Effects of Feeding Different Chelated Copper and Zinc Sources on Growth Performance and Fecal Excretions of Weanling Pigs**

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ABSTRACT : Two feeding trials were conducted to study the effects of different chelated copper and zinc compounds on the performance and fecal excretions of weanling pigs. In Exp. 1, 150 weanling pigs (L×Y×D, 12.30±2.07 kg) were randomly assigned to five dietary treatments: 170 ppm Cu from $CuSO_4$, 85 ppm Cu from Cu amino-chelate (CAC), 170 ppm Cu from CAC, 85 ppm Cu from Cu-Lysine (CL), and 170 ppm Cu from CL. In Exp. 2, 150 weanling pigs (L×Y×D, 12.52±1.80 kg) were randomly assigned to five dietary treatments: 120 ppm Zn from $ZnSO_4$, 60 ppm Zn from Zn-amino-chelate (ZAC), 120 ppm Zn from ZAC, 60 ppm Zn from Zn-Methionine (ZM), and 120 ppm Zn from ZM. In both experiments, pigs were randomly distributed to the treatments following a randomized complete block design on the basis of body weight as the blocking variable. Each experiment was conducted for 28 days. Blood and fecal samples were collected to determine mineral contents as affected by the dietary treatments. There was no difference ($p>0.05$) in ADG and ADFI among treatments, but F/G was improved ($p<0.05$) in pigs fed diet with 170 ppm CAC than 85 ppm CL but not different ($p>0.05$) to the control (170 ppm $CuSO_4$). Regardless of copper source, concentration of Cu in serum and feces were higher in pigs fed diet with 170 ppm Cu than pigs fed diet with 85 ppm Cu (Exp 1). In Exp 2 the ADG was higher ($p<0.05$) in pigs fed diet with 120 ppm ZM than in pigs fed diets with 120 ppm $ZnSO_4$ and 60 ppm ZAC and ZM. The serum zinc concentration was generally higher ($p<0.05$) in pigs fed diet with organic source than the control group ($ZnSO_4$). Also, there was a trend towards a decrease in fecal excretions of zinc when dietary zinc level was low. The efficacy of the two chelated copper and zinc sources is similar in terms of growth performance. The fecal excretions for Cu and Zn could be reduced in pigs fed low level of these minerals using organic sources.
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Key Words : Cu, Zn, Chelate, Complex, Excretion

INTRODUCTION

Improvements in growth performance of weanling pigs fed diets containing high levels of copper and zinc have been widely accepted in swine industry.

Copper requirement is very low (5-6 ppm) in young pigs (NRC, 1998). However, copper has growth stimulating effect at high inclusion rate. Copper stimulates growth of pigs when fed at the levels of 100 to 250 ppm as copper sulfate as well reviewed by NRC (1998) and Han (2000). Likewise, a growth promoting effect of zinc has been reported in weanling pigs fed diets containing high levels of zinc (2,000-3,000 ppm Zn from zinc oxide) (Kavanagh, 1992; Hill et al., 1986). Contradictory reports were also demonstrated by Schell and Kornegay (1996).

On the other hand, the biological availabilities of copper and zinc are affected by sources and animal species (Ammerman et al., 1995). In pigs, copper salts such as copper sulfate are more bioavailable than cupric sulfide and cupric oxide (Cromwell et al., 1998; Sazzad et al., 1993). Among zinc sources which are commonly used in young pig diets, zinc sulfate is also more bioavailable than zinc oxide (NRC, 1998).

Interest in using organic mineral complexes as mineral sources for animals has increased because of higher bioavailability than inorganic mineral sources (Schell and Kornegay, 1996). As listed in AAFCO (1997), these chelated organic minerals include metal amino acid chelates- a soluble metal salt with amino acids, metal amino acid complexes- a soluble metal with an amino acid, or metal proteinates- a soluble salt with amino acids and/or partially hydrolyzed protein.

