Effects of zinc sources supplementation on performance of broiler chickens

M. Badawi[1], M. Ali[2] and A. Behairy[3]

[1]Dept. of Nutrition and Clinical Nutrition, Faculty of Veterinary Medicine, Zagazig University, Egypt.
[2]Dept. of Animal Wealth Development, Faculty of Veterinary Medicine, Zagazig University, Egypt.
[3]Dept. of Physiology, Faculty of Veterinary Medicine, Zagazig University, Egypt.
drmohamedbadwi@yahoo.com

Abstract: This trial was performed to study the effects of addition and/or substitution of various form of zinc sources (inorganic, organic and nano zinc) on performance, economic efficiency, blood metabolites and zinc concentration in tissue (breast muscle and liver) of broiler chickens. A total of 525 day old chicks were divided into seven groups with five replicates per group (75 chicks/group; 15 chicks/replicate). birds fed on 7 experimental diets; group 1: control basal diet without zinc supplement, group 2: 40 ppm inorganic Zn ($ZnSO_4$), group 3: 40 ppm organic Zn methionine (Zn-Met), group 4: 40 ppm nano zinc oxide (nano ZnO), group 5: 20 ppm $ZnSO_4$+20 ppm Zn-Met, group 6: 20 ppm $ZnSO_4$+20 ppm nano ZnO, group 7: 20 ppm Zn-Met+20 ppm nano ZnO. This experiment was extended for 6 weeks. Individual body weights and feed residues were measured weekly. At the trial end, collect blood and tissue samples after slaughter five birds/group. The overall BW, BWG and FCR were significantly improved in the Zn supplemented groups. Return, net profit or partial and collective efficiency measures were significant different between all group. There was significant increase in concentrations of serum total protein, HDL-cholesterol and ALP in groups supplemented with Zn. Furthermore, there was significant increase in serum; breast and liver zinc concentration in experimental groups. Compared to inorganic-Zn form, supplementation and/or substitution with organic-Zn and/or nano-Zn form had a positive influence on the overall performance, Zn concentration in bird's serum, tissue, and increase return and net profit so; its addition and/or substitution will improve productive and economic efficiency.

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1. Introduction

With the growing demands for food safety and health; scientists directed their attention toward enriching the poultry meat with some of the essential bioactive nutrients such as zinc (Zn) via supplementation of their diets with Zn in doses higher than those supplemented in the traditional diets leading to good health, better growth and optimum reproductive efficiency which reflect on overall economy **(Salim *et al.*, 2012).**

Zinc (Zn) is a nutritionally indispensable trace element that is required for normal growth, bone development, feathering, appetite regulation, metabolic functioning of nearly 300 biochemical enzymes, hormone production, cell division, protein and DNA synthesis for all avian species **(Yan *et al.*, 2016)**; so, it can affect animals production and reproduction performance **(Tsai *et al.*, 2016)**. Zinc deficiency in animals causes a decrease in feed intake, growth, serum insulin like growth factor-I and growth hormone (GH), and lowered hepatic production of insulin-like growth factor-I, GH receptor and GH binding protein **(Chrastinova *et al.*, 2016)**.

Zinc is commonly added to broiler diets as inorganic feed-grade zinc; sulfate monohydrate ($ZnSO_4.H_2O$), chloride ($ZnCl_2$) and oxide (ZnO) or organic forms; organic acid, proteinate or amino acid complex/chelate **(Yan *et al.*, 2016)**. Organic Zn bioavailability relative to that of inorganic form (85% to 117%) depending on the variable **(Schlegel *et al.*, 2013)**. Zinc oxide nanoparticles (ZnO NPs) can be used effectively as a feed additive in the poultry diets **(Handy *et al.*, 2008)**.

Nano minerals particles size is less hence surface area is more therefore better absorption and utilization **(Rajendran, 2013)**. Structure of Nano materials atoms at their surface is a greater percentage hence surface area is high reactivity **(Sirelkhatim *et al.*, 2015)**.

Nanoparticles can effectively fulfill the mineral requirements in the animal body, promote growth rate and feed efficiency **(Sahoo *et al.*, 2014)**. Many studies have shown that inorganic or organic sources of Zn in the diets of broilers can promote growth performance, but these findings are inconsistent **(Gajula *et al.*, 2011)**. Dietary supplementation with organic zinc or nano-zinc oxide in broilers could have ameliorative effect on growth and FCR **(Sahoo *et al.*, 2016)**. Inorganic, chelated form or ZnO NPs supplementation is marginally improved the serum total protein, albumin, glucose and cholesterol levels **(Sahoo *et al.*, 2014)**.

The present experiment was performed to determine and compare the effects of addition and/or substitution of different forms of dietary supplemental zinc on growth performance, economic efficiency, blood metabolites and zinc concentration in tissue (breast muscle and liver) of broiler chickens.

2. Methods

Animals, Feeding, Experimental design

In this study, using 525 one–day old Cobb unsexed broiler chicks (with an average weight 44 g) and obtained from commercial hatchery. The birds were randomly weighed and divided into 7 groups with 5 replicates per group (75 chicks/group; 15 chicks/replicate). Vaccination the chicks against Newcastle and Gamboro diseases. The birds were housed in separated clean pens and kept under continuous lighting system with suitable temperature till experimental end. The basal diet was formulated to meet the requirements **(NRC, 1994)** during starter period (0-3 wks; CP 23.00% and ME 3204 kcal/kg diet) and grower-finisher period (3-6 wks; CP 20.00% and ME 3209 kcal/kg diet). The diets were offered in mash form. Providing feed and water *ad-libitum*. Experimental feedstuffs and diets were analyzed for nutrients (DM, CP, EE, and ash) as described by **(AOAC, 2002)** procedures. Zinc analysis of the diets was digested using concentrated nitric acid; diluted with 0.125 M HCl at 1:2 to 1:30 as appropriate; filtered using 0.2 µm syringe filter (Corning, USA) and measured by using atomic absorption spectrophotometer with an oxidizing air acetylene flame (ICP; Flame Modula S, Germany).

Table 1. Ingredient and proximate chemical composition (%) of the experimental diets.

Stage of growth / Ingredients & cost/kg (LE)*	Experimental diets	
	Starter (0-3 wks)	Grower-finisher (3-6 wks)
yellow corn (2.19)	57.00	63.37
Soybean meal, 48% (4.4)	25.40	23.65
Corn gluten, 60% (7.1)	6.50	3.50
Fish meal, 65% (18.5)	4.00	2.50
Soybean oil (9)	3.60	3.40
Calcium carbonate (0.12)	1.20	1.20
Ca. dibasic phosphate (5.5)	1.50	1.50
Common salt (11)	0.30	0.30
Premix1 (25)	0.30	0.30
DL- Methionine, 98% (65)	0.10	0.12
Lysine, Hcl, 78%(25)	-	0.06
Mycotoxplus** (65)	0.10	0.10
Calculated composition		
ME, Kcal/Kg	3204.31	3209.92
CP, %	23.01	20.01
EE, %	2.72	2.78
CF, %	2.41	2.42
Ca, %	1.15	1.07
Available phosphorus, %	0.47	0.44
Lysine, %	1.20	1.10
Methionine, %	0.56	0.50
Basal level of zinc (ppm)	30.50	28.14
Analyzed composition		
Moisture, %	9.70	9.30
CP, %	22.10	19.26
EE, %	2.70	2.71
CF, %	2.50	2.51
Zinc (ppm)	27.5	26.00

[1] Mineral premix used in the diets was Zn free.

G1= control basal diet without zinc supplement, G2= 40 ppm $ZnSO_4$, G3= 40 ppm Zn-Met, G4= 40 ppm nano ZnO, G5= 20 ppm $ZnSO_4$+20 ppm Zn-Met, G6= 20 ppm $ZnSO_4$+20 ppm nano ZnO, G7= 20 ppm Zn-Met+20 ppm nano ZnO.

* Ingredients price in March, 2016.

Broiler chickens fed on 7 experimental diets; group 1: control basal diet without zinc supplement, group 2: 40 ppm inorganic Zn ($ZnSO_4$), group 3: 40 ppm organic Zn methionine (Zn-Met), group 4: 40 ppm nano zinc oxide (nano ZnO), group 5: 20 ppm $ZnSO_4$+20 ppm Zn-Met, group 6: 20 ppm $ZnSO_4$+20 ppm nano ZnO, group 7: 20 ppm Zn-Met +20 ppm nano ZnO. Inorganic minerals where obtained from Al-Gomhouria Company for chemicals, Egypt. Organic zinc were obtained from Bio-chrome (Products of Alltech, Inc. (Nicholasville, KY, USA). The ZnO NPs was purchased from faculty of science of Beni Suef University which was a white powder with a measured ZnO NPs content of purity ≥99.99% and size of nanoparticles was 27 nm.

Growth performance parameters

Individual chicks were weighed weekly to determine body weight (BW), also amount of feed intake (FI). Body weight gain (BWG) and feed conversion ratio (FCR) were calculated.

Economic efficiency measurements

I. Cost parameters are classified according to the methods implied by **(Ahmed, 2007)**.

1. Total fixed costs (TFC): In this condition each chick took the same value of price of labor, litter, purchased chicks, veterinary medicaments (drugs, vaccine and veterinary supervision), water and electrolyte, building and equipment depreciation (1%), so these parameters considered as a fixed costs for each group of chicks **(Sara, 2007)**.
2. Total variable costs (TVC) included feed price and feed additives costs. It was estimated during the experiment.
3. Total costs (TC) was calculated from the summation of total fixed costs and total variable costs.

II. Returns parameters

1. Total returns (TR) from chick sale = Body weight x kg price (17 LE in March, 2016.).
2. Net Profit was calculated as = Total returns – Total costs

III. Measurement of efficiency of feed additives

1. Collective measures of efficiency was calculated according to **(Omar, 2003)** as Total return / total cost (TR/TC), Total return / Total variable cost (TR/TVC), Net profit / Total cost and Net profit / Total variable cost.
2. Partial measures of efficiency was calculated according to **(Fardos, 2009)** as Feed additive cost / Total return, Feed additive cost / Total cost and Feed additive cost / Total variable cost.

Blood sampling and biochemical analysis

At the end of experiment (42 days), five birds/group were randomly selected and slaughtered for collection of blood serum samples to determine some biochemical metabolites using diagnostic kits (Roch Diagnostics, GmbH, USA). Glucose **(Tietz, 2006)**; total cholesterol **(Pisani *et al.*, 1995)**; triglyceride **(Stein and Myers, 1995)**; HDL-cholesterol **(Nitschke and Tall, 2005)**; and LDL-cholesterol **(Sonntag and Scholer, 2001)**. Total protein and albumin **(Burtis *et al.*, 2006)**, while globulin was calculated by difference between total protein and albumin. Serum AST; aspartate-aminotransferase **(Murray, 1984)**; ALT; alanine-aminotransferase **(Young, 2001)** and alkaline phosphatase (ALP) were determined as described by **(Scherwin, 2003)**. Quantitative determination of serum Zinc concentration by Buck scientific 210 VGP Atomic Absorption Spectrophotometer **(Zantopoulos *et al.*, 1996).**

Zinc content (ppm) in body tissues (breast muscle and liver)

Samples from breast muscle and liver were collected (5 samples / group) and measured as the same method used for analysis of the dietary Zn.

Statistical analysis

The obtained results were subjected to one way ANOVA using **(Statisitx 9,0, 2008)**. Significant means were separated by LSD test. Statement of statistical significance were based on ($P<0.05$).

3. Results

The overall growth performance results are shown in Table (2) revealed beneficial effects for supplementation and substitution of Zn. There were significant ($P < 0.05$) increase in the overall BW, BWG and FCR of the experimental groups if compared with the control. There wasn't significantly ($P > 0.05$) different FI was detected among the dietary treatments up to 6th weeks if compared with the control. On comparison to their performance parameters between dietary treatment was differed non-significantly ($P > 0.05$).

The economic efficiency results as shown in Table (3), there is non-significant differences ($P>0.05$) between all groups for feed costs, TVC and total costs. There is significant differences ($P<0.05$) between all groups for return and net profit, G4 showed a highest return and net profit values respectively while, G1 showed the lowest values respectively. There is significant differences ($P<0.05$) between all groups for collective economic efficiency measures, G4 showed higher values were noticed in comparing with other groups for TR/TC, TR/TVC, Net profit / Total cost and Net profit / Total variable cost % respectively. There is significant differences ($P<0.05$) between all groups for partial economic efficiency measures, G4 showed the highest values for feed additive cost / total return, feed additive cost / total cost and feed additive cost / total variable cost % respectively while, G1 showed zero values for the feed additives meanwhile, G2 and G6 showed the lowest values respectively.

Table 2. Effect of addition and/or substitution of inorganic zinc with their organic and nano zinc sources on the overall (0-6 wks) growth performance (means±SE).

Parameter	Experimental diets							P value
	G1	G2	G3	G4	G5	G6	G7	
Initial BW, g	44.26 ±0.95	44.16 ±0.92	44.37 ±0.91	44.25 ±0.93	44.36 ±0.40	44.28 ±0.33	44.16 ±0.53	1.000
Final BW, g	1790.60 $\pm 29.08^{b}$	1884.40 $\pm 31.79^{a}$	1954.00 $\pm 22.62^{a}$	1960.00 $\pm 24.70^{a}$	1910.40 $\pm 32.39^{a}$	1912.80 $\pm 36.65^{a}$	1946.30 $\pm 34.09^{a}$	0.003
Absolute Body gain, g	1746.30 $\pm 28.60^{b}$	1840.20 $\pm 31.95^{a}$	1909.60 $\pm 23.26^{a}$	1915.70 $\pm 24.68^{a}$	1866.00 $\pm 32.26^{a}$	1868.50 $\pm 36.76^{a}$	1902.10 $\pm 33.33^{a}$	0.003
Total feed intake, g	3281.20 ±13.38	3249.20 ±32.48	3287.50 ±13.36	3283.60 ±11.67	3266.50 ±25.22	3257.20 ±18.41	3277.00 ±13.05	0.772
Feed conversion rate	1.88 $\pm 0.02^{a}$	1.76 $\pm 0.03^{b}$	1.72 $\pm 0.01^{b}$	1.71 $\pm 0.01^{b}$	1.75 $\pm 0.01^{b}$	1.74 $\pm 0.02^{b}$	1.72 $\pm 0.02^{b}$	0.001

[ab] Means in the same row with different superscripts are significantly different at ($P < 0.05$).
G1= control basal diet without zinc supplement, G2= 40 ppm $ZnSO_4$, G3= 40 ppm Zn-Met, G4= 40 ppm nano ZnO, G5= 20 ppm $ZnSO_4$+20 ppm Zn-Met, G6= 20 ppm $ZnSO_4$+20 ppm nano ZnO, G7= 20 ppm Zn-Met+20 ppm nano ZnO.

Table 3. Effect of addition and/or substitution of inorganic zinc with their organic and nano zinc sources on economic measures of broiler chickens (means±SE).

Parameter	Experimental diets							P value
	G1	G2	G3	G4	G5	G6	G7	
Feed costs	13.81 ±0.06	13.71 ±0.14	13.91 ±0.06	13.96 ±0.05	13.80 ±0.11	13.79 ±0.08	13.89 ±0.06	0.443
Total variable costs	14.03 ±0.05	13.93 ±0.14	14.13 ±0.05	14.17 ±0.05	14.02 ±0.11	14.01 ±0.08	14.12 ±0.05	0.425
Total cost	28.96 ±0.05	28.86 ±0.14	29.06 ±0.06	29.11 ±0.05	28.95 ±0.11	28.94 ±0.08	29.04 ±0.05	0.432
Total returns	29.69 $\pm 0.49^{b}$	31.28 $\pm 0.54^{a}$	32.46 $\pm 0.06^{a}$	32.57 $\pm 0.08^{a}$	31.72 $\pm 0.55^{a}$	31.76 $\pm 0.63^{a}$	32.34 $\pm 0.58^{a}$	0.003
Net profit	0.72 $\pm 0.46^{b}$	2.42 $\pm 0.58^{a}$	3.41 $\pm 0.05^{a}$	3.46 $\pm 0.09^{a}$	2.77 $\pm 0.45^{a}$	2.82 $\pm 0.58^{a}$	3.29 $\pm 0.54^{a}$	0.002
Total return / total cost (TR/TC) %.	102.49 $\pm 1.58^{b}$	108.41 $\pm 2.01^{a}$	111.73 $\pm 0.19^{a}$	111.90 $\pm 0.33^{a}$	109.55 $\pm 1.52^{a}$	109.73 $\pm 1.99^{a}$	111.33 $\pm 1.83^{a}$	0.002
Total return / Total variable cost (TR/TVC) %.	211.51 $\pm 3.10^{b}$	224.64 $\pm 4.72^{a}$	229.79 $\pm 0.74^{a}$	229.74 $\pm 0.98^{a}$	226.16 $\pm 2.39^{a}$	226.60 $\pm 3.80^{a}$	229.05 $\pm 3.44^{a}$	0.003
Net profit / Total cost %.	2.49 $\pm 1.58^{b}$	8.41 $\pm 2.01^{a}$	11.73 $\pm 0.19^{a}$	11.90 $\pm 0.33^{a}$	9.55 $\pm 1.52^{a}$	9.73 $\pm 1.99^{a}$	11.33 $\pm 1.83^{a}$	0.002
Net profit / Total variable cost %.	5.14 $\pm 3.25^{b}$	17.45 $\pm 4.21^{a}$	24.12 $\pm 0.41^{a}$	24.43 $\pm 0.71^{a}$	19.67 $\pm 3.08^{a}$	20.08 $\pm 4.07^{a}$	23.28 $\pm 3.73^{a}$	0.002
Feed additive* cost / Total return%.	0.00 $\pm 0.00^{c}$	0.11 $\pm 0.06^{bc}$	0.29 $\pm 0.03^{ab}$	0.43 $\pm 0.05^{a}$	0.27 $\pm 0.13^{ab}$	0.11 $\pm 0.07^{bc}$	0.33 $\pm 0.14^{ab}$	0.13
Feed additive cost / Total cost %.	0.00 $\pm 0.00^{c}$	0.12 $\pm 0.07^{bc}$	0.32 $\pm 0.04^{ab}$	0.49 $\pm 0.06^{a}$	0.30 $\pm 0.14^{ab}$	0.12** $\pm 0.08^{bc}$	0.37 $\pm 0.16^{ab}$	0.13
Feed additive* cost / Total variable cost %.	0.00 $\pm 0.00^{c}$	0.25 $\pm 0.14^{bc}$	0.65 $\pm 0.07^{ab}$	1.00 $\pm 0.12^{a}$	0.62 $\pm 0.29^{ab}$	0.25** $\pm 0.16^{bc}$	0.76 $\pm 0.33^{ab}$	0.13

[abc] Means in the same row with different superscripts are significantly different at ($P < 0.05$).
G1= control basal diet without zinc supplement, G2= 40 ppm $ZnSO_4$, G3= 40 ppm Zn-Met, G4= 40 ppm nano ZnO, G5= 20 ppm $ZnSO_4$+20 ppm Zn-Met, G6= 20 ppm $ZnSO_4$+20 ppm nano ZnO, G7= 20 ppm Zn-Met+20 ppm nano ZnO.

- Cost in this table in March, 2016.

The studied blood metabolites as shown in Table (4) weren't significantly (P>0.05) changed in serum concentrations of glucose, total cholesterol, LDL-cholesterol, triglyceride, albumin, globulin, AST and ALT among birds fed the dietary treatments compared to control group. There was significant (P < 0.05) increase levels in total serum protein, HDL-cholesterol and ALP for Zn supplemented groups.

Table 4. Effect of addition and/or substitution of inorganic zinc with their organic and nano zinc sources on serum biochemical parameters of broiler chickens (means±SE).

Parameter	Experimental diets							P value
	G1	G2	G3	G4	G5	G6	G7	
Glucose (mg / dl)	205.63 ±5.77	201.93 ±5.91	201.80 ±6.09	195.34 ±2.00	200.49 ±4.18	195.49 ±2.86	191.45 ±2.04	0.355
Total Cholesterol (mg / dl)	137.11 ±4.33	132.67 ±3.70	129.67 ±3.16	128.20 ±3.76	134.00 ±2.63	136.43 ±2.66	137.17 ±3.70	0.461
Triglyceride (mg / dl)	71.99 ±4.97	67.43 ±5.13	70.33 ±2.77	60.73 ±5.54	63.17 ±3.05	63.88 ±1.76	64.08 ±1.46	0.386
HDL-cholesterol (mg / dl)	74.20 ±0.18[b]	81.55 ±0.75[ab]	90.46 ±3.55[a]	84.47 ±0.85[a]	87.14 ±5.01[a]	86.37 ±3.25[a]	86.77 ±4.16[a]	0.048
LDL-cholesterol (mg / dl)	63.47 ±1.05	59.57 ±3.65	60.59 ±4.12	61.16 ±3.11	60.54 ±4.17	57.97 ±2.86	54.14 ±0.26	0.520
Total protein (g / dl)	2.94 ±0.34[b]	3.65 ±0.15[ab]	3.90 ±0.04[a]	3.49 ±0.22[ab]	3.13 ±0.06[b]	2.92 ±0.14[b]	3.40 ±0.21[ab]	0.028
Albumin (g / dl)	1.21 ±0.18	1.57 ±0.18	1.42 ±0.25	1.51 ±0.02	1.42 ±0.06	1.43 ±0.11	1.49 ±0.04	0.745
Globulin (g / dl)	1.73 ±0.23	2.08 ±0.03	2.48 ±0.26	1.98 ±0.24	1.71 ±0.01	1.49 ±0.03	1.91 ±0.17	0.037
AST (IU / dl)	45.63 ±2.81	46.30 ±2.16	45.24 ±2.47	45.58 ±2.38	44.30 ±2.07	44.56 ±2.07	46.27 ±2.75	0.995
ALT (IU / dl)	9.01 ±1.66	9.12 ±0.88	9.24 ±1.18	13.43 ±2.03	7.63 ±1.26	14.56 ±3.93	9.60 ±0.62	0.183
ALP (IU / dl)	87.18 ±5.74[c]	119.70 ±7.03[b]	132.92 ±4.49[ab]	118.07 ±6.52[b]	146.92 ±4.01[a]	116.37 ±3.50[b]	126.77 ±3.17[b]	0.000
Zinc (mg / dl)	0.93 ±0.07[b]	1.03 ±0.09[b]	1.05 ±0.09[b]	1.32 ±0.04[a]	0.91 ±0.03[b]	0.97 ±0.05[b]	1.08 ±0.04[b]	0.013

[abc] Means in the same row with different superscripts are significantly different at (P < 0.05).
G1= control basal diet without zinc supplement, G2= 40 ppm $ZnSO_4$, G3= 40 ppm Zn-Met, G4= 40 ppm nano ZnO, G5= 20 ppm $ZnSO_4$+20 ppm Zn-Met, G6= 20 ppm $ZnSO_4$+20 ppm nano ZnO, G7= 20 ppm Zn-Met+20 ppm nano ZnO.

The data showed in Table (5) revealed that Zn deposition was significantly (P<0.05) increased in breast muscle and liver with dietary addition and/or substitution of inorganic Zn with either organic or nano Zn, however, partial substitution of inorganic Zn with either organic or nano Zn had no significant (P>0.05) influence on Zn deposition in breast muscle compared to the control group. G4 showed higher values while, G2 showed the lowest values were noticed compared to the control group.

Table 5. Effect of dietary addition and/or substitution of inorganic zinc with their organic and nano zinc sources on serum and tissue concentration of Zn (means±SE).

Traits studied	Experimental diets							P value
	G1	G2	G3	G4	G5	G6	G7	
Breast zinc (ppm)	1.84 ±0.22[c]	2.66 ±0.18[b]	4.58 ±0.22[a]	4.63 ±0.22[a]	2.16 ±0.15[bc]	2.17 ±0.09[bc]	2.33 ±0.27[bc]	0.000
Liver zinc (ppm)	9.25 ±0.41[c]	13.54 ±0.50[bc]	28.57 ±3.43[a]	28.86 ±3.81[a]	20.08 ±2.31[ab]	20.37 ±2.53[ab]	26.73 ±4.23[a]	0.001

[abc] Means within the same raw carrying different superscripts are significantly different at ($P \leq 0.05$).
G1= control basal diet without zinc supplement, G2= 40 ppm $ZnSO_4$, G3= 40 ppm Zn-Met, G4= 40 ppm nano ZnO, G5= 20 ppm $ZnSO_4$+20 ppm Zn-Met, G6= 20 ppm $ZnSO_4$+20 ppm nano ZnO, G7= 20 ppm Zn-Met+20 ppm nano ZnO.

4. Discussion

Effects on broiler performance

Beneficial effects for supplementation and/or substitution of Zn on overall growth performance are supported by **Ahmadi *et al.* (2013)** and **Sahoo *et al.* (2016)** who reported that significant (P<0.05) higher performance parameters in broilers fed on diets contain ZONPs. Also, performance parameters for birds fed with 100% organic Zn were significantly (P < 0.05) higher than group fed 50% organic and 50% inorganic **(Abdallah *et al*., 2009)**. Positive effects on performance parameters might be related to role of zinc as an integral part of more than 300 enzyme systems that are involved in metabolism of energy nucleic acids and protein **(Tabatabaie *et al*., 2007)**; increasing nutrients digestibility under the heat and cold stress **(Sahin and Kucuk, 2003)**; improved its bioavailability and utilization of the consumed feed **(Sahoo *et al*., 2016)**. The higher value for nano-Zn groups might be due to nano-ZnO is smaller particle size, faster diffusion and higher uptake in the GIT **(Sahoo *et al*., 2016)**; participates in oxidation reactions with a variety of organic compounds and the permeability of nano-ZnO can also prevent adverse gastrointestinal reactions and improve the absorption of medicine **(Zhao *et al*., 2014)**; allows higher interactions with other organic and inorganic molecules **(Zaboli *et al*., 2013)** or can translocate from these entry portals into the circulatory and lymphatic systems, and ultimately to body tissues and organs **(Al-Rasheed *et al*., 2014)**. In contrast of our study, zinc supplement in broilers diets had no significant effect on total BW and FCR **(Pimental *et al*., 1991)**.

Effects on blood metabolites

There was significant increase in total serum protein presented in G2, G3, G4 and G7 if compared with other groups or control. This is in agreement with **(Bahakaim *et al*., 2014)** who found that plasma total protein, albumin and globulin was increased with Zn dietary supplementation in broiler. This increase might be attributed to the role of zinc in protein synthesis **(Ibs and Rink, 2003).**

The data revealed that HDL-cholesterol was significant increase by the addition and/or substitution of dietary organic or nano-zinc sources if compared with inorganic or control groups. This data are in accordance with **Roberson and Edwards (1994)** reported a significant increase in the serum HDL-cholesterol in the zinc supplemented group. Also, **Fawzy *et al*. (2016)** which reported increase in serum HDL-cholesterol level in broiler chickens by dietary addition of various zinc sources.

As the same of our result, **Parák and Straková (2011)** reported that no significant changes in the total cholesterol, triglycerides and glucose levels when supplementing of Zn sources. On the contrary to our findings, **Hazim *et al*. (2011)** showed that Zn supplementation in broilers diets lead to increased plasma total cholesterol. The change of serum cholesterol levels may be due to Zn role in enzyme action as an integral part of several enzymes (metalloenzymes) which are important in lipid digestion and absorption **(Hazim *et al*., 2011).**

Our results registered no significant effect on AST and ALT enzymes. This result agreed the finding of **Ahmadi *et al*. (2014)** who reported that different levels of nano-ZnO in dietary feed have no significantly effects on ALT and AST activities in serum of broilers. On the contrary to our findings, **Sharideh *et al*. (2015)** reported that dietary supplementation of zinc oxide (ZnO) increased activity of LDH, ALT and AST. The possible cause for these differences is suggested to be related to using doses and time of animal exposed as showed by **Sharma *et al*. (2009)** who recorded that ZONPs induce the oxidative stress and increase the plasma level of ALT and AST.

The study revealed a significant (P < 0.05) increase in serum ALP levels in all zinc supplemented groups when compared with the control, while a significant (P < 0.05) increase of serum zinc in G4 fed diets supplemented with 100% nano-ZnO if compared with other groups.

Zn is an integral component of ALP. Therefore ALP activity will be used as one of the indicator to know the Zn status **(Sahoo *et al*., 2014)**. The organic Zn supplemented groups was significantly (P<0.05) higher in serum ALP and zinc concentrations than inorganic Zn supplemented group **(Idowu *et al*., 2011)**. The increased serum Zn concentration in nano-Zn group confirmed that the zinc retention in nano-Zn was increased **(Tsai *et al*., 2016)**. Also, **Yalçınkaya *et al*. (2012)** reported that serum Zn and Fe levels were lower in control group than those in Organic Zn group. Plasma Zn and Ca were significantly elevated by increasing Zn levels in diets **(Bahakaim *et al*., 2014)**.

The significant increase in serum ALP activity in birds fed of nano-ZnO as compared to other group may be attributed to the action of vitamin D_3, which increasing calcium absorption into the extracellular fluid and possibly promoting the ALP formation in the epithelial cells **(Guyton and Hall, 2006)** or increased cholesterol concentrations by nano-ZnO **(Fathi *et al*., 2016)**.

The findings are adversely with the results of **(Karamouz *et al*., 2010)** who showed that zinc supplementation had no significant effect on serum ALP activity, but with increasing Zn levels, serum ALP levels were reduced earlier than normal Zn level feeding.

Effects on tissue zinc concentration

The data revealed significant ($P < 0.05$) increase in breast and liver zinc concentration. The retention of zinc was higher in liver of broiler after its absorption **(Ahmadi *et al*., 2013)**. The level of Zn in all of the vital organs (pancreas, liver, and spleen) was comparatively higher in all of the Zn-supplemented groups compared to un-supplemented group **(Shinde *et al*., 2006)**. On the contrary, **Salim *et al*. (2012)** found that tissue mineral concentration had no significant difference between the inorganic control group and the organic complexed trace mineral group.

5. Conclusions

Dietary supplementation and/or substitution of inorganic zinc with their organic and nano-zinc sources to broiler diets had obvious significant effects in improvements of the performance parameters also, increase return and net profit. In addition, Zn had positive significant effects on the serum and tissue concentration of Zn. We recommend addition and/or substitution of different forms of dietary supplemental zinc to broiler diets to reach better results. So, in future, when nanoparticle industry expanded as feed grade for animal or poultry use become economic.

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