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EFFECT OF DIETARY ADDITION OF ZINC ENRICHED *SPIRULINA* ON GROWTH AND PHYSIOLOGICAL PERFORMANCE IN GROWING RABBITS.

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The present experiment was carried out to evaluate the effects of Zinc-enriched Spirulina (Zn-Sp) supplementation as an organic Zn source on the growth performance, nutrients digestibility, carcass characteristics, blood parameters and economic efficiency of growing rabbits. A total of forty eight male NZW rabbits (35 days old) were allotted to four groups (12 rabbits for each), 4 replicates (3 rabbits for each). Three levels of Zn-Sp (50, 75 and 100 mg Zn-Sp/kg diet) were compared to a control group without Zn-Sp addition. The results have shown that dietary Zn-Sp supplementation caused an increase (P<0.05) in final live body weight at 13 weeks. Supplementation of 75 and 100 mg Zn-Sp improved (P<0.05) body weight gain compared to the control group during the whole experiment period. The increases in body weight gain were 10.93 and 10.63% for 75 and 100 mg Zn-Sp, respectively compared to the control group. On the other hand, at all experimental periods, rabbits fed diets supplemented with 75 and 100 mg Zn-Sp consumed less (P<0.05) feed intake than those fed control diet or 50 mg Zn-Sp. As well as, diets supplemented with Zn at 50, 75 and 100 mg Zn-Sp improved (P<0.05) FCR throughout the experimental period (8weeks). Dietary Zn-Sp supplementation at 100 mg led to a significant increase in all nutrients digestibility In addition; Zn-Sp supplementation had insignificant effect on the CF digestibility. Feeding rabbits on diets supplemented with Zn-Sp at a level of 100 mg/kg DM increased (P<0.05) DCP%, TDN and DE (kcal/kg) compared to the control group. The obtained results also showed that supplementing rabbit diets with Zn-Sp at each tested level increased (P<0.05) hot carcass weight, dressing percentage, total edible parts (%), serum total protein and HDL, serum Zn concentrations, total antioxidant capacity (T-AOC) levels in comparison to the control group. Conversely, a significant decrease (P<0.05) was observed in serum total cholesterol and LDL concentrations compared with the *rabbits fed the control diet. The economical efficiency of diets supplanted with 50, 75 and 100 mg Zn-Sp increased by 14.94, 33.0 and 33.48% over the control group.*

In conclusion*, the present results indicated that supplementation of Zn-Sp could be used as an organic source of Zinc for rabbits. It has more bioavailability and caused an improvement in growth performance and digestibility without any adverse effects on the health status of rabbits.*
Keywords: Zinc, rabbit, physiology, growth, digestibility, carcass**.**

Zinc is commonly supplemented to diets for rabbit, livestock and poultry because many natural feed ingredients are marginally deficient in Zn and rabbit diets are rich in phytate content that may reduce the availability of zinc. It is worthy to note that zinc affects growth, reproduction, and the immune system of animals by influencing enzyme activity and gene expression of proteins. Besides, zinc deficiency can depress the DNA synthesis or cell division required for normal organ development because zinc is a structural component of around 1000 metalloenzymes, including those involved in gene replication, such as DNA and RNA polymerases. (Prasad, 1993; Pallauf, 2005 and Bhowmik *et al*., 2010).

Zinc is an essential trace mineral serves some roles in an animal's body such as the controlling of growth by affecting on feed intake, secretion of mitogenic hormones and gene expression of proteins (Huerta *et al*., 2002). Yoldi *et al*. (1993) stated that many metalloenzymes involved in the metabolism of carbohydrates, lipids, protein, and nucleic acids require zinc for their functions. Zinc also induces synthesis of metallothionein, a metal binding protein that may scavenge hydroxide radicals (Prasad *et al*., 2004). In addition to an antioxidant role, Zn may affect immunity via its important role in cell replication and proliferation (Prasad *et al*., 2004; Weiss and Spears, 2006).

Rabbits are small animals, which are very economic to buy and rear, compared to larger animals. Moreover, they are taking on an increasingly important role in meat production throughout the world (Biagini *et al*., 2016**).** Mateos *et al*. (2010) reported that zinc requirements for rabbits are 25- 60 mg Kg^{-1} dry matter, with the higher values proposed for does and bucks. Practical commercial diets contain a wider range of zinc (40– 140 mg kg^{-1}). Because of zinc's environmental impact, the maximum level allowed in the European Union (EU) for rabbit feeds is 150 mg kg^{-1}. While, Ren *et al*., (2014) suggested that zinc supplementation for the rabbit is 70-140 mg/kg. Recently, zinc has been a modifier of the wide spectrum of biological activities and its deficiency has been related to various dysfunctions and alterations of normal cell metabolism (Chrastinová *et al*., 2015 and Borah *et al*., 2014).

The organic source of Zn provided by *Spirulina* suggests its use in rabbit feeding. Algal biomass can be enriched by biogenic trace elements like selenium, zinc or iodine and act as sources of these elements in highly biologically available forms. It is necessary to mention that *Spirulina* (*Atrhrospira platensis*) is a blue- green micro alga. Furthermore, its chemical composition includes proteins (55%-70%), carbohydrates (15%-25%), essential fatty acids (18%), vitamins, minerals (0.16 ppm Zn) and pigments like carotenes, chlorophyll *a* and phycocyanin. It is a rich source in phycocyanin, an antioxidant biliprotein pigment, and carotenoids (Cheong *et al*., 2010 and Gaese, 2012). Moreover, Lokapirnasari *et al*. (2016) confirmed that *Spirulina sp.* could be used as feed additive to increase immunity in broiler chicken.

On the basis of these considerations, the present research was conducted to evaluate the effect of Zn supplementation at levels of (50, 75 and 100mg /kg diet) for rabbit diets through Zinc enriched *Spirulina* as an organic source on growth performance, nutrients digestibility, carcass characteristics, blood parameters and economical efficiency.

MATERIALS AND METHODS

The current study was performed at Borg-El Arab, Alexandria Governorate, Experimental Station of Animal Production, Animal Production Research Institute, Agricultural Research Center, Ministry of Agriculture, Egypt.

Algae preparation

The strain of *Spirulina platensis* (*Arthrospira platensis*) was obtained from Agricultural Microbiology Department, National Research Centre (NRC), Giza, Egypt, The principles of the cultivation system and modification of culture medium by the addition of inorganic zinc source are described in Gaese (2012). The biomass concentration was 1 g of dry mass/L. Resultant Zinc-enriched *Spirulina* contained 100.17 mg Zn for each 1 gm dry algae.

Animals, feeding, and management

A total number of forty eight of weaned New Zealand White (NZW) male rabbits at 5 weeks of age with average initial live body weight (744.79±17.56 g) were randomly assigned to four experimental groups (12 rabbits for each), 4 replicates (3 rabbits for each). Rabbits were randomly housed in individual cages (60×40×24 cm). Feed and water were offered *ad libitum* throughout the experimental period (8 weeks). Each group was fed on one of experimental diets from 5 to 13 weeks of age. Live body weight and feed intake were recorded weekly. Four pelleted diets for growing rabbits were formulated and nutrients requirements were adjusted according to the recommendations of Lebas (2013) as shown in Table 1. Diets were pelleted and analysed. The first experimental group received daily untreated pelleted diet (control). The second, third and fourth experimental groups received daily pelleted diet supplemented with 50, 75 and 100 mg Zn-Sp/kg diet, respectively. The control diet, thus containing only the endogenous Zn contained in the ingredients of the diet (107.81 mg Zn/kg DM).

Digestibility trial

At the end of the experimental period, digestibility trial was carried out on four rabbits per treatment. These rabbits were housed individually in metabolic cages which allowed for the collection of feces and urine separately for five consecutive days collection according to European reference method for rabbit digestion trials (Perez *et al*. 1995). The experimental diets were offered daily and fresh water was provided at all times. During the test period, daily feed intake and feces excreted were accurately determined. Feces of each animal were dried, ground and stored until analysis. Digestible energy (DE, Kcal/Kg diet)) was calculated as follow: TDN × 44.3 according to Schneider and Flatt (1975).

Analytical methods

Chemical analyses of both experimental diets and feces were performed using the methods of A.O.A.C (2000) for determining moisture, crude protein (CP), crude fiber (CF), ether extract (EE), nitrogen free extract (NFE), ash. Calcium and Zinc were determined by atomic absorption spectrophotometer and phosphorous was determined colorimetrically using spectrophotometer.

Carcass characteristics and blood samples

At the end of the experimental period (13 weeks old), three male rabbits from each group were randomly taken, fasted for 12 hours, individually weighed and immediately slaughtered. Slaughter procedure and carcass analysis were carried out as described by Blasco and Ouhayoun (1996). After complete bleeding, pelt, viscera and tail were removed and then the carcass and giblets (liver, heart, and kidney) were weighed. Dressing percentage included relative weights of the carcass, giblets and head were estimated. Blood samples (5 ml from each rabbit) were collected

Table 1. Feed ingredients and chemical composition of rabbit basal diet (%DM basis).

Feed Ingredient	**(%)**	**Chemical analysis (%DM basis)**	
Soybean meal (44% CP)	19.60	Dry matter (DM)	86.89
Barley	17.10	Organic matter (OM)	90.90
Wheat bran	25.08	Crude protein (CP)	17.63
Yellow corn	7.00	Crude fiber (CF)	13.40
Clover hay	24.50	Ether extract (EE)	1.90
Molasses	3.00	Nitrogen free extract (NFE)	57.97
Limestone	1.08	Ash	9.10
Di- calcium phosphate	1.71	ADF	17.02
DL-Methionine	0.28	Methionine[b]	0.68
Sodium chloride	0.35	Lysine[c]	0.99
Vit.-Min. premix[a]	0.30	Calcium	1.27
Total	**100**	Available Phosphours	0.55
		Digestible energy (Kcal/Kg DM)[d]	2599.49
		Zn (mg/kg DM)[e]	107.81

[a]***Vit. And Min. premix per kg contains***: Vit A 6000 IU; Vit $D_3$450 IU; Vit E 40 mg; Vit K_3 1 mg; Vit B_1 1 mg; Vit B_2 3 mg; Niacin 180 mg; Vit B_6 39 mg; Vit B_{12} 2.5 mg; Pantothenic acid 10 mg; biotin 10 mg; folic acid 2.5 mg; choline chloride 1200 mg; Manganese 15 mg; Zinc 60 mg; Iron 38 mg; Copper 5 mg; Selenium 0.1 mg; Iodine 0.2 mg; Selenium 0.05 mg.

(b,c,e) : Calculated on the basis of the ingredients composition.

(d) Digestible energy (DE) was calculated according to Lebas (2013) using the following equation: $DE = 15.627 + 0.000982\ CP^2 + 0.0040\ EE^2 - 0.0114\ MM^2 - 0.169\ ADF \pm 1.250$ MJ/kg DM. DE in M Joules /kg DM ; DM = Dry matter ; CP = %Crude protein in DM; EE = % Ether extract (lipids) in DM; MM =% minerals (ash) in DM; ADF = % Acid detergent fibre in DM ; CF = % Crude fibre in DM.

at slaughtering time in heparinized glass tubes. Blood serum was separated by centrifugation at 3000 rpm for 15 minutes. The collected serum was stored at -20°C until assay. Blood serum total protein, albumin, total cholesterol, LDL, HDL-cholesterol, aspartate aminotransferase (AST) and alanine aminotransferase (ALT) were colormetrically determined using commercial kits (purchased from Bio-diagnostic, Egypt), according to the manufacturers' instructions. Serum total protein was determined according to Orsonneau *et al.* (1989) and albumin was estimated according to Doumas *et al.*, (1971). Serum globulins values were obtained by subtracting albumin values from the corresponding total protein values. The albumin/globulin ratio was calculated. Blood serum cholesterol and transaminases were determined according to Richmond (1973) and Reitman and Frankel (1957), respectively. Serum LDL- and HDL-cholesterol were determined according to the method of Wieland and Seidel (1983) and Lopez-Virella *et al.* (1977), respectively. Zinc concentration in serum was determined by using atomic absorption analysis. Blood serum total antioxidant capacity (T-AOC) was measured according to Koracevic *et al.* (2001).

Economical efficiency

To determine the economical efficiency of the experimental treatments, the costs of feed required for producing one kg of body weight gain was calculated. The cost of the experimental diets was calculated according to the price of different ingredients prevailing at the local market as well as the price of tested materials at the time of experimentation. Economical efficiency was calculated as a ratio between the return of weight gain and the cost of consumed feed.

Statistical analysis

The obtained data were statistically analyzed by one-way analysis of variance using the general linear model procedure of SAS® Software Statistical Analysis (SAS 2002). Differences among treatment means were tested by Duncan's Multiple Range-Test (Duncan, 1955). All results were analyzed using this model:

$$Y_{ij} = \mu + T_i + E_{ij} \;;$$

Where: Y_{ij}= the observation of ij; μ = the overall mean; T_i= the effects of i (treatments) and E_{ij}= the experimental random error.

RESULTS AND DISCUSSION

Growth performance

The effects of dietary supplementation of Zn-Sp as an organic zinc source under each tested level on rabbits performance are presented in Table 2. The results revealed that dietary Zn-Sp supplementation caused a significant increase ($P<0.05$) in final live body weight at 13 weeks old compared to the control group. While, there was an insignificant increase in live body weight at 10 weeks old with adding Zn-Sp to rabbit diets. Supplementation of 75 and 100 mg Zn-Sp improved ($P<0.05$) body weight gain during the whole experiment period compared to the control group. The increases in the average daily body weight gain were 10.93 and 10.63% for 75 and 100 mg Zn-Sp, respectively. Similarly, dietary supplementation of Zn-Sp enhanced ($P<0.05$) the feed conversion ratio during both experimental periods, (10-13 weeks) and (5-13 weeks) compared to the control group. On the other hand, at all experimental periods, rabbits fed diets supplemented with 75 and 100 mg Zn-Sp consumed less ($P<0.05$) feed than those fed the control diet and 50 mg Zn-Sp diet.

Similar to our findings, Meshreky *et al*. (2015) demonstrated that rabbits fed diets supplemented with Zn at levels of 100 or 200 mg/kg diet were significantly ($P<0.01$) higher in live body weight at 22 weeks of age and total body weight gain. Furthermore, Chrastinová *et al*. (2015)

Table 2. Effect of feeding different levels of Zn-Sp on the growth performance of growing rabbits.

Items	Supplementation of Zn-Sp (mg/kg DM)				
	Control	50 Zn-Sp	75 Zn-Sp	100 Zn-Sp	±SEM
Live body weight (g) at:					
5 weeks	742.5	743.33	744.58	748.75	36.29
10 weeks	1450.42	1472.92	1503.75	1507.08	31.59
13 weeks	2027.50[b]	2124.41[a]	2171.83[a]	2170.42[a]	33.59
Daily body weight gain (g) from:					
5– 9 weeks	25.28	26.06	27.11	27.08	0.71
10 –13weeks	20.61	23.27	23.86	23.69	1.13
5 –13 weeks	22.95 [b]	24.66 [ab]	25.48 [a]	25.39 [a]	0.73
Daily feed consumption (g) from :					
5– 9 weeks	102.40 [a]	98.22 [ab]	93.06 [c]	94.16 [bc]	1.60
10 –13weeks	96.69 [a]	95.22 [a]	90.74 [b]	83.08 [c]	0.94
5 –13 weeks	98.91 [a]	97.92 [a]	92.79 [b]	90.89 [b]	1.15
Feed conversion ratio (Feed/Gain) from:					
5– 9 weeks	4.05 [a]	3.76 [ab]	3.43 [b]	3.47 [b]	0.14
10 –13weeks	4.69 [a]	4.09 [b]	3.80 [b]	3.50 [b]	0.21
5 –13 weeks	4.30 [a]	3.97 [b]	3.64 [b]	3.57 [b]	0.13

a, b, Means within the same row with different superscripts are significant1y different at P< 0.05.

reported that increase in average body weight gain was noted in the rabbits groups fed 27.47 g Zn $SO_4.H_2O$ and 38.46 g Glycinoplex-Zn. Also, Ayyat and Marai (2000) reported that supplementing rabbits diets with 100, 200 or 300 Zn mg kg^{-1} significantly (P<0.05) increased live body weight and average daily gain, but had no effect on feed intake and feed conversion ratio. Likewise, Selim *et al*. (2012) found that supplementation of Zn in rabbit diets at 100 or 200 mg kg^{-1} diet improved (P<0.05) live weight gain and FCR compared to the higher level of 400 mg kg^{-1} diet. While, our results were contrary to those obtained by Casado *et al*. (2011) who stated that addition of Zn to the rabbit's diet at 200 ppm had no effect on daily feed intake, daily weight gain and FCR.

The best weight gain allotted to rabbit groups fed diets containing 75 and 100 mg Zn-Sp. This improvement may due to greater bio-efficacy of Zn-Sp relative to an inorganic Zn source. Therefore, Zn-Sp could provide more Zn for absorption, consequently improved growth performance as observed in previous studies (Schell and Kornegay, 1996 and Batal *et al.*, 2001). It is well known that higher absorption capacity of Zn-Sp allows low inclusion rates of zinc and makes mineral balance in animal easier to maintain (Jahanian and Rasouli, 2015). Zn-Sp as an organic source of Zn does not allow phytate to chelate Zn to a way that reduces its availability for rabbits. Whereas, Baker and Halpin, (1988) stated that diets contained corn, soybean meal and wheat bran as the control diet are rich in phytate content that reduced Zn bioavailability of these feed ingredients. Further confirmation of the positive effect of Zn-Sp on performance has been obtained from Spirulina which has hematinic and antioxidant effects as well as growth promoting, because of its high protein, essential amino acids, essential fatty acids, minerals, vitamins, carotenoids and other antioxidant active constituents, which promote growth and maintain health (Alvarenga *et al*. 2011).

Nutrients digestibility and nutritive values of experimental diets

The results in Table (3) indicate the effect of supplemental different levels of Zn-Sp on the nutrients digestibility and nutritive values of the dietary treatments. It could be noticed that dietary Zn-Sp supplementation at 100 mg/kg diet led to a significant increase in all nutrients digestibility. However, there were an insignificant differences among rabbits groups fed diets supplemented with 50 or 75 mg Zn-Sp and the control diet regarding digestibility of DM, OM, CP, EE, CF and NFE. In addition, Zn-Sp supplementation had no effect on the CF digestibility.

Concerning the effect of experimental diets on nutritive values, supplementing rabbit diets with Zn-Sp at level of 100 mg/kg DM increased ($P<0.05$) DCP%, TDN% and DE (kcal/kg) compared to the control group. However, there were insignificant increases in all nutritive values with adding Zn-Sp to rabbits diets at levels 50 or 75 mg Zn-Sp compared to the control group. In this concoction, Meshreky *et al*. (2015) found that rabbits fed diets supplemented with Zn-Met or $ZnSO_4$ at 100 or 200 mg/kg diet improved nutrients digestibility and nutritive values expressed as TDN and DCP of diets. Also, Abd El-Rahim *et al*. (1995) reported that the values of nutrients digestibility were significantly higher in rabbits fed diets supplemented with 170 mg Zn (as ZnSO4)/kg diet, but there was no effect when they were fed diets supplemented with 58, 115, and 285 mg Zn/kg of diet compared to the control group. Contrary to our findings, Hong *et al*. (2002) stated that there was also no difference in the digestibility of nutrients in broiler chickens supplemented with 100 ppm Zn as Zn-methionine (Zn-Met).

These results confirmed that Zn-Sp supplementation into rabbit diets improved the nutrients digestibility especially the supplemental level at 100 mg Zn-Sp. This enhancement may be related to zinc from organic sources which is protected by the organic ligand (protein, methionine, or lysine) from reacting with feed antagonists, such as phytate to form

Table 3. Effect of feeding different levels of Zn-Sp on nutrients digestibility and nutritive values of experimental treatments.

	Supplementation of Zn-Sp (mg/kg DM)				
Items	**Control**	**50 Zn-Sp**	**75 Zn-Sp**	**100 Zn-Sp**	**±SEM**
Nutrients digestibility (%)					
Dry matter (DM)	64.45 [b]	69.22 [ab]	69.26[ab]	76.37 [a]	2.58
Organic matter (OM)	66.22 [b]	71.06 [ab]	71.37 [ab]	77.89 [a]	2.57
Crude protein (CP)	68.07 [b]	72.18 [ab]	72.14 [ab]	78.79 [a]	2.61
Crude fiber (CF)	52.15	56.27	51.44	52.79	3.37
Ether extract (EE)	73.04 [b]	74.47 [b]	74.95 [b]	81.87 [a]	1.97
Nitrogen free extract (NFE)	69.16 [b]	74.83 [ab]	75.13 [ab]	81.17 [a]	2.89
Nutritive values					
DCP (%)	11.77 [b]	12.68 [ab]	11.57 [ab]	13.39 [a]	0.53
TDN (%)	64.27 [b]	70.35 [ab]	67.72 [ab]	75.97 [a]	2.78
DE(Kcal/kg)	2847.16 [b]	3116.50 [ab]	2999.99 [b]	3365.47 [a]	123.33

a,b, Means within the same row with different superscripts are significant1y different at P< 0.05.

insoluble complexes and this organic form of the mineral is protected from unwanted interactions in the gastrointestinal tract. It is worthy to note that zinc from organic sources is absorbed by the intestinal cells as an ion and it had an increase in bioavailability than the inorganic source (Wedekind *et al*., 1992 and Ledoux, 2005). It has been hypothesized that organic sources of trace minerals with the optimal complex or chelation strength could arrive at absorptive sites in the small intestine with intact structure, rendering superior bioavailability to inorganic sources (Ashmead, 1993).

Carcass characteristics

The carcass characteristics of the experimental rabbit groups are summarized in Table 4. Supplementation of rabbit diets with Zn-Sp at each tested level increased (P<0.05) hot carcass weight, dressing percentage and total edible parts (%) compared with the rabbits group fed the control diet. The higher hot carcass weights could be due to higher live body weight of the rabbit fed diets supplemented with Zn-Sp. These results are in agreement with the previous study conducted by (Jahanian and Rasouli, 2015) who found that ZnMet improved (P<0.05) carcass yield in broiler chicks. In contrary, Selim *et al*. (2012) demonstrated that adding Zn levels as zinc oxide to rabbit diets (50, 100, 200 and 400mg kg^{-1} diet) did not significantly affect carcass traits (Dressing%, liver and kidney %). Also, Ayyat and Marai (2000) reported that supplementing rabbit diets with 100, 200 or 300 Zn mg kg^{-1}had no effect on dressing yield of the rabbits compared with the control.

Dietary supplementation of Zn-Sp had no significant effects on head %, spleen %, heart%, kidney % and giblet weight%. In addition, rabbits fed diet supplemented with 100 mg Zn-Sp achieved the lowest ($P<0.05$) non edible parts % among all the experimental groups followed by 50 and 75 mg Zn-Sp then the control group. As well as, there was a significant difference between the rabbit fed diet supplemented with 75 mg Zn-Sp and those fed control diet in liver weight%. However, an addition of 75 mg Zn-Sp showed numerically lower liver weight (%) compared to the other groups.