The results of feeding these organic minerals have been inconsistent in pigs. Several researchers reported that organic complexes of copper appeared to have equal bioavailability to copper sulfate (Stansbury et al., 1990; van Heugten and Coffey, 1992; Coffey et al., 1994; Apgar et al., 1995), while Zhou et al. (1994) reported that pigs fed copper lysine complex grew faster than those fed copper sulfate. Hill et al. (1986) and Swinkels et al. (1991) also reported that there was no difference in zinc bioavailability between organic and inorganic zinc sources. But limited data are available to compare the efficacy of chelated Cu and Zn sources between metal amino chelates and metal amino complexes.

Therefore, the objectives of this study were to compare

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the effect of the different chelated copper and zinc sources on the growth performance and fecal excretions of weanling pigs.

MATERIALS AND METHODS

Experimental design, animals and diets

Two feeding trials were conducted to study the effects of different chelated copper and zinc sources on the performance and fecal excretions of weanling pigs. Five dietary treatments were used in both experiments. In exp. 1, the control diet contained 170 ppm Cu from $CuSO_4$. Diets 2 and 3 contained 85 and 170 ppm Cu from Cu-amino acid chelate (CAC), respectively. Cu-Lysine (CL) was used as source of copper for diets 4 and 5 containing 85 and 170 ppm Cu, respectively. On the other hand, the control diet in exp. 2 contained 120 ppm Zn from $ZnSO_4$. Diets 2 and 3 contained 60 and 120 ppm Zn from Zn-amino chelate (ZAC), respectively. Zn-methionine (ZM) provided 60 and 120 ppm Zn for diets 4 and 5, respectively. CAC, CL, ZAC, and ZM were obtained from Tongwoo Mineral Company, Korea. All diets were formulated to meet or exceed the nutrient requirements listed in NRC (1998) (table 1).

In each experiment, 150 weaned pigs (L×Y×D) with an average body weight of 12.30±2.07 kg and 12.52±1.81 kg for Exp. 1 and 2, respectively were allotted to 5 dietary treatments in a randomized complete block design, on the basis of body weight as the blocking variable. Three replications of thirty pigs per replicate were used for each treatment.

Each experiment was conducted for 28 days. Pigs were housed in pens (180 cm × 190 cm) with partially slotted floors (55.50%) and were fed their treatment diet *ad libitum* and free access to water from nipple waterers. Pigs were weighed and feed intake was recorded at d 0, d 14 and d 28. Blood samples were collected from nine pigs per treatment on d 14. Pigs were bled via venipuncture from the jugular vein 4 h after feeding. Blood samples were centrifuged (Rotina 48R, Hettich, Germany) at 3,000 rpm for 15 minutes. Serum was carefully removed into plastic vials and stored at -20°C until mineral analyses.

Digestibility trial

Determination of nutrient digestibility was conducted and initiated at d 21 during each experiment. Extra fifteen growing pigs were used for each experiment. Pigs were placed in individual metabolic cages and randomly allotted to 5 dietary treatments. Each treatment was replicated 3 times. Pigs were fed diet containing 0.25% chromic oxide for 4 days. A grab sample of feces was taken from each pig for 3 days. Fecal samples were pooled, dried in an air forced drying oven at 60°C and ground with a 1 mm mesh Wiley mill for chemical analyses.

Chemical and statistical analyses

Proximate analysis of experimental diets and fecal samples were carried out according to AOAC (1990) method. Chromium (Cr) and phosphorus (P) were determined using UV-vis spectrophotometer (V-550, Jasco, Japan). Gross energy value of diets and feces were measured using an adiabatic oxygen bomb calorimeter (Model 1261, Parr Instrument Co., Molin, IL). Serum and fecal samples were analyzed for copper (Cu) and zinc (Zn) using atomic absorption spectrophotometer (GBC-904: GBC, Aus.).

Data collected in both experiments were subjected to analyses of variance using the General Linear Model (GLM) Procedure of SAS (1985). Treatment mean comparison was done using the Duncans Multiple Range Test (DMRT) (Duncan, 1955).

