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ZINC-AMINO ACID COMPLEXES FOR SWINE[1,2,3]

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ABSTRACT

Two experiments were conducted to determine the effect of sources of dietary zinc on gain, feed conversion and blood and bone traits of swine. In the first experiment 96 pigs were used in a 28-d study. The pigs were fed diets with no supplemental Zn or with either 9 or 12 ppm supplemental Zn from zinc sulfate ($ZnSO_4$), zinc methionine (ZnMet) or zinc methionine with picolinic acid (ZnMet w/PA), each with or without 5% added corn oil. There were differences ($P<.05$) in average daily gain (ADG) and average daily feed intake (ADFI) between the pigs fed the two organic Zn sources, with those fed ZnMet w/PA showing the better gains and feed conversion. However, neither organic Zn source resulted in pig performance that was different from either the diet with no supplemental Zn or the diets supplemented with Zn from $ZnSO_4$. In the second experiment the same dietary Zn sources and treatments were fed as in Exp. 1 except that corn oil was deleted as a variable. No differences in ADG, ADFI, feed/gain (F/G) or in changes in serum Zn or Cu were observed among treatments during either the 21-d nursery or the 56-d growing periods. During the subsequent 56-d finishing period ADG and ADFI were greater ($P<.01$) for pigs fed the Zn-supplemented diets than for those fed the diets without supplemental Zn. There were no differences among treatments in F/G during the finishing period. Zn content of bone ash was lower ($P<.01$) in the non-Zn-supplemented pigs. These data suggest that the Zn sources used are of similar biological value and do not support the theory that picolinic acid aids Zn absorption.
(Key Words: Pigs, Zinc, Methionine, Picolinic Acid, Bones.)

Introduction

The use of chemical chelation to improve biological availability of minerals has received increased attention in the last decade. Evans and Hahn (1974) found two metal-binding components in rat intestine and suggested that the low molecular weight fraction was involved with zinc transport across the intestinal epithelium. Subsequently, Evans and Johnson (1979) isolated and characterized a low molecular weight, Zn-binding ligand in human milk. This ligand was identified as picolinic acid, a metabolite of tryptophan and a strong, bidentate chelating agent. Evans (1980) suggested that picolinic acid, produced in the exocrine glands of the pancreas and secreted into the intestinal lumen, forms a zinc complex that facilitates absorption through the mucosal wall. Evidence suggesting that picolinic acid may aid Zn uptake in humans with Zn malabsorption has been reported by Krieger (1980). However, this effect was not observed in Zn-deficient calves (Flagstad, 1981).

Hanson et al. (1958) reported that essential fatty acid deficiency and zinc deficiency in swine were similar in dermal histology, and that supplementation with essential fatty acids was as effective as zinc for the treatment of parakeratosis.

The purpose of the present research was to: 1) determine the nutritional value of inorganic and organic sources of Zn for swine, 2) determine the effect of picolinic acid on Zn uptake and 3) determine the effect of additional essential fatty acids on zinc nutrition of growing-finishing swine.

Experimental Procedure

Exp. 1. Ninety-six crossbred pigs (Yorkshire × Landrace × Hampshire) were randomly allotted to a 4 × 2 factorial arrangement of treatments. The dietary treatments were: no supplemental Zn, zinc sulfate ($ZnSO_4 \cdot H_2O$),

