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Effect Of Adding Organic And Inorganic Zinc To Diets In Lessening The Negative Impact Of Heat Stress On Growing Male New Zealand White Rabbits

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ABSTRACT:

This study aimed to evaluate the effects of dietary organic Zinc Ethylene-diamine-tetra-acetic acid (Zinc EDTA) and inorganic zinc oxide (ZnO) supplementation on the growth, feed efficiency, blood parameters, physiological indicators, and carcass traits of growing male New Zealand White (NZW) rabbits under Egyptian heat-stress conditions. A total of thirty weaned male NZW rabbits were randomly assigned (625 ± 5.39 g) to three experimental groups. The 1st group was fed basal diet without Zn supplementation as control group; while the 2nd group was fed with Zn-EDTA (50 mg/kg diet), and the 3rd group was fed with ZnO (50 mg/kg diet) for the duration of 5-13 weeks of age.

*The results indicated that zinc supplementation significantly (P< 0.01) increased body weight, daily weight gain, and relative growth rate in both Zinc EDTA and ZnO groups as compared to the control group. The Zinc EDTA group had the best feed conversion ratio and protein efficiency ratio. Blood parameters were also, significantly (P<0.01) affected by zinc supplementation, which was: Zinc EDTA group had significant (P< 0.01) increase**s** in serum total protein, whereas both Zinc EDTA and ZnO significantly reduced serum ALT, AST, and urea levels when compared to control group. In carcass traits, both Zinc EDTA and ZnO groups had significantly (P< 0.01) higher carcass weight and carcass percentage compared to the control group. Moreover, the economic efficiency was improved, both Zinc EDTA and ZnO groups showed higher return of gain and profit margin as compared to the control group, especially with Zinc EDTA group was yielding the highest profit margin.*

***Conclusively,**, from these results, it could be concluded that dietary zinc supplementation, particularly in the form of Zinc EDTA, provides significant benefits* *for improving growth performance, feed efficiency, health, and economic outcomes in male NZW rabbits exposed to heat stress, in Egypt.*

Keywords: Heat stress; growth; carcass traits; blood parameters; organic zinc; rabbits.

INTRODUCTION

Recent awareness of global climate change has underscored its impact on agricultural practices, particularly livestock production. Societies that perceive higher risks from climate change are more likely to take adaptive measures. Raising awareness is a crucial first step in mitigating its effects and reducing vulnerability. Given agriculture's direct exposure to climate fluctuations, farmers provide firsthand insights into its consequences and potential adaptation strategies (Ricart *et al.*, 2023). Rabbits, known for their prolific breeding and efficient feed conversion, are widely used in both small-scale and commercial farming. However, they are highly susceptible to heat stress, which can impair physiological functions, reduce productivity, and compromise animal welfare (Marai *et al.*, 2002; Zeferino *et al.*, 2013). With rising global temperatures, rabbit farming faces increasing challenges, necessitating strategies to enhance resilience and maintain productivity (Goswami *et al.*, 2025). To mitigate heat stress, various dietary interventions have been explored to improve rabbit growth, immune response, and overall resistance (Oladimeji *et al.*, 2022). Among these, mineral supplementation plays a key role in promoting thermal tolerance and physiological stability (Ebeid *et al.*, 2023).

Zinc, an essential trace element, supports numerous of biological functions including enzyme activity, immune response, and antioxidant defense (Barceloux, 1999; Shinde *et al.*, 2006). It is also, crucial for skeletal development, protein synthesis, and cellular functions (Garcia-Contreras *et al.*, 2011; Lukac and Massanyi, 2007). However, its bioavailability varies depending on its dietary source, affecting its efficacy as a feed additive (Swiatkiewicz *et al.*, 2014). Rabbit diets often contain grains, soybean meal, wheat bran, and cottonseed meal, which are high in phytates that bind zinc, reducing its absorption (Baker and Halpin, 1988). To compensate for this, supplemental zinc is necessary (Cavalcante and Ferreira, 2000). Traditionally, inorganic zinc sources such as ZnO have been used due to their high zinc concentration and stability (Ferreira *et al.*, 2002). However, recent studies suggest that organic zinc forms, such as zinc methionine or Zn-EDTA, offer superior absorption and efficacy (Droke *et al.*, 1998; Downs *et al.*, 2000). Research has demonstrated that organic zinc improves immune response and growth performance more effectively than inorganic sources (Shinde *et al.*, 2006; Meshreky *et al*, 2015). Moreover, zinc can play an important role for the animals in many aspects such as antioxidant, glandular development, protein synthesis, carbohydrate metabolism, nutrition, production performance and function as a cofactor in more than 300 metalloenzymes (Salim *et al*. 2008).

