Evaluation of Metal-Amino Acid Chelates and Complexes at Various Levels of Copper and Zinc in Weanling Pigs and Broiler Chicks**

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ABSTRACT : Feeding trials using weanling pigs and broiler chicks were conducted to evaluate the efficacy of different metal-amino acid chelates and complexes at various levels of copper and zinc on the performance and fecal excretions. A total of 200 weanling pigs (Large White × Yorkshire × Duroc, 11.20±0.81 kg) were randomly assigned to 5 dietary treatments following a randomized complete block design. Each treatment was replicated 4 times with 10 pigs per pen. The dietary treatments were designated as : A-diet containing 170 ppm Cu from $CuSO_4$ and 120 ppm Zn from $ZnSO_4$, B-diet containing 85 ppm Cu from Cu-amino acid chelate (CAC) and 60 ppm Zn from Zn-amino acid chelate (ZAC), C-diet containing 170 ppm Cu from CAC and 120 ppm Zn from ZAC, D-diet containing 85 ppm Cu from Cu-lysine complex (CL) and 60 ppm Zn from Zn-methionine complex (ZM), and E-diet containing 170 ppm Cu from CL and 120 ppm Zn from ZM. On the other trial, 144 of one day old broiler chicks were randomly distributed to 6 dietary treatments following a completely randomized design. Each treatment was replicated 3 times with 8 chicks per replicate. The dietary treatments were as follows: 1-diet with 60 ppm Cu from $CuSO_4$ and 40 ppm Zn from $ZnSO_4$, 2-diet with 120 ppm Cu from $CuSO_4$ and 80 ppm Zn from $ZnSO_4$, 3-diet with 60 ppm Cu from CAC and 40 ppm Zn from ZAC, 4-diet with 120 ppm Cu from CAC and 80 ppm Zn from ZAC, 5-diet with 60 ppm Cu from CL and 40 ppm Zn from ZM, and 6-diet with 120 ppm Cu from CL and 80 ppm Zn from ZM. In Exp. 1 with pigs, there was no difference on average daily gain and average daily feed intake observed among treatments. There was improvement ($p<0.05$) on the overall feed conversion ratio (FCR) of pigs fed diet containing 120 ppm Zn and 170 ppm Cu from metal-amino acid chelates relative to those fed diet containing inorganic sources of Cu and Zn but equally efficient as those fed diet containing metal-amino acid complexes. Pigs fed diet containing either metal-amino acid chelates or complexes as sources of Cu and Zn had higher ($p<0.05$) Cu and Zn concentration in serum and lower ($p<0.05$) in feces than those receiving diet with inorganic sources. In Exp. 2 with broiler chicks, the overall FCR was not different among treatments. Higher ($p<0.05$) Cu and Zn concentration in serum was obtained from birds fed diet with 60 ppm Cu and 40 ppm Zn from metal-amino acid chelates compared to those fed diet with inorganic sources of Cu and Zn. Also, the feces collected from birds fed diet with either metal-amino acid chelates or complexes contained generally lower Cu and Zn than those birds fed diet with inorganic sources. The higher the dietary level of Cu and Zn the higher the Cu and Zn concentration in the feces. Based on the results, both metal-amino acid chelates and complexes of Cu and Zn at low levels (Zn 60 ppm, Cu 85 ppm for weanling pigs and Zn 40 ppm, Cu 60 ppm for broiler chicks) are not different from that of high levels of inorganic sources in maintaining growth performance and serum concentration. The fecal excretions for Cu and Zn were greatly reduced when organic sources were used. *(Asian-Aust. J. Anim. Sci. 2001. Vol 14, No. 12 : 1734-1740)*

Key Words : Chelates, Complexes, Concentration, Excretion, Performance

INTRODUCTION

Most swine producers often use supplemental copper and zinc at concentrations higher than NRC (1998) requirements to improve growth performance. Copper stimulates growth of pigs when fed at the levels of 100 to 250 ppm (NRC, 1998; Han, 2000), whereas the growth promoting effect of zinc has been reported to be 2,000-3,000 ppm in weanling pigs (Hill et al., 1986; Kavanagh, 1992). Aside from the growth promoting potential of copper and zinc, Hawbaker et al. (1961) and Bunch et al. (1965) stated that copper acts in an antibiotic-like fashion by influencing the microflora. Also, Dupont et al. (1994) reported that zinc inhibits the hemolysin activity of *Serpulina hyodysenteriae,* a virulence factor in the pathogenesis of swine dysentery.