Table 1. Ingredient and calculated nutrient composition of basal diet for both Exp. 1 and 2

Ingredient	%
Corn	50.78
Soybean meal	33.30
Bakery-byproduct	5.00
Animal fat	4.70
Fish meal	3.00
Dicalcium phosphate	1.35
Limestone	0.60
Vitamin premix[1]	0.30
Trace mineral premix[2]	0.20
Salt	0.30
L-Lysine (78%)	0.12
CTC	0.10
Mecadox[3]	0.10
DL-Methionine (50%)	0.10
Choline chloride (25%)	0.05
Total	100.00
Calculated nutrient composition	
ME (kcal/kg)	3,400
Crude protein	20.98
Calcium	0.78
Av. Phosphorus	0.40
Lysine	1.30
Met+Cys	0.74

[1] Supplied per kg diet: 1,750 IU vitamin A, 200 IU vitamin D_3, 11 IU vitamin E, 0.50 mg vitamin K, 0.05 mg biotin, 0.40 g choline, 0.30 mg folacin, 12.50 mg niacin, 9.00 mg pantothenic acid, 3.00 mg riboflavin, 1.00 mg thiamin, 1.50 mg vitamin B_6, 15.00 μg vitamin B_{12}.

[2] Trace minerals except Cu and Zn supplied per kg diet: 0.25 mg Mn, 3 mg Fe, 80 mg I, 0.25 mg Se.

[3] Per kg diet: 50 mg mecadox.

RESULTS

Experiment 1

There were no differences in ADG observed among treatments (table 2), but the ADFI of pigs fed diet with 170 ppm CAC was lower ($p<0.05$) than the control after the 2nd week of feeding. Also, the overall F/G ratio of pigs fed diet with 170 ppm CAC was improved ($p<0.05$) compared to pigs fed diet with 85 ppm CL but not different ($p>0.05$) from the control.

Copper concentrations in the serum taken from pigs fed diet with 85 ppm CAC or CL were lower ($p<0.05$) as compared to 170 ppm (table 3). Also Cu contents in feces were higher ($p<0.05$) in pigs fed diet with 170 ppm than 85 ppm, regardless of Cu source. Digestibility of nutrients was not affected by feeding different sources of Cu.

Table 2. Growth performance of weaning pigs fed diet with Cu-amino-chelate (CAC) and Cu-lysine (CL)

	$CuSO_4$ (170)	CAC (ppm)		CL (ppm)		SE
		85	170	85	170	
0-2 week						
ADG, g	596	561	554	568	588	28.25
ADFI[1], g	874[a]	806[ab]	733[b]	855[ab]	863[ab]	79.45
F/G	1.47	1.43	1.32	1.50	1.47	0.17
2-4 week						
ADG, g	683	637	701	641	643	29.78
ADFI, g	1155	1169	1167	1189	1160	75.45
F/G	1.69	1.84	1.67	1.85	1.81	0.20
0-4 week						
ADG, g	639	587	628	605	616	25.04
ADFI, g	1003	967	950	1022	1012	85.74
F/G[1]	1.57[ab]	1.65[ab]	1.51[b]	1.69[a]	1.64[ab]	0.17

[1] Values with different superscripts of the same row are significantly different ($p<0.05$).

Experiment 2

There were no differences among treatments in the ADG, ADFI, and F/G ratio of pigs between 0-2 or 2-4 weeks of feeding. But the overall ADG of pigs fed 120 ppm ZM was higher ($p<0.05$) than in pigs fed the control diet and pigs fed diet with 60 ppm, either from ZAC or ZM (table 4).

Serum Zn concentrations were higher ($p<0.05$) in pigs fed diet with either ZAC or ZM than the control group (table 5). There was a trend towards a decrease in fecal excretions of Zn when dietary Zn level was low. No significant differences ($p>0.05$) in nutrients digestibility were observed among treatments.

DISCUSSION

Previous researchers have speculated that organically chelated and complexed metals are more efficiently utilized by the animal than that of similar minerals in their inorganic forms. Based from the results obtained in Exp. 1, the ADG and ADFI were not affected by the source with different levels of Cu. Similar response was reported by Coffey et al. (1994) and Apgar et al. (1995) that organic complexes of Cu appeared to have equal bioavailability to their sulfate salts. But the percentage improvements from Cu-lys additions were greater than those for $CuSO_4$ for growth rate and feed intake. In addition, other researchers have reported positive response in using organic mineral sources. Apgar and Kornegay (1996) demonstrated that ADG tended to be higher for pigs fed Cu-lys than for pigs fed $CuSO_4$. However, contrary results were also reported. Du et al.