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zinc methionine (ZnMet) and zinc methionine with picolinic acid (ZnMet w/PA), each fed with or without 5% added corn oil as an essential fatty acid source. There were three pens/treatment with two barrows and two gilts/pen. Average initial weight of the pigs for the 28-d study was 13.0 kg. Feed and water were offered ad libitum. The experimental pens had concrete walls and floors. Feeders were made of galvanized metal, but were painted with a non-Zn-based paint to minimize intake of non-dietary sources of Zn. All other sources of possible environmental zinc contamination were minimized as much as was practical. Water supplied from nipple waterers was from the City of Lincoln, Nebraska and contained 1.1 ppm Zn by analysis. The corn-soybean meal basal diet (composition and analysis presented in table 1) was formulated to meet NRC (1979) requirements (except Zn) and to contain 18% crude protein, .65% Ca and .50% P. The low zinc levels were used to create a zinc-stress situation for the pigs and thus, accentuate any differences among zinc sources. Detection of possible differences among sources would be minimized if adequate zinc levels were fed. By analysis, diets with no added corn oil contained 36 ppm Zn; those diets with 5% added corn oil contained 33 ppm Zn. The Zn-supplemented diets were formulated to contain 45 ppm total Zn. Pigs were weighed at 7-d intervals. Non-fasted blood samples were taken initially and at 14-d intervals for serum Zn, Cu and albumin determinations. Blood samples were taken from the brachial region of each pig using a blood-collecting syringe[7]. Serum was prepared for analysis by diluting 1.0 ml serum with 4.0 ml .1 N HCl for Zn and Cu determination by atomic absorption spectroscopy. Serum albumin was analyzed by the bromocresol green method of Doumas et al. (1971). A skin scoring system, similar to that described by Lewis et al. (1956), was used to assess visual evidence of parakeratotic lesions, with a score of 1 indicating no lesions and 5 indicating severe lesions. The composite scores of seven evaluators were used for skin lesions. All response criteria were analyzed by orthogonal contrasts as described by Steel and Torrie (1980) and calculated by the Statistical Analysis System (SAS, 1979).

[7]Serum Monovette #02,263, Walter Sarstedt, Inc., U.S. Rt. 1, Princeton, NJ 08540.

Exp. 2. Two hundred forty Yorkshire x Landrace pigs were fed the same four Zn treatments that were fed in Exp. 1. Corn oil was deleted as a variable in this experiment. During the nursery phase each treatment was replicated three times with 10 barrows and 10 gilts randomly assigned to each replicate. Average initial pig weight was 7.5 kg for the 21-d nursery phase. Ninety-six pigs (four barrows and four gilts/replicate) nearest the mean pen weight were pre-selected for bleeding and continuation through a 112-d growing-finishing phase. Average pig weight at the start of the growing-finishing phase was 16.2 kg. Feed and water were offered ad libitum. Possible environmental zinc contamination was again minimized as much as was practical. Water contained .4 ppm Zn by analysis. Feeders were made of stainless steel for the nursery phase and wood for the growing-finishing phase. The basal diet was composed primarily of corn, soybean meal and cornstarch (composition and analysis, table 2). The nursery diets were formulated to contain 16% crude protein, .65% Ca, .50% P and 26 ppm Zn. The growing-finishing basal diet was formulated to contain 14% crude protein, .65% Ca, .50% P and 24 ppm Zn. The Zn-supplemented diets were formulated to contain 40 ppm total Zn. Pigs were weighed at weekly intervals during the nursery phase and at 2-wk intervals during the remainder of the experiment. Non-fasted blood samples were taken initially, at the end of the nursery period and at 28-d intervals during the remainder of the study. Serum samples were analyzed as described previously.

At the end of the experiment, three barrows and one gilt from each replicate were slaughtered and the metatarsals of the left hind foot were collected from each animal for subsequent bone analysis. The feet were autoclaved at 121 C for 15 min to facilitate removal of muscle and connective tissue from the bones. Physical properties and strength of each metatarsal were measured as described by Crenshaw et al. (1981). The bones were then sectioned and dried at 105 C overnight. The dried bones were next extracted with anhydrous ethyl ether for 36 h. The dried fat-free bones were then ashed at 600 C for 8 h. The ashed bones were ground to a fine powder and samples of the powdered ash were dissolved in 20 ml 6 N HCl, filtered, and diluted appropriately for analysis of Ca, Zn and Cu by atomic absorption spectroscopy. Samples of the extracted filtrate were analyzed

TABLE 1. DIET COMPOSITION (EXP. 1)

Item	Treatments							
	Basal		$ZnSO_4$		ZnMet		ZnMet w/PA	
	1	2	3	4	5	6	7	8
	–[a]	+[a]	–	+	–	+	–	+
	g/kg							
Ingredient								
Corn (IFN 4-02-861)	576.0	520.0	576.0	520.0	576.0	520.0	576.0	520.0
Soybean meal (44% protein; IFN 5-04-604)	243.0	249.0	243.0	249.0	243.0	249.0	243.0	249.0
Sugar (IFN 4-04-701)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Dried whey (IFN 4-01-186)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Corn oil		50.0		50.0		50.0		50.0
Dicalcium phosphate (18.5% P; IFN 6-01-080)	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Limestone (IFN 6-02-632)	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Iodized salt	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Trace mineral mix[b]	.5	.5	.5	.5	.5	.5	.5	.5
Vitamin premix[c] + CSP 250[d]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
$ZnSO_4 \cdot H_2O$, mg/kg[e]			40.0	52.4				
ZnMet, mg/kg[e]					45.5	59.4		
ZnMet w/PA, mg/kg[e]							53.5	70.0
Total	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0
Analysis								
Protein, %	17.3	17.2	17.3	17.1	17.5	16.9	17.4	17.0
Ca, %	.62	.60	.65	.59	.64	.60	.62	.59
P, %	.56	.53	.54	.52	.56	.55	.55	.53
Zn, mg/kg	36	33	40	41	43	42	46	40

[a]Corn oil.

[b]Provided the following in mg/kg complete diet: Fe, 100; Mn, 50; Cu, 10.

[c]Provided the following per kg of complete diet: vitamin A, 3,300 IU; vitamin D_3, 440 IU; vitamin E, 22 IU; riboflavin, 2.2 mg; D-pantothenic acid, 13.2 mg; niacin, 17.6 mg; choline chloride, 770 mg; vitamin B_{12}, 22 μg; menadione sodium bisulfite, 2.2 mg; ethoxyquin, 4.4 mg.

[d]Chlorotetracycline .11 g/kg, sulfamethazine .11 g/kg and penicillin .055 g/kg.

[e]Provided 9 mg Zn/kg to diets without corn oil and 12 mg Zn/kg to diets with added corn oil; diets 1, 3, 5 and 7 were not isocaloric with diets 2, 4, 6 and 8.

TABLE 2. DIET COMPOSITION (EXP. 2)

Item	Treatments							
	Nursery phase				Growing-finishing phase			
	Basal 1	$ZnSO_4$ 2	ZnMet 3	ZnMet w/PA 4	Basal 1	$ZnSO_4$ 2	ZnMet 3	ZnMet w/PA 4
	g/kg[a]							
Ingredient								
Corn (IFN 4-02-861)	271.4	271.4	271.4	271.4	327.2	327.2	327.2	327.2
Soybean meal (44% protein; IFN 5-04-604)	310.5	310.5	310.5	310.5	254.0	254.0	254.0	254.0
Tallow (IFN 4-08-127)	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Corn starch	250.0	250.0	250.0	250.0	350.0	350.0	350.0	350.0
Sugar (IFN 4-04-701)	100.0	100.0	100.0	100.0				
Dicalcium phosphate (18.5% P; IFN 6-01-080)	12.8	12.8	12.8	12.8	13.8	13.8	13.8	13.8
Limestone (IFN 6-02-632)	6.8	6.8	6.8	6.8	6.5	6.5	6.5	6.5
Iodized salt	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Trace mineral mix[a]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Vitamin premix[b] + antibiotic[c]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Selenium premix[d]	.5	.5	.5	.5	.5	.5	.5	.5
$ZnSO_4 \cdot H_2O$, mg/kg[e]		66.1				66.1		
ZnMet, mg/kg[e]			75.1				75.1	
ZnMet w/PA, mg/kg[e]				88.3				88.3
Total	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0	1,000.0
Analysis								
Protein, %	16.3	16.2	16.5	16.3	14.3	14.1	14.2	13.8
Ca, %	.67	.65	.62	.61	.61	.61	.63	.58
P, %	.53	.58	.57	.52	.50	.52	.51	.47
Zn, mg/kg	27	42	42	39	23	36	34	36

[a]Provided the following in mg/kg complete diet: Fe, 100; Mn, 50; Cu, 10.

[b]Provided the following per kg of complete diet: vitamin A, 3,300 IU; vitamin D_3, 440 IU; vitamin E, 22 IU; riboflavin, 2.2 mg; D-pantothenic acid, 13.2 mg; niacin, 17.6 mg; choline chloride, 770 mg; vitamin B_{12}, 22 μg; menadione sodium bisulfite, 2.2 mg; ethoxyquin, 4.4 mg.

[c]Nursery phase, carbadox .055 g/kg complete diet; growing-finishing phase terramycin, .055 g/kg complete diet.

[d]Provided .1 mg Se per kg complete diet.

[e]Provided 15 mg Zn/kg complete diet; included in trace mineral mix in the amounts listed above.

for P by modification of methods described by AOAC (1980), using p-methyl-aminophenol sulfate as the reducing agent.

Data were analyzed statistically as described for Exp. 1.

Results and Discussion

Exp. 1. The effects of source of supplemental Zn and level of corn oil on average daily gain (ADG), average daily feed intake (ADFI) and feed/gain (F/G) are summarized in table 3. Pigs fed diets with ZnMet w/PA consumed more feed and gained faster ($P<.05$) than pigs fed diets with ZnMet. There were, however, no differences between pigs fed the two organic Zn sources and pigs fed the unsupplemented basal diets or the basal diets plus 9 or 12 ppm Zn from $ZnSO_4$. Overall, pigs fed diets with ZnMet w/PA tended to gain faster and consume more feed than those fed the other diets.

Pigs fed the diets with 5% added corn oil ate less feed than the pigs fed the diets without corn oil, probably a reflection of differences in energy levels between the diets. As expected, the addition of 5% corn oil improved ($P<.05$) the efficiency of feed conversion. There were no interactions observed between Zn source and corn oil addition for ADG, ADFI or F/G.

The effects of Zn source and addition of corn oil on changes in serum Zn, Cu and albumin are presented in table 4. The values represent the change between the initial and final bleedings. The values are expressed in this manner to minimize effects of initial individual pig variations. The change in serum Zn was greater ($P<.05$) in pigs fed the diets with 5% corn oil than in pigs fed the diets without corn oil. This is probably due to the lower ADFI of the pigs fed the diets with corn oil. The reduction in serum Zn was accompanied by a corresponding increase in serum Cu and reflects the

TABLE 3. EFFECT OF ZINC SOURCE AND CORN OIL ADDITION ON PIG PERFORMANCE (EXP. 1)[a]

Zinc source	Added corn oil 0%	Added corn oil 5%	Avg for Zn source	CV[b]
	Avg daily gain, kg[c]			7.70
No Zn supplement	.69	.71	.70	
$ZnSO_4$	.68	.69	.69	
ZnMet	.64	.67	.66	
ZnMet w/PA	.72	.73	.73	
Avg for corn oil	.68	.70		
	Avg daily feed intake[c], kg			12.90
No Zn supplement	.98	.89	.94	
$ZnSO_4$	.97	.94	.96	
ZnMet	.88	.87	.88	
ZnMet w/PA	1.07	1.00	1.04	
Avg for corn oil	.98	.93		
	Feed/gain[d]			7.22
No Zn supplement	1.41	1.25	1.33	
$ZnSO_4$	1.42	1.35	1.39	
ZnMet	1.38	1.29	1.34	
ZnMet w/PA	1.48	1.38	1.43	
Avg for corn oil	1.42	1.32		

[a] 28-d test period; avg initial wt 13.0 kg.

[b] Coefficient of variation.

[c] ZnMet vs ZnMet w/PA ($P<.05$).

[d] 0% vs 5% corn oil ($P<.05$).

TABLE 4. EFFECT OF ZINC SOURCE AND CORN OIL ADDITION ON CHANGE (FINAL-INITIAL) IN SERUM ZINC, COPPER AND ALBUMIN (EXP. 1)

Zinc source	Added corn oil 0%	Added corn oil 5%	Avg for Zn source	CV[a]
	Change in serum Zn[b], mg/dl			81.61
No Zn supplement	−.34	−.71	−.53	
$ZnSO_4$	−.48	−.59	−.54	
ZnMet	−.54	−.54	−.54	
ZnMet w/PA	−.33	−.65	−.49	
Avg for corn oil	−.42	−.62		
	Change in serum Cu[c], mg/dl			169.35
No Zn supplement	.08	.20	.14	
$ZnSO_4$	.09	.13	.11	
ZnMet	.16	.25	.21	
ZnMet w/PA	.28	.03	.16	
Avg for corn oil	.15	.15		
	Change in serum albumin[c], g/dl			58.47
No Zn supplement	−1.02	−1.45	−1.24	
$ZnSO_4$	−1.13	−1.35	−1.24	
ZnMet	−1.16	−1.22	−1.19	
ZnMet w/PA	−.91	−.97	−.94	
Avg for corn oil	−1.06	−1.25		

[a]Coefficient of variation.

[b]0% vs 5% added corn oil ($P<.05$).