An explainable reason for greater carcass yield may be attributed to participation of Zn in DNA and protein biosynthesis throughout the body. 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 (Coleman, 1992; Kaim and Schwederski, 1994). Besides to that, Zn-Sp may serve in increasing tissue supply of Zn as well as bioactive

Table 4. Effect of feeding diets supplemented with different levels of Zn-Sp on carcass characteristics of growing rabbits.

Items	**Supplementation of Zn-Sp (mg/kg DM)**				
	Control	**50 Zn-Sp**	**75 Zn-Sp**	**100 Zn-Sp**	**±SEM**
Hot carcass weight (g)	1095.55 ^{c}	1243.82 ^{b}	1218.02 ^{b}	1403.57 ^{a}	34.13
Dressing (%)	54.85 ^{c}	61.75 ^{ab}	58.30 ^{b}	63.11 ^{a}	1.23
Head weight (%)	4.62	4.54	4.71	4.07	0.24
Spleen weight %	0.11	0.12	0.17	0.25	0.04
Liver weight (%)	3.02 ^{a}	2.89 ^{a}	2.20 ^{b}	2.61 ^{ab}	0.19
Heart weight (%)	0.36	0.40	0.33	0.38	0.02
Kidneys weight (%)	0.65	0.65	0.57	1.88	0.67
Giblets weight (%)[1]	4.04	3.94	3.10	4.87	0.73
Total edible parts (%)[2]	58.89 ^{c}	65.69 ^{ab}	61.40 ^{b}	67.98 ^{a}	1.45
None edible parts (%)	41.11 ^{a}	34.30 ^{bc}	38.59 ^{ab}	32.01 ^{c}	1.45

a, b,c Means within the same row with different superscripts are significant1y different at P< 0.05,
(1) Giblets **%**= (Liver+ kidney + heart) / Pre-slaughter weight (g)*100
(2) Total edible parts **%**= (Carcass wt. + Edible giblets wt.) / Pre-slaughter weight (g)*100.

compounds of algae. Probably, both Zn and algae bioactive compounds are more bioavailable and promote protein biosynthesis. Several authers cited that *Spirulina platensis* is an important natural source of vitamin B12, vitamin E, ascorbic acid, tocopherols and it has proteins (55%-70%), glutamic acid, aspartic acid, Isoleucine, carbohydrates (15%-25%), essential fatty acids (18%), minerals, natural mixed carotene and xanthophylls, chlorophyll and phycocyanin. (Gaese, 2012; Zahroojian *et al*. 2013; Rosario Josephine, 2015). Whereas, vitamin B_{12} was successfully precipitated into *Loingissimu drosi* meat of rabbits (Dalle Zott *et al*. 2014).

Blood biochemical parameters

The results of blood serum parameters are given in Table 5. The obtained results showed that feeding dietary Zn-Sp (50, 75 or 100 mg/kg diet) resulted in significant increases (P<0.05) in serum total protein, HDL and Zn concentrations in comparison to the control group. Conversely, a significant decrease (P<0.05) was observed only in 75 mg Zn-Sp group for serum total cholesterol and in all treatment groups for LDL concentrations when compared to control group. Zn-Sp supplementation had no effect on the concentrations of AST, ALT, albumin, globulin and A/G ratio. However, addition Zn-Sp to rabbit diets numerically increased albumin, globulin and A/G ratio compared to control group. It could be observed that dietary supplementation of Zn-SP at levels of 75 and 100 mg/kg DM led to significant increase (P<0.05) in antioxidant status of rabbit as

Table 5. Blood biochemical parameters of growing rabbits fed diets supplemented with different levels of Zn-Sp.

Item	**Supplementation of Zn-Sp (mg/kg DM)**				
	Control	**50 Zn-Sp**	**75 Zn-Sp**	**100 Zn-Sp**	**±SEM**
Biochemical parameters					
Total protein, g/dl	6.23 [d]	6.65 [c]	7.27 [b]	7.73 [a]	0.11
Albumin, g/dl	3.72	3.93	4.24	4.50	0.26
Globulin, g/dl	2.50	2.71	3.03	3.22	0.20
A/G ratio	1.57	1.50	1.43	1.46	0.23
Total cholesterol,mg/dl	112.74 [a]	95.82 [ab]	86.21 [ab]	82.91 [b]	8.24
LDL	65.65 [a]	48.43 [b]	43.31 [bc]	38.31 [c]	1.86
HDL	24.26 [c]	26.91 [bc]	28.46 [b]	32.50 [a]	1.13
AST,u/l	33.13	34.56	37.70	34.57	2.28
ALT, u/l	44.25	45.00	44.12	46.37	1.72
Serum mineral concentration					
Zn (ppm)	136.05 [d]	147.75 [c]	161.90 [b]	175.32 [a]	1.61
Antioxidant status					
Total antioxidant capacity (T-AOC, mMol/L)	0.56 [c]	0.95 [bc]	1.18 [b]	1.98 [a]	0.13

a, b,… Mean values with the same letter within the same row did not differ significantly (P>0.05).

measured by total antioxidant capacity (T-AOC) as Zn-SP levels increased. Rabbit fed diets supplemented with 75 and 100 mg Zn-SP recorded the highest (P<0.05) levels of T-AOC compared to the control group.

The results of the present study agree with Jahanian and Rasouli (2015) who reported that Zn-methionine supplementation at levels of 25,50, 75 and 100 mg reduced cholesterol content in broiler chicks. In contrast, Ren *et al*. (2006) found that zinc supplementation in rabbit diets at 1 g/kg for 8 weeks did not produce a significant change in total cholesterol and LDL. Also, Selim *et al*. (2012) stated that adding of Zn at levels of 50, 100 or 200 mg kg^{-1} diet did not significantly affect Zn concentration in blood serum in rabbit.

These results confirm that supplementing rabbit's diets with Zn-Sp have a positive effect on serum total protein concentration. It might be due to better utilization of Zn-Sp as organic source as well as zinc plays an important role in the protein biosynthesis (Prasad, 1995). Furthermore, Rosario and Josephine (2015) demonstrated that minerals were transformed into natural organic forms by *Spirulina* and become chelated with amino acids and are therefore more easily assimilated by the body. Also, Zn-Sp might help in maintaining a better physiological status through efficient utilization of dietary protein, carbohydrates, lipids and minerals for rabbits.

The increase of globulin levels could be attributed to that Zn may affect immunity via its important role in cell replication and proliferation (Weiss and Spears, 2006). Zinc has been shown to reduce the catabolic response induced by immune stimulation and may be effective in promoting growth (Rymer and Givens, 2005). Zn-Sp is more available; subsequently, reduce total cholesterol due to the reduction in LDL synthesis as dietary Zn is increased (Samman and Roberts, 1988). Zinc acts as an indirect antioxidant and it reduces the accumulation of cholesterol or oxidized lipid (Jenner *et al*., 2007). Besides, Abdel-Daim, (2014) confirmed that *Spirulina* has the promising growth promoting, hematinic and hepatoprotective activities. Also, supplementation with *Spirulina* resulted in reducing serum concentrations of total cholesterol, LDL- cholesterol and elevating of HDL-cholesterol (Serban *et al*., 2016).

Furthermore, in our study, there is a significant increase in the serum T-AOC concentration due to Zn-Sp supplementation. Whereas, Zn plays a very important role in the anti-oxidant defense system of the body and its deficiency has been linked to oxidative damage of the cell membrane leading to oxidative stress (Salgueiro *et al*. 2000). However, it is speculated that Zn scavenges free radicals by increased synthesis of metallothionein (Prasad *et al*. 2004). As well as, Zn may play a role in suppressing the creation of free radicals, as it is a substantial part of the anti-oxidative enzyme copper-zinc superoxide dismustase (Khan, 2011).

Economical evaluation

Table 6. illustrated the effects of the Zn-Sp supplementation on economical efficiency. Significant improvement was mainly observed in economical efficiency and net revenue with supplementation of 50, 75 and 100 mg Zn-Sp in rabbit diets compared to the control group. The economical efficiency of 50, 75 and 100 mg Zn-Sp supplementations increased by 14.94, 33.0 and 33.48% over the control group, respectively; while net revenue raised by 14.35, 25.44 and 26.97%. it is worthy to outline that economical efficiency increased in parallel to the gradual increasing of Zn-Sp supplementations. Additionally, rabbits fed diet supplemented with 100 mg Zn-Sp achieved the best net revenue and economical efficiency. However, the control group had the lowest net return and economical efficiency. These results are in good agreement with Ayyat and Marai (2000) who stated that feed cost slightly increased with increasing dietary zinc level, while the profit percentage increased with increasing dietary Zn level up to 200 mg zinc/kg diet.

Table 6. Economical efficiency of rabbit diets supplemented by different levels of Zn-Sp.

Item	Supplementation of Zn-Sp (mg/kg DM)			
	Control	**50 Zn-Sp**	**75 Zn-Sp**	**100 Zn-Sp**
Initial weight (Kg)	0.7425	0.7433	0.7445	0.7445
Final weight (Kg)	2.027	2.124	2.171	2.17
Average total weight gain/rabbit (kg)	1.284	1.380	1.426	1.425
Total revenue /rabbit (LE)[1]	35.966	38.659	39.942	39.914
Total feed intake/rabbit (Kg)[2]	5.538	5.483	5.196	5.089
Price of feeding/kg (LE)	3.00	3.015	3.015	3.015
Total feed cost /rabbit (LE)	16.614	16.531	15.665	15.343
Net revenue/rabbit (LE)[3]	19.352	22.128	24.276	24.570
Economical efficiency(EE)[4]	1.164	1.338	1.549	1.601
Relative economical efficiency (REE)[5]	100	114.91	133.03	137.48

[1] Assuming that the price of one kg LBW equal, 28L.E.
[2] According to the price of ingredients available at the experimental time.
[3] Net revenue/rabbit = Total revenue /rabbit (LE) - Total feed cost /rabbit (LE)
[4] EE = Net revenue / Total feed cost / rabbit (LE).
[5] REE = EE of treatments other than the control/ EE of the control group.