Table 3. Cu concentrations in serum and feces of weanling pigs fed diets with Cu-amino-chelate (CAC) and Cu-lysine (CL) and nutrient digestibility

Item	$CuSO_4$ (170 ppm)	CAC (ppm)		CL (ppm)		SE
		85	170	85	170	
Cu concentration						
Serum (mg/l)[1, 2]	1.92[a]	1.52[b]	1.80[a]	1.59[b]	2.01[a]	0.29
Feces (mg/kg)[1, 3]	1,910[a]	1,260[b]	1,930[a]	1,377[b]	2,050[a]	371.74
Nutrient digestibility (%)						
Dry matter	86.4	86.8	87.0	87.1	87.4	1.16
Gross energy	86.6	86.8	86.6	86.9	87.3	1.06
Crude protein	85.6	86.5	87.4	87.0	87.2	2.09
Crude fat	77.3	75.4	75.8	72.4	74.4	3.06
Calcium	77.8	76.3	76.5	75.4	76.0	1.90
Phosphorus	55.0	53.1	52.5	52.2	51.5	3.13

[1] Values with different superscripts of the same row are significantly different ($p<0.05$).

[2] N = 9/treatment. [3] N = 3/treatment.

Table 4. Growth performance of weanling pigs fed diet with Zn-amino-chelate (ZAC) and Zn-methionine (ZM)

	$ZnSO_4$ (120 ppm)	ZAC (ppm) 60	ZAC (ppm) 120	ZM (ppm) 60	ZM (ppm) 120	SE
0-2 week						
ADG, g	594	605	606	587	626	19.24
ADFI, g	868	881	878	857	852	95.71
F/G	1.46	1.46	1.45	1.46	1.36	0.15
2-4 week						
ADG, g	698	690	706	704	742	31.28
ADFI, g	1154	1241	1220	1246	1201	92.20
F/G	1.65	1.80	1.73	1.77	1.62	0.20
0-4 week						
ADG[1], g	646[b]	647[b]	656[ab]	646[b]	684[a]	17.80
ADFI, g	1011	1061	1049	1052	1026	76.32
F/G	1.57	1.64	1.60	1.63	1.50	0.15

[1] Values with different superscripts of the same row are significantly different ($p<0.05$).

(1996) studied the utilization of Cu in Cu-proteinate, Cu-lys complex and $CuSO_4$ in two experiments. They reported that utilization of Cu was great from the proteinate in one experiment and the complex form in the second study. Very little research has been published to document the efficacy of Cu chelates and complexes.

Even though there were no significant differences in ADG and feed intake between dietary levels of Cu and inorganic source in this study, there was improved feed efficiency in dietary treatment 170 ppm CAC compared to 85 ppm CL and numerically better than 170 ppm CL or $CuSO_4$. The improved F/G ratio seemed to be due primarily to less feed intake in pigs fed CAC 170 ppm. This may indicate that at equal level of Cu (170 ppm), Cu from CAC tended to be more available than from either CL or $CuSO_4$. In contrast, Coffey et al. (1994) suggested that pigs receiving Cu in the form of Cu-lys grew at a faster rate and tended to consume more feed and utilize their feed more efficiently than those fed $CuSO_4$.

Regardless of mineral source the level of Cu in the diet generally influenced the Cu concentration in the serum. This result supports the research reports of Apgar et al. (1995) indicating that serum Cu concentration increased linearly with increasing dietary Cu levels during wk 1 to 5 but the response to added Cu was similar for $CuSO_4$ and Cu-lys. On the other hand, Zhou et al. (1994) reported numerically lower serum concentrations in pigs fed Cu from Cu-lys than pigs fed Cu from $CuSO_4$. The same trend was observed on the fecal Cu concentration. The higher the level of copper in the diet the higher the amount of Cu excreted in the feces regardless of mineral source. Similarly, Apgar and Kornegay (1996) have shown concentration of Cu in feces to be higher for pigs fed elevated Cu from both $CuSO_4$ and Cu-lys than for controls. The data from the present study further show that ADG was not impaired when Cu from CAC and CL was added at one half of the control ($CuSO_4$). This provides the possibility of reducing fecal excretions of Cu with reduced dietary Cu without sacrificing growth rate of pigs. Reducing dietary Cu concentrations without adversely affecting growth is appealing, because of current environmental concerns regarding the excretion of Cu in animal waste (Armstrong et al., 2000).