[c]None of the differences were significant.

well-documented Zn-Cu biological interaction (Ritchie et al., 1963). None of the other changes in serum Zn, serum Cu or albumin were different among treatments.

Serum albumin is considered to be the primary carrier of readily available Zn in the body (Smith et al., 1979). Because no differences were observed among treatments for changes in serum albumin, any differences in performance or blood criteria apparently were not due to differences in amounts of carrier proteins.

Overall, skin scores for parakeratosis revealed a slight to moderate dermatitis in the ventral areas between the hind legs, with only a few of the pigs having any major involvement. The overall average lesion score was 1.49. No differences were found among treatments.

Exp. 2. The effects of Zn source on ADG, ADFI and FG conversion are presented in table 5. During the 21-d nursery phase there were no differences among treatments for ADG or ADFI. Pigs fed the two organic Zn sources had a better F/G ($P<.06$) than those fed $ZnSO_4$. None of the Zn-supplemented diets resulted in F/G ratios that were different from pigs fed the non-Zn-supplemented diet. This finding is consistent with the results of Exp. 1.

None of the differences in performance observed during the 56-d growing phase were significant. During the 56-d finishing period, pigs fed the Zn-supplemented diets had greater ($P<.01$) ADG and ADFI than pigs fed the unsupplemented diet. No differences in feed conversion among treatments were observed during this phase.

The effect of Zn source on change in serum Zn and Cu is presented in table 6. The changes represent the difference between the initial and final concentrations during each phase of the study. Differences in serum Zn between the two experiments are probably due to differences in Zn content of diets prior to the start of each experiment (70 ppm Zn previous to Exp. 1 and 30 ppm Zn prior to Exp. 2). None of the differences among treatments were significant

TABLE 5. EFFECT OF ZINC SOURCE ON PIG PERFORMANCE DURING NURSERY, GROWING AND FINISHING PHASES (EXP. 2)

Period	No Zn supplement	Zn source[a]			CV[b]
		$ZnSO_4$	ZnMet	ZnMet w/PA	
Nursery phase[c]					
ADG, kg	.42	.40	.40	.42	4.88
ADFI, kg	.70	.68	.66	.70	5.14
F/G	1.67	1.72	1.63	1.66	2.56
Growing phase[d]					
ADG, kg	.62	.62	.64	.64	4.62
ADFI, kg	1.56	1.51	1.55	1.48	5.53
F/G	2.51	2.42	2.43	2.32	6.35
Finishing phase[e]					
ADG[f], kg	.74	.79	.81	.82	3.05
ADFI[g], kg	2.29	2.39	2.46	2.55	2.26
F/G	3.08	3.04	3.05	3.10	1.81

[a]Each source supplied 15 ppm of supplemental Zn.

[b]Coefficient of variation.

[c]21-d test period; avg initial wt 7.5 kg.

[d]56-d test period; wt range 16.2 to 51.5 kg.

[e]56-d test period; wt range 51.5 to 95.8 kg.

[f]No supplemental Zn vs supplemental Zn ($P<.01$).

[g]$ZnSO_4$ vs organic Zn ($P<.05$).

during the nursery or growing phases. During the finishing phase there was a difference ($P<.06$) in the change in serum Zn between pigs fed ZnMet and ZnMet w/PA, with the pigs fed the ZnMet w/PA showing an increase in serum Zn concentration. The pigs fed ZnMet exhibited no change in serum Zn. However, changes in serum Zn in pigs fed diets with the organic Zn sources were not different ($P>.46$) from pigs fed the non-Zn-supplemented or $ZnSO_4$ diets. Changes in serum Cu were different ($P<.05$) between the non-Zn-supplemented and Zn supplemented pigs, with the pigs fed the non-Zn-supplemented diets showing the greater increase in serum Cu levels. The minimal changes in serum levels would indicate that the pigs were very near homeostasis with respect to Zn and Cu.

The bone data presented in tables 7, 8 and 9 are the average values of the third and fourth metatarsal bones from 12 pigs per treatment. The effect of Zn source on bone mineralization is shown in table 7. No differences were observed in the percentage of bone ash or Ca. Pigs fed ZnMet w/PA had a lower ($P<.01$) P content than those fed ZnMet (17.02 vs 17.45%). Zn content of the bone ash was lower ($P<.01$) in pigs fed the non-Zn-supplemented control diet than pigs fed the Zn-supplemented diets. Thus, the Zn content of bones reflected the amount of Zn in the diets and the Zn apparently available for body storage. There were no differences due to treatments in amounts of Cu in bone ash.