Therefore, this study aimed to compare the effects of dietary supplementation with organic (Zn-EDTA) and inorganic (ZnO) zinc sources on the growth performance, carcass characteristics, and blood biochemical responses of growing male New Zealand White (NZW) rabbits under Egyptian summer conditions. By evaluating their impact on heat stress resilience, the findings will contribute to optimizing feeding strategies for sustainable and efficient rabbit farming in the face of climate change.

MATERIALS AND METHODS

During the Egyptian summer months of June through July 2023, this study was carried out at Rabbitry of the Animal Production Department, Faculty of Agriculture, Zagazig University, Egypt, aiming to assess and contrast the effects of dietary zinc supplementation in both organic (Zn EDTA) and inorganic (ZnO) forms on growth performance, carcass characteristics, and blood biochemical reactions of developing male New Zealand White (NZW) rabbits under hot climate conditions.

Experimental rabbits, diets and management:

Thirty weaned male NZW rabbits, with similar weight (initial average weight 625 ± 5.39 g) at five weeks of age, were randomly allocated to three experimental groups (ten rabbits in each group) using a completely randomized design. A basal diet, designed to fulfill the fundamental nutritional needs of growing rabbits according to the National Research Council (NRC, 1977), was used. The basal diet was supplemented with zinc at three levels: 0.0, 50 mg/kg diet as Zn-EDTA, and 50 mg/kg diet as ZnO. Thus, three experimental diets were prepared for the duration of 5-13 weeks of age.

The rabbits were individually housed in a well-ventilated, open-sided Rabbitry, featuring individual galvanized-wire cages, feed and automatic nipple drinkers. Each rabbit functioned as an experimental unit. The cage measured 55 cm in length, 50 cm in breadth, and 40 cm in height. Prior to the trial, the Rabbitry and all its equipment (cages, feeders, and drinkers) were thoroughly disinfected, and all necessary managerial practices and biosecurity measures were strictly followed.

Feed (in pelleted form) and fresh water were provided *ad libitum* to all experimental groups. All the experimental groups were managed in the same way. The ingredient composition and calculated nutritional analysis of the basal (control) diet are presented in Table 1.

Table 1: Composition and calculated analysis of the basal diet used in this study

Ingredients:	%	**Calculated analysis** *	Contents
Alfalfa hay	30	Digestible energy, kcal/kg	2503
Wheat bran	27	Crude protein (%)	16.08
Yellow corn	16	Ether extract (%)	2.75
Barley grains	12	Crude fiber (%)	12.99
Soybean meal (44% CP)	10	Ca (%)	0.79
Molasses	3.0	Total P (%)	0.63
Ground limestone	0.5	Lysine (%)	0.72
Dicalcium phosphate	0.4	Methionine (%)	0.31
Common salt	0.5	Methionine + Cystine (%)	0.62
Vit. & Min. Premix[§]	0.5		
DL-Methionine	0.1		
Total	100		

[§]Each kilogram contains: Vit. A, 12,000 IU; Vit. D_3, 2,200 IU; Vit. E, 10.0 mg; Vit. K, 2.0 mg; Vit. B_1, 4.0 mg; Vit. B_2, 1.5 mg; Pantothenic acid, 6.3 mg; Vit. B_6, 1.7 mg; Vit. B_{12}, 0.03 mg; Biotin, 3.3 mg; Folic acid, 0.83 mg; Choline chloride, 200 mg; Mn, 5.00 mg; Fe, 12.5 mg; I, 0.33 mg; Se, 0.65 mg and Mg 66.79 mg.
*Calculated analysis (As fed basis: NRC, 1977).

Temperature-humidity index (THI):

The temperature-humidity index (THI), which indicates the thermal comfort level for rabbits, was calculated using the equation proposed by Marai *et al* (2001):

$$THI = db°C - [(0.31 - 0.31 \times RH) \times (db°C - 14.4)]$$

Where db°C represents the dry bulb temperature in Celsius, and RH refers to relative humidity (%). The calculated THI values were used to assess the intensity and severity of heat stress (HS) based on environmental conditions, classified as follows: Very severe heat stress (> 30°C), Severe heat stress (28.9-29.9°C), Moderate heat stress (27.8-28.8°C), and no heat stress (< 27.8°C).

