J.Animal and Poultry Prod., Mansoura Univ., Vol.10 (3): 59 - 66, 2019

Effect of Dietary Zinc-Methionine on Growth, Carcass Traits, Antioxidants and Immunity of Growing Rabbits

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ABSTRACT

Effect of dietary zinc-methionine (Zn-Me), on growth performance, carcass characteristics, anti-oxidant status, immunity, liver and kidney functions of NZW growing rabbits was studied. Total of 80 rabbits were assigned into 4 groups fed basal diet with 0 (G1), 50 (G2), 100 (G3) and 150 (G4) mg of Zn-Me/kg diet, respectively. The average of body weight, weight gain, daily feed intake and feed conversion, performance index and viability rate were recorded at age intervals from 5 to 13 wk. The carcass characteristics, hematological and biochemicals, anti-oxidant and Immunoglobulins in serum were determined at the termination of the experimental period (13 wk). Results revealed that Zn-Me (100mg/kg diet) addition increased ($P<0.05$) growth performance (body weight of rabbits at 9 and 13 wk of age, and daily gain of rabbits at 5~13 wk of age interval), hemoglobin, red blood cells, platelets and hematocrit, and neutrophils and eosinophils, serum total proteins, glucose, total anti-oxidant capacity, glutathione reduced ,glutathione S-transferase and superoxide dismutase, and immunoglobulins concentrations. The count of blood cells and lymphocytes, monocytes and acidophils percentages, and triglycerides, creatinine, urea concentrations, and enzyme activity and thiobarbituric acid-reactive substances concentration decreased ($P<0.05$) as affected by Zn-Me (100mg/kg diet). The carcass net weight, dressing percentages (based on carcass net carcass weight or plus edible organs), and spleen and heart weight percentages were ($P<0.05$) the highest in G3 compared with other groups. In conclusion, dietary supplementation with zinc-methionine (100 mg/kg diet) can improve growth performance, lipid profile, immunity and anti-oxidant status, without adversely effects on kidney and liver functions of growing rabbits.

Keywords: rabbits, zinc-methionine, growth performance, anti-oxidant status, immunity.

INTRODUCTION

Among different livestocks, rabbit has a great attention due to their notability in meat production, and productive, reproductive and economic efficiencies (Basavaraj *et al*., 2011; El-Ratel, 2017). Rabbit meat considered as a vital protein source for human consumption due to its high quality, low fat and low cholesterol content (Jones, 1990). For maximizing production of rabbit meat, there is a wide need for necessary dietary additives to improve growth performance of growing rabbits (Hassan *et al*., 2017).

Trace minerals have important part in enhancing growth efficiency, reproductive performance and immunity of animals (Suttle, 2010). Zinc (Zn) as a trace element contributes in several biological processes, for normal growth, development of bone, feathering, immune response, regulation of appetite and activity of many enzymes of body metabolism, e.g. carbohydrate, energy, and protein (Sahin *et al*. 2009; Salim *et al*. 2011). In addition, Zn plays a necessary role in the anti-oxidant defense system, through it is a component of superoxide dismutase (Powell, 2000), and increasing a cystine-rich protein as a scavenger of free radical (Oteiza *et al*., 1996).

The Zn is absorbed in the small intestine and an intestinal pool of Zn may be formed by binding the metal to the intestinal metallothionein or Zn may be transported by albumin plasma to the liver (Prasad, 1993). A family of Zn transporters that play an important role in the regulation of Zn metabolism at the intracellular level in mammalians has been described. They structurally consist of six transmembrane domains, an intracellular histidine-rich region, and the amino and carboxy terminus, which resides intracellularly (Tako *et al*., 2005).

Animals requirement micro-elements in small amounts, and these micro-elements play an important function in all processes of physiological, from bone structure to maintaining the proteins and lipids structure In the intensive production, their addition is obligatory, since it has been the only way to provide them in sufficient amounts required for health and production optimums (Pajtáš *et al*., 2009; Chrastinová *et al*, 2015).

Because many natural food ingredients show marginal Zn deficiency, this micronutrient is commonly supplemented to diets for animals. Regardless of the fact that certain micro-elements are present in food in sufficient quantities, subclinical or clinical symptoms of their deficiency appear. This can be caused by their different and changeable availability, or the micro-elements are present in form that cannot be used. Obtained results showed that the presence of certain substances in food (phytic acid and oxalic acid), as well as interaction with other nutrients in the digestive tract, influences resorption mechanisms. Resorption of micro-elements is not dependent only on their content in food, but also on the animals' age, electrochemical reactions in the intestine and on the microelement form. Mineral salts, such as oxides, carbonates, chlorides and sulphates are most frequently used. Today, in supplementation of in-organic forms of minerals, the use of so-called „chelate“forms, i.e. organically bonded micro-elements, is becoming more frequent. Enteric diseases frequently occur in rabbits around the weaning period, leading to an extensive use of antibiotics. Therefore, anti-microbial agents are searched for to prevent and/or overcome infections. Prevention and treatment of clostridial infections by natural substances or phyto-additives are important because of animal mortality and economic losses (Chrastinová *et al*., 2010; Chrastinová *et al*., 2016; Marcin *et al*., 2006).

Zinc-methionine (Zn-Me) is organic-zinc, which is freed from free divalent cations for chelation in intestinal lumen by phytic-acid. Thus it is metabolized in a various processes which facilitate improve Zn absorption (Burrell *et al*., 2004). In this line, Zn-Me could be beneficially incorporated at lower levels in broiler diet compared with inorganic-Zn for catching higher Zn bioavailability, and

lowering excretion of Zn to environment (Sunder *et al*., 2013).

Therefore, the effect of dietary supplementing different levels of Zn-Me (0, 50, 100 and 150 mg/kg diet) on productive, carcass characteristics, blood biochemicals, enzyme activity, anti-oxidant and immunity capacity in growing rabbits were investigated.

MATERIALS AND METHODS

The current experiment was conducted at a private rabbit farm, Dakahlia Governorate, in co-operation with Faculty of Agriculture, Animal Production Department, Damietta University.

Weaned rabbits (n=80) were similarly divided into four groups (20/group). All NZW rabbits used in this study aged five wks at the start of the experiment and averaged 678.71±3.707 g live body weight (LBW). All rabbits were exposed to similar managerial and environmental conditions. Rabbits were kept in community battery cages with ten replicates (2 /cage of the same sex), in wire cages (25 x 50 x 35 cm), install in a close rabbit house with suitable ventilation.

Rabbits in the 1st group were fed on commercial pelleted diet as a basal diet (BD) without supplementation (G1, control). Rabbits in the 2nd (G2), 3rd (G3) and 4th (G4) groups were fed on BD supplemented with 50, 100 and 150 mg of Zinc-methionine (Zn-Me)/kg diet, respectively. The weekly amount of each experimental diet was well mixed with their determined level of Zn-Me in homogenous form. The experimental period continue from 5 - 13 wk of age.

The BD was formulated to cover all fundamental, nutrient requirements for growing rabbit (De Blas and Mateos, 1998). Ingredients of BD included berseem hay (33%), barley grain (24.6%), wheat brain (17%), soybean meal (17%), molasses (3%), Di-calcium phosphate (1.6%), limestone (1%), DL-methionine (0.2%), sodium chloride (0.5%), premix (0.3%) and contained 17.36% CP, 13.45% CF, 1.61% EE, 61.77 % NFE, 5.81% ASH and 2412 Kcal/Kg diet as digestible energy

The LBW and feed intake (FI) were recorded at 5, 9 and 13 wk of age, then average daily gain (ADG) and feed conversion ratio (FCR) were calculated at age intervals 5 to 9, 9 to13 and 5 to13 wk. Dead bunnies number during the experimental period was recorded, while viability rate (VR) was calculated. Performance index (PI) was calculated as the following:

PI = (Final LBW (kg)/feed conversion ratio) x100.

Samples of blood were collected at the termination of the experimental period (13 wk of age), from five rabbits/ group during slaughter, into two test tubes for each animal, one with heparin for hematological parameters and another test tube without heparin for other blood parameters in blood serum. Concentration of hemoglobin (Hb), value of hematocrit (Ht), red (RBCs) and white (WBCs) blood cells count and platelets. Also, Erythrocytic index, including mean corpuscular volume, mean corpuscular hemoglobin and mean corpuscular hemoglobin concentration in whole blood samples were determined (Wintrobe, 1967). Lymphocytes, monocytes, eosinophils and neutrophils percentages were determined (Lucky, 1977).

The collected blood samples in clean tube without anti-coagulant were centrifuged (3000 rpm for 20 min), then blood serum was isolated and kept at -20°C until assayed. Total protein (TP), albumin (AL), glucose, cholesterol, triglycerides, high (HDL) and low (LDL) density lipoproteins, creatinine and urea concentrations, activity of aspartate (AST) and alanine (ALT) transaminases were determined using (Bio-Merieux, Laboratory Reagents and Products, France). Concentration of globulin (GL) was obtained by difference between TP and AL. Total antioxidant capacity (TAC), glutathione content (GSH), glutathione peroxidase (GPx), glutathione S-transferase (GST), superoxide dismutase (SOD) and thiobarbituric acid-reactive substances (TBARS) were assayed in serum by available kits (Bio Diagnostic Research). Concentration of immunoglobulins in blood serum was determined by commercial ELISA kits (Kamiya Biomedical Company, USA).

Five rabbits per group were chosen, fasted for 12 h, weighed and slaughtered to estimate carcass characteristic at 13 wk of age. Weights of carcass parts and body internal organs and calculated relative to LBW of each rabbit.

Data were statistically analyzed by one-way ANOVA design (SAS, 2002). Mortality rate were statistically analyzed using Chi-Square test. The percentage values were transformed by arcsine values before analysis. The group significant differences were tested by Duncan's multiple range test (Duncan 1955) and set at $P<0.05$.

RESULTS AND DISCUSSION

Growth performance parameters:

Results in Table (1) revealed that live body weight (LBW) of rabbits at 9 and 13 wk of age, and average daily gain (ADG) of rabbits at 5~13 wk of age interval were ($P<0.05$) higher in G2 and G3 than in G1 and G4. However, the effect of Zn-Me on daily feed intake (FI), feed conversion ratio (FCR), performance index and viability rate were not significant at all age intervals, except feed conversion ratio during 9~13 wk was ($P<0.05$) the best in G3 than in other group (Table 1).

These results indicated beneficial effects of dietary supplementation of Zn-Me (100 mg/diet) on growth performance of growing rabbits. In accordance with these findings, Hrastinová *et al*. (2018) showed that the addition of 50 mg Zn/kg diet is sufficient to achieve optimal growth performance, increased FCR ($P<0.05$) and ADG of growing rabbits. Also, Amen and Sulaiman (2016) found that ADG and final LBW of rabbits treated with dietary Zn supplementation were ($P<0.05$) increased compared with control. While, FI were not significant by treatment with Zn and control groups. The dietary Zn levels (100 mg/kg) significantly increased LBW and ADG, but had no effect on daily FI as compared to control (Ayyat and Marai, 2000). However, Dietary Zn levels (50, 100 or 200 mg/kg diet) had no significant effect on FCR of growing rabbits at 13 wk (Ayyat and Maria, 2000; Nessrin *et al*., 2012).

Table 1. Effect of dietary zinc-methionine supplementation on growth performance of growing rabbits at different ages.

Item	G1 (Control)	Experimental group			SEM	P-value
		G2 (50 mg Zn-Me /kg)	G3 (100 mg Zn-Me /kg)	G4 (150 mg Zn-Me /kg)		
Average live body weight (g)						
At 5 wk (Initial)	677.56	678.71	678.65	680.65	3.707	0.9485
At 9 wk	1372.38^{c}	1394.94^{ab}	1404.88^{a}	1388.18^{b}	3.922	0.0001
At 13 wk (Final)	2094.25^{c}	2123.94^{b}	2147.41^{a}	2099.18^{c}	3.982	0.0001
Average daily gain (g)						
At 5~9 wk	24.82^{d}	25.58^{b}	25.94^{a}	25.27^{c}	0.034	0.0001
At 9~13wk	25.78^{c}	26.04^{b}	26.52^{a}	25.39^{d}	0.031	0.0001
At 5~13 wk	25.29^{c}	25.81^{b}	26.21^{a}	25.33^{c}	0.025	0.0001
Average daily feed intake (g)						
At 5~9 wk	64.50	64.47	64.35	63.94	1.003	0.9775
At 9~13wk	112.56	111.76	111.53	111.24	1.334	0.9110
At 5~13 wk	88.53	88.12	87.94	87.59	0.726	0.8348
Feed conversion ratio (g feed/g gain)						
At 5~9 wk	2.60	2.52	2.48	2.53	0.060	0.7858
At 9~13 wk	4.36^{a}	4.29^{ab}	4.21^{b}	4.38^{a}	0.059	0.0360
At 5~13 wk	3.50	3.41	3.36	3.46	1.879	0.4314
Performance index (%)	59.91	62.29	63.91	60.67	1.888	0.8254
Viability rate*	80	85	90	90	-	-

Different superscripts in the same row indicate significant difference among means at P<0.05. *Chi-square test.

In goats, Kundu *et al*. (2014) found significantly higher LBW at birth and ADG of kids born from dams receiving 50 or100 ppm of Zn compared with those of control. In sheep, ewes supplemented with 100 ppm Zn improved LBW of their lambs at birth and weaning compared with control ewes (Ali *et al*., 1998). Recently, (Saleh *et al*. (2018) concluded that dietary Zn-Me supplementation increased LBW and ADG, and enhanced FCR in broilers. Also, Sahin *et al*. (2005) presumed that Zn picolinate addition (30 or 60 mg/kg) enhanced parameters in to heat stress quails.

Zinc is a very important trace element that is involved in a wide range of metabolic activities and productive performances as a growth (Underwood and Suttle, 1999). One possible demonstration for such enchantments might be related to Zn is considered of critical importance in maintaining the structure of metalloproteins like insulin, growth hormone and growth factor (Khan *et al*. 2014; Midilli *et al*. 2014).

Blood parameters:

Hematological parameters:

Treatment of rabbit with Zn-Me at a level of (100 mg/kg) increased (P<0.05) Hb concentration, RBCs count, platelets and Ht value, and percentages of neutrophils and eosinophils, while decreased (P<0.05) WBCs count and percentages of lymphocytes, monocytes and acidophils in G3 compared with other groups. While erthrocytic values of mean corpuscular volume, mean corpuscular hemoglobin and mean corpuscular hemoglobin concentration were not affected (P≥0.05) by Zn-Me treatment. Also, treatment of rabbit with Zn-Me at a level of (50 mg/kg) significantly improved (P<0.05) all previous traits as compared to G1, while increasing Zn-Me level to 150 mg/kg failed to improve all hematological parameters in comparing with control group (Table 2). It is of interest to note that increasing Hb concentration in G2 and G3 was assigned by increasing RBCs count and value of Ht as affected with Zn-Me level up to 100 mg/kg. The observed decreased in WBCs count was associated with decreasing percentages of lymphocytes and acidophils, and marked increase in neutrophils (Table 2).

Hematological parameters are good indicators of rabbit physiological status (Khan and Zafar, 2005). In this respect, Ht, Hb and MCH are major indices for evaluating circulatory erythrocytes (Chineke *et al*., 2006). Lymphocytes are considered the main WBCs types and a good indicator of the immune response (Wieslaw *et al*., 2006).

In comparable with the present results on rabbits, Ahmed *et al*. (1997) showed that RBCs count and Ht values were increased significantly by copper addition of growing rabbit diet. In this respect, Zn has significant role in Hb formation and hence, more Zn availability in organic Zn supplemented group might have promoted better Hb synthesis in treatment group in goat (Chavan *et al*., 2016). Also, Shinde *et al*. (2012) and Mondal *et al*. (2013) showed similar results in adult rams and lambs, respectively.

The role of reactive oxygen species (ROS) in the mechanism of RBCs damage in diabetic patients was implicated by Palmieri *et al.* (2001). Thus, enhancing most erythrocytic index after Zn-Me treatment in this paper, might be related to the strong anti-oxidant effect of Zn on hematopoietic cells, which appears to be particularly vulnerable in the presence of unchecked accumulation of ROS (Fathi *et al*., 2016).

Blood biochemicals:

Data of protein fractions, carbohydrate metabolism and lipid metabolism indicated better healthy status function of rabbits in G2 and G3, being the best in G3, in terms of increase (P<0.05) in TP and glucose concentrations and reducing triglycerides, creatinne and urea concentrations, and AST and ALT activities. However, there were insignificant differences in serum albumin, globulin, albumin/globulin ratio, cholesterol, HDL and LDL concentrations (Table 3).

Table 2. Effect of dietary zinc-methionine supplementation on hematological parameters of growing rabbits at 13 weeks of age.

Parameter	G1	Experimental group			SEM	P-value
	(Control)	G2 (50 mg Zn-Me /kg)	G3 (100 mg Zn-Me /kg)	G4 (150 mg Zn-Me /kg)		
RBCs (x 10^6/mm^3)	4.93^c	5.24^b	5.73^a	4.98^c	0.0181	0.0001
WBCs (x 10^3/mm^3)	7.15^a	6.87^c	6.31^d	7.01^b	0.0307	0.0001
Platelets (x 10^3/mm^3)	222.67^c	236.00^b	251.00^a	230.00^{bc}	2.3511	0.0002
Hemoglobin (mg/dl)	9.40^c	9.85^b	10.57^a	9.45^c	0.0278	0.0001
Hematocrit (%)	37.33^b	41.67^b	48.33^a	39.00^b	1.5811	0.0002
Erythrocytic index						
MCV (μ3)	62.67	63.30	63.61	63.00	3.5590	0.9974
MCH (pg)	20.33	21.33	21.00	20.67	2.5980	0.9934
MCHC (g/dl)	33.10	33.30	33.63	33.23	2.2395	0.9985
Leucocyte fraction (%):						
Lymphocytes	57.27^a	51.66^b	48.89^c	51.64^b	1.1335	0.0008
Monocytes	6.01^a	5.24^b	5.39^b	5.11^b	0.1617	0.0149
Neutrophils	33.24^b	39.33^a	39.80^a	39.73^a	0.1711	0.0123
Acidophils	2.05^a	1.92^b	1.88^c	1.97^b	0.0221	0.0004
Eosinophils	1.43^d	1.85^b	4.04^a	1.55^c	0.0256	0.0001

Different superscripts in the same row indicate significant difference among means at P<0.05.

Table 3. Effect of dietary zinc-methionine supplementation on biochemicals and enzyme activity in serum of growing rabbits at 13 weeks of age.

Parameter	G1	Experimental group			SEM	P-value
	(Control)	G2 (50 mg Zn-Me /kg)	G3 (100 mg Zn-Me /kg)	G4 (150 mg Zn-Me /kg)		
Blood biochemical:						
Total proteins (g/dl)	5.95^c	6.14^b	6.20^a	6.04^{bc}	0.0442	0.0176
Albumin (AL) (g/dl)	3.48	3.52	3.54	3.50	0.0270	0.5015
Globulin (GL) (g/dl)	2.46	2.61	2.66	2.54	0.0412	0.0553
AL/GL ratio	1.41	1.35	1.33	1.38	0.0261	0.2151
Glucose (mg/dl)	72.67^c	84.66^b	98.65^a	78.33^{bc}	2.8480	0.0011
Total cholesterol (mg/dl)	134.70	129.67	127.03	131.33	1.8221	0.0890
Triglycerides (mg/dl)	124.93^a	110.00^b	87.17^c	116.00^b	2.2619	0.0001
HDL (mg/dl)	55.33	61.33	64.00	58.67	2.3094	0.1265
LDL (mg/dl)	37.66	34.67	32.33	35.100	1.4807	0.1684
Creatinine (mg/dl)	0.82^a	0.74^{bc}	0.70^c	0.78^{ab}	0.0162	0.0041
Urea (mg/dl)	44.73^a	42.37^a	34.38^b	43.72^a	2.2032	0.0379
Enzyme activity (IU/l)						
AST	57.33^a	52.33^b	44.67^c	54.33^{ab}	1.3944	0.0012
ALT	46.37^a	39.02^{ab}	35.33^b	41.12^{ab}	2.2319	0.0449

Different superscripts in the same row indicate significant difference among means at P<0.05.

Borah *et al*. (2013) showed that serum TP concentration significantly increased by adding 500 ppm of Zn, while AL concentration was not affected by different level of Zn supplementation in growing pig. Also, Shinde *et al*. (2006) found that blood TP level increased (P< 0.05) by Zn addition compared with control. Contrary, some authors found that that the concentration of TP and globulin in serum of weaning piglets were not affected by capsulated or modified ZnO (Wang *et al*., 2013: Cho *et al*., 2015). In comparable with the recent results of Zn-Me supplementation in different species, Mostafa *et al* (2019) found significant increase in TP and AL in She-camel. Also, serum TP and AL concentrations showed significant increase in dairy calves (Dresler *et al*., 2016). Plasma TP increased with Zn dietary supplementation in broiler (Bahakaim *et al*., 2014).

In lactating cows, Gaafer *et al*. (2011) found significant increase in plasma TP, AL and GL concentrations during lactation period in animals fed Zn-Met supplemented diet (10 g/h/d). In addition, concentration of TP, AL and GL were higher in all of the Zn supplemented treatment (Shinde *et al*., 2006). Blood TP and AL concentrations during pregnancy and lactation increased (P<0.05) in goat does (Abu El-Ella *et al*., 2014) and buffaloes (Zeedan *et al*., 2008 and 2009) by biogen-Zn addition.

The significant increase in blood TP with Zn-Met addition may indicate increased synthesis of protein resulted from increased anabolic hormone secretion that is responsible for utilization of amino acids (El-Masry and Habeeb, 1989). In this concern, El-Masry and Marai (1991) related the differences in serum proteins to change in thyroid hormone level, and AL or GL concentrations. Increasing TP concentration might be assigned to the role of Zn in protein synthesis (Ibs and Rink, 2003).

In harmony with the obtained increase in glucose concentration increased (P<0.05) in she-camels treated with Zn-Me (Mostafa *et al*., 2019), and during pregnancy and lactation periods of goats (Abu El-Ella *et al*., 2014) or buffaloes (Zeedan *et al*., 2008 and 2009) supplemented with Biogen-Zn (BZ).

In addition, Badawi *et al*. (2017) found that cholesterol, LDL, AL and GL concentration were not affected (P≥ 0.05) in birds fed the dietary Zn compared with control of broiler chickens. Parák and Straková (2011) found that no significant alteration in concentration of cholesterol as affected by Zn addition. However diets, Hazim *et al*. (2011) reported that Zn addition leads to

increase total cholesterol. The alteration of cholesterol concentration 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.

Results of decreasing creatinine and urea concentrations as well as enzyme activities in G3 may indicate that Zn-Me treatment had positive effect on kidney and liver function of treated rabbits, consequently healthy status of rabbits treated with 100 mg/kg diet. In disagreement with these results, Elhendy *et al*. (2008) found that serum concentrations of urea and creatinine were not affected by Zn deficiency in growing rats. Ahmadi *et al*. (2014) showed insignificant effects of different dietary levels of nano-ZnO in broiler on serum ALT and AST activities. While, dietary Zn-O addition improving activities of ALT and AST. The observed confliction of Zn treatments may be related to variation in animal species, Zn dose and time and duration of treatment (Sharideh *et al*., 2015).

Anti-oxidant and immunity response:

The TAC, GST, SOD and GSH increased (P<0.05), while TBARS concentration decreased (P<0.05) in rabbit serum in G2 and G3 than in G1 and G4, being the best in G3. Also, rabbits in G2 and G3 showed significantly (P<0.05) higher in IgG, IgM and IgA concentrations than in control, reflecting higher immune response of treatment groups than in control, being the highest in G3 (Table 4).

According to the obtained results, dietary Zn-Me supplementation up to 100 mg/kg diet improved anti-oxidative properties and humoral immunity in rabbits. Similar results were reported on broilers under high ambient temperature of broiler chickens (Saleh *et al*., 2018). Also, organic- Zn addition was increase the anti-oxidant enzymes activity and decrease lipid peroxidation in heat stressed poultry (Sahin *et al*. 2005; Khan *et al*. 2012; Rao *et al*. 2016). The GSH-Px is located firstly in the cytosol and has a general specificity in the detoxification of lipid hydro-peroxides and organic hydro-peroxides (Khan *et al*. 2011). Moreover, Zn is its preventing lipid peroxidation through inhibiting GSH depletion (Prasad 1997). The Zn stimulate production of Zn-metallothionein, which is an effective scavenger for hydroxyl radical and providing protection against immune-mediated free radical attack (Laudadio *et al*., 2012).

Table 4. Effect of dietary zinc-methionine supplementation on antioxidant capacity, lipid peroxidation and immunoglobulins in serum of growing rabbits at 13 weeks of age.

Parameter	G1 (Control)	Experimental group			SEM	P-value
		G2 (50 mg Zn-Me /kg)	G3 (100 mg Zn-Me /kg)	G4 (150 mg Zn-Me /kg)		
Antioxidant parameters:						
TAC (mmol/l)	0.32^{c}	0.41^{b}	0.49^{a}	0.37^{bc}	0.0185	0.0016
GST (IU)	1.23^{b}	1.29^{ab}	1.35^{a}	1.25^{b}	0.02082	0.0128
SOD (IU)	6.29^{b}	6.37^{a}	6.40^{a}	6.34^{ab}	0.0199	0.0144
GSH (mg/dl)	14.26^{c}	14.44^{b}	14.95^{a}	14.34^{bc}	0.0294	0.0001
Lipid peroxidation (nmol/ml)						
TBARS	1.16^{a}	1.09^{ab}	0.91^{c}	1.05^{b}	0.0280	0.0018
Immunoglobulins (mg/dl):						
IgG	519.25^{c}	537.66^{ab}	544.65^{a}	534.33^{b}	2.6159	0.0008
IgM	132.07^{b}	138.00^{b}	146.33^{a}	136.33^{b}	2.0833	0.0079
IgA	155.75^{c}	165.74^{b}	178.33^{a}	161.67^{bc}	1.8906	0.0002

Different superscripts in the same row indicate significant difference among means at P<0.05.

In rabbits, Dietary Zn supplementation can modulate SOD activity (Alissa *et al*., 2004). The Zn addition for two months enhanced the serum levels of Zn, anti-oxidant status, and lipid peroxidation in hemodialysis patients (Mazani *et al*., 2013). The positive effect might be connected with the anti-oxidative characteristic of Zn (Sahin *et al*., 2009). The Zn plays a key role in inhibition of ROS, because it is a co-factor of the main anti-oxidative enzyme Cu-Zn-SOD which reduce lipid peroxidation (Prasad and Kucuk, 2002). The Zn is necessary component of SOD enzyme, which has important role in the anti-oxidant defense system (Powell, 2000).

Organic-Zn supplementation enhanced the immunity response of the male guinea pigs as compared to inorganic Zn source (Shinde *et al*., 2006). Similarly, under heat stress, Zn is an important element for all aspects of immunity (Chand *et al*. 2014; Abudabos *et al*. 2017).

Dietary Zn supplementation increased total IgM and IgG antibody titres of broilers (Bartlett and Smith, 2003). The obtained results are in agreement with those of Chand *et al*. (2014), reported that anti-body titre increased (P≤0.05) due to dietary Zn addition. The Zn plays an important role in polynucleotide transcription and thus in the genetic expression process. The Zn also has a vital role in the immune system and affects several aspects of humoral and cellular immunity (Sunder *et al*., 2008). Zinc can affect thymulin secretion from the thymus gland, which stimulates production of T-cells.

Carcass traits:

Results showed that carcass net weight, dressing percentages (based on carcass net carcass weight or plus edible organs), and spleen and heart weight percentages were significantly (P<0.05) the highest in G3 compared with other groups. However, relative weights of in-edible organs were not affected significantly by Zn-Me treatment (Table 5).

In accordance with the present results, in quails, Zn picolinate addition (30 or 60 mg/kg) enhanced carcass quality (Sahin *et al*., 2005). However, Al-Khalifa (2006) found that additional dietary of Zn (50, 100, and 200 ppm) had no significant effect on dressing percentage of rabbits. Also, Ayyat and Marai (2000) showed that adding rabbit diets with 100, 200 or 300 Zn mg/kg had no effect on dressing yield compared with the control.

Table 5. Effect of dietary zinc-methionine supplementation on carcass traits of growing rabbits at 13 weeks of age.

Parameter	G1 (Control)	Experimental group			SEM	P-value
		G2 (50 mg Zn-Me /kg)	G3 (100 mg Zn-Me /kg)	G4 (150 mg Zn-Me /kg)		
Pre-slaughter weight (g)	2108.80^{b}	2109.400^{b}	2129.60^{a}	2108.00^{b}	5.064	0.0217
Carcass net weight (g)	1088.60^{b}	1104.20^{b}	1134.40^{a}	1093.20^{b}	5.663	0.0001
Dressing (%)*	51.620^{c}	52.345^{b}	53.268^{a}	51.858^{c}	0.157	0.0001
Weight of edible organs (%):						
Head	5.10	5.15	5.19	5.13	0.120	0.9584
Liver	2.57	2.60	2.61	2.59	0.098	0.9922
Kidney	0.58	0.59	0.60	0.580	0.077	0.9967
Heart	0.28^{b}	0.29^{b}	0.30^{a}	0.28^{b}	0.002	0.0001
Spleen	0.04^{c}	0.05^{b}	0.05^{a}	0.05^{a}	0.001	0.0001
Testes	0.175	0.179	0.180	0.176	0.0014	0.8796
Total	8.748	8.842	8.94	8.812	0.2355	0.9524
Dressing (%)**	60.37^{b}	61.19^{ab}	62.20^{a}	60.67^{b}	0.3570	0.0116
Abdominal fat (%)	0.86	0.84	0.81	0.85	0.0795	0.9620
Weight of in-edible organs (%):						
Lung	0.89	0.89	0.89	0.89	0.0030	0.7162
GIT	0.179	0.182	0.183	0.182	0.0022	0.8083
Skin	18.34	18.43	18.50	18.38	0.2788	0.9787
Blood	2.84	2.85	2.86	2.87	0.1759	0.9998
Total	40.07	40.40	40.54	40.29	0.4458	0.8920

Different superscripts in the same row indicate significant difference among means at P<0.05. GIT: Gastro-intestinal tract.
***Based on net carcass weight. ** Based on weight of carcass and edible organs.**

CONCLUSION

Dietary supplementation with zinc-methionine at a level of 100 mg/kg diet can improve growth performance, lipid profile, immunity and anti-oxidant status of growing rabbits without adversely effects on liver and kidney function.

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تأثيرالزنك ميثيونين على خصائص النمو، صفات الذبيحة، مضادات الاكسدة والمناعة للارانب النامية

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تهدف هذه الدراسة الى تقييم تأثير اضافة الزنك ميثيونين فى علائق الارانب النامية على خصائص النمو، صفات الذبيحة، حالة مضادات الاكسدة، المناعة ووظائف الكلى والكبد. استخدم فى هذه الدراسة 80 من الارانب النامية قسمت الى 4 مجاميع ، غذيت الارانب فى المجموعة الاولى على عليقة كنترول بينما غذيت الارانب فى المجموعة الثانية ،الثالثة والرابعة على عليقة الكنترول مضاف اليها 50، 100 و 150 مللجم زنك ميثيونين / كجم عليقة على التوالى من عمر 5حتى 13 اسبوع . تم تسجيل وزن الجسم الحى، استهلاف العليقة اليومى، الزيادة اليومية فى الوزن، معدل استهلاك العلف ، مؤشر الاداء ومعدل النفوق. كما تم تقدير خصائص الذبيحة ،خصائص الدم الهيماتولوجية والبيوكيمياية ،حالة مضادات الاكسدة والاستجابة المناعية فى الاسبوع 13. وقد اظهرت النتائج ان اضافة الزنك ميثيونين بتركيز 100مللجم/كجم عليقة (المجموعة الثالثة) ادى الى زيادة معنوية ($P<0.05$) فى خصائص النمو، صفات الذبيحة، وتركيز الهيموجلوبين، عدد كرات الدم الحمراء، وقيمة الصفائح الدموية والهيموتكريت و الخلايا الاحادية والمتعادلة والبروتين الكلى، الجلوكوز ومضادات الاكسدة الكلية، والجلوتاثيون اس ترنسفيراز، سوبراكسيد ديزميوتاز،الجلوتاثيون المختزل والهيموجلوبيولونات. كما ادت المعاملة الزنك ميثيونين بتركيز 100مللجم/كجم عليقة (المجموعة الثالثة) الى نقص معنوى ($P<0.05$) عدد كرات الدم البيضاء، الخلايا القاعدية و الجلسريدات، اليوريا، الكرياتنين و نشاط انزيمات الكلى والكبد و تركيز المواد المتفاعلة مع حمض ثيوباربيتوريك. نستخلص من الدراسة ان اضافة الزنك ميثيونين بتركيز 100مللجم/كجم عليقى يمكن ان يحسن من الاداء الانتاجى وصورة الدهن، والاستجابة المناعة ونشاط مضادات الاكسدة للارانب النامية.