The effects of Zn source on bone physical characteristics are presented in table 8. The outside diameters of the bones in both the perpendicular and parallel axes (with respect to direction of forces applied during testing) were larger ($P<.05$) in pigs fed the Zn-supplemented diets than in pigs fed diets without supplemental Zn. This same effect was also observed ($P<.01$) for the inside diameter measurements. The net result was smaller diameter bones in pigs fed the diets without supplemental Zn, but there were no differences in bone wall thickness ($P>.71$) or dry fat-free weight ($P>.18$).

The effect of Zn source on mechanical characteristics of bones is presented in table 9. Peak force, a flexure test to measure compressive and tensile forces that bones can withstand, was not different ($P>.18$) among treatments. The moment of inertia (a measure of kinetic energy of the bone matrix with consideration for

TABLE 6. EFFECT OF ZINC SOURCE ON CHANGE (FINAL-INITIAL) IN SERUM ZINC AND COPPER CONCENTRATION DURING NURSERY, GROWING AND FINISHING PHASES (EXP. 2)

Period	No Zn supplement	Zn source[a]			CV[b]
		$ZnSO_4$	ZnMet	ZnMet w/PA	
Nursery phase[c]					
Change serum Zn, mg/dl	−.15	−.04	−.11	−.11	66.53
Change serum Cu, mg/dl	.24	.19	.10	.14	75.68
Growing phase[d]					
Change serum Zn, mg/dl	.15	.16	.23	.19	36.23
Change serum Cu, mg/dl	.38	.34	.37	.29	18.41
Finishing phase[e]					
Change serum Zn[f], mg/dl	.04	.01	.00	.07	145.77
Change serum Cu[g], mg/dl	.34	.16	.21	.19	30.55

[a]Each source supplied 15 ppm of supplemental Zn.

[b]Coefficient of variation.

[c]21-d test period; wt range 7.5 to 16.2 kg.

[d]56-d test period; wt range 16.2 to 51.5 kg.

[e]56-d test period; wt range 51.5 to 95.8 kg.

[f]ZnMet vs ZnMet w/PA ($P<.06$).

[g]No supplemental Zn vs supplemental Zn ($P<.05$).

geometrical shape) was greater ($P<.05$) in bones from pigs fed the Zn-supplemented diets (.21 cm^4) than in bones from pigs fed the diets without supplemental Zn (.17 cm^4). The distance from the neutral axis to the extreme outer fiber of the bone (C) was different ($P<.10$) between non-Zn-supplemented pigs and Zn-supplemented pigs and is a reflection of the differences in inside and outside diameters described previously. Stress, a calculated value of force per unit area recognizing the complex geometrical shape to which the force is applied, was higher ($P<.10$) in bones from pigs fed diets without supplemental Zn than in bones from pigs fed added Zn.

Deformation is a measure of a bone's capacity to bend during testing. Means for this response were different ($P<.10$) between the two organic Zn sources, with bones from pigs fed the ZnMet w/PA exhibiting greater flexibility (.35 cm for pigs fed ZnMet vs .54 cm for pigs fed ZnMet w/PA). Modulus of elasticity is a measure of

TABLE 7. EFFECT OF ZINC SOURCE ON MINERAL CONTENT OF METATARSAL BONES (EXP. 2)[a]

Criteria	No Zn supplement	Zn source[b]			CV[c]
		$ZnSO_4$	ZnMet	ZnMet w/PA	
Bone ash, %	61.59	61.89	61.78	62.26	1.59
Ca, %	33.74	33.60	33.19	33.62	1.88
P[d], %	17.34	17.35	17.45	17.02	.75
Zn[e], ppm	147.7	180.3	169.9	176.5	5.73
Cu, ppm	4.6	4.6	4.5	4.6	7.22

[a]Values are an average of 12 pigs per treatment, expressed on dry, fat-free basis.

[b]Each source supplied 15 ppm of Zn.

[c]Coefficient of variation.

[d]ZnMet vs ZnMet w/PA different ($P<.01$).

[e]No supplemental Zn vs supplemental Zn ($P<.01$).