Growth performance and physiological parameters of rabbits:

Live body weight (LBW) and feed intake (FI) of individual kits were measured weekly, starting at 5 weeks of age at the study's initiation and continuing until 13 weeks of age at the study's termination. Feed conversion ratio (FCR) and body weight gain (BWG) were assessed weekly during the trial. For the whole trial period (5-13 weeks of age, the average daily weight gain (DWG) was calculated as follows:

[Final LBW (g) minus the initial LBW (g)]/ number of days, and FCR was determined by dividing DFI (g) by DWG (g).

Additionally, the relative growth rate (RGR, %) was computed as 100 × BWG / [0.5 × (Initial LBW + Final LBW)].

Protein efficiency ratio (PER) was calculated as the total weight gain divided by the total protein consumed.

The pulse rate, respiration rate, and rectal temperature of the rabbits were recorded at midday on three consecutive days during the fourth week of the trial (9 weeks of age. These parameters were measured for each rabbit following the methodology described by Ayyat *et al.* (2021).

Carcass characteristics of rabbits:

At the end of the experiment (13 weeks of age), three rabbits from each treatment group were randomly chosen and euthanized following a 12-hour fasting interval. Subsequent to the documentation of the pre-slaughter live body weight, the rabbits were meticulously euthanized, skinned, and eviscerated. The weights of the hot carcass (empety body weight without the head and giblets (liver and kidneys), along with the hind, middle, and fore parts were documented. The carcass weight percentage was calculated using the formula:

Carcass weight (%) = Hot carcass weight / live body weight before slaughter) × 100.

Blood biochemical parameters and economic evaluation:

Three blood samples per treatment were obtained in non-heparinized test tubes, during slaughter. Prior the coagulation of blood, the samples were centrifuged to isolate the serum. The serum samples were subsequently frozen at –20°C for future examination.

The blood serum concentrations of albumin (ALB: Doumas *et al.*, 1971), total protein (TP: Doumas *et al.*, 1981), triglycerides (TRI: Fossati and Prencipe, 1982), total cholesterol (TC: Allain *et al.*, 1974), Urea-N (UN) and creatinine (CRE) by the methods of Lyman (1986), alanine aminotransferase (ALT) and aspartate aminotransferase (AST: Reitman and Frankel, 1957) were measured using commercial kits. Serum globulin (GLO) levels were calculated by subtracting serum ALB from serum TP.

Economic efficiency:

The economic assessment was conducted based on the equations outlined by Ayyat *et al.* (2018). The profit margin was calculated as the total revenue from rabbit weight gain minus the total feed cost. Other overhead costs were assumed to remain constant. The cost of one kilogram of feed was set at 17 Egyptian pounds (EGP), while the market price of one kilogram of live rabbit body weight was 90 EGP.

Statistical analysis

Statistical analysis was performed as a completely randomized design according to Snedecor and Cochran (1982) using the SAS Program, (SAS, 2006). To exclude the effect of pre-slaughter weight on carcass parameters, an analysis of covariance (ANCOVA) was applied to the data of hot carcass and organ weights. Covariance analysis was conducted for carcass traits data to account for variations in pre-slaughter weight among the study groups.

The variations among averages of the different experimental groups were calculated, using Duncan's multiple range test, according to Duncan (1955).

RESULTS AND DISCUSSION

Temperature-humidity index (THI):

The average values of air temperature and relative humidity during the experimental period (5-13 weeks of age) were 40.63±0.96°C and 56.50±0.33%, respectively. The calculated value of THI was 37.09°C. Weekly calculated THI values exceeding 30.00°C indicated that the experimental animals were subjected to very severe heat stress throughout the entire experimental period (Table 2).

Table 2. The temperature-humidity index during the experimental periods

Experimental period (weeks)	Temperature, °C	Humidity (%)	*THI
Week 1	38.40	56.00	35.1
Week 2	38.70	55.25	35.3
Week 3	39.60	55.25	36.1
Week 4	39.55	55.25	36.1
Week 5	41.30	56.00	37.6
Week 6	41.45	57.50	37.9
Week 7	42.55	58.50	38.9
Week 8	43.50	58.25	39.7
Overall mean	40.63±0.96	56.50±0.33%	37.01

*THI was calculated according to the equation of Marai *et al*. (2001) as: THI = Tem - [(0.31 - 0.31 × RH) (T - 14.4)], where RH = relative humidity as a fraction (percentage/100), and Tem = the ambient temperature in Celsius.

Heat stress negatively affected rabbit growth performance by decreasing feed intake, body weight gain, and FCR. Additionally, it influenced physiological and carcass traits. Heat stress is harmful to the well-being of all livestock, with rabbits being particularly vulnerable due to their sensitivity to elevated temperatures. