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Effect of Sources and Levels of Dietary Zinc on the Performance, Carcass Traits and Blood Parameters of Broilers

■Author(s)

Zakaria HA[I]
Jalal M[I]
AL-Titi HH[I]
Souad A[I]

[I] Animal Production Department, Faculty of Agriculture, The University of Jordan, Amman-11942, Jordan.

■Mail Address

Corresponding author e-mail address
Hana Abdul-Hadi Zakaria
Animal Production Department, Faculty of Agriculture, The University of Jordan, Amman-11942, Jordan.
Tel: 00962798515389
Email: zakariah@ju.edu.jo

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ABSTRACT

A total of 400 one-day-old, straight-run, commercial (Ross 308) broiler chicks were used to evaluate the effects of two dietary levels of zinc (Zn) sources on broiler chick performance, carcass traits and blood parameters. Corn-soybean diets were formulated for three rearing phases (starter, grower and finisher). The two dietary treatments applied consisted of the addition per kg of diet of 80mg of inorganic Zn (ZnO) (T1), or 80mg of ZnO plus 42mg of an organic Zn-amino acid complex (Availa-Zn120; Zinpro Corporation, Eden Prairie, MN, USA), totaling 122mg of the combined organic and inorganic Zn sources (T2). Birds were distributed according to a completely randomized design in the two treatments with eight replicates (pens) of 25 birds each. Feed and water were provided *ad libitum*. On day 42, blood samples were taken from four birds closest to the group average weight per replicate (32 per treatment) and then slaughtered for carcass evaluation. The results of this study did not find any significant effect of either of the evaluated Zn sources on broiler growth performance. Mortality rate was significantly lower (p<0.05) by the higher Zn concentration and the Zn sources group (T2). Carcass yields were not significantly influenced by the treatments. Breast quality showed significant improvement (p<0.05) in shear force (T2), indicating juicier meat. Higher concentrations (p<0.05) of Zn, Phosphorus (P), and total protein in blood were noted in (T2). Birds fed a mixture of organic and inorganic Zn source (T2) presented overall better results.

INTRODUCTION

Zinc (Zn) is an essential trace element in all living systems – from bacteria, plants and animals to humans – and plays an important role in various biological activities in animals, especially in fast-growing poultry (Liu *et al*., 2011). Poultry diets are commonly supplemented with Zn since many feed ingredients are marginally deficient in this trace element (Bao *et al*., 2007). The variable content of Zn in poultry feeds, particularly in the components of concentrate mixtures for poultry, and the fact that Zn binds with phytic acid inside the intestine to form complexes that make it unavailable for absorption, justifies the necessity to maintain a proper balance of this element in the feed mixture (Yan and Waldroup, 2006). Zn is added to broiler diets in inorganic feed-grade forms, such as zinc sulfate ($ZnSO_4$) (Rossi *et al*., 2007) or zinc oxide (ZnO) (Wojciech *et al*., 2007, Jahanian *et al*., 2014). Organic Zn sources, such as Zn methionine (Zn-Me) and Zn amino acid complex (ZnAA), have been used in the poultry feed industry owing to their potentially higher Zn bioavailability (Berger *et al*., 2006; Salim *et al*., 2010) when compared with the inorganic forms. Generally, it is accepted that bioavailability of trace mineral supplements from organic sources is higher than that of the inorganic sources owing to the ability of organic compounds, such as

amino acids, to bind strongly to divalent minerals under physiological pH conditions (Cheng *et al*., 2005;Yan and Waldroup, 2006; Ao *et al.,* 2009). Conflicting data have been reported regarding the relative efficacy of different organic compared with inorganic Zn sources in enhancing broiler performance (Hess *et al.,* 2001; Swiatkiewicz *et al.,* 2001). Zn requirements have been estimated to be 37 mg/kg from organic sources (Ao *et al*., 2007) and 84 mg/kg from inorganic sources (Huang *et al*., 2007). The National Research Council (NRC, 1994) states that Zn requirements of broilers are 40 mg/kg regardless of the source. However, poultry diets are often formulated to contain dietary Zn concentrations over 80mg/kg to achieve maximum performance (Jahanian *et al*., 2014). Producers of Ross (308) chicks recommend 100mg/kg for Zn. Burrell *et al*. (2004) reported improved performance when broilers consumed diets formulated to contain 110mg Zn/kg. Excessive supplementation of inorganic Zn can cause environmental pollution resulting from the low utilization of this element. Therefore, using Zn sources with higher bioavailability may reduce the excretion of Zn. This subject has been extensively researched in many countries, but no information in literature cited examines the effects of higher concentrations of Zn in the diet by combining conventional inorganic Zn sources (ZnO) with organic sources, such as a Zn-amino acid chelate on the growth performance, meat quality, and blood parameters of broilers. The objective of this study was to evaluate the effect of broiler diets supplemented with different forms and levels of Zn: ZnO (80 mg/kg) as inorganic source, or higher concentrations of Zn (122 mg/kg) from a combination of ZnO with an organic Zn source (Availa-Zn120; Zinpro Corporation, Eden Prairie, MN, USA) on broiler performance, carcass and parts yields, meat quality and blood parameters.

MATERIALS AND METHODS

Birds and experimental diets

All procedures regarding bird handling and use are in accordance with guidelines set forth by the Jordanian Society for the Protection of Animals (SPANA, issued in 2007).

The experiment was conducted at poultry research farm of the University of Jordan. Birds were housed in a naturally-ventilated, open-sided chicken house divided in 16 floor pens. A total of 400 one-day-old, straight-run, commercial (Ross 308) broiler chicks were reared under standard management practices (Ross Management Guide, 2009).

Birds were fed one of two dietary treatments, each with eight replicates of 25 birds per replicate pen), in a completely randomized design. A regular corn-soybean pelleted diet was formulated for three rearing phases: starter (1-21 days), grower (22-35 d), and finisher (36-42 d), as are shown in Table 1. The two dietary treatments consisted of the basal diet supplemented with 80mg/kg of ZnO (T1, control) as inorganic Zn source in the trace mineral premix, or the basal diet supplemented with 80mg/kg of ZnO in the trace mineral premix plus 42 mg/kg of an organic Zn source added on top (zinc-methionine; Availa-Zn120; Zinpro Corporation, Eden Prairie, MN, USA), totaling 122 mg of Zn per kg of diet (T2). The Zn-amino acid chelate contained 12% Zn. The recommended dose for broilers is 350g/MT feed, which gives 42 g of Zn-AA per MT of complete feed, given as per product feeding instructions of Zinpro (Zinpro Corporation) (Table 2). The composition of the experimental diets was analyzed according to the AOAC (2000).

Table 1 – % Diet Composition

Ingredient	Starter (0-21 d)	Grower (22-35 d)	Finisher (36-42 d)
		(%)	
Corn	55.75	59.85	64.15
Soybean meal (48 % CP)	38.00	32.50	28.00
Vegetable Oil	2.10	3.50	3.70
Limestone (ground)	1.60	1.60	1.60
Monocalcium phosphate	1.13	1.05	1.05
NaCl	0.25	0.25	0.25
DL-methionine (98%)	0.22	0.20	0.20
L-Lysine-HCl (98.5%)	0.25	0.23	0.23
Threonine	0.06	0.05	0.05
Vitamin premix[1]	0.10	0.10	0.10
Mineral premix[2]	0.10	0.10	0.10
Choline Chloride (60%)	0.08	0.08	0.08
Coccsidiostat	0.05	0.05	0.05
*Concentrate 2.5%	0.31	0.44	0.44
NutrientChemical Composition:			
ME, kcal/kg feed	3,000	3,100	3,150
Crude Protein, %	22.50	19.50	18.50
Methionine, %	0.60	0.54	0.48
Lysine, %	1.40	1.25	1.10
Threonine, %	0.90	0.80	0.73
Tryptophan, %	0.24	0.22	0.20
Ca, %	1.00	0.90	0.85
P, non-phytate, %	0.48	0.45	0.45

[1]Vitamin premix provided per kilogram of diet:vitamin A, 120000 IU; vitamin D_3, 3500 IU; vitamin E, 40 mg; vitamin B_1, 2.5 mg; vitamin B_2, 8 mg; vitamin B_6, 5.0 mg; vitamin, riboflavin, 150 µg; B_{12}, 30 µg; biotin, 150 µg; folic acid, 1.5 mg; niacin, 45 mg; pantothenic acid, 13 mg..

[2]Trace mineral premix provided per kilogram of diet:Fe, 60 mg; Cu, 10 mg; Mn, 80 mg; Zn, 80 mg; I, 1 mg; Se, 0.20 mg.

*Concentrate 2.5% contains:0.05% Lysophospholipids, 0.035% Xylanase, 0.025% Probiotic, 0.025% Coccidiostat 0.005% Phytase and 0.05-0.185% corn gluten.

Table 2 – Concentrations of Zn mg/kg in zinc supplements

Zinc supplements	T_1	T_2
Zinc oxide	80	80
[1]Availa Zinc	-	42
Total Zn in diets (mg/kg)	80	122

[1] Zn 120 was added on top of the diets containing 12% Zn, recommended dose for broilers 350g/MT

120g/kg*0.35kg =42 g of AA complexed Zn/MT of complete feed.

T_1:addition of ZnO in the trace mineral premix (80 mg/kg).

T_2:combination of ZnO in the trace mineral premix with Availa Zn added on top of diet (122mg/kg)

Daily temperatures were determined by a sensor located in the center of each room at 9 cm above the floor. Birds were given a 23L: 1D lighting regimen daily, and feed and water were provided *ad libitum* throughout the experiment. Birds were weighed upon arrival (initial body weight was 40±0.3 g) and once a week until the end of the experiment (final body weights were 1930 g (T1) and 1865.22 g (T2), as shown in Table 3).

Table 3 – Effect of levels and sources of Zn (inorganic and organic) on performance of broilers

Parameters	Treatments (ZnO,T_1) (ZnO+AvailaZn,T_2)			
	T_1	T_2	SEM[2]	*p* value
Body weight (g/bird):				
Production Stages				
0 – 21 days	687.50	713.00	28.10	*NS*
0 – 42 days	1950.50	1898.25	48.52	*NS*
Body weight gain (g/bird):				
Production Stages				
0 – 21 days	654.50	680.00	28.06	*NS*
0 – 42 days	1930.00	1865.22	44.73	*NS*
Feed intake (g/bird):				
Production Stages				
0 – 21 days	845.50	825.25	25.43	*NS*
0 – 42 days	3469.75	3345.75	53.69	*NS*
Feed conversion ratio (g feed :g bodyweight gain):				
Production Stages				
0 – 21 days	1.34	1.32	0.0531	*NS*
0 – 42 days	1.76	1.82	0.0646	*NS*
Mortality rate (%)				
Production Stages				
0 – 21 days	4.50[b]	1.00[a]	0.530	*0.02*
0 – 42 days	4.80[b]	1.25[a]	0.638	*0.01*

[a-b] Means within rows with varying superscripts differ significantly *($p<0.05$)* [2]SEM:standard error of the mean[3]Level of significance was set at *$p<0.05$,* NS:Not Significant

Growth performance

Production parameters were measured on a weekly basis per pen, and included feed intake (FI), feed conversion ratio (FCR), body weight (BW), and body weight gain (BWG). Mortality was observed and recorded daily; any bird that died was weighed, and its weight was used to correct both FI and FCR. Adjusted FCR was calculated using total feed intake per pen divided by the total weight gain of surviving birds and weight of birds that died or were removed from that pen.

Sample collection for carcass evaluation and blood sampling

On day 42 of the feeding trial, birds were fasted for 10 hours. Four birds per replicate (16 per treatment), with BW closest to the mean BW of the replicate were selected, weighed, and slaughtered according to animal welfare regulations in Jordan.

Two blood samples (3 mL) were obtained from the wing vein of each bird and centrifuged at 3000 rpm for 10 min to measure the blood levels of glucose, cholesterol, calcium (Ca), phosphorous (P), total protein, albumin and Zn using commercial kits (Boehringer Mannheim Hitachi 704, automatic analyzer, Tokyo, Japan). All the analyses were carried out in duplicate.

After slaughter, birds were scalded in a water tank at 55°C-60°C for 30 seconds, and then plucked and eviscerated. Feet, shanks, neck, and head were removed, and carcasses were immediately weighed to obtain post-slaughter hot carcass weight without giblets. Giblets are the total yield of liver, heart and gizzard, which were removed and weighed, in addition to fat pad relative to body weight. Carcasses were refrigerated at 2°C-3°C for 24 hours, after which they were weighed to obtain cold carcass weight as a percentage of live weight (Asku *et al*., 2008). Carcasses were then dissected into different commercial parts (breast, thighs, and wings) to determine their yields. Parts yield were calculated relative to carcass weight and expressed as a percentage (Abdullah *et al*., 2010). Breast fillets were evaluated for the meat quality attributes pH, color, water-holding capacity, cooking loss, and shear force.

Meat quality measurements

Meat pH values were determined by using the iodo acetate method (Jeacocke, 1977) on a pH meter (pH spear, model 35634-40, Eurotech Instruments, Malaysia). The pH was measured at three points in the cranial area of the pectoral superficial muscle (*Pectoralis major*) at about 5 cm from the sternum line (Abdullah & Matarneh, 2010).

Color measurements were taken on the same area as the pH from each sample using a colorimeter (12 MM Aperture U 59730-30, Cole-Parameter International Inc., Pittsford, NY, USA). Three measurements were taken at each point on the medial portion of the

pectoralis major muscle. Meat lightness (L*), redness (a*), and yellowness (b*) values were determined against a standard white ceramic reference.

Water-holding capacity (WHC) was measured (Barbut, 2002) based on the technique modified by Wilhelm *et al*. (2010)using a raw meat sample with initial weight of 5 g (one per replicate) Each sample was cut into smaller pieces and covered with two filter papers (qualitative, 185mm circles, fine crystalline retention) and two thin plates of quartz material, then pressed with the weight of 2500 g for 5 min. The meat samples were then removed from the filter paper, and their weight was recorded (final weight). WHC was calculated as the difference between the initial and final weight divided by the initial sample weight and expressed as a percentage (Al-Owaimer *et al*., 2014).

Cooking loss and shear force measurements

Breast samples of about 250 g were weighed and placed in sealed bags without air in a freezer at -20ºC. Breast samples were then thawed, and removed from the plastic bags to determine weight loss. Samples were then individually placed in sealed plastic bags, cooked in a thermostatically-controlled water bath at 85ºC for 25 minutes until maximum internal temperature of 80ºC was achieved. Samples were then removed and put under running cold water to cool down for 45 minutes, then well dried and weighed to determine cooking loss. Cooking loss was calculated the percentage of cooked sample weight relative to fresh sample weight (Al-Owaimer *et al*., 2014).

The cooked pieces of meat were cut to obtain six cores (20×13×13 mm) of each breast sample (6-8 carrots of 1.25cm diameter) using a metal cylinder to determine meat shear force according to Bratcher *et al*. (2005) (Warner-Bratzler Meat Shear Apparatus/ INSTRON, G-R Manufacturing Co., 1317 Collins LN, Manhattan, Kansas, 66502, USA).

Statistical Analysis

Data were submitted to analysis of variance (ANOVA) according to a completely randomized design using the PROC Mixed procedure of SAS (Version 9.4, SAS Institute Inc., Cary, NC, 2013). Pairwise differences between means were determined using PDIFF option of LSMEANS statement. The main effects of the two treatments with eight replicates each on growth performance, carcass yield, meat quality and blood parameters were tested. The overall level of statistical significance was set at $p<0.05$; tendencies were reported when $0.05\leq p\leq 0.10$. Pen means were used as the experimental units for all variables evaluated.

RESULTS

Growth Performance

The evaluated treatments did not significantly affect BW, BWG, FI, and FCR (Table 3). The mortality rate (Table 3) recorded with the T2 diet (1.25%) was significantly lower ($p<0.05$) compared with that recorded with the T1 diet (4.80%).

Carcass yield, Meat Quality and Blood Parameters

The different carcass traits studied were not affected when combining two different sources of Zn to the bird feed and the higher concentration of Zn (Table 4). Carcass and breast, thigh, wing, back, neck, fat pad and internal organs yields were not affected by Zn source or the high Zn concentration. Zinc source and level did not influence the meat quality attributes pH, cooking loss, and water-holding capacity measured in 42-day-old broilers (Table 5). Meat color values (L*), redness (a*), and yellowness (b*) were not affected either. However, breast meat shear force was significantly higher ($p<0.05$) in T2 compared with T1 (3.53 vs. 4.14 kg/cm^2).

Table 4 – Effect of levels and sources of Zn (inorganic and organic) on dressing, cuts percentages and organ weights of broilers

Parameters	Treatments			
	T_1	T_2	SEM[1]	*p* value[2]
Carcass Weight (g)	1908.42	1856.92	52.73	*NS*
Dressing yield[3] (%)	74.74	75.10	1.58	*NS*
Fat Pad yield[4] (%)	1.12	1.29	0.169	*NS*
Breast yield[5] (%)	34.90	35.10	1.64	*NS*
Thigh yield[5](%)	28.39	27.81	0.937	*NS*
Wings yield[5] (%)	9.70	10.27	0.349	*NS*
Back yield[5] (%)	13.32	13.59	0.720	*NS*
Neck yield[5] (%)	13.40	13.39	0.559	*NS*
Liver Weight(g)	55.42	50.83	3.52	*NS*
Heart Weight(g)	13.30	14.16	1.22	*NS*
Gizzard Weight(g)	27.50	25.00	1.74	*NS*

[1] SEM:standard error of the mean

[2] Level of significance was set at *p<0.05*

[3]Carcass yield = (cold carcass weight/live weight)*100%

[4]Abdominal fat % = (abdominal fat weight/cold carcass weight)*100%

[5]Parts yield = (part weight/cold carcass weight)*100%.

T_1:ZnO (80 mg Zn / Kg).

T_2:ZnO+ Availa Zn (122 mg Zn /Kg).

NS:Not significant

The treatments did not significantly affect the blood parameters of broilers chicks, except for P (mg/dL), total protein (mg/dL) and Zn (ug/dL) (Table 6).

Table 5 – Effect of levels and sources of Zinc (inorganic and organic) on meat quality characteristics of broilers

Parameters	Treatments			
	T_1	T_2	SEM[1]	*p-Value*[2]
Breast pH (24 h post mortem)	5.93	5.92	0.007	*NS*
Breast cooking loss (%)	31.94	31.98	0.51	*NS*
Breast water holding capacity (%)	37.63	35.56	1.45	*NS*
Breast meat shear force (kg/cm^2)	4.14[a]	3.53[b]	0.41	0.02
L* (Breast meat lightness)	52.13	51.50	1.97	*NS*
a* (Breast meat redness)	3.52	3.38	0.24	*NS*
b* (Breast meat yellowness)	17.94	18.08	1.76	*NS*

[a-b] Means within rows with varying superscripts differ significantly *(p<0.05)*

[1] SEM:standard error of the mean

[2]Level of significance was set at *p<0.05*

T_1:ZnO (80 mg Zn /Kg).

T_2:ZnO+ Availa Zn (122 mg Zn/Kg).

NS:Not significant

Table 6 – Effect of levels and sources of Zinc (inorganic and organic) on the blood analysis of broilers

Parameters	Treatments			
	T_1	T_2	SEM[1]	*p-Value*[2]
Glucose (mg/dL)	215.63	209.25	11.38	*NS*
Cholesterol (mg/dL)	99.88	100.50	9.23	*NS*
Calcium (mg/dL)	9.74	10.66	0.495	*NS*
Phosphate (mg/dL)	6.16[b]	7.56[a]	0.332	*0.01*
Total Protein (mg/dL)	3.33[b]	3.63[a]	0.198	*0.05*
Albumin (mg/dL)	1.07	1.10	0.036	*NS*
Zinc (ug/dL)	149.13[b]	186.88[a]	13.06	*0.05*

[a-b] Means within rows with varying superscripts differ significantly *(p<0.05)*

[1]SEM:standard error of the mean

[2]Level of significance was set at *p<0.05*

T_1:ZnO (80 mg Zn /Kg).

T_2:ZnO+ Availa Zn (122 mg Zn/Kg)

NS:Not significant

DISCUSSION

Growth performance

Performance responses were not significantly different between the Zn levels and sources of used. Previous studies have shown no effect of Zn source on growth performance (Jondreville *et al.,* 2007; Rossi *et al.,* 2007; Schlegel *et al.,* 2010; Anil *et al.,* 2012; Salim *et al.,* 2012). Saenmahayak *et al*. (2010) reported that, regardless of its form, the dietary supplementation of Zn in excess of 40mg/kg of diet did not improve the growth rate of male broilers. Anil *et al*. (2012) stated that the supplementation of inorganic or organic Zn at 20, 40, 60, and 80 ppm levels did not influence feed intake of broilers. Sandoval *et al.* (1999) and Jahanian *et al*. (2008) also observed that inclusion of organic Zn sources had no beneficial effect on broiler feed efficiency. However, Kucuk *et al*. (2003), Burrell *et al*. (2004), and Ao *et al*. (2006) reported improvements in the growth performance, weight gain and feed efficiency of broilers when organic Zn was added above the NRC recommendation levels. Performance alone may not be a good indicator of the Zn requirements of broilers, especially when corn-soybean meal diets are fed, possibly because these ingredients contain the minimum Zn levels required for growth (Huang *et al*., 2007).

Mortality rate during the rearing period was significantly lower (p<0.05) in T2-fed birds (1.25%) compared with those fed the T1 diet (4.80%), as shown in Table 3. This reflects the role of Zn in stimulating the development of the immune system, as providing a sufficient bioavailable Zn source results in healthier birds and decreases mortality (Salim *et al.,* 2011).

The inconsistent effects of dietary Zn on broiler growth performance have been attributed to several factors, such as the amount of Zn present in the basal diet (Leeson & Summers 2005), the selective metabolism of Zn by different enzymes that affect some parameters of broiler performance, differences in the physical-chemical properties of the supplemented Zn source used (Zhao *et al.,* 2010), and the presence of other dietary ligands, such as phytate and Ca, which form insoluble complexes with Zn and interfere with its absorption (Salim *et al*., 2012).

Carcass yield, Meat Quality, and Blood Parameters

The different carcass traits evaluated in this study were not affected by different Zn sources fed to broilers (Table 4). This is consistent with Liu *et al.* (2011), who stated that dietary Zn levels and sources did not influence the abdominal fat percentage or the carcass traits of broilers. Rossi *et al*. (2007) and Anil *et al*. (2012b) reported that carcass yields were

not influenced by the addition of dietary organic Zn or when different levels of inorganic Zn and Mn were fed to broilers. Savari *et al.* (2015) concluded that there was no influence of ZnO on carcass traits. Jahanian *et al*. (2008) observed that dietary Zn levels of up to 40mg/kg did not have any significant effect on cooked-meat yield, in contrast with results obtained by Wojciech *et al.* (2007), who demonstrated the positive influence of organic Zn forms on the percentage of breast muscles in the carcass. Tronina *et al*. (2007) stated that organic Zn could increase the proportion of breast and leg muscles, dressing percentage and fat content in the breast and leg muscles of broilers. Liver and heart weights were not significantly different between the T2 group and the T1 group, in contrast with Jahanian *et al.* (2008), who reported that increasing Zn supplemental levels from 40 to 80 mg/kg from both inorganic and organic Zn sources increased liver weight percentage. Several factors may affect the final results of the trials, such as Zn source and concentrations, management practices applied, or environmental conditions under which experiments were conducted.

The meat quality indices evaluated in this study were not affected by Zn source or level, except for meat shear force. Meat color is one of the indicators of meat quality, and Zn has the ability to bind myoglobin and increase its oxygenation, which allows the maintenance of meat color; however, no significant effect on meat color was detected in our study. Our results are partially consistent with work conducted by Saenmahayak *et al.* (2010) in terms of carcass weight and parts yields, but in contrast with breast color, as those authors reported an increase in the redness a* value of the breast meat.

Breast meat shear force was significantly different between broilers fed inorganic Zn (ZnO) and the higher Zn level of the combination of ZnO with Zn-AA (Availa-Zn 120). Lower shear force value (p<0.05) in the T2 group compared with the T1 group (3.53 kg/cm^2 vs. 4.14 kg/cm^2) is an indication that meat from the T1 group was tougher and less juicy, since a greater SF value indicates lower meat tenderness. Organic and higher concentrations of Zn mixed with the inorganic source improved meat quality by helping to hold cells more tightly together in discrete units (Rossi *et al*., 2007) and to promote protein synthesis, collagen formation and optimal activity of the enzymes that affect meat quality (Saenmahayak *et al*., 2010). Many factors influence meat tenderness, such as age, sex, and dietary factors (Salim *et al.,* 2012; Devrim *et al*., 2009), and this may explain the contradictory results obtained in different trials conducted. There is limited information on the effects of organic Zn sources on broiler carcass and meat quality, and further experiments are needed to elucidate the effect of Zn on meat quality (Hess*et al.,* 2001).

Blood parameters were not affected by the two sources of Zn except for P, total protein and Zn concentration (Table 6). This is in agreement with Sarvari *et al*., (2015), who reported that serum parameters were not affected by ZnO. Higher blood total protein levels may be explained by the increase in the digestion time with slower passage time of feed in the digestive tract owing to the action of organic Zn since it plays a major role in the body enzyme system, physiology, metabolism and growth and it is necessary to promote protein synthesis (Berger, 2006). Feng *et al*. (2009) reported increased serum total protein and calcium concentrations when zinc-glycine chelate was added to the diet. However, Barman *et al*. (2009) did not report any significant effect of different dietary Zn supplementation levels on serum protein concentration. Jahnian & Rasouli (2015) reported no effects on plasma zinc concentration when inorganic zinc was replaced by Zn-methionine. Increased blood Zn levels are used as an indication of its biological availability in live animals (Liu *et al*., 2011). Similar findings were reported by Mohanna & Nys (1999) and Anil *et al*. (2012), who observed that blood Zn concentration increased with dietary Zn content. Ao *et al*. (2009) and Johnson & Fakler (1998) also stated that feeding premixes containing organic forms of chemical bonds of Zn (Zn-methionine and amino-acid Zn complex) resulted in higher blood Zn levels. The increase in serum Zn levels is related to the higher absorption and lower interaction with other organically-complexed minerals in the digestive tract compared with inorganic trace minerals, increasing the bioavailability of Zn bound to amino acids/proteins, and therefore it is easily absorbed because of such structures (Devrim *et al*., 2009).

The higher P level in the T2 group relative to T1may be explained by the interrelation between Zn and P, since P plays a major role in bone formation, and Zn deficiency results bone abnormalities (Collins *et al*., 1991). Phosphorus is usually present in meat in the form of phosphates that significantly contribute for the water-holding capacity of meat, which is related to shear force (Kucuk *et al.,* 2008). Feng *et al.* (2009) reported no effect on blood P levels when zinc-glycine was added to the diet. Zn is present in all cells and participates in a wide variety of metabolic processes,

and Zn enzymes are involved in the biosynthesis and degradation of carbohydrates, lipids, proteins, and nucleic acids (Kaim & Scwederski, 1994).

CONCLUSIONS

Performance responses were not significantly affected by the evaluated Zn levels and sources, and therefore, either source of supplemental Zn can be used in broiler diets without affecting bird performance.

The broilers fed with the highest dietary Zn level from both organic and inorganic sources presented higher Zn, P, and total protein levels relative to the lower levels evaluated.

Future research on dietary Zn supplementation will aid understanding both the absorption mechanisms and metabolic pathways of different Zn sources and their effects on meat quality.

Conclusions are based on this trial only and cannot be drawn upon by the basis of Zn sources and levels applied.

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The manuscript does not contain clinical studies or patient data.

CONFLICT OF INTEREST

None

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