It is therefore speculated that presence of both copper and zinc in the diet beyond the level recommended by NRC (1998) would further enhance the growth performance of animals. However the high concentration of bioavailable zinc in the diet may significantly reduce the copper availability because these metals are antagonistic to some degree (Hatfield et al., 2001). Thus, providing these metals in readily available form would reduce the inclusion rate in the diet.

The influence of form of supplemental copper and zinc has been well documented. The oxide form of Cu was reported to be nearly as effective as the sulfate form, but feeding high levels of Cu in sulfide form did not enhance growth rate (Cromwell et al., 1978). Previous research in broiler chicks indicated that an organic form such as cupric citrate was effective in stimulating growth at lower

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concentrations than $CuSO_4$ (Pesti and Bakalli, 1996; Ewing et al., 1998). Wedekind et al. (1992) reported that a Zn-methionine complex was more bioavailable than $ZnSO_4$ as measured by Zn content of the tibia of chicks, but not for weanling pigs (Wedekind et al., 1994). Studies with pigs showed that Zn from Zn-methionine and in inorganic Zn salt were equally effective in maintaining growth performance and serum Zn level (Kornegay and Thomas, 1975; Hill et al., 1986; Swinkels et al., 1996). Similarly, 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. But very little information is available comparing the effectiveness of the different Cu and Zn-amino acid chelates and complexes.

Hence, the objectives of this study were to evaluate the efficacy of the different metal-amino acid chelates and complexes at various levels of copper and zinc in weanling pigs and broiler chicks.

MATERIALS AND METHODS

Copper and zinc sources

Cu-amino acid chelate (CAC), Zn-amino acid chelate (ZAC), Cu-lysine complex (CL) and Zn-methionine complex (ZM) were used as test materials for experiments on weanling pigs and broiler chicks. As defined by the Association of American Feed Control Officials AAFCO (1998), metal-amino acid chelates (CAC and ZAC) are products resulting from the reaction of a metal ion from a soluble metal salt with amino acids to form coordinate covalent bonds (heterocyclic ring structure). Whereas, metal-amino acid complexes (CL and ZM) are products resulting from complexing of a soluble salt with an amino acid(s). These products were manufactured by Tongwoo TMC Co., Ltd., Korea.

Experiment 1

A 28 day feeding trial was conducted to determine the efficacy of metal-amino acid chelates and complexes at various levels of Cu and Zn on the growth performance and fecal excretions of weanling pigs. A total of 200 weanling pigs (L × Y × D, 11.20±0.81 kg) were randomly assigned to 5 dietary treatments following a randomized complete block design. Each treatment was replicated 4 times with 10 pigs per pen. The dietary treatments were designated as : A-diet containing 170 ppm Cu from $CuSO_4$ and 120 ppm Zn from $ZnSO_4$, B-diet containing 85 ppm Cu from Cu-amino acid chelate (CAC) and 60 ppm Zn from Zn-amino acid chelate (ZAC), C-diet containing 170 ppm Cu from CAC and 120 ppm Zn from ZAC, D-diet containing 85 ppm Cu from Cu-lysine complex (CL) and 60 ppm Zn from Zn-methionine complex (ZM), and E-diet containing 170 ppm Cu from CL and 120 ppm Zn from ZM. Experimental diets were formulated to meet or exceed the nutrient requirements listed in NRC (1998) (table 1).

Pigs were housed in pens (180 × 190 cm) with partially slotted floors (55.5%) and were allowed ad libitum access to diets from self-feeders and to water from nipple waterers. Pigs were weighed and feed intake was recorded at d 0, d 14 and d 28. On d 14, feeds were withdrawn from the feeders. After 4 h, blood samples were collected from 9 pigs per treatment. Pigs were bled via venipuncture from the jugular vein. 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 for mineral analysis.