Similar results as in Exp. 1 were obtained in Exp. 2, that ADG and ADFI were not affected by the source with different levels of zinc on the 2nd and 4th week of feeding. However, pigs fed diet with ZM 120 ppm appeared to gain weight faster than pigs receiving $ZnSO_4$ 120 ppm. With equal amount of feed intake of pigs fed diets with Zn from different sources, any improvement in ADG maybe attributed to availability of nutrient from the source. Schell and Kornegay (1996) compared the availability of Zn from ZnO, Zn-methionine, Zn-lysine and $ZnSO_4$. They reported that the bioavailability of Zn was lowest for ZnO and intermediate for Zn-lysine and Zn-methionine in reference to $ZnSO_4$. Whereas Hill et al. (1986) and Swinkels et al. (1991) reported no difference in zinc bioavailability between organic and inorganic sources. Much more when

Table 5. Zinc concentration in serum and feces of growing pigs fed experimental diets and nutrient digestibility

Item	$ZnSO_4$ (120 ppm)	ZAC (ppm) 60	ZAC (ppm) 120	ZM (ppm) 60	ZM (ppm) 120	SE
Zn concentration						
Serum (mg/l)[1,2]	1.08[b]	1.61[a]	1.67[a]	1.42[a]	1.47[a]	0.36
Feces (mg/kg)[3]	1,480	1,330	1,457	1,360	1,420	191.9
Nutrient digestibility (%)						
Dry matter	85.7	84.6	85.1	85.0	85.6	1.41
Gross energy	85.7	85.3	85.1	85.2	85.9	1.31
Crude protein	84.8	82.7	83.8	86.3	85.2	2.46
Crude fat	75.3	74.6	74.1	73.5	74.7	2.43
Ca	76.6	76.9	74.1	71.9	72.0	3.52
P	57.4	55.6	56.2	53.1	54.1	2.69

[1] Values with different superscripts of the same row are significantly different ($p<0.05$).
[2] N = 9/treatment. [3] N = 3/treatment.

the diets were adequately supplemented with lysine, the $ZnSO_4$ and Zn-Lysine complexes seemed to be equally effective in promoting growth performance (Cheng et al. 1998). Thus, substitution of ZM for $ZnSO_4$ failed to improve performance of weanling pigs (Kornegay and Thomas, 1975; Spears, 1989).

However, it is evident from the results that both ZAC and ZM influenced the zinc concentration in the serum. The zinc concentrations in serum were higher in pigs fed either ZAC or ZM than pigs fed diet with $ZnSO_4$. This suggests that organically chelated or complexed forms of zinc have higher retention than $ZnSO_4$. Spears (1989) stated that the advantage of organic Zn compared with inorganic Zn was higher retention rather than improved absorption. Again, this statement is in contrast to the reports of Schell and Kornegay (1994) and Cheng and Kornegay (1995) that both $ZnSO_4$ and Zn-Lysine were equally effective in maintaining Zn concentration of serum of weanling pigs.

The results further showed that 60 ppm Zn in the diet had similar effect on the overall performance of pigs as that with 120 ppm regardless of source. This clearly implied that level of zinc in the diet could be reduced from 120 to 60 ppm without adversely affecting the growth performance of pigs and subsequently reducing the amount of zinc being excreted, an environmentally friendly.

IMPLICATIONS

In terms of growth performance, the organically chelated and complexed forms of copper and zinc are equally effective as that of their inorganic salts. However, the level of copper and zinc in the diet could be reduced to as much as 50% (170 to 85 and 120 to 60 ppm, respectively) when organic sources are used, thus reducing fecal excretions of copper and zinc.

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