THE EFFECTS OF DIETARY MINERAL REGIMEN ON STARTER PIG GROWTH PERFORMANCE AND BLOOD AND IMMUNE PARAMETERS

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Summary

Two hundred sixty-six weanling pigs (initially 12.46 lb and 21 d of age) were used in a 34-d growth assay to evaluate the effects of various mineral supplementation regimens on starter pig growth, immune status, blood parameters, and liver mineral status. Pigs were fed either a control diet, 3,000 ppm zinc (Zn) in phase I and 2,000 ppm Zn in phase II and III, 250 ppm copper during the entire trial, or a combination of these three diets. These results support our current recommendations of adding zinc oxide in diets of pigs weighing up to 25 lb and copper sulfate in diets fed to pigs from 25 to 50 lb.

(Key Words: Starter, Zinc, Copper, Performance, Pigs.)

Introduction

Recent research at Michigan State University, Louisiana State University, and Kansas State University has shown the benefits of increasing Zn in starter pig diets. Previous research at Kansas State found that feeding 3,000 ppm Zn to pigs weighing less than 15 lb and 2,000 ppm Zn to pigs weighing 15 to 25 lb resulted in the greatest growth response. At Michigan State University, researchers found a similar response to added Zn in starter pig diets. Limited research is available examining the effects of supplementing copper sulfate in diets for pigs previously fed high levels of zinc oxide. Therefore, the objectives of this experiment were to determine the effects of various Zn and Cu supplementation regimens on growth performance, hepatic mineral accumulation, whole blood parameters, and lymphocyte proliferative responses.

Procedures

A total of 266 weanling pigs (initially 12.46 lb and 21 d of age) was used in a 34-d growth assay to compare the effects of various mineral supplementation regimens on the growth performance, mineral status, and immune parameters of starter pigs. The six replicate pens per treatment had six or seven pigs per pen. The pigs were blocked by weight and ancestry, then assigned to one of the seven dietary treatments (Table 1). The diets were fed in three phases: phase I (d 0 to 7), phase II (d 7 to 22), and phase III (d 22 to 34). Diets were formulated to contain 1.6, 1.35, and 1.20% lysine and .44, .40, and .32% methionine during phases I, II, and III, respectively. All of the diets were corn-soybean meal-based. The phase I diets were pelleted and contained 25% dried whey, 7.5% spray-dried porcine plasma, 1.75% spray-dried blood meal, and 5% soybean oil (Table 2). The phase II diets were fed in a meal form and contained 10% dried whey, 2.5% spray-dried blood meal, and 3% soybean oil. Phase III diets were fed in the meal form and were simple corn-soybean meal-based diets containing no alternative protein sources. Zinc oxide (72% Zn) and copper sulfate were added at the expense of cornstarch to provide the experimental miner-

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al treatments. These were designed to represent similar dietary mineral additions in a commercial phase-feeding program (Table 1). Phase I diets contained either 3,000 ppm Zn from zinc oxide, 250 ppm Cu from copper sulfate, or no supplemental minerals. Phase II and III diets contained either 2,000 ppm Zn from zinc oxide, 250 ppm Cu from copper sulfate, or no supplemental minerals.

The pigs were housed in an environmentally controlled nursery in 5 ft × 5 ft pens with a self-feeder and two nipple waterers to allow ad libitum access to feed and water. The pigs were weighed and feed disappearance was measured weekly to calculate ADG, ADFI, and F/G. Feed samples were collected and analyzed for total mineral profile and crude protein content.

Blood samples were collected by jugular venapuncture every 7 days to determine white blood cell count, red blood cell count, platelet count, hemoglobin content, and hematocrit (packed cell volume). Additional blood samples were analyzed for ceruloplasmin content on d 0, 7, 22, and 34. Ceruloplasmin is the primary Cu transport protein which is thought to contain as much as 90% of the plasma Cu pool. Leukocyte transformation assays were conducted on d 0 and 34. Leukocyte proliferative responses to mitogen stimulation were conducted on d 0 and 34 for pigs fed no added mineral, or those fed Zn or Cu for the entire trial. Mitogens specific for both B- and T-cell lymphocyte populations were used. To assess the hepatic accumulation of trace minerals, liver biopsies were collected on d 0, 22, and 34.

Results and Discussion

Growth Performance. During phase I (d 0 to 7 postweaning), ADG and F/G were not affected by mineral supplementation. This response contradicts previous research where supplemental Zn from zinc oxide resulted in a dramatic improvement in both ADG and ADFI. Two items may explain the responses observed in phase I: 1) the short period of feeding (7 d versus 14 d in previous research) and 2) the excellent growth of the pigs. The pigs used in this trial were the first set in this nursery following the depopulation/repopulation of our research farm. This contributed to the excellent performance observed in this trial

During phase II (d 7 to 22 postweaning), all pigs remained on the same phase I mineral supplementation except treatment 6. Pigs assigned to treatment 6 were fed a diet containing 3,000 ppm Zn during phase I and a diet with no mineral supplementation during phase II.

Analysis of growth performance during phase II showed that pigs fed the diet containing Zn (treatments 3, 4, and 5) grew faster than pigs fed the diets with no mineral supplementation ($P<.01$) or 250 ppm Cu from copper sulfate ($P<.05$) or the pigs switched from Zn to no supplemental minerals ($P<.01$). Pigs fed the diets with 2,000 ppm Zn had better feed efficiency than pigs fed the control diets ($P<.05$) or pigs fed the diet containing Cu ($P<.10$) and pigs switched from the Zn to the diet containing no supplemental minerals ($P<.10$). Pigs fed the diets containing Zn were almost 1.5 lb heavier ($P<.01$) than pigs fed the control diets and diet containing copper sulfate. This response supports our previous findings that adding Zn in both the phase I and II diets improves growth performance of the weanling pig.

On d 22, pigs were switched to phase III (d 22 to 34) diets. During the first week of phase III (d 22 to 28), pigs fed dietary treatment 6 (Zn d 0 to 22, nothing d 22 to 34) grew faster than the pigs on treatment 5 (Zn d 0 to 22, Cu d 22 to 34; $P<.05$). During the same period, pigs fed treatment 3 (Zn d 0 to 34) had better F/G than pigs fed treatment 5 (Zn d 0 to 22, Cu d 22 to 34). During the second half of phase III (d 28 to 34), no differences were detected for ADG, ADFI, or F/G. However, pigs fed dietary regimen 3 (Zn d 0 to 34) had the lowest ADG and ADFI. This may indicate the start of Zn overload; however, no differences occurred between treatments 3 and 4 in liver mineral levels and whole blood parameters. For the entire phase III period, no differences

were detected for ADG, ADFI, or F/G. However, pigs fed dietary regimen 3 (Zn d 0 to 34) and 4 (Zn d 0 to 22, nothing d 22 to 34) were heavier than pigs fed treatment 1 (nothing d 0 to 34).

For the entire 34 d growth assay, pigs fed dietary mineral regimens 3 (Zn d 0 to 34) and 4 (Zn d 0 to 22, nothing d 22 to 34) grew faster than pigs fed the control mineral regimen, treatment 1 ($P < .05$). The increased weight of the pigs fed the diets containing Zn in the phase I and II diets demonstrates the importance of including zinc oxide in the diets of weanling pigs.

Blood Analysis. Whole blood analysis revealed that numbers of white blood cells, red blood cells, and platelets; hemoglobin; and hematocrit of all pigs were within normal ranges found in the young pig (data not shown). This indicates that the addition of supplemental Cu and Zn did not have a detrimental effect upon whole blood parameters. Differences were found for pigs fed the diet containing Cu during phase I. They had decreased values compared to pigs fed the control and Zn-containing diets for d 7 red blood cell count, hemoglobin, and hematoctrit. Although these differences were significant, the values did not fall outside of levels accepted as normal for the young pig.

The data collected from the assays showed that supplemental Cu and Zn did not affect the plasma ceruloplasmin concentrations.

Leukocyte proliferative assays were conducted on d 0 and 34 to assess the level of immune system activation and the effects that mineral supplementation might have had upon the immune system. The data from both days indicate that, although levels of mitogenic activity were numerically different between treatments, the addition of supplemental Cu and Zn failed to influence lymphocyte proliferative response to mitogen stimulation.

Liver Analysis. Liver samples collected on d 22 indicated that pigs fed the diet with no added Cu or Zn had decreased concentrations of both of these minerals (Table 4). Pigs fed the diet containing Zn (treatments 3 and 4) had elevated levels for Zn and intermediate levels of Cu in the liver. This indicates that the increased dietary Zn was sequestered by the liver and that the addition of Zn to the diet did not inhibit the uptake of Cu.

When liver samples were collected on d 34, the Zn level for pigs switched from the Zn to control diet were actually higher than that for the pigs maintained on the Zn diet. Unlike d 22 liver samples, Cu levels for the two groups of pigs fed Zn during the first two phases were lower compared to the pigs fed the control and Cu-containing diets. This may have been in response to an antagonistic effect of supplementing high levels of Zn in the diet upon Cu uptake by the intestinal brush border. Copper and Zn, apparently are taken up by the same mechanisms; therefore, overloading the pig's gut with Zn may inhibit the uptake of Cu.

The data from both d 22 and 34 liver samples indicate that plasma mineral levels need to be analyzed to more accurately assess the mineral status of the entire pig. When mineral levels of peripheral tissues drop, the liver sequesters the mineral, without regard to levels in the peripheral tissues, to ensure adequate mineral levels in the liver. If the circulating plasma levels of these minerals are different, we may be able to determine whether supplemental Zn and Cu have an effect upon the mineral status of the young pig.

In conclusion, this trial indicates that feeding 3,000 ppm and 2,000 ppm Zn, from zinc oxide, in the phase I and II diets, respectively, resulted in the greatest growth performance during phases I and II. The data further indicate that following the Zn supplementation with Cu resulted in the greatest growth in phase III. The immune status, determined by leukocyte proliferative assay and ceruloplasmin levels, was not affected by mineral supplementation regimen.

Table 1. Dietary Mineral Supplementation Regimens[a]

	Dietary treatments[b]						
Period	1	2	3	4	5	6	7
d 0 to 7	0	0	Zn	Zn	Zn	Zn	Cu
d 7 to 22	0	0	Zn	Zn	Zn	0	Cu
d 22 to 34	0	Cu	Zn	0	Cu	0	Cu

[a]266 pigs were housed at 6 or 7 pigs/pen with 6 replicate pens/treatment.
[b]Zinc was fed at 2,000 ppm during phase I and 2,000 ppm during phases II and III. Copper was fed at 250 ppm throughout the trial.

Table 2. Composition of Diets[a]

Ingredient, %	Phase I	Phase II	Phase III
Corn	45.21	53.79	62.60
Soybean meal (46.5% CP)	16.90	25.86	31.94
Dried whey	20.00	10.00	--
Spray-dried plasma protein	6.70	--	--
Spray-dried blood meal	1.75	2.50	--
Soybean oil	5.00	3.00	--
Monocalcium phosphate	1.47	1.89	1.51
Limestone	.92	.84	1.95
Antibiotic[b]	1.00	1.00	1.00
Cornstarch[c]	.39	.24	.24
DL-Methionine	.15	.08	--
L-Lysine HCl	.10	.15	.11
Vitamin premix	.25	.25	.25
Trace mineral premix	.15	.15	.15
Salt	.10	.25	.35
Total	100.00	100.00	100.00

[a]Pigs were fed the phase I and phase II diets from d 0 to 14 and d 14 to 28, respectively.
[b]Provided 150 g/ton apramycin in phase I diets and 50 g/ton carbadox in phase II and III diets.
[c]Zinc oxide (.393% in phase I, and .24% in phases II and III) and copper sulfate (.093%) replaced cornstarch to from experimental diets.

Table 3. The Effects of Mineral Supplementation Regimen in Starter Pig Diets on Growth Performance[a]

	Mineral treatments[b]										
d 0 to 7	0	0	Zn	Zn	Zn	Zn	Cu				
d 7 to 22	0	0	Zn	Zn	Zn	0	Cu				
d 22 to 34	0	Cu	Zn	0	Cu	0	Cu		Contrasts (P <)		
Item	1	2	3	4	5	6	7	CV	1 vs 3	1 vs 7	3 vs 7
Phase I (d 0 to 7)											
ADG, lb	.70	.65	.68	.67	.68	.69	.67	11.4	.62	.54	.91
F/G	.89	.87	.92	1.00	1.01	.95	.95	16.2	.78	.55	.75
Phase II (d 7 to 22)											
ADG, lb	.82	.82	.94	.95	.88	.80	.85	10.5	.04	.59	.11
F/G	1.48	1.43	1.28	1.44	1.34	1.58	1.57	15.4	.14	.50	.04
Phase III (d 22 to 34)											
d 22 to 28											
ADG, lb	1.05	1.19	1.19	1.06	0.99	1.23	1.11	16.5	.19	.55	.47
F/G	1.89	1.85	1.68	1.96	2.04	1.70	1.84	7.6	.33	.83	.44
d 28 to 34											
ADG, lb	1.54	1.56	1.48	1.64	1.70	1.50	1.62	14.4	.24	.65	.46
F/G	1.84	1.77	1.78	1.769	1.60	1.82	1.76	14.2	.69	.58	.88
Overall											
ADG, lb	1.29	1.37	1.33	1.35	1.35	1.37	1.37	6.8	.46	.17	.51
F/G	1.86	1.71	1.73	1.83	1.74	1.76	1.76	9.5	.19	.30	.77
d 0 to 34											
ADG, lb	.96	.98	1.02	1.03	1.00	.98	.99	4.9	.04	.29	.31
F/G	1.56	1.49	1.43	1.56	1.48	1.56	1.56	9.2	.11	.98	.11
Pig Weights											
d 7	17.38	17.18	17.25	17.13	17.23	17.29	16.89	3.9	.76	.23	.36
d 22	29.73	29.54	31.34	31.35	30.48	29.29	29.69	4.6	.05	.96	.05
d 28	36.00	36.73	38.47	37.69	36.41	36.67	36.42	4.4	.01	.66	.04
d 34	45.24	46.09	47.32	47.51	46.63	45.69	46.16	3.7	.05	.40	.23

[a]Means derived from 266 pigs housed at 6 or 7 pigs/pen and 6 replicate pens/treatment
[b]Zinc was fed at 2,000 ppm during phase I and 2,000 ppm during phases II and III. Copper was fed at 250 ppm throughout the trial.

Table 4. The Effects of Mineral Supplementation Regimen in Starter Pig Diets on Liver Mineral Levels[ab]

Phase I	0	Zn	Zn	Cu							
Phase II	0	Zn	Zn	Cu							
Phase III	0	Zn	0	Cu		Contrasts (P <)					
Item	1	3	4	7	CV	1 - 3	1 - 4	1 - 7	3 - 4	3 - 7	4 - 7
d 22											
Copper, ppm	8.56	63.13	73.73	280.5	55.7	.59	.77	.0002	.80	.0001	.0001
Iron, ppm	445.00	550.83	424.33	346.33	26.8	.14	.77	.17	..08	.01	.27
Manganese, ppm	12.09	8.94	12.44	9.80	36.3	.18	.88	.33	.14	.71	.26
Zinc, ppm	116.32	335.17	293.30	151.18	52.3	.0056	.02	.61	.55	.02	.05
d 34											
Copper, ppm	57.25	30.09	38.35	247.8	123.9	.72	.79	.02	.91	.01	.01
Iron, ppm	562.17	582.06	600.50	471.50	27.5	.84	.67	.32	.85	.26	.17
Manganese, ppm	9.87	7.72	15.29	9.97	91.5	.73	.36	.99	.24	.72	.37
Zinc, ppm	137.10	148.13	194.33	106.10	34.5	.73	.07	.31	.17	.20	.01

[a]Means derived from liver samples collected from one pig/pen/date/diet (6 pigs/treatment/date).
[b]Baseline (d 0) hepatic mineral levels: Cu = 199.74; Fe = 1175.25; Mn = 8.259; Zn = 337.5 ppm.