Digestibility trial was conducted to determine the

Table 1. Ingredient and calculated nutrient composition of basal diets for feeding and digestibility trials (Exp. 1)

Ingredient	%
Corn	49.89
Soybean meal	33.08
Bakery-byproduct	8.00
Animal fat	3.30
Fish meal	2.00
Dicalcium phosphate	1.65
Limestone	0.50
Vitamin premix[1]	0.30
Trace mineral premix[2]	0.20
Salt	0.25
L-Lysine (78%)	0.30
CTC[3]	0.10
Tiamulin[4]	0.10
Mecadox[5]	0.10
DL-Methionine (50%)	0.18
Choline chloride (25%)	0.05
Total	100.00
Calculated nutrient composition	
ME, kcal/kg	3,350
Crude protein, %	20.50
Calcium, %	0.80
Avail. phosphorus, %	0.42
Lysine, %	1.35
Met+Cys, %	0.75

[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 ug 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.

[3,4,5] Supplied per kg diet: 100 mg chlorotetracycline, 40 mg tiamulin, and 50 mg mecadox.

nutrient digestibility of the experimental diets and the concentration of minerals excreted in the feces. Fifteen pigs (13.5±1.6 kg) were randomly distributed to 15 metabolic cages and randomly assigned to 5 dietary treatments (3 pigs/treatment). Pigs were fed experimental diets mixed with 0.25% chromic oxide for 5 days. A grab sample of feces was collected from each pig for 3 days. Fecal samples were pooled, dried in an air forced drying oven at 60°C and ground with a 1mm mesh Wiley mill for chemical analysis.

Experiment 2

A total of 144 day-old broiler chicks were used in this study. Chicks were randomly distributed to 6 dietary treatments following a completely randomized design. Each treatment was replicated 3 times with 8 chicks per treatment. The dietary treatments were as follows: 1-diet with 60 ppm Cu from $CuSO_4$ and 40 ppm Zn from $ZnSO_4$, 2-diet with 120 ppm Cu from $CuSO_4$ and 80 ppm Zn from $ZnSO_4$, 3-diet with 60 ppm Cu from CAC and 40 ppm Zn from ZAC, 4-diet with 120 ppm Cu from CAC and 80 ppm Zn from ZAC, 5-diet with 60 ppm Cu from CL and 40 ppm Zn from ZM, and 6-diet with 120 ppm Cu from CL and 80 ppm Zn from ZM.

Basal diets were formulated to contain 21% and 19% crude protein for broiler starter and broiler finisher, respectively (table 2). Both diets were isocaloric at 3,200 ME (kcal/kg). Birds were fed broiler starter from d 0 to 2 wk and broiler finisher from 2-4 wk. Birds were fed their respective diet *ad libitum* and free access to water. Birds were weighed and feed intake was recorded at d 0, wk 2, and wk 4.

On wk 3, total fecal collection was made to determine nutrient digestibility of diets and concentration of Cu and Zn in the feces. Feces was quantitatively collected from 3 cages of each treatment for 4 days. Total feces was weighed, dried in an air forced drying oven at 60°C and ground with 1 mm mesh Wiley mill for chemical analysis. Total feed intake for that particular period was also recorded.

After feeding trial, blood samples were collected from 3 birds for each treatment. Similar preparation and analysis were done as in weanling pigs.

Chemical and statistical analyses

Proximate analysis of experimental diets and fecal samples from both experiments were carried out according to AOAC (1990) method. Chromium and phosphorus 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). Blood serum and fecal samples were analyzed for copper and zinc using atomic absorption spectrophotometer (GBC-904: GBC, Aus.).

Table 2. Ingredient and calculated nutrient composition of basal diets for broiler chicks (Exp. 2)

Ingredient (%)	Starter	Finisher
Corn	60.39	61.35
Soybean meal	22.68	24.80
Fish meal	6.00	3.00
Corn gluten	5.00	4.44
Animal fat	3.17	3.63
Dicalcuim phosphate	0.87	1.09
Limestone	0.84	1.14
Methionine	0.34	0.05
Salt	0.25	0.25
Vitamin premix[1]	0.20	0.10
Trace mineral premix[2]	0.10	0.10
Lysine	0.09	-
Choline	0.07	0.05
Total	100.00	100.00
Calculated nutrient composition		
ME, kcal/kg	3,200	3,200
Crude protein, %	21.00	19.00
Lysine, %	1.20	1.05
Met+Cys, %	0.86	0.73
Calcium, %	1.00	0.85
Avail. phosphorus, %	0.45	0.30

[1] Supplied per kg diet: 1,500 IU vitamin A, 200 IU vitamin D_3, 10 IU vitamin E, 0.50 mg vitamin K, 0.15 mg biotin, 1,000 mg choline, 0.55 mg folacin, 30 mg niacin, 10 mg pantothenic acid, 3.6 mg riboflavin, 1.80 mg thiamin, 3.5 mg pyridoxine, 0.01 mg vitamin B_{12}.

[2] Trace minerals except Cu and Zn supplied per kg diet: 60 mg Mn, 80 mg Fe, 0.35 mg I, 0.15 mg Se.

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

RESULTS

Experiment 1

There were no differences ($p>0.05$) on the overall average daily gain (ADG) and average daily feed intake (ADFI) among treatments (table 3). Except on d 14 to 21 the feed intake of pigs fed diets supplemented with either metal-amino acid chelates or complexes was similar ($p>0.05$) but lower ($p<0.05$) than in pigs fed diet containing inorganic sources. Also, an improvement in feed conversion ratio (FCR) was observed ($p<0.05$) in pigs fed a diet containing 120 ppm Zn and 170 ppm Cu from metal-amino acid chelates, relative to inorganic sources but this improvement was not significantly different ($p>0.05$) from pigs fed a diet containing 120 ppm Zn and 170 ppm Cu from metal-amino acid complexes. Moreover, pigs fed diets with metal-amino acid complexes performed equally as those of the inorganic sources. The different sources of Cu

Table 3. Effect of metal-amino acid chelates and complexes with various levels of Cu and Zn on growth performance of weanling pigs

Treatment*	A	B	C	D	E	SE
d 0-14						
ADG (g)	448	452	496	487	501	41.66
ADFI (g)	753	807	708	790	779	82.15
Feed conversion ratio[1]	1.68[ab]	1.78[a]	1.43[c]	1.61[b]	1.55[bc]	0.13
d 14-21						
ADG (g)	698	691	706	701	691	38.03
ADFI (g)[1]	1,222[a]	1,120[b]	1,156[b]	1,159[b]	1,151[b]	47.85
Feed conversion ratio	1.75	1.62	1.64	1.67	1.67	0.10
d 0-21						
ADG(g)	573	571	601	594	597	25.06
ADFI(g)	988	962	934	974	964	46.54
Feed conversion ratio[1]	1.72[a]	1.68[a]	1.55[b]	1.64[ab]	1.62[ab]	0.09

* Treatment: A, Zn 120 ppm as $ZnSO_4$, Cu 170 ppm as $CuSO_4$; B, Zn 60 ppm as ZAC, Cu 85 ppm as CAC; C, Zn 120 ppm as ZAC, Cu 170 ppm as CAC; D, Zn 60 ppm as ZM, Cu 85 ppm as CL; E, Zn 120 ppm as ZM, Cu 170 ppm as CL.

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

and Zn failed to influence nutrient digestibility (table 4).

In table 5, pigs fed a diet containing 120 ppm Zn and 170 ppm Cu from either metal-amino acid chelates or complexes had a higher ($p<0.05$) Cu and Zn concentration in serum and a lower fecal concentration compared to those fed diet with inorganic sources.

Experiment 2

No significant differences ($p>0.05$) in weight gain, feed intake and FCR were found among broiler chicks fed diets with different levels of Cu and Zn from the same sources (table 6). However, broiler chicks fed a diet with 60 ppm Cu and 40 ppm Zn from metal-amino acid chelates had a higher ($p<0.05$) weight gain and a better ($p<0.05$) FCR than those fed diet containing 120 ppm Cu and 80 ppm Zn from inorganic sources. The overall performance of broiler chicks was not different among treatments.

