



## Improved Broiler Chick Performance by Dietary Supplementation of Organic Zinc Sources

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**ABSTRACT :** Two inorganic (zinc sulfate and zinc oxide) and three organic (zinc acetate, zinc-methionine, and zinc-lysine) zinc sources were evaluated for their effects on the performance and carcass characteristics of broiler chicks. The birds were randomly assigned to one control (non-supplemented) and 15 treatment (supplemented) groups consisting of four replicates of 10 chicks each in a 5×3 factorial arrangement of treatments (five zinc sources and three supplemental zinc levels). Birds were kept in floor pens in a temperature-controlled room from 1 to 42 d of age and fed a non-supplemented basal diet (control) or the basal diet supplemented with 40, 80 or 120 mg/kg of Zn as mentioned sources. Dietary zinc source had considerable effect on feed intake in all experimental periods. Increasing Zn level from 80 to 120 mg/kg decreased the average feed intake in the growth stage ( $p < 0.01$ ) and also in the entire experimental period ( $p < 0.001$ ). Similarly, the average daily gain during the entire trial period was affected by the type of Zn source ( $p < 0.001$ ) and supplemental level ( $p < 0.01$ ). One degree of freedom contrast comparisons showed that the inclusion of organic zinc sources into the diets caused significant increases in feed intake and body gain when compared with inorganic counterparts. Except in wk 1, dietary supplementation with organic sources improved ( $p < 0.05$ ) feed conversion ratio; FCR values were not affected by dietary Zn source or supplementation level. Breast meat yield increased with supplemental levels of organic Zn sources; however, other carcass parameters were not affected by dietary Zn source. On the other hand, organic versus inorganic zinc supplementation caused a significant increase in liver, breast and carcass weight percentages. The present findings suggest that supplemental levels of organic Zn compounds had beneficial effects on broiler performance, and Zn requirements can be reduced using these feed supplements in poultry rations. (**Key Words :** Broiler Chicks, Organically Zn Compounds, Zinc-methionine, Zinc-lysine, Performance, Carcass Characteristics)

### INTRODUCTION

Zinc is present in all cells and participates in a wide variety of metabolic processes by virtue of its diverse catalytic roles in over 200 enzymes. Zn enzymes are involved in the synthesis and/or degradation of carbohydrates, lipids, proteins, and nucleic acids and encompass all known classes of enzymes (Falchuk and Vallee, 1985; Kaim and Schwederski, 1994). Its deficiency arrests cell proliferation, while in multicellular organisms it also results in abnormal differentiation and development leading to extensive teratological abnormalities. It has not been possible to account for these effects of Zn deficiency on the basis of the function(s) of any one or combination of its known metalloenzymes. However, the disciplines of

molecular genetics and Zn metallobiochemistry have recently evolved conceptual frameworks and experimental approaches which potentially may provide the basis for understanding the biological essentiality of Zn (Falchuk and Vallee, 1985).

Zinc must be supplemented to most diets of poultry and pigs to meet the nutritional requirements for this element, because of the poor availability of zinc in plant feed ingredients caused by the binding of Zn by phytate (Oberleas et al., 1962; O'Dell et al., 1964; Ellis et al., 1982; Fordyce et al., 1987). In addition, much natural feeding stuffs are marginally deficient in zinc (Baker and Ammerman, 1997; Cao et al., 2002). Numerous experiments have been conducted during the last 50 yr to estimate the bioavailability of Zn in supplemental sources and dietary ingredients; however, there are considerable confusion concerning bioavailability of this nutritionally trace element in various supplements for chickens and pigs. Using weight gain as a response variable, Edwards (1959) reported that Zn from analytical grade and technical grade

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**Table 1.** Chemical composition of basal diets (%) in starter and grower stages

Ingredients (%)	Starter (1-21 d)	Grower (21-42 d)
Corn (yellow)	54.31	62.02
Soybean meal	38.41	31.31
Sunflower oil	3.00	0.75
Poultry fat	-	2.25
Dicalcium phosphate	1.85	1.35
Limestone	1.22	1.32
Common salt	0.40	0.30
Mineral premix <sup>1</sup>	0.25	0.25
Vitamin premix <sup>2</sup>	0.25	0.25
DL-methionine	0.16	0.06
Variable <sup>3</sup>	0.15	0.15
Nutrient composition		
ME (kcal/kg)	3,000	3,030
Crude protein (%)	21.57	18.94
Ether extract (%)	5.99	6.26
Methionine (%)	0.49	0.36
TSAA <sup>4</sup> (%)	0.84	0.68
Lysine (%)	1.18	1.01
Threonine (%)	0.84	0.74
Tryptophan (%)	0.32	0.27
Arginine (%)	1.40	1.21
Calcium (%)	0.94	0.85
Non-phytate P (%)	0.43	0.34
Sodium (%)	0.17	0.14
Zinc (mg/kg)	25.87	24.18

<sup>1</sup> Zinc-free mineral premix. Provided per kilogram of diet: Mn (from MnSO<sub>4</sub>·H<sub>2</sub>O), 60 mg; Fe (from FeSO<sub>4</sub>·7H<sub>2</sub>O), 50 mg; Cu (from CuSO<sub>4</sub>·5H<sub>2</sub>O), 6 mg; I (from Ca (IO<sub>3</sub>)<sub>2</sub>·H<sub>2</sub>O), 1 mg; Se, 0.20 mg.

<sup>2</sup> Provided per kilogram of diet: vitamin A (from vitamin A acetate), 8,700 IU; cholecalciferol, 2,300 IU; vitamin E (from DL- $\alpha$ -tocopheryl acetate), 16 IU; vitamin B<sub>12</sub>, 0.31 mg; riboflavin, 6.6 mg; niacin, 28 mg; calcium pantothenate, 35 mg; menadione (from menadione dimethyl-pyrimidinol), 1.50 mg; folic acid, 0.80 mg; thiamine, 3 mg; pyridoxine, 2.50 mg; biotin, 30 mg; ethoxyquin, 125 mg.

<sup>3</sup> Variable amounts of zinc sources and inert filler (washed builders sand). Zinc sources added in place of an equivalent weight of sand.

<sup>4</sup> TSAA: total sulfur amino acids.

ZnO as well as Zn metal powder was 100% bioavailable for young chicks relative to analytical grade ZnSO<sub>4</sub>·7H<sub>2</sub>O. The next year, Roberson and Schaible (1960) also using chick weight gain as the response scale reported that ZnO was as bioavailable as ZnSO<sub>4</sub>, but they did not clearly identify either compound. Some researchers (Spears, 1989; Wedekind et al., 1992) have reported greater bioefficacy for organic Zn sources than that observed for inorganic forms, including Zn oxide and Zn sulfate; consequently, organic forms of the trace element have been used with increasing pattern by the feed industry. An enhanced bioavailability of a mineral source could reduce the amount of a mineral that is added to a diet to meet mineral nutritional requirements, which would reduce the amount of mineral excreted by birds (Cheng et al., 1998). The use of organic complexes of trace element, such as Zn-lysine (ZnLys) and Zn-methionine (ZnMet), has received more attention because of

their potential of higher bioavailability. Previous studies with pigs (Hill et al., 1986; Swinkels et al., 1991), however, have failed to show differences in Zn bioavailability between organic (complexes or chelates) and inorganic Zn sources. Yet, marked differences in bioavailability have been documented in poultry diets (Wedekind et al., 1992). The data reported by Wedekind et al. (1992) indicated that, for chicks fed corn-soybean meal diets, Zn from a Zn-methionine complex was 206% bioavailable relative to a ZnSO<sub>4</sub>·H<sub>2</sub>O standard (i.e. 100%), where ZnO provided only 61% bioavailable Zn. There are conflicting data reported regarding the relative efficacy of different organic versus inorganic Zn sources in enhancing broiler performance. The research presented herein, therefore, aimed to compare bioefficacy of various inorganic and organic Zn compounds in the light of their effects on the performance and carcass characteristics in broiler chicks.

## MATERIALS AND METHODS

### Birds, treatments and managing schedule

The present study was performed in the research farm of Ferdowsi University of Mashhad (Mashhad, Iran). A total of six hundred-forty day-old Ross×Ross male broiler chicks were randomly allotted to four pen replicates of 10 birds for each of sixteen dietary treatments such that each pen had a similar initial weight and weight distribution. Randomization of experimental pens was performed in according to a randomized complete block design (RCBD) in which each pen replicate was repeated one time in each location. The basal corn-soybean meal diets (Table 1) containing 25.9 and 24.2 mg Zn/kg as fed basis (by analysis) were formulated to meet or exceed nutritional requirements of broiler chicks (NRC, 1994) in starter and grower stages, respectively. Dietary treatments included the basal diet or basal diet supplemented with 40, 80, or 120 mg/kg added Zn as feed-grade Zn sulfate or Zn oxide (as conventional inorganic sources), Zn-methionine, Zn-lysine (Zinpro Corporation, Edina, MN), or Zn acetate (as organically Zn compounds). The basal diets were formulated using Zn-free mineral premix, so that contained minimum amount of zinc. Experimental Zn concentrations were achieved by replacing an appropriate amount of inert filler (washed builders sand) with each of the mentioned sources. All of the diets were calculated and/or measured to contain equal concentrations of methionine, lysine and other nutrients except of Zn which was of interest. Chicks were housed in the floor pens made up painted partitions which placed at thermostatically-controlled room. Chicks were maintained on a 24 h constant lighting regimen and had free access to feed and tap water containing no detectable Zn in all times. Feed and water were provided using plastic instruments to minimize environmental Zn contamination.

The temperature was set at 33°C during the first week of age and was reduced by 3°C/week until the birds were 4 weeks old. Feed intake and body weight were measured weekly per pen after 4 h feed withdrawal and mortality was recorded daily to correct feed consumption and to adjust feed:gain data. Two randomly-selected birds from each pen replicate were weighed, and slaughtered by cervical cutting at the final day (42 d of age) of experiment. Liver, pancreas and heart were precisely collected immediately after the chicks were slaughtered and weighed separately (heart was cleaned of adhered fat before weighing). Carcass eviscerated manually. After the eviscerated weights had been obtained, breast and thigh were cut (skinless) and weighed to compare organic and inorganic Zn sources for their influences on meat yield and carcass efficiency.

### Chemical analysis

Prior to formulating the diets, the ingredients and Zn sources used were analyzed for crude protein (Kjeltec Auto 1030 Analyzer, Tecator), ether extract, crude fiber, and ash content according to standard procedures of AOAC (1995). Zinc concentration in feeding stuffs, water and Zn sources were determined by atomic absorption spectrophotometry (Perkin Elmer, Precisely AAnalyst 200, Absorption spectrophotometer). Samples of feedstuffs and Zn sources were dried at 105°C for 12 h; all samples were then dry-ashed at 550°C for 16 h, solubilized in HCl, and filtered through 42 Whatman filter paper. Drinking water was concentrated 10-fold by evaporation on a hot plate. Zinc sources were refluxed for 4 h in 1:1 (vol:vol) concentrated HCl:HNO<sub>3</sub>, then filtered through 42 Whatman paper and brought to an appropriate volume with deionized water (Anonymous, 1982). Zinc sources were also analyzed for other trace elements using spectrophotometric method.

### Statistical analysis

Data were subjected to general linear model procedures of SAS (SAS Institute, 1999) as a 5×3 factorial arrangement of treatments with zinc source and dietary supplemental Zn concentration as the main effects and appropriate interactions. Initial design was randomized complete block design; however, since the effect of block on studied parameters was insignificant, this item was not considered in the final model. Pen was used as the experimental unit. For data related to carcass measurements, the means data of two slaughtered birds were pooled and participated in the analysis of variance. Duncan's multiple range tests (Duncan, 1955) was used to separate treatment means at  $p < 0.05$  significant level. Single degree of freedom contrasts were made among treatment means to compare inorganic vs. organic Zn sources, sulfate (as the standard source) vs. other Zn forms, and also control (non-supplemented) group with supplemented ones.

## RESULTS

The zinc sources studied herein (zinc sulfate, zinc oxide, zinc acetate, zinc-methionine, and zinc-lysine) were determined to be containing 32.64, 75.73, 28.83, 9.31, and 9.52% zinc as fed basis, respectively. Only inorganic zinc sources (Zn sulfate and Zn oxide) were contained Fe ions, that determined to be 1,486 and 29,650 mg/kg, respectively. Cu<sup>2+</sup> content of Zn sulfate, Zn oxide and Zn acetate was determined to be 27, 609, and 9.4 mg/kg, respectively; while, zinc-amino acid complexes had not any detectable copper. The manganese was contained only in inorganic zinc sources so that zinc sulfate and zinc oxide were contained 1,572 and 492 mg Mn<sup>2+</sup>/kg, respectively.

The effects of source and supplemental zinc level on performance parameters are shown in Table 2. Feed consumption was significantly ( $p < 0.001$ ) affected by zinc sources in the all experimental periods. Almost in all cases, the highest feed intakes were assigned to chicks fed on ZnMet-supplemented diets, followed by chicks given ZnLys-diets. The least feed intakes were attributed to sulfate-supplemented chicks. Introduction of organic zinc sources in replacing with Zn sulfate into the diets caused approximately 4.4% increase in average total feed intake, while when only zinc-amino acid complexes were compared with sulfate, feed intake increased by 4.7%. The chicks supplemented with another inorganic zinc source (zinc oxide) consumed more feed than sulfate-supplemented group. Dietary zinc concentration had no significant effect on feed intake during wk 1 to 5 (data not shown); however, significant effects were observed in grower and entire experimental periods in which feed intakes were declined along with increasing supplemental level from 80 to 120 mg Zn/kg. Also, zinc source interacted with dietary Zn concentration in terms of feed intake. Contrast comparisons showed that dietary organic zinc supplementation increased feed consumption by broiler chicks. Single degree of freedom contrasts between control (non-supplemented group) and supplemented groups showed that there was no significant difference between feed consumption from non-supplemented and supplemented diets.

As shown in Table 2, the best gains were allotted to chicks fed on zinc-amino acid-supplemented diets, followed by chicks given acetate source. Inclusion of zinc-amino acid complexes instead of zinc sulfate (as the standard source) led to 4.6% increase in average total body weight gain. The change in dietary zinc source resulted in highly significant ( $p < 0.01$ ) alterations in body weight gains. Weight gains were not affected by added Zn level in any 5 initial weeks (data not shown); however, in grower and entire trial period weight gains improved ( $p < 0.01$ ) by increasing Zn level from 40 to 80 mg/kg and reversely affected as supplemental level increased to 120 mg/kg. Contrast comparisons made

**Table 2.** Effects of varying levels of supplemental zinc from organic and inorganic sources on feed intake, body weight gain (g/d per bird), and feed conversion ratio (g feed / g gain) of broiler chicks during entire 42 d period

Source	Supplemental level (mg/kg)	Daily feed intake			Body weight gain			Feed conversion ratio		
		1-21 d	21-42 d	1-42 d	1-21 d	21-42 d	1-42 d	1-21 d	21-42 d	1-42 d
Control	0	42.2	139.4	90.8	27.5	73.9	50.7	1.53	1.89	1.79
Zn sulfate	40	41.7	136.0	88.8	27.2	72.4	49.8	1.53	1.88	1.78
	80	41.0	135.6	88.3	27.1	72.8	49.9	1.51	1.86	1.77
	120	40.5	134.6	87.5	26.5	71.5	49.0	1.53	1.88	1.79
Zn oxide	40	40.0	137.3	88.6	25.8	73.4	49.6	1.55	1.87	1.79
	80	41.1	138.7	89.9	27.3	74.0	50.7	1.51	1.87	1.77
	120	42.3	140.3	91.3	27.8	73.5	50.7	1.52	1.91	1.80
Zn acetate	40	42.0	139.7	90.9	27.1	74.1	50.6	1.55	1.89	1.80
	80	42.5	143.2	92.9	28.0	77.3	52.7	1.52	1.85	1.76
	120	41.8	140.1	90.9	27.9	75.0	51.4	1.50	1.87	1.77
ZnMet	40	44.1	144.4	94.3	29.0	75.6	52.3	1.52	1.91	1.80
	80	42.6	142.3	92.5	28.2	76.6	52.4	1.51	1.86	1.77
	120	42.0	139.1	90.6	27.7	74.2	51.0	1.52	1.87	1.78
ZnLys	40	44.2	143.7	94.0	28.7	75.2	51.9	1.54	1.91	1.81
	80	43.1	141.6	92.3	28.6	76.3	52.5	1.51	1.86	1.76
	120	41.8	139.2	90.5	27.6	74.7	51.1	1.52	1.87	1.77
Pooled SE		0.64	0.59	0.52	0.36	0.80	0.41	0.02	0.02	0.02
----- Probability -----										
Source		***	***	***	***	***	***	NS	NS	NS
Concentration		NS	***	**	NS	**	**	NS	NS	*
Source×concentration		*	***	***	**	NS	NS	NS	NS	NS
Contrasts										
Control vs. others		NS	NS	NS	NS	NS	NS	NS	NS	NS
Sulfate vs. other suppl.		*	***	***	**	***	***	NS	NS	NS
Organic vs. inorganic		***	***	***	***	***	***	NS	NS	NS

NS: not significant; \* p<0.05; \*\* p<0.01; \*\*\* p<0.001.

among treatment means showed that the introduction of organic Zn sources instead of conventional inorganic ones was associated with considerable improvements in growth rates of broiler chicks in the all experimental periods. All together, supplementation of experimental diets with dietary zinc supplements had no significant influence on body weight gains as compared with control birds (non-supplemented group).

Except of wk 1 in that organic zinc sources improved feed conversion ratio (data not shown), dietary zinc source had no significant effect on FCR values (Table 2). Almost in all cases, FCR values were also not affected by dietary Zn concentration, although overall FCR was improved by supplemental level of 80 mg Zn/kg of diet. Contrast comparisons among inorganic and organic zinc sources, and between sulfate and other zinc sources failed to show any significant differences concerning FCR values.

As presented in Table 3, increasing supplemental Zn level from 40 to 80 or 120 mg/kg, caused significant (p<0.05) decrease in pancreas weight percentage. Except of breast meat yield, none of organ weights or carcass parameters studies herein (liver, pancreas, heart, thigh or carcass percentages) were affected by dietary zinc source. Contrast comparisons between organic and inorganic zinc supplements indicated that organic zinc supplementation

had beneficial effects on carcass and breast weight percentages. Similarly, liver weight percentage increased by dietary inclusion of organic zinc sources. Except of relative heart weight which was reduced in control group (birds fed non-supplemented diets), none of carcass parameters were affected by dietary zinc supplementation.

## DISCUSSION

Zinc is commonly added as a supplement to all formulated poultry diets. Currently, there are two feed-grade Zn sources commonly used by the animal feed industry: ZnO (72% Zn) and ZnSO<sub>4</sub>·H<sub>2</sub>O (36% Zn). Of the supplemental Zn fed, 80 to 90% is ZnO (mostly Waelz-processed ZnO; Batal et al., 2001), which is less bioavailable for poultry than reagent-grade or feed-grade Zn sulfate (Wedekind and Baker, 1990; Sandoval et al., 1997; Edwards and Baker, 1999). However, the sulfates (acid salts) are highly water soluble, allowing reactive metal ions to promote free radical formation. This reaction can lead to the breakdown of vitamins and ultimately to the degradation of fats and oils, decreasing the nutritive value of the diets. Oxides are less reactive but also less bioavailable (Batal et al., 2001). In addition to high reactivity, water solubility of sulfates declines chick's

**Table 3.** Effects of varying levels of supplemental zinc from organic and inorganic sources on relative organ weights and carcass efficiency of broiler chicks measured at 42 days of age (% of live body weight)

Source	Supplemental level (mg/kg)	Liver	Pancreas	Heart	Carcass	Breast <sup>1</sup>	Thigh <sup>2</sup>
Control	0	2.04	0.24	0.40	66.73	19.19	18.86
Zn sulfate	40	1.97	0.25	0.45	67.58	18.25	20.30
	80	2.23	0.25	0.44	66.79	19.06	19.37
	120	2.11	0.23	0.45	67.02	19.80	18.51
Zn oxide	40	2.10	0.25	0.47	65.67	19.32	18.34
	80	2.07	0.21	0.47	68.64	21.00	17.41
	120	2.08	0.24	0.45	67.22	18.67	19.38
Zn acetate	40	2.03	0.26	0.44	67.53	19.75	19.35
	80	2.03	0.22	0.43	68.52	20.16	19.40
	120	2.34	0.21	0.45	69.08	20.15	19.15
ZnMet	40	2.25	0.25	0.47	68.01	19.66	18.48
	80	2.44	0.24	0.43	68.34	20.55	19.57
	120	2.04	0.24	0.44	67.46	19.99	20.73
ZnLys	40	2.36	0.23	0.45	67.56	19.71	18.11
	80	2.20	0.24	0.44	68.07	20.69	18.98
	120	2.08	0.22	0.42	68.41	21.36	20.03
Pooled SE		0.08	0.01	0.02	0.72	0.58	0.55
----- Probability -----							
Source		NS	NS	NS	NS	*	NS
Concentration		NS	*	NS	NS	*	NS
Source×concentration		**	NS	NS	NS	NS	*
Contrasts							
Control vs. others		NS	NS	*	NS	NS	NS
Sulfate vs. other suppl.		NS	NS	NS	NS	*	NS
Organic vs. inorganic		*	NS	NS	*	**	NS

<sup>1,2</sup> Breast and thigh weight percentages are expressed as skinless weights.

NS: not significant; \* p<0.05; \*\* p<0.01

appetite and consequently reduce feed intake. Loss in appetite appears to be responsible for decline of feed intake in sulfate-supplemented chicks in the present study, consequently resulted in slower growth rate of this group as compared with others. In their study, Sandoval et al. (1997) showed that chicks fed on sulfate-supplemented diets consumed less feed than those fed other Zn sources. Dietary supplementation with organic zinc sources improved feed intake. Similar to our results, Wedekind et al. (1992) reported increase in weight gain and total tibia Zn in birds fed ZnMet diets. These observations were contributed, in part, to increased consumption of basal diet (Wedekind et al., 1992). In the present study, increasing supplemental Zn level up to 80 mg/kg as oxide or acetate was associated with linear increase in feed intake. Probably, lower absorption rate of Zn from these two sources caused the higher levels of supplemented Zn be needed to meet nutritional requirements of chicks for this nutritionally trace element. In according to our opinion, Sahin et al. (2005) stated that zinc-picolinate (and probably zinc-amino acid complexes) was highly absorbable. Citrate, gluconate, and acetate forms were not absorbed as well as the zinc picolinate form, whereas the sulfate form is the most poorly absorbed.

Higher absorption rate of ZnPic source (Hahn and Baker, 1993) and also zinc-amino acid complexes allows lower inclusion rates of zinc supplements and makes mineral balance in animal body easier to maintain. It appears that the greater absorption rate of ZnMet and ZnLys to be responsible for higher decrease in feed intake of birds fed on higher levels (80 and 120 mg Zn/kg) of Zn supplied by these organically-Zn compounds than sulfate-supplemented group. The best weight gains allotted to birds fed on zinc-amino acid complexes. Dietary inclusion of ZnMet complex led to highest weight gains among the all zinc sources evaluated herein. The greater bioefficacy of ZnMet and/or ZnLys relative to sulfate or oxide forms suggests that the metabolism of these Zn complexes differs from metabolism of Zn supplied by inorganic Zn sources.

The lack of responses in feed intake and weight gain to added Zn levels up to 120 mg/kg, may be due to increased synthesis of intestinal metallothionein. Zinc intake has been shown to induce intestinal metallothionein synthesis (Sandoval et al., 1997). Increased synthesis of this zinc binding protein is associated with reduced zinc absorption. This protein will influence the regulation of Zn absorption and possibly the response of broiler chicks to supplemental

levels of zinc from different sources. The single degree of freedom contrast among control (non-supplemented group) and treatment groups showed that zinc supplementation had no additional effect on feed intake or weight gain. The lack of increase in feed intake or body weight gain with added Zn indicates that the amount of the element in the non-supplemented control diet was adequate for growth specially during starting period of life despite of the fact that NRC (1994) suggested that 40 mg/kg as the requirement for broiler chicks. The contribution of Zn from the remaining yolk sac and easier permeability of the still developing gastrointestinal tract may have contributed to this observation (Cao et al., 2002). Of course, the presence of data from sulfate- and oxide-supplemented birds as well as adverse effect of the highest (120 mg/kg) level of added Zn in calculations may be, in part, responsible for lack of priority of zinc-supplemented groups compared with non-supplemented one.

The best FCR values in wk 1 (data not shown) assigned to the chicks fed on ZnMet-supplemented diets that did not differ from other organic sources. It appears that the better FCR values in the initial weeks by organic Zn supplementation may be related to proper feathering. The essential amino acids lysine, methionine, and cyst(e)ine stimulate wool (and probably feather) growth (Reis and Sahlu, 1994; Puchala et al., 1995). Apart from the major nutrients such as protein, many vitamins and trace elements are essential for fiber (and feather) growth. Zinc functions directly in the process of feather growth; thus, Zn deficiencies can seriously affect feather growth (Reis, 1989). Higher bioavailability of organic zinc sources may supply zinc and essential amino acids (Met and Lys) requirements for rapid feathering and, in turn, decrease maintenance requirements because of insulating action of feathers.

The lack of improvement in feed conversion efficiency by dietary inclusion of organic zinc sources may be due to the higher feed consumption from organic zinc-supplemented diets. In agreement with results presented here, Sandoval et al. (1999) observed that feed conversion from d 15 through d 21 was not affected ( $p > 0.10$ ) by the dosing method or Zn source.

Increasing supplemental Zn level over than 40 mg/kg, caused significant ( $p < 0.05$ ) decrease in pancreas weight percentage. The exact mechanism involved is unclear; however, it seems that with 40 mg added Zn/kg, pancreas functions properly, while exceeded Zn levels are excreted along with feces.

It appears that Zn contained in non-supplemented control diet is not sufficient for proper pancreatic function, while exceeded levels of added zinc are not also needed for this organ and organs such that. Dietary zinc source tended ( $p = 0.0683$ ) to affect liver weight. The heaviest livers were assigned to chicks fed on ZnMet-supplemented diets. The

response of liver weight percentage to increasing supplemental Zn level was different among studied zinc sources, resulted signifying ( $p < 0.01$ ) zinc level by zinc source interaction; however, the reasonable explanation for this observation remains to be elucidated.

Increasing Zn level was associated with improved breast meat percentage. In addition, dietary inclusion of organic zinc sources caused to favorable changes in breast meat yield ( $p < 0.01$ ) and carcass efficiency ( $p < 0.05$ ). Commercially available ZnMet and ZnLys complexes provide both Zn and Met, and Zn and Lys, respectively. Hempe and Cousins (1989) suggested that ZnMet and CuLys complexes are transported intact from the intestinal lumen into the mucosal cells. If ZnMet and ZnLys are absorbed and transported without modification, the complexes may provide a means of increasing tissue supply of Met and Lys, which should improve animal productivity when Met and Lys are limiting amino acids (Puchala et al., 1999).

In conclusion, it appears that organic Zn sources provide more bioavailable zinc than feed-grade zinc sulfate or zinc oxide, support broiler productivity in the better manner. In addition, the greater bioefficacy of organic sources specially ZnMet and ZnLys relative to conventionally-used inorganic sources in enhancing chick performance suggest that metabolism of these commercial products differs from that of Zn supplied by inorganic zinc sources. With organic zinc sources, however, the zinc requirements are less. On the other hand, the organic zinc sources have more likelihood to be toxic and reduce animal performance when include into the diets in higher levels.

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## REFERENCES

- Anonymous. 1982. Analytical Methods for Atomic Absorption Spectrophotometry, Perkin-Elmer Corp., Nor Walk, CT.
- AOAC. 1995. Official Methods of Analysis. 16<sup>th</sup> ed. Association of Official Analytical Chemists, Arlington, VA.
- Baker, D. H. and C. B. Ammerman. 1997. Zinc bioavailability. In: Bioavailability of nutrients for animals: amino acids, minerals, and vitamins (Ed. C. B. Ammerman, D. H. Baker and A. J. Lewis). Academic Press, San Diego, CA, pp. 367-398.
- Batal, A. B., T. M. Parr and D. H. Baker. 2001. Zinc bioavailability in tetrabasic zinc chloride and the dietary zinc requirement of young chicks fed soy concentrate diet. *Poult. Sci.* 80:87-90.
- Cao, J., P. R. Henry, S. R. Davis, R. J. Cousins, R. D. Miles, R. C. Littell and C. B. Ammerman. 2002. Relative bioavailability of

- organic zinc sources based on tissue zinc and metallothionein in chicks fed conventional dietary zinc concentrations. *Anim. Feed Sci. Technol.* 101:161-170.
- Cheng, J., E. T. Kornegay and T. Schell. 1998. Influence of dietary lysine on the utilization of zinc from zinc sulfate and a zinc-lysine complex by young pigs. *J. Anim. Sci.* 76:1064-1074.
- Duncan, D. B. 1955. Multiple range and multiple F tests. *Biometrics* 11:1-42.
- Edwards, Jr., H. M. 1959. The availability of chicks to zinc in various compounds and ores. *J. Nutr.* 69:306-308.
- Edwards, Jr., H. M. and D. H. Baker. 1999. Bioavailability of zinc in several sources of zinc oxide, zinc sulfate, and zinc metal. *J. Anim. Sci.* 77:2730-2735.
- Ellis, R., E. R. Morris and A. D. Hill. 1982. Bioavailability to rats of iron and zinc in calcium-iron-phytate and calcium-zinc-phytate complex. *Nutr. Res.* 2:319-322.
- Falchuk, K. H. and B. L. Vallee. 1985. Zinc and chromatin structure, composition and function. In: Trace elements in man and animals (Ed. C. F. Mills, I. Bremner and J. K. Chesters). CAB Publishing, UK, pp. 48-55.
- Fordyce, E. J., R. M. Forbes, K. R. Robbins and J. W. Erdman, Jr. 1987. Phytate $\times$ calcium/zinc molar ratios: Are they predictive of zinc bioavailability? *J. Food Sci.* 52:421-428.
- Hahn, J. D. and D. H. Baker. 1993. Growth and plasma zinc responses of young pigs fed pharmacologic levels of zinc. *J. Anim. Sci.* 71:3020-3024.
- Hempe, J. M. and R. J. Cousins. 1989. Effect of EDTA and zinc-methionine complex on zinc absorption by rat intestine. *J. Nutr.* 119:1179-1187.
- Hill, D. A., E. R. Peo, Jr., A. J. Lewis and J. D. Crenshaw. 1986. Zinc-amino acid complexes for swine. *J. Anim. Sci.* 63:121-130.
- Kaim, W. and B. Schwederski. 1994. Bioinorganic chemistry: inorganic elements in the chemistry of life. John Wiley and Sons Ltd, England. pp. 401.
- National Research Council. 1994. Nutrient Requirements of Poultry. 9<sup>th</sup> rev. ed. Natl. Acad. Press, Washington, DC.
- Oberleas, D., M. E. Muhrer and B. L. O'Dell. 1962. Effects of phytic acid on zinc availability and parakeratosis in swine. *J. Anim. Sci.* 21:57-61.
- O'Dell, B. L., J. M. Yohe and J. E. Savage. 1964. Zinc availability in the chick as affected by phytate, calcium and ethylenediamine tetraacetate. *Poult. Sci.* 43:415-419.
- Puchala, R., S. G. Pierzynowski, T. Sahlu and S. P. Hart. 1995. Effects of amino acids administered to a perfused area of the skin in Angora goats. *J. Anim. Sci.* 73:565-570.
- Puchala, R., T. Sahlu and J. J. Davis. 1999. Effects of zinc-methionine on performance of Angora goats. *Small Ruminant Res.* 33:1-8.
- Reis, P. J. 1989. The influence of absorbed nutrients on wool growth. In: The biology of wool and hair (Ed. G. E. Rogers, P. J. Reis, K. A. Ward and R. C. Marshall). Chapman and Hall Publishing, London, UK, pp. 185-203.
- Reis, P. J. and T. Sahlu. 1994. The nutritional control of growth and properties of mohair and wool fibres: a comparative review. *J. Anim. Sci.* 72:1899-1906.
- Roberson, R. H. and P. J. Schaible. 1960. The availability to the chicks of zinc as the sulfate, oxide or carbonate. *Poult. Sci.* 39:835-837.
- Sahin, K., M. O. Smith, M. Onderci, N. Sahin, M. F. Garsu and O. Kucuk. 2005. Supplementation of zinc from organic and inorganic source improves performance and antioxidant status of heat-stressed quail. *Poult. Sci.* 84:882-887.
- Sandoval, M., P. R. Henry, C. B. Ammerman, R. D. Miles and R. C. Littell. 1997. Relative bioavailability of supplemental inorganic zinc sources for chicks. *J. Anim. Sci.* 75:3195-3205.
- Sandoval, M., P. R. Henry, R. C. Littell, R. D. Miles, G. D. Butcher and C. B. Ammerman. 1999. Effect of dietary zinc source and method of oral administration on performance and tissue trace mineral concentration of broiler chicks. *J. Anim. Sci.* 77:1788-1799.
- SAS Institute. 1999. SAS Statistics User's Guide. Statistical Analytical System. 5<sup>th</sup> rev. ed. Carry, NC, SAS Institute Inc.
- Spears, J. W. 1989. Zinc methionine for ruminants: Relative bioavailability of zinc in lambs and effects of growth and performance of growing heifers. *J. Anim. Sci.* 67:835-843.
- Swinkels, J. W. G. M., E. T. Kornegay, K. E. Webb, Jr. and M. D. Lindemann. 1991. Comparison of inorganic and organic zinc chelate in zinc depleted and repleted pigs. *J. Anim. Sci.* 69 (Suppl. 1):358 (Abstr.).
- Wedekind, K. J. and D. H. Baker. 1990. Zinc bioavailability in feed-grade sources of zinc. *J. Anim. Sci.* 68:684-689.
- Wedekind, K. J., A. E. Hortin and D. H. Baker. 1992. Methodology for assessing zinc bioavailability: Efficacy estimates for zinc-methionine, zinc sulfate, and zinc oxide. *J. Anim. Sci.* 70:178-187.