This situation can be explained considering that Zn-Sp supplementation had positive effect on performance of growing rabbits. Therefore, rabbits groups fed diets supplemented with 50, 75 and 100 mg Zn-Sp recorded the higher body weight gain and lower total feed cost than the control group. As demonstrated in this study, supplementing rabbit diets with Zn-Sp enhanced the overall health of rabbits without ameliorating the impaired digestive function, so it caused increase of final live body weight and body weight gain. In addition, it achieved the best feed efficiency.

Conclusively, from these results, it could be recommended to add Zn-Sp as an organic zinc source to growing rabbit diets at level 100 mg/kg diet to achieve optimum growth without any adverse effect on rabbits health, as well as to improve the nutrients digestibility.

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تـأثير اضافـة الطحـالب الغنيــة بالزنـك علي النمو والأداء الفسيولوجي في الأرانب النامية

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تم إجراء التجربة الحالية لتقييم تأثيرات إضافة الطحالب الغنية بالزنك علي أداء النمو ومعاملات الهضم وخصائص الذبيحة وقياسات الدم والكفاءة الاقتصادية للارانب النامية من عمر ٥ اسابيع الي عمر ١٣ اسبوع. حيث تم اختبار الطحالب الغنية بالزنك كمصدر زنك عضوي، تم توزيع عدد ٤٨ ارنب نيوزلندي ذكور لأربعه مجموعات كل مجموعه بها ١٢ ارنب و٤ مكررات كل مكرر به ٣ ارانب. تم مقارنة ثلاثة مستويات (٥٠و ٧٥ و ١٠٠ ملجم زنك- طحالب) بمجموعه الكنترول بدون إضافة الطحالب الغنية بالزنك.

اظهرت النتائج أن إضافة الطحالب الغنية بالزنك قد زادت من وزن الجسم النهائي عند الاسبوع ١٣ مقارنة بمجوعه الكنترول. وحسنت إضافة ٧٥ و ١٠٠ ملجم زنك-طحالب من الزيادة الوزنية للجسم أثناء مدة التجربة وكانت نسبة الزيادة ١٠,٩٣ و ١٠,٦٣% علي الترتيب. وعلي العكس في كل فترات التجربة استهلكت الأرانب المغذاه علي ٧٥ و ١٠٠ ملجم زنك-طحالب أقل كمية علف مأكول من المجموعه المغذاه علي العليقة الكنترول أو ٥٠ ملجم زنك-طحالب بالإضافة لذلك فقد حسنت العلائق المضاف إليها ٥٠ و ٧٥و ١٠٠ ملجم زنك-طحالب من معامل التحويل الغذائي خلال مده التجربة.

أدت إضافة ١٠٠ ملجم زنك-طحالب إلي زيادة معنوية في معاملات الهضم بالإضافة إلي ان إضافة الزنك-طحالب إدي إلي تأثير غير معنوي علي معامل هضم الالياف الخام. وزادت تغذية الأرانب علي العلائق المضاف اليها زنك-طحالب بنسبة ١٠٠ ملجم/كجم مادة جافة من نسبة البروتين المهضوم ومجموع المركبات الغذائية المهضومة والطاقة المهضومة مقارنة بمجموعة الكنترول.

زادت إضافة الطحالب الغنية بالزنك إلي علائق الارانب من وزن الذبيحة ونسبة التصافي ومجموعه الاجزاء المأكولة والبروتين الكلي في سيرم الدم والكوليسترول عالي الكثافة وتركيز الزنك في سيرم الدم ومستويات القدرة التأكسدية الكلية مقارنة بمجموعة الكنترول. وعلي العكس فقد لوحظ إنخفاض معنوي في تركيز كوليسترول الدم والكوليسترول منخفض الكثافة مقارنة بالارانب المغذاه علي العليقة الكنترول.

زادت الكفاءة الأقتصادية للعلائق المضاف إليها ٥٠ و ٧٥ و ١٠٠ ملجم زنك-طحالب بنسبة ١٤,٩٤ و ٣٣,٠٠ و ٣٣,٤٨% منسوبة للكنترول.

التوصية: تشير النتائج الحالية إلي أنه يمكن إضافة الطحالب الغنية بالزنك كمصدر زنك عضوي في علائق الأرانب له إتاحة عالية ويسبب تحسن في إداء النمو والهضم بدون تأثيرات سلبية علي الحالة الصحية للأرانب.