The nutrient digestibility was not affected either by the metal-amino acid chelates or complexes as sources of Cu and Zn in the diet (table 7). Birds fed diet with 60 ppm Cu and 40 ppm Zn from metal-amino acid chelates had a higher ($p<0.05$) Cu and Zn concentration in serum than those fed diet with inorganic sources, but the Cu concentration was not different from birds fed diet with metal-amino acid complexes (table 8). Moreover the feces collected from birds fed a diet with either metal-amino acid chelates or complexes contained generally lower Cu and Zn ($p<0.05$).

Table 4. Effect of metal-amino acid chelates and complexes with various levels of Cu and Zn on the digestibility of nutrients[1]

Treatment*	A	B	C	D	E	SE
Dry matter	78.62	79.26	78.95	79.31	80.75	2.31
Gross energy	77.88	78.05	77.42	78.38	79.68	2.25
Crude protein	75.31	74.69	74.67	75.84	77.79	2.33
Crude fat	70.10	70.58	69.81	72.29	71.38	3.62
Calcium	64.06	63.38	63.89	58.67	59.01	4.89
Phosphorus	52.64	45.29	46.36	41.57	43.89	6.30

* Treatment: A, Zn 120 ppm as $ZnSO_4$, Cu 170 ppm as $CuSO_4$; B, Zn 60 ppm as ZAC, Cu 85 ppm as CAC; C, Zn 120 ppm as ZAC, Cu 170 ppm as CAC; D, Zn 60 ppm as ZM, Cu 85 ppm as CL; E, Zn 120 ppm as ZM, Cu 170 ppm as CL.

[1] Not significant ($p>0.05$).

Table 5. Cu and Zn concentrations in serum and feces of growing pigs fed experimental diets (n=3)[1]

Treatment*	A	B	C	D	E	SE
Serum (mg/l)						
Cu						
d 14	1.60[b]	1.76[ab]	1.98[a]	1.75[ab]	2.02[a]	0.21
d 28	1.49[bc]	1.38[c]	1.70[a]	1.66[ab]	1.80[a]	0.18
Zn						
d 14	1.44[b]	1.50[ab]	1.55[ab]	1.52[ab]	1.74[a]	0.16
d 28	1.64[ab]	1.60[b]	1.72[ab]	1.61[b]	1.83[a]	0.13
Feces (mg/kg)						
Cu	1,870[a]	615[d]	1,165[b]	785[c]	1,240[b]	451.90
Zn	1,555[a]	795[c]	1,240[b]	1,155[b]	1,560[a]	297.36

* Treatment: A, Zn 120 ppm as $ZnSO_4$, Cu 170 ppm as $CuSO_4$; B, Zn 60 ppm as ZAC, Cu 85 ppm as CAC; C, Zn 120 ppm as ZAC, Cu 170 ppm as CAC; D, Zn 60 ppm as ZM, Cu 85 ppm as CL; E, Zn 120 ppm as ZM, Cu 170 ppm as CL.

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

Birds fed a diet with the high level of Cu and Zn from inorganic sources had the highest ($p<0.05$) concentration of Cu and Zn in the feces.

DISCUSSION

In this study metal-amino acid chelates and complexes were used to provide Cu and Zn at concentrations lower than the reported pharmacological concentrations (250 ppm Cu and 3,000 ppm Zn) but higher than the recommendations of NRC (1998). The addition levels of Cu and Zn in weanling pigs and broiler chicks were established by the maximum allowance levels and industry levels in Korea. In case of pigs, due to environmental contamination, the allowance levels of Cu and Zn in the diets were controlled

Table 6. Growth performance of broiler chicks as affected by the metal-amino acid chelates and complexes with various levels of Cu and Zn

Treatment*	1	2	3	4	5	6	SE
0-2 wk							
Weight gain, g	544	537	546	523	525	545	59.01
Feed intake, g	780	776	775	760	797	790	29.61
Feed conversion ratio	1.43	1.45	1.42	1.45	1.52	1.45	0.17
2-4 wk							
Weight gain, g[1]	791[ab]	754[b]	873[a]	815[ab]	829[ab]	844[ab]	61.46
Feed intake, g[1]	1499[ab]	1463[b]	1490[ab]	1440[b]	1500[ab]	1594[a]	69.54
Feed conversion ratio[1]	1.90[ab]	1.95[a]	1.72[b]	1.79[ab]	1.81[ab]	1.89[ab]	0.13
0-4 wk							
Weight gain, g	1334	1290	1418	1351	1354	1389	91.63
Feed intake, g[1]	2278[ab]	2238[ab]	2265[ab]	2189[b]	2297[ab]	2384[a]	88.71
Feed conversion ratio	1.71	1.74	1.60	1.66	1.70	1.72	0.09

* 1: Cu 60 ppm as $CuSO_4$, Zn 40 ppm as $ZnSO_4$, 2 : Cu 120 ppm as $CuSO_4$, Zn 80 ppm as $ZnSO_4$, 3 : Cu 60 ppm as CAC, Zn 40 ppm as ZAC, 4 : Cu 120 ppm as CAC, Zn 80 ppm as ZAC, 5 : Cu 60 ppm as CL, Zn 40 ppm as ZM, 6 : Cu 120 ppm as CL, Zn 80 ppm as ZM.

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

Table 7. Nutrient digestibility as affected by the metal-amino acid chelates and complexes with various levels of Cu and Zn in broiler chicks[1]

Treatment*	1	2	3	4	5	6	SE
Dry matter	83.98	85.43	85.88	86.19	86.29	85.99	1.25
Gross energy	82.82	84.92	84.25	83.88	84.69	83.60	1.63
Crude protein	75.13	75.98	79.41	81.96	81.97	81.66	2.54
Crude fat	63.67	71.05	69.12	58.84	83.56	73.43	3.62
Ash	44.84	45.70	44.29	48.59	47.00	43.73	2.11
Calcium	34.70	50.23	49.33	44.68	55.63	54.38	7.51
Phosphorus	46.58	51.00	48.81	50.33	49.56	49.09	6.25

* 1: Cu 60 ppm as $CuSO_4$, Zn 40 ppm as $ZnSO_4$, 2 : Cu 120 ppm as $CuSO_4$, Zn 80 ppm as ZnSO4, 3 : Cu 60 ppm as CAC, Zn 40 ppm as ZAC, 4 : Cu 120 ppm as CAC, Zn 80 ppm as ZAC, 5 : Cu 60 ppm as CL, Zn 40 ppm as ZM, 6 : Cu 120 ppm as CL, Zn 80 ppm as ZM.

[1] Not significant ($p<0.05$).

by government law (MAF, 1999). The maximum dietary levels of Cu and Zn in the weanling pig diet are 170 and 120 ppm, respectively.

In Exp. 1 with weanling pigs, there was no improvement on ADG and ADFI but there was a significant improvement in FCR. Results from previous studies revealed that adding 250 ppm Cu increased a circulation by portal-drained viscera which enhanced the absorptive capacity of the enterocytes of the small intestine and led to improved performance (Yen and Nienaber, 1993). However, addition of 250 ppm Cu to diets containing 3,000 ppm Zn in the oxide form did not lead to an additive growth response (Smith et al., 1997 and Hill et al., 2000). In this study the metal-amino acid chelates providing 120 ppm Zn and 170 ppm Cu improved FCR at d 14 and the overall FCR of weanling pigs. At high levels of Zn and Cu weanling pigs fed diets with metal-amino acid chelates utilized feeds more efficiently than in pigs fed diet with inorganic form of the same metals. It is likely that diet containing metal-amino acid chelates provided enough Zn and Cu to meet young pigs' need for these minerals. In addition, pigs fed diet with either metal-amino acid chelates or complexes consumed relatively less amount of feed compared to pigs fed diets with inorganic form of Zn and Cu. This result supports Close (1998) statement that due to higher rate of digestion and absorption in the gastrointestinal tract, less may be needed in the diet to meet the animals' requirements. Earlier studies done by Grassmann and Kirchgessner (1974) showed that absoption rate of Cu in the form of Cu-amino acid complexes was higher than that in the organic form for rats.

The nutrient digestibility was not affected by the different metal-amino acid chelates and complexes at various levels of Zn and Cu. This indicates that the sources of these metals in the diet had provided enough Zn and Cu to meet the animals' requirements, hence, no increased digestibility of nutrients observed.

In addition, the basal diet was formulated to meet or exceed the nutrient requirements listed in NRC (1998). However it was observed that pigs fed diet with 120 ppm Zn and 170 ppm Cu from either chelates or complexes had higher Cu concentration in serum than that of pigs fed diet with inorganic sources of these minerals. Likewise the Cu concentration in serum of weanling pigs fed diet with 60 ppm Zn and 85 ppm Cu from organic sources was similar to pigs fed diet with 120 ppm Zn and 170 ppm Cu from inorganic sources. These results can be partly explained by higher retention of Cu from organic source than from inorganic source.

On the other hand, the Zn concentration in serum appeared to be influenced by the dietary levels rather than

Table 8. Cu and Zn concentrations in serum and feces of broiler chicks fed experimental diets (n=3)

Treatment*	1	2	3	4	5	6	SE
Serum (mg/l)							
Cu[1]	1.92[b]	1.92[b]	2.66[ab]	3.04[a]	2.46[ab]	2.72[a]	0.54
Zn[1]	3.15[c]	3.14[c]	4.67[ab]	5.27[a]	3.87[bc]	3.88[bc]	0.89
Feces (mg/l)							
Cu[1]	506.50[b]	663.67[a]	450.67[b]	524.67[b]	459.67[b]	522.67[b]	85.53
Zn	494.50	564.67	413.00	482.33	408.67	552.33	98.35

* 1 : Cu 60 ppm as $CuSO_4$, Zn 40 ppm as $ZnSO_4$, 2 : Cu 120 ppm as $CuSO_4$, Zn 80 ppm as $ZnSO_4$, 3 : Cu 60 ppm as CAC, Zn 40 ppm as ZAC, 4 : Cu 120 ppm as CAC, Zn 80 ppm as ZAC, 5 : Cu 60 ppm as CL, Zn 40 ppm as ZM, 6 : Cu 120 ppm as CL, Zn 80 ppm as ZM.
[1] Values with different superscripts of the same row are significantly different ($p<0.05$).

by the sources. The higher the level of Zn and Cu in the diet the higher the Zn concentration in serum. Conversely, the amount of Zn and Cu excreted in the feces was very much high in pigs fed diet with inorganic sources of Zn and Cu and in pigs fed diet with 120 ppm Zn and 170 ppm Cu from metal-amino acid complexes.

In Exp. 2, results revealed that at 2 to 4 wk birds fed diet with 60 ppm Cu and 40 ppm Zn from metal-amino acid chelates gained more weights and utilized feeds more efficiently compared to birds fed diet with 120 ppm Cu and 80 ppm Zn from inorganic sources. But the overall performance did not differ among treatments except for birds fed diet with 120 ppm Cu and 80 ppm Zn from metal-amino acid complexes. These birds consumed more feeds compared to birds fed diet with metal-amino acid chelates of the same Cu and Zn level. This suggests that to some extent, metal-amino acid complexes had enhanced palatability of the feed but not necessarily a higher availability of minerals for growth stimulation.

The performance of birds was not affected by the treatment. There was no differences observed on nutrient digestibility among treatments. However, the Cu and Zn concentration in serum was higher in birds fed diet with either metal-amino acid chelates or complexes than in birds fed diet with inorganic sources. Also, the Cu and Zn concentration in serum of birds fed diet with 60 ppm Cu and 40 ppm Zn from either metal-amino acid chelates or complexes was comparable to birds fed diet with 120 ppm Cu and 80 ppm Zn from inorganic sources. Likewise, the concentration of Cu and Zn excreted in the feces was reduced in birds fed diet with either metal-amino acid chelates or complexes. The higher the dietary level of Cu and Zn the higher the amount excreted.

IMPLICATIONS

Organically bound minerals such as chelates and complexes could be used at considerably lower concentrations (Zn 60 ppm and Cu 85 ppm for weanling pigs; Zn 40 ppm and Cu 60 ppm for broiler chicks) than inorganic sources while maintaining growth performance and serum concentration, and reducing excretion of Zn and Cu in animal waste.

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