vs. mean of other treatments, linear and nonlinear effects of P level within MSP and MBM (with the basal diet included in both regressions), and the mean of MSP vs. the mean of MBM. In Exp. 2, the main effects of P source and P level, and the interaction were tested. In all instances, pen was considered the experimental unit. Unless stated otherwise, an alpha level of 0.05 was considered statistically significant.

Results

Composition of Meat and Bone Meals

The composition of the MBM is shown in Table 1. The protein and fat contents were higher in the MBM used in Exp. 2 compared with that used in Exp. 1, as were all the essential AA except histidine. Ash, Ca, and P concentrations were slightly higher in the MBM used in Exp. 1 than in Exp. 2. The variation in composition of the two MBM is common to this ingredient (Knabe, 1995).

Most of the nutrients in the two MBM sources approximated the levels listed by the NRC (1998) for MBM. Crude fat tended to be slightly less than the 10.9% listed by NRC (1998), but CP, Ca, and P were close to the levels listed by NRC (1998). The values listed by NRC (1998) are slightly higher for lysine (2.51%) and histidine (0.91%), but were lower for arginine, isoleucine, cystine, phenylalanine, and valine compared with the MBM sources (Table 1).

Experiment 1

Body weight gain, efficiency of feed utilization, and all the bone traits were improved linearly ($P < 0.01$) when P was added to the basal diet, but feed intake was not significantly affected by additional P (Table 4). The responses were similar for the two P sources, except for femur strength. For that trait, MSP inclusion resulted in stronger bones ($P < 0.05$) than MBM inclusion.

Slope ratio analysis of the femur and metatarsal-metacarpal strength and metacarpal ash weight data were used to compute P bioavailability estimates (Table 5). Regression of treatment means for the two sources of P on daily supplemental P intake resulted in good fits with r^2 values averaging 0.994 for femur strength, 0.978 for metacarpal-metatarsal strength, and 0.952 for metacarpal ash in grams. Because the basal diet was used to calculate the slopes of the two regression lines when regressed on added P intake, both slopes, in theory, should intersect zero on the y-axis. Forcing the y-intercept resulted in bioavailability estimates of 80 to 95%, with an average of 87%. When the regressions were unforced, the bioavailability estimates for P were slightly higher, from 83 to 106%, with an overall average of 95%. An average of these estimates obtained from these two procedures gives an overall average of 91% for the relative bioavailability of P in MBM. In most instances, the r^2 values were slightly higher when the y-intercept was unforced vs. forced.

Experiment 2

Growth rate, daily feed intake, and feed:gain of finishing pigs were not affected by the source of supplemental P nor by the level of added P (Table 6). Feeding the MBM- vs. the DCP-supplemented diet during the second finishing phase seemed to increase growth rate, but the difference was not significant. There was no evidence of a P source × level interaction for any of the other performance traits.

Scanned carcass backfat depth, LM depth or area, and estimated carcass lean were not affected by source or level of added P (Table 6), and there was no evidence of any interaction between source and level of added P. The calculated carcass lean gain (mean = 333 g/d) is equivalent to 316 g of carcass fat-free lean gain, assuming the former value includes 5% fat in the lean. The fat-free lean gain of the pigs in this study was intermediate to pigs with an average (300 g/d) to high-medium (325 g/d) lean growth rate, as defined by NRC (1998).

Metacarpal breaking strength was similar for the two sources of added P (Table 6). Bone strength was increased ($P < 0.01$) by feeding the higher level of P during the two finishing stages, and this increase occurred with both the DCP- and MBM-supplemented diets.

Discussion

Meat and bone meal and meat meal have been widely used in animal feeds for many years (Franco and Swanson, 1996). According to AAFCO (2000), MBM is described as the rendered product from mammal tissues, including bone, exclusive of any added blood, hair, hoof, horn, hide trimmings, manure, stomach, and ruminal

Table 6. Dicalcium phosphate vs. meat and bone meal as sources of P at two levels on performance, carcass traits, and bone strength of finishing pigs, Exp. 2[a]

	DCP[b]		MBM[b]		
Phase I P, %:	0.45	0.40	0.45	0.40	
Item Phase II P, %:	0.55	0.50	0.55	0.50	SE
Finishing phase I (45 to 78 kg)					
ADG, kg	0.82	0.85	0.84	0.85	0.03
ADFI, kg (as-fed basis)	2.35	2.43	2.41	2.39	0.07
Feed:gain	2.87	2.86	2.87	2.82	0.05
Finishing phase II (78 to 110 kg)					
ADG, kg	0.89	0.91	0.94	0.95	0.03
ADFI, kg (as-fed basis)	2.95	3.18	3.03	3.08	0.07
Feed:gain	3.32	3.49	3.23	3.24	0.08
Overall (45 to 110 kg)					
ADG, kg	0.85	0.88	0.89	0.89	0.02
ADFI, kg (as-fed basis)	2.63	2.77	2.70	2.71	0.06
Feed:gain	3.10	3.15	3.05	3.03	0.04
Scanned carcass traits[c]					
Backfat depth, mm	21.1	21.2	21.4	21.7	0.7
LM depth, mm	61.7	58.0	59.0	59.0	1.0
LM area, cm^2	40.8	39.0	39.8	39.7	0.5
Estimated lean, %	53.1	52.6	52.6	52.4	0.45
Lean gain, g/d	330	337	333	332	12
Metacarpal strength, kg[d]	178	194	182	194	5

[a] Each diet was fed to 25 finishing pigs in five replications of five pigs per pen during a 77-d experimental period. Average initial and final BW were 45.1 and 109.7 kg, respectively.

[b] DCP = dicalcium phosphate; MBM = meat and bone meal.

[c] Pigs were scanned at an average weight of 105 kg (68 d on test). Fat depth and LM depth were adjusted to a common weight of 105 kg BW.

[d] Main effect of P level, $P < 0.01$.

fed diets supplemented with DCP in diets calculated to meet NRC requirements. Even when MBM was included in the diets to provide 0.1 percentage point additional P, performance was not decreased compared with feeding corn-soybean meal diets. The decrease in growth performance from moderate to high levels of MBM inclusion reported by Peo and Hudman (1962) and Evans and Leibholz (1979) was apparently due to deficient levels of trypophan and the low bioavailability of tryptophan (Knabe et al., 1989) in MBM. The studies by Cromwell et al. (1991) clearly demonstrated that the decreased performance associated with inclusion of high levels of MBM could be prevented with the inclusion of 3 g of tryptophan/kg of MBM.

Implications

The results of this study indicate that for swine, the bioavailability of phosphorus in meat and bone meal is approximately 91% relative to that in monosodium phosphate. Meat and bone meal, when supplemented with tryptophan, can supply all the supplemental phosphorus and nearly all the supplemental calcium in corn-soybean meal diets for finishing pigs without negatively affecting growth performance or bone integrity.

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