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Relative bioavailability of phosphorus in inorganic phosphorus sources fed to growing pigs

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ABSTRACT: The relative bioavailability of P in 5 sources of inorganic P was determined using growing pigs. The 5 sources of inorganic P were dicalcium phosphate (DCP), monocalcium phosphate (MCP) containing 50% MCP (MCP50), MCP containing 70% MCP (MCP70), MCP containing 100% MCP (MCP100), and monosodium phosphate (MSP). A total of 11 diets were formulated. The basal diet was formulated to contain 0.10% P, and 10 additional diets were formulated by adding 0.07 or 0.14% P from each of the 5 P sources to the basal diet. Growing pigs (n = 44; initial BW: 16.8 ± 4.3 kg) were individually housed and randomly allotted to the 11 experimental diets. Feed was provided on an ad libitum basis throughout the 28-d experimental period. At the conclusion of the experiment, all pigs were killed, and 4 bones (i.e., the third and fourth metacarpals on both front feet) were harvested. Bone-breaking strength, bone ash, and Ca and P concentrations were determined. The concentration of bone ash increased ($P < 0.05$) as MCP50, MCP70, MCP100, or MSP were added to the basal diet, and the concentration of bone P also increased ($P < 0.05$) as MCP70, MCP100, or MSP were added to the basal diet. The relative bioavailability of P in each of the feed phosphates was determined using slope ratio methodologies based on breaking strength, and expressed relative to MSP. The slope of the regression line for diets containing MSP or MCP100 was steeper ($P < 0.05$) than the slope for pigs fed the diet containing DCP, but not different ($P > 0.05$) from that of pigs fed diets supplemented with MCP50 or MCP70. In conclusion, P in MSP and MCP100 is more bioavailable than P in DCP, but there were no differences within MCP sources.

Key words: bone ash, bone-breaking strength, phosphorus, pig, relative bioavailability

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INTRODUCTION

Diets fed to growing pigs usually contain a source of inorganic P, which has a greater availability and digestibility than organic P from plant feed ingredients. The inorganic P, therefore, compensates for the low availability and digestibility of P in plant feed sources. Monocalcium phosphate (**MCP**) and dicalcium phosphate (**DCP**) are common sources of inorganic P used in the US feed industry. It is believed that P in MCP is more digestible than P in DCP (Grimbergen et al., 1985; Eekhout and De Paepe, 1997), but because most feed phosphates designated as MCP or DCP in reality are mixtures of MCP and DCP, differences within a source may exist. Under practical conditions, inorganic P sources designated as MCP may contain between 50 and 70% MCP, and it is expected that the greater the content of MCP, the greater the availability of P. Likewise, if water is attached to the P molecule, there is a greater availability of P than if no water is attached (Grimbergen et al., 1985). However, in a recent experiment, it was shown that neither the apparent nor the true total tract digestibility of P in DCP and MCP are different and that the concentration of MCP in a feed phosphate does not influence the digestibility of P (Petersen and Stein, 2006). The true total tract digestibility of P in a feed phosphate is believed to be an accurate indicator of the bioavailability of P, and if that is true then it is not expected that a difference in the bioavailability of P in DCP and MCP exists as previously believed, but this hypothesis has not been tested. Thus, it was the objective of this experiment to test the hypothesis that the relative bioavailability of P in DCP and MCP is not different.

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

	Diet[1]										
Item	Basal	DCP	DCP	MCP50	MCP50	MCP70	MCP70	MCP100	MCP100	MSP	MSP
Casein	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Corn	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Cornstarch	51.27	50.87	50.48	50.83	50.42	50.85	50.43	50.87	50.48	50.76	50.26
Sugar	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Potato protein[2]	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Solka-Floc[3]	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Limestone	0.23	0.26	0.28	0.30	0.36	0.32	0.41	0.34	0.44	0.47	0.70
DCP	—	0.37	0.74	—	—	—	—	—	—	—	—
MCP50	—	—	—	0.37	0.74	—	—	—	—	—	—
MCP70	—	—	—	—	—	0.33	0.66	—	—	—	—
MCP100	—	—	—	—	—	—	—	0.29	0.58	—	—
MSP	—	—	—	—	—	—	—	—	—	0.27	0.54
L-Lys·HCl	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
DL-Met	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
L-Thr	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
L-Trp	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
K_2CO_3	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
MgO_2	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamins[4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Minerals[5]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