TABLE 8. EFFECT OF ZINC SOURCE ON PHYSICAL CHARACTERISTICS OF METATARSAL BONES[a] (EXP. 2)

Criteria	No Zn supplement	Zn source[b]			CV[c]
		$ZnSO_4$	ZnMet	ZnMet w/PA	
Length, cm	8.05	8.04	8.03	8.04	2.02
ODPD[de], cm	1.29	1.32	1.36	1.33	2.16
ODPL[ef], cm	1.47	1.54	1.55	1.53	2.22
IDPD[gi], cm	.92	.98	1.01	.98	1.18
IDPL[hi], cm	1.01	1.05	1.06	1.03	1.25
BWT[j], cm	.21	.21	.21	.21	1.92
DFF[k], g	12.37	12.70	12.79	13.01	3.68

[a]Values are an average of 12 pigs per treatment.

[b]Each source supplied 15 ppm of Zn.

[c]Coefficient of variation.

[d]ODPD = outside diameter perpendicular to application of force.

[e]No supplemental Zn vs supplemental Zn ($P<.05$).

[f]ODPL = outside diameter parallel to application of force.

[g]IDPD = inside diameter perpendicular to application of force.

[h]IDPL = inside diameter parallel to application of force.

[i]No supplemental Zn vs supplemental Zn ($P<.01$).

[j]BWT = bone wall thickness [(ODPD − IDPD) + (ODPL − IDPL)] /4.

[k]DFF = dry, fat-free wt.

rigidity and the capacity of bone to return to its original shape after deformation. The higher the modulus of elasticity the more rigid the bone. Treatment means for this trait were not different ($P>.16$), but there was a tendency for the bones from the non-Zn-supplemented pigs to be more rigid than bones from the Zn-supplemented pigs. There was also a tendency for the bones from pigs fed the ZnMet w/PA to be more flexible than the bones from pigs fed the $ZnSO_4$ or ZnMet. Bones from pigs fed the diets with ZnMet w/PA had the greatest defor-

TABLE 9. EFFECT OF ZINC SOURCE ON MECHANICAL CHARACTERISTICS OF METATARSAL BONES[a] (EXP. 2)

Criteria	No Zn supplement	Zn source[b]			CV[c]
		$ZnSO_4$	ZnMet	ZnMet w/PA	
Peak force, kg	127.7	125.0	132.3	139.3	7.75
Moment of inertia, cm^4	.17	.20	.22	.20	9.39
C[de], cm	.85	.89	.89	.88	2.22
Stress, kg/cm^2	810	710	720	790	6.92
Deformation[f], cm	.36	.36	.35	.54	25.79
Modulus of elasticity, kg/cm^2	6046	5084	5297	4054	22.59

[a]Values are an average of 12 pigs per treatment.

[b]Each source supplied 15 ppm of Zn.

[c]Coefficient of variation.

[d]C is the distance from the neutral axis to the extreme outer fiber of the bone.

[e]No supplemental Zn vs supplemental Zn ($P<.10$).

[f]ZnMet vs ZnMet w/PA ($P<.10$).

mation, the lowest modulus of elasticity and the lowest P content. Together these three factors suggest that there may be a metabolic interaction between P mineralization of bone and picolinic acid.

The low level of Zn in the control diet (50% of 1979 NRC requirement) did not result in differences among treatments in percent bone ash or the proportion of Ca, P or Cu in the bone ash. Low dietary Zn did, however, depress Zn concentration in the bone ash as one might expect. The low Zn diet also resulted in bones of less thickness but greater strength and a tendency for greater rigidity. This indicates that the bones from pigs on the low Zn diet may have had a more tightly bound mineral matrix and a more compact bone, resulting in the same amount of mineralization of bones of lesser thickness.

None of the differences in mechanical characteristics of bone between the $ZnSO_4$ and the two organic Zn sources were significant. There was a general trend for the bones from pigs fed the ZnMet w/PA to have greater peak force (bone breaking strength), higher stress value, greater deformation values and lower modulus of elasticity (less rigidity) than bones from pigs fed the other three treatments, suggesting that the bones from pigs fed the ZnMet w/PA had strong but relatively flexible bones which may be an advantage for pigs reared in total confinement.

The data presented suggest that the Zn sources used are of similar biological value and the data do not support the theory that picolinic acid aids Zn absorption.

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