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Effects of the Calcium and Phosphorus Ratio in High Zinc Diets on Performance and Nutrient Digestibility in Weanling Pigs

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Abstract: Forty-eight crossbred (Landrace x Yorkshire) barrows, weighing an average of 7.55 ± 0.54 kg, were allotted to one of four dietary treatments containing approximately 2,400 ppm Zn. Four corn-soybean meal based diets (20.4% crude protein and 0.60-0.63% phosphorus) were formulated to contain 0.83 % Ca (Ca:P, 1.31:1), 0.91 % Ca (Ca:P, 1.51:1), 1.01 % Ca (Ca:P, 1.65:1) or 1.17 % Ca (Ca:P, 1.91:1). Daily gain and feed intake were unaffected by dietary treatment ($p>0.05$). Feed conversion was affected quadratically ($p<0.01$) for the periods from 0 to 14 d, 14 to 28 d and overall by increasing dietary calcium concentration. There was no effect of calcium level on the digestibility of dry matter, crude protein, acid detergent fibre, energy, ash, phosphorus, zinc and iron. The digestibility of fat and calcium in the 1.17 % calcium diet was significant lower than for the other diets ($p<0.05$). In addition, the digestibility of copper in the 0.83 % calcium diet was significantly lower than for the 1.01 % calcium diet ($p<0.05$). There was no effect of calcium level on the digestibility of amino acids except for arginine with the digestibility of arginine in the 1.041 % calcium diet being significantly lower than the other diets ($p<0.05$). In conclusion, feeding higher calcium levels than NRC requirement in diets containing pharmacological levels of Zn level improved feed conversion. The results suggest that the level of calcium recommended by NRC for weanling pigs may be insufficient for optimal performance when pigs are fed diets containing pharmacological levels of zinc.

Key words: Calcium, phosphorus, zinc oxide, performance, digestibility, pigs

INTRODUCTION

The zinc requirement for nursery pigs listed in the National Research Council's[1] Nutrient Requirements for Swine is 100 ppm. However, it is a common practice in the feed industry to add 2,000 to 3,000 ppm Zn as ZnO in diets fed to recently weaned pigs[2]. This practice is based on the results of several research trials that have indicated improved nursery pig performance as a result of zinc supplementation[3-5]. High concentrations of dietary zinc (Zn) in the form of zinc oxide (ZnO) also decrease the incidence of nonspecific post-weaning scours[4]. However, if the high zinc containing diets are fed for more than two to three weeks, they may result in zinc toxicosis[6]. High dietary calcium reduces the severity of zinc toxicity[7].

The zinc requirement of pigs is increased when excessive levels of calcium are fed[8-10]. Excess calcium not only decreases the utilization of phosphorus but also increases the pig's requirement for zinc in the presence of phytate[11,12]. When the molar ratio of cations (zinc and calcium) was 2:1 or 3:1 with phytate, the formation of an insoluble complex was much more likely[13].

Based on these observations, we hypothesized that pharmacological concentrations of Zn in nursery diets may alter the requirement for dietary calcium. An optimal calcium and phosphorus ratio is considered essential to the use of pharmacological levels of Zn in weanling pigs. Therefore, this experiment assessed the effects of calcium level in the diet on performance and nutrient digestibility in nursery diets containing high levels of zinc.

MATERIALS AND METHODS

Growth trial: Forty-eight crossbred (Landrace x Yorkshire) barrows were weaned at approximately 24 days of age and fed a commercially prepared diet for five days to allow the pigs to adapt to solid feed. At the start of the experiment, the barrows (7.55 ± 0.54 kg BW) were allotted to one of four dietary treatments from outcome groups based on initial weight. Four corn-soybean meal diets (20.4% crude protein and 0.60-0.63% phosphorus; Table 1) were formulated to contain 0.83, 0.91, 1.01 and 1.17% Ca with all diets containing approximately 2400 ppm zinc. All nutrients were supplied in the diet to meet or exceed current recommendations for

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Table 1: Ingredient composition of diets formulated to determine the effects of the calcium to phosphorus ration in high zinc diets on weanling pig performance

Calcium, %	0.83	0.91	1.01	1.17
Phosphorus, %	0.63	0.60	0.61	0.61
Ingredient, % as fed				
Corn, expanded	31.51	31.2	30.88	30.56
Soybean meal, dehulled	26.00	26.00	26.00	26.00
Bakery by-product	10.00	10.00	10.00	10.00
Whey	13.75	13.75	13.75	13.75
Fishmeal	5.00	5.00	5.00	5.00
Lard	3.00	3.00	3.00	3.00
Soybean oil	1.50	1.50	1.50	1.50
Celite-545	1.00	1.00	1.00	1.00
Sugar	2.00	2.00	2.00	2.00
Yeast culture	2.50	2.50	2.50	2.50
L-Lysine	0.23	0.23	0.23	0.23
Methionine	0.20	0.20	0.20	0.20
Threonine	0.10	0.10	0.10	0.10
Calcium carbonate	0.45	0.76	1.08	1.40
Mono-calcium phosphate	0.26	0.26	0.26	0.26
Vitamin-trace mineral premixa	2.50	2.50	2.50	2.50

[a] The vitamin and trace mineral premix for the experimental diet provided the following per kilogram of diet: Fe, 100 mg; Cu, 10 mg; Mn, 20 mg; Zn, 2,400 mg; I, 0.35 mg; Se, 0.20 mg; Vitamin A, 20,000 IU; Vitamin D3, 2,000 IU; Vitamin E, 100 mg; Vitamin K, 3 mg; Thiamin, 4 mg; riboflavin, 7.0 mg; pyridoxine, 5 mg; Vitamin B12, 0.05 mg; Pantothenic acid, 16 mg; Niacin, 35 mg; Biotin, 0.18 mg; Folic acid 1.3 mg; Choline, 350 mg

Table 2: Analyzed chemical composition (% as fed) of the experimental diets

Calcium, %	0.83	0.91	1.01	1.17
Phosphorus,	0.63	0.60	0.61	0.61
Chemical analysis				
Dry matter	91.61	91.59	91.73	91.83
Crude protein	20.42	20.42	20.3	20.42
Ether extract	8.82	9.13	8.69	7.26
Ash	5.99	6.05	6.41	6.27
Acid detergent fibre	3.93	2.89	2.73	3.58
Minerals				
Calcium	0.83	0.91	1.01	1.17
Phosphorus	0.63	0.6	0.61	0.61
Zinc, ppm	2,405.00	2,369.00	2,363.00	2,334.00
Iron, ppm	166.00	168.00	183.00	199.00
Copper, ppm	96.00	94.00	100.00	102.00
Amino acids				
Arginine	1.22	1.3	1.21	1.33
Histidine	0.58	0.66	0.56	0.59
Isoleucine	0.95	0.96	0.95	0.94
Leucine	1.75	1.94	1.78	1.99
Lysine	1.38	1.59	1.42	1.49
Methionine + Cystine	0.75	0.75	0.78	0.76
Phenylalanine	1.03	0.96	0.98	0.93
Threonine	0.96	0.92	0.92	0.94
Valine	0.99	1.06	0.94	0.99

the 10-kg pig[1]. The diets were fed in crumble form.

The pigs were housed in groups of two in 1.2 x 2.0 m concrete floored pens equipped with a single feeder and a nipple waterer to provide free access to feed and water. Each treatment was fed to six replicate pens of pigs. The air temperature was controlled at 30°C during the first 5 days and the temperature was decreased by 1°C every seven days until it reached 24°C at the end of the experiment. Pigs weights and feed disappearance were recorded every 7 d to determine daily gain, feed intake and feed conversion during the 28 day experiment.

Digestibility trial: Celite 545 (Fluka, Switzerland) was added to all diets as a digestibility marker. On days 11 to 15, fecal samples were collected from each pen with the accumulation of the five-day fecal collection subsequently being pooled. The fecal samples were oven dried for 72 h at 55°C, allowed to equilibrate for 24 h at room temperature and then ground through a 1.0 mm screen with a Cyclotec grinder (Model 1093, FOSS, Denmark). Digestibility coefficients for dry matter, crude protein, acid detergent fibre, energy, amino acids, calcium, phosphorus, zinc, iron, and copper were calculated using the equations for the indicator method described[14].

Chemical analysis: Samples of the diets and feces were analysed in triplicate according to the methods of the[15] . Analyses were conducted for moisture (AOAC method 930.15), crude protein (AOAC method 984.13), acid detergent fibre (AOAC method 973.18), ash (AOAC method 942.05) and ether extract (AOAC method 920.39). Calcium was determined by an atomic absorption Spectrophotometer (Shimazu, AA625 Japan), and phosphorus was analyzed using a UV-vis. Spectrophotometer (Hitachi, U-1100, Japan). Zinc, copper and iron analysis of the feed and feces was performed using Inductively-Coupled Plasma Emission Spectroscopy (Leeman Labs, PS-SPEC, USA) after pre-digestion with 70% nitric acid. Gross energy was measured using an Adiabatic Oxygen Bomb Calorimeter (Model 1241, Parr Instrument Co., Molin, IL). An amino acid analysis of the feed and feces was performed using a L8500-Hitachi Amino Acid Analyzer after hydrolysis for 24 h 6 N HCl. Performic acid hydrolysis was performed for analysis of sulfur-containing amino acids. Celite (HCL-Insoluble Ash) analysis was conducted according to the description provided by[16].

Statistical analysis: The data were analyzed as a randomized block design using the Analysis of Variance procedures described by[17]. Pigs were blocked on the basis of initial weight and the pen was considered the experimental unit for all performance and digestibility data. The model included the effects of replication (i.e., block), treatment, and replication x treatment (error). The comparison of means was performed by the Least Significant Difference (LSD) method and accepting the default value of 0.05 for alpha. Linear and quadratic effects of Ca level on performance were also examined. The correlations between mineral digestibilities were computed with treatment as a weighting factor.

RESULTS AND DISCUSSION

Animal performance and nutrients digestibility: The effects of dietary calcium level on pig performance are presented in Table 3. Daily gain and feed intake were

Table 3: Effect of altering the level of calcium in high-zinc nursery pig diets on pig performance[a]

Calcium, %	0.83	0.91	1.01	1.17	SEM	Contrasts, p-value	
Phosphorus, %	0.63	0.60	0.61	0.61		Linear	Quadratic
Day 0 to 14							
Daily gain g/day	426	438	443	425	12	0.964	0.245
Feed intake, g/day	538	507	513	523	13	0.506	0.146
Feed conversion	1.27x	1.16z	1.17yz	1.23xy	0.02	0.326	0.002
Day 14 to 28							
Daily gain g/day	746	761	754	743	18	0.857	0.466
Feed intake, g/day	1,178	1,138	1,113	1,156	37	0.595	0.286
Feed conversion	1.58x	1.49yz	1.48z	1.56xy	0.03	0.466	0.004
Day 0 to 28							
Daily gain g/day	586	599	598	584	8	0.879	0.121
Feed intake, g/day	858	823	813	839	24	0.552	0.22
Feed conversion	1.47[x]	1.37[y]	1.36[y]	1.44[xy]	0.03	0.449	0.006

[a] Six replicate pens of two pigs per pen for the performance data.
[xyz] Within a row, means with no or a common superscript do not differ (p>0.05)

Table 4: Effect of altering the level of calcium in high-zinc nursery diets on nutrient digestibility[a]

Calcium, %	0.83	0.91	1.01	1.17	
Phosphorus, %	0.63	0.60	0.61	0.61	SEM
Dry matter	87.7	88.4	88.3	86.1	1.03
Crude protein	84.9	85.7	86	83	1.48
Crude fat	88.3[x]	89.7[x]	89.4[x]	85.1[y]	8.99
Acid detergent fibre	48.1	43.5	44.8	46.8	2.47
Gross energy	88.2	89.1	89.2	87.2	0.93
Calcium	61.4[x]	61.7[x]	60.4[x]	53.1[y]	2.04
Phosphorus	61.5	62	62.6	57.4	2.32
Copper	33.8[y]	35.3[xy]	38.6[x]	35.2[xy]	1.15
Zinc	30	30.5	30.6	27	4.55
Iron	35.7	36.7	37.9	32.1	4.71

[a] Six replicate pens of two pigs per pen for the digestibility data.
[x,y] Within a row, means with no or common superscript do not differ (P>0.05)

unaffected by dietary treatment. Feed conversion was affected quadratically for the 0 to 14 day period (p=0.002), the 14 to 28 day period (p=0.004) and the overall experiment (p=0.006) due to increased calcium level. The apparent fecal digestibilities of the nutrients contained in the experimental diets are shown in Table 4. There was no effect of the calcium level on the digestibility of dry matter, crude protein, acid detergent fibre, gross energy, phosphorus, zinc and iron. The digestibility of fat and calcium in the 1.17% calcium diet was significantly lower than for the lower calcium containing diets (p<0.05). In addition, the digestibility of copper in the 0.83% calcium diet was significantly lower than for the 1.01% calcium diet (p<0.05).

Correlations between mineral digestibilities: The correlations between mineral digestibilities are shown in Table 5. Digestibility of calcium was highly correlated with iron (p=0.0001), phosphorus (p=0.0001), zinc (p=0.0001) and ash (p=0.0001). The digestibility of copper was not

Table 5. Correlation coefficients between mineral digestibilities

Item	Ca	Cu	Fe	P	Zn
Cu	0.2142				
P-value	0.3139				
Fe					
P-value	0.7938	0.3228			
	0.0000	0.1240			
P	0.7849	0.2213	0.6697		
P-value	0.0000	0.2987	0.0003		
Zn	0.7316	0.3022	0.8351	0.7485	
P-value	0.0000	0.1512	0.0000	0.0000	
Ash	0.7929	0.3726	0.7223	0.9518	0.7138
P-value	0.0000	0.0729	0.0001	0.0000	0.0001

Table 6: Effect of altering the level of calcium in high-zinc nursery diets on the apparent fecal digestibility (%) of amino acids[a]

Calcium, %	0.83	0.91	1.01	1.17	
Phosphorus, %	0.63	0.60	0.61	0.61	SEM
Arginine	87.6[y]	90.9[x]	92.6[x]	91.4[x]	1.04
Histidine	89.6	89.9	91.5	90.2	2.86
Isoleucine	85	85.1	85	85.8	2.95
Leucine	73	72.2	72.4	71.7	4.42
Lysine	87.8	88.3	88.6	86.9	1.44
Methionine	81.9	82.2	82.3	81.3	2.09
Phenylalanine	86.7	88.1	88.7	89.1	1.13
Threonine	83.3	84	86	84	2
Valine	85.4	85.5	86.9	86	1.29

[a]Six replicate pens of two pigs per pen for the digestibility data.
[x,y]Within a row, means with no or common superscript do not differ (p>0.05).

correlated with calcium (p=0.3139), iron (p=0.1240), phosphorus (p=0.2987), and zinc (p=0.1512), but was moderately correlated with ash (p=0.0729). The digestibility of iron was highly correlated with calcium (p<0.0001), phosphorus (p=0.0003), zinc (p=0.0001) and ash (p=0.0001). Digestibility of phosphorus was highly correlated with calcium, phosphorus, zinc and ash (p=0.0001). The digestibility of zinc was highly correlated with calcium, iron, phosphorus and ash (p=0.0001).

Amino acid digestibility: The apparent fecal digestibility coefficients for the amino acids in the experimental diets are shown in Table 6. There was no effect of the calcium level on the digestibility of any of the amino acids except for arginine. The digestibility of arginine in the 0.83% Ca diet was significantly lower than for the other diets (p<0.05). Significant quadratic effects for feed conversion were exhibited in this experiment. The pigs that consumed 0.91 and 1.01% dietary calcium tended to be the most efficient in utilizing feed with pigs fed 0.83 and 1.17% calcium having poorer feed conversions. These data are similar to those reported by[18] where diets that contained 0.95% calcium promoted the most efficient feed conversions compared with higher and lower inclusion levels. However, our results are in contrast to those of[19], who reported that lowering the Ca:P ratio from 1.5:1 to 1.0:1 in a grower diet linearly decreased feed:gain ratio.

These results suggest that excess zinc increases the pig's requirement for calcium. Support for this hypothesis can be obtained from the work of[13], who reported that when the molar ratio of zinc and calcium was 2:1 or 3:1 with phytate, the formulation of an insoluble complex was much greater

The results of the digestibility study showed that as the percentage of calcium in the diet increased, calcium digestibility decreased. This supports the work of [20] who showed that calcium digestibility was significantly reduced by a high dietary calcium level. The decrease in calcium digestibility in our experiment is also in agreement with experiments in which finishing pigs were fed diets with various Ca:P ratios and supplemented with microbial phytase[19]. Lowering the dietary Ca:P ratio from 1.5:1 to 1.0:1 had no effect on the pH of the digesta in the small or large intestines of finishing pigs[21]. Therefore, the detrimental effect of feeding the 1.17% calcium diet on calcium digestibility in the present study are not likely due to an increase in pH in the small intestine.

Feeding higher levels of calcium also decreased the digestibility of crude fat. One possible mechanism to explain the detrimental effects of a higher calcium level on calcium and fat digestibility is that calcium complexes with fatty acids in the gut of lumen to form insoluble metallic soaps, thereby reducing fat and calcium digestibility. A report by[22] showed that ether extract digestibility was significantly reduced by a high dietary Ca level in one trial but not in another. Atteh and Leeson[23] reported increased formation of insoluble soaps between calcium and dietary fats as dietary calcium concentration increased.

Pigs given the diet containing 1.01% of calcium had significantly higher copper digestibility than pigs fed 0.83% calcium. One possible explanation for this response in this experiment may be the known interactions between calcium and copper[24].

Altering the levels of calcium in the diet had no effect on the fecal digestibility of any amino acid with the exception of arginine. An explanation as to why arginine should be affected differently than the other amino acids is not readily apparent.

The overall results of this experiment show that feeding higher calcium levels than NRC requirement in diets containing pharmacological levels of Zn level improved feed conversion. These results suggest that the level of calcium recommended by NRC for weanling pigs may be insufficient for optimal performance when pigs are fed diets containing pharmacological levels of zinc. Additional definitive research is needed to more clearly establish whether the performance of pigs fed various calcium levels is affected by supplementation of pharmacological level of zinc.

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