[1]DCP = dicalcium phosphate; MCP50 = monocalcium phosphate with 50% purity; MCP70 = monocalcium phosphate with 70% purity; MCP100 = monocalcium phosphate with 100% purity; MSP = monosodium phosphate.

[2]Potato protein concentrate, Avebe America Inc., Princeton, NJ.

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

[4]The vitamin premix provided per kilogram of diet: 10,032 IU of vitamin A acetate; 992 IU of vitamin D_3 as D-activated animal sterol; 88 IU of vitamin E as α tocopherol acetate; 1.5 mg of vitamin K as menadione dimethylpyrimidinol bisulfate; 0.4 mg of biotin; 60 mg of niacin; 25 mg of pantothenic acid; 10 mg of riboflavin; and 0.05 mg of vitamin B_{12}.

[5]The trace mineral premix provided per kilogram of diet: Cu, 23 mg as copper sulfate; Fe, 110 mg as iron sulfate; I, 0.275 mg as potassium iodate; Mn, 23 mg as manganese sulfate; Se, 0.275 mg as sodium selenite; and Zn, 114 mg as zinc oxide.

MATERIALS AND METHODS

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at South Dakota State University.

Diets, Animals, and Experimental Design

The 5 sources of inorganic P that were used included 1 source of DCP, 2 sources of feed-grade MCP (**MCP50** and **MCP70**), 1 source of a purified food-grade MCP (**MCP100**), and a purified food-grade anhydrous monosodium phosphate (**MSP**). Dicalcium phosphate, MCP50, and MCP70 contain a mixture of MCP and DCP, and the concentrations of MCP and DCP were estimated by the producing companies at 29 and 57%, 50 and 15%, and 70 and 10% in DCP, MCP50, and MCP70, respectively. The remaining compounds in these phosphates are the sum of unreacted calcium carbonate, magnesium phosphate, ferrous phosphate, aluminum phosphate, calcium sulfate, and various other components (Baker, 1989). The concentration of analyzed P was 18.8, 18.8, 21.0, 24.0, and 25.7% for DCP, MCP50, MCP70, MCP100, and MSP, respectively.

A total of 11 diets were formulated (Tables 1 and 2). The basal diet contained corn, casein, potato protein concentrate, sucrose, and cornstarch. Ten additional diets were formulated by adding 0.07 and 0.14% inorganic P to the basal diet from each of the 5 sources of inorganic P. Each source of inorganic P was, therefore, used in 2 diets. In all diets, the P source was included at the expense of corn starch. Limestone was used as an inorganic Ca source and included at varying amounts to bring the Ca:P in all diets to 1.3:1. Solka-Floc (Fiber Sales and Development Corp., Urbana, OH) was included in all diets as a source of fiber, whereas vitamins and minerals, other than Ca and P, were included at amounts that met or exceeded NRC requirements (NRC, 1998).

A total of 44 growing barrows (initial BW: 16.8 ± 4.3 kg) were randomly allotted to the 11 diets with 4 pigs per diet. All pigs were the offspring of SP-1 boars that were mated to Line 13 females (Ausgene Intl. Inc., Gridley, IL). Pigs were penned in individual grower pens equipped with a fully slatted floor, a feeder, and a nipple drinker. Pigs had ad libitum access to water and feed throughout the 28-d experiment.

Sample Collections, Measurements, and Chemical Analysis

Daily feed allotments were recorded, as well as initial and final BW of the pigs. At the conclusion of the experiment, pigs were killed by electrocution and exsan-

Table 2. Analyzed nutritional composition of experimental diets (as-fed basis)

	Diet[1]										
Item	Basal	DCP	DCP	MCP50	MCP50	MCP70	MCP70	MCP100	MCP100	MSP	MSP
ME,[2] kcal/kg	3,790	3,773	3,758	3,772	3,754	3,773	3,756	3,774	3,758	3,769	3,750
CP, %	12.68	12.71	12.86	12.83	12.84	13.79	13.61	12.68	12.70	13.01	12.65
Ca, %	0.13	0.20	0.30	0.21	0.30	0.19	0.28	0.20	0.27	0.19	0.28
P, %	0.12	0.18	0.25	0.17	0.23	0.17	0.24	0.18	0.23	0.20	0.26
Arg, %	0.51	0.58	0.62	0.54	0.48	0.50	0.51	0.55	0.55	0.55	0.52
His, %	0.28	0.32	0.34	0.29	0.25	0.27	0.27	0.28	0.30	0.29	0.28
Ile, %	0.58	0.66	0.71	0.61	0.53	0.57	0.57	0.60	0.62	0.62	0.58
Leu, %	1.15	1.33	1.41	1.21	1.05	1.13	1.13	1.20	1.23	1.23	1.16
Lys, %	0.92	1.03	1.07	0.94	0.85	0.88	0.91	0.93	0.97	0.96	0.93
Met, %	0.48	0.55	0.57	0.52	0.47	0.49	0.50	0.51	0.52	0.53	0.51
Phe, %	0.65	0.74	0.79	0.68	0.61	0.64	0.64	0.67	0.69	0.69	0.65
Thr, %	0.49	0.56	0.60	0.52	0.45	0.48	0.49	0.51	0.52	0.52	0.50
Trp, %	0.15	0.18	0.20	0.21	0.21	0.20	0.19	0.15	0.14	0.15	0.15
Val, %	0.73	0.84	0.89	0.74	0.65	0.69	0.70	0.75	0.75	0.76	0.71

[1]DCP = dicalcium phosphate; MCP50 = monocalcium phosphate with 50% purity; MCP70 = monocalcium phosphate with 70% purity; MCP100 = monocalcium phosphate with 100% purity; MSP = monosodium phosphate.
[2]Values were calculated (NRC, 1998).

guination. The third and fourth metacarpals on both front feet were removed and individually packaged in plastic bags and frozen until analyzed. Bone-breaking strength was determined in these bones using an Instron Instrument (Instron Corp., Canton, MA). The instrument measures kilograms of force required to break the metacarpal when placed on supports 3.5 cm apart. Force was applied to the shaft of the bone by an instrument moving at 5 cm/min and measured by a pressure-sensitive cell and recorded on a graph recorder.

All diets were analyzed for DM and CP (method 4.1.06 and method 4.2.06, respectively; AOAC, 2000). Amino acids in the diets were analyzed on a HPLC AA analyzer (Chrom Tech, Apple Valley, MN) using ninhydrine for postcolumn derivatization and nor-leucine as the internal standard. Samples were hydrolyzed with 6 *N* HCl for 24 h at 110°C (method 4.1.11 alternative 3; AOAC, 1998). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (method 4.1.11 alternative 1; AOAC 1998). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (method 988.15; AOAC, 1998).

Bones were defatted in ether extract for 3 d and ashed in a muffle furnace at 600°C for 16 h for the determination of total bone ash. Diets and bone ash samples were analyzed for Ca and P using an atomic absorption spectrophotometer (methods 4.8.03 and 3.4.11, respectively; AOAC, 2000.

Calculations and Statistical Analysis

At the conclusion of the experiment, feed consumption for each pig was summarized to calculate ADFI. Initial BW was subtracted from final BW to calculate ADG, and the G:F was also calculated for each pig.

Data for pig performance, bone-breaking strength, bone ash, bone Ca concentration, bone P concentration, and bone Ca:P were analyzed as a complete randomized block design with an extra diet and treatments consisting of the 5 P sources and 2 levels of added P (0.07 and 0.14%) in a 5 × 2 factorial arrangement. The pig was the experimental unit. The effect of dietary P was analyzed using ANOVA in the PROC MIXED procedure (SAS Inst. Inc., Cary, NC). The main effects were P source, P level, and source × level interactions. Metacarpal-breaking strength was regressed on actual P intake from each P source using a regression analysis (Littell et al., 1997), and the basal diet was included in all 5 regressions. Slopes of the resulting regression lines were determined and compared among the 5 P sources to express the bioavailability of P in DCP, MCP50, MCP70, and MCP100 relative to MSP as described by Cromwell (1992). All analyses included verification that the 3 basic assumptions for slope-ratio analyses were met (Littell et al., 1997). Slopes of the regression lines were separated using contrast statements in PROC MIXED. An α-value of 0.05 was used to assess significance among means, and $P > 0.05$ and < 0.10 was considered a trend.

RESULTS

Pigs stayed healthy throughout the experiment and readily consumed their diets. One pig fed the diet containing 0.07% P from MCP50 died before the completion of the experiment and was excluded from all calculations.

The basal diet contained slightly more P than expected, but diets that were formulated to contain 0.07% more P than the basal diet analyzed between 0.05 and 0.08% more P than the basal diet (Table 2). Likewise, diets that were formulated to contain 0.14% more P than the basal diet analyzed between 0.11 and 0.14% more P than the basal diet. Thus, the P-supplemented

diets all contained amounts of P that were close to expected values.

All diets were formulated to contain Ca in amounts that were 1.3 times greater than the concentration of P. The actual analyzed amounts of Ca were between 0.95 and 1.30 times the amounts of P in the diets. We assumed that the slightly smaller Ca:P in some of the diets compared with expected ratios did not influence the results of the experiment. Likewise, the concentrations of CP and AA were close to expected values.

Neither the source of P nor the amount of P influenced ADG, ADFI, or G:F (Table 3), but the amount of P in the diets influenced ($P < 0.01$) daily P intake with pigs fed the diets formulated to contain 0.14% P from the inorganic P sources having a greater P intake than pigs fed the diets formulated to contain 0.07% P from inorganic P sources. The source of P influenced ($P < 0.05$) the amount of metacarpal bone ash, metacarpal-breaking strength, total bone Ca concentration, and total bone P concentration, but not the concentration of metacarpal bone ash, total amount of bone Ca, amount of bone P, or the total bone Ca:P (Table 4). The concentration of bone ash, total bone Ca concentration, total bone P concentration, total bone Ca:P, and the amount of ash, Ca, and P in the bones increased ($P < 0.05$) as the P in the diets increased. There was also a tendency ($P = 0.08$) for an increase in bone-breaking strength as the P in the diets increased. There was a source × level interaction ($P < 0.05$) in the concentration of bone ash and the amount of bone ash, with pigs fed the diet containing 0.14% P from MSP having a decreased concentration of bone ash and a decreased total amount of bone ash compared with pigs fed the diet containing 0.07% P from MSP, whereas for all other sources of P, the greatest inclusion levels resulted in increased bone ash concentration and an increased amount of ash in the bones compared with the least inclusion levels.

The P in DCP, MCP50, MCP70, and MCP100 had bioavailabilities of 57, 83, 80, and 109%, respectively, relative to MSP (Figure 1). The slopes of the regression lines for MSP and MCP100 were steeper ($P < 0.05$) than the slope for DCP, but not different from those of MCP50 and MCP70.

DISCUSSION

Less inclusion of dietary P usually results in slower and less efficient BW gain than if P is included at adequate amounts (Cromwell et al., 1972). However, in the present experiment, no effect of P level on ADG or G:F was observed. The reason we failed to obtain a reduction in ADG and G:F with reduced P may be that the P in the basal diet was relatively high and that the experimental period was only 28 d. Spencer et al. (2000) conducted a similar experiment and also reported that no differences in ADG or G:F were obtained. It is, therefore, possible that growth depressions as a result of reduced intake of P are obtained only if pigs are fed a diet that is more deficient in P than the basal diet used in the present experiment or if the experiment is longer than 28 d.

The values for bone-breaking strength that were obtained in this experiment are similar to those reported by Coffey et al. (1994), and it has been shown that pigs fed a diet deficient in P have less bone-breaking strength than pigs fed a diet adequate in P (Hall et al., 1991). In the current experiment, bone-breaking strength tended to increase with P in the diet. The results demonstrate that the P in the 5 sources of inorganic P used in this experiment has different bioavailabilities with P in MSP and MCP100 having the greatest bioavailability and P in DCP the least. This response is consistent with results reported by Coffey et al. (1994) and Hall et al. (1991). The ranking among the P sources that was obtained for breaking strength is also similar to the ranking that was obtained based on values for total tract digestibility of P in the same 5 sources of inorganic phosphate (Petersen and Stein, 2006).

The increase in bone ash concentration and the total quantity of ash in the bones as P in the diet increased demonstrate that an increase in the quantities of dietary P can increase the amount of absorbed P, which in turn can be used for increased bone tissue synthesis. This may increase the thickness of the bone, and, therefore, the amount of ash in the bone. The bone ash concentration is influenced by this to a lesser extent. This observation indicates that the regulation of bone tissue synthesis is mainly in the thickness of the bone, and not in the composition of the bone. These results are in agreement with Cromwell et al. (1972) who reported that increases in bone-breaking strength are caused by increases in bone thickness. If more P is absorbed and available for bone tissue synthesis, then the bone will become thicker. Increases of P above the requirement of the pig do not result in increased bone-breaking strength (Cromwell et al., 1972).

The current data show that the bioavailability of P in DCP is only 57% of that in MSP. This is considerably less than data from previous reports (Grimbergen et al., 1985; Nelson et al., 1990; Cromwell, 1992). The results for the relative bioavailability of P in feed grade MCP are also less than that reported by NRC (1998) and others (Grimbergen et al., 1985; Nelson et al., 1990), but they are in agreement with values reported by Jongbloed et al. (1991). Results of the present experiment also agree with data reported by Eekhout and De Paepe (1997) who compared the relative bioavailability of P in DCP to the availability of P in feed grade MCP. The reason for the different results among experiments is most likely that the bioavailability of P in the standard source used varied among experiments. The source of MSP used in the present experiment was a food-grade quality of MSP that may have had a greater availability of P than the sources used in some of the previous experiments, which results in decreased values for the relative bioavailability of P in the test feed

Table 3. Influence of treatment on pig performance[1,2]

	Basal	DCP		MCP50		MCP70		MCP100		MSP			*P*-value		
Response	0	0.07	0.14	0.07	0.14	0.07	0.14	0.07	0.14	0.07	0.14	SEM	Source	Level	Source × level
ADG, g	298	330	393	331	413	365	408	408	369	350	398	38	0.96	0.13	0.52
ADFI, g	955	1,040	1,100	1,036	1,280	1,138	1,130	1,123	1,118	1,095	1,148	67	0.62	0.12	0.31
G:F	0.32	0.32	0.36	0.32	0.33	0.32	0.36	0.36	0.32	0.32	0.34	0.03	0.99	0.52	0.51
Daily P intake, g	1.13	1.85	2.75	1.79	2.92	1.92	2.74	2.04	2.61	2.22	2.94	0.14	0.21	0.001	0.38

[1]Data are means of 4 observations per diet.

[2]DCP = dicalcium phosphate; MCP50 = monocalcium phosphate with 50% purity; MCP85 = monocalcium phosphate with 70% purity; MCP100 = monocalcium phosphate with 100% purity; MSP = monosodium phosphate. The numbers below each diet refer to the percentage of added P.

Table 4. Influence of treatment on bone ash and bone-breaking strength[1,2]

	Basal	DCP		MCP50		MCP70		MCP100		MSP			*P*-value		
Response	0	0.07	0.14	0.07	0.14	0.07	0.14	0.07	0.14	0.07	0.14	SEM	Source	Level	Source × level
Metacarpal ash, %	45.1	48.3	51.0	50.2	51.9	48.5	51.7	48.8	52.0	50.5	50.6	0.9	0.28	0.001	0.04
Metacarpal ash, g	2.73	2.86	3.32	3.05	3.66	3.02	3.48	3.13	3.66	3.47	3.18	0.13	0.02	0.001	0.001
Breaking strength, kg	18.4	27.9	30.4	29.5	35.2	28.6	34.8	26.0	41.3	35.3	40.8	3.0	0.001	0.08	0.30
Total ash Ca, %	32.5	32.2	31.3	32.0	31.9	32.6	32.3	32.6	32.5	32.5	32.0	0.4	0.003	0.008	0.43
Total ash P, %	16.6	16.6	16.7	16.3	17.1	16.9	17.4	17.2	17.4	17.2	17.2	0.2	0.001	0.05	0.08
Total bone Ca:P	1.96	1.94	1.88	1.96	1.86	1.93	1.86	1.90	1.87	1.89	1.87	0.02	0.46	0.001	0.31
Total bone Ca, g	0.89	0.92	1.04	0.97	1.17	0.98	1.12	1.02	1.19	1.12	1.02	0.07	0.20	0.009	0.08
Total bone P, g	0.45	0.48	0.53	0.50	0.63	0.51	0.61	0.54	0.63	0.60	0.55	0.04	0.19	0.002	0.08

[1]Data are means of 4 observations per diet.

[2]DCP = dicalcium phosphate; MCP50 = monocalcium phosphate with 50% purity; MCP70 = monocalcium phosphate with 70% purity; MCP100 = monocalcium phosphate with 100% purity; MSP = monosodium phosphate. The numbers below each diet refer to the percentage of added P.

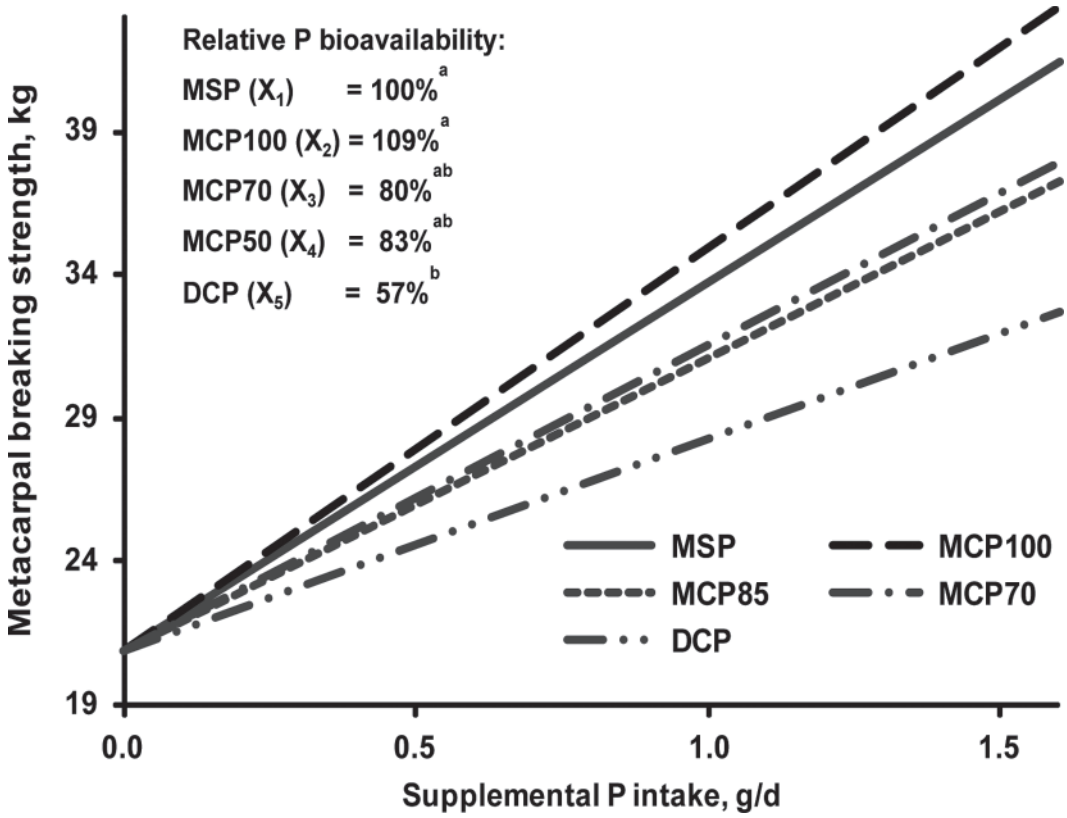

Figure 1. Bioavailability of P in 4 sources of inorganic P relative to monosodium phosphate (MSP). DCP = dicalcium phosphate; MCP50 = monocalcium phosphate with 50% purity; MCP70 = monocalcium phosphate with 70% purity; MCP100 = monocalcium phosphate with 100% purity. $Y = 20.9 + 12.9\ X_1 + 14.1\ X_2 + 10.2\ X_3 + 10.6\ X_4 + 7.4\ X_5$. The SE was 2.04, 2.55, 2.61, 2.63, and 2.73 for X_1, X_2, X_3, X_4, and X_5, respectively, and 2.18 for the intercept. Values on the x-axis are based on analyzed values for P. [a,b]Values lacking a common letter are different ($P < 0.05$).

phosphates. This hypothesis is supported by the fact that bone ash concentration and bone Ca and P did not increase between the 2 amounts of MSP that were used in this experiment, indicating that the requirement of the pig may have been met at the least inclusion level. The MSP used in the current experiment was an analytical grade MSP, but the quality of the MSP used in previous experiments was not reported. One of the biggest disadvantages of the relative availability procedure is that all data are related to a standard and because the availability of P in the standard may vary among experiments, comparisons across experiments are not possible.

There were no differences in any of the response criteria measured among MCP50, MCP70, and MCP100, although the values for MCP100 in most instances were numerically greater than the values from the other 2 sources. These results indicate that the concentration of MCP in a feed phosphate designated as MCP does not influence the availability of P. However, the availability of P in MCP100 was greater than in DCP. These results agree with data obtained for the total tract digestibility of P in the same 5 sources of P (Petersen and Stein, 2006).

Differences in Ca:P may influence P digestibility and bone mineralization (Huyghebaert et al., 1980; Brady et al., 2002). In the current experiment, we attempted to keep Ca:P at 1.3:1 in all diets, and the analyzed values showed that the actual ratios varied between 0.95:1 and 1.3:1. Reductions in P digestibility as a consequence of differences in Ca:P have usually been observed if the Ca:P increased greater than 1.5:1 (Liu et al., 1998; Brady et al., 2002). It is, therefore, unlikely that the small differences among diets in the present experiment influenced the results.

To keep the Ca:P constant, the inclusion of limestone varied among diets, and different proportions of the total Ca in the diets were provided by limestone. However, the majority of the Ca in all diets was supplied by either limestone or the inorganic P source. If the digestibility of Ca from limestone is different from that of Ca in DCP or MCP, then this difference may have influenced the ratios among digested Ca and P. We are, however, not aware of any published data that have compared the digestibility of Ca in limestone and the digestibility of Ca in feed phosphates.

In conclusion, the availability of P in feed grade MCP and DCP relative to MSP may be less than demonstrated in previous reports, with DCP having the least availability. However, there are no differences in P availability among MCP sources regardless of the concentration of DCP and MCP in these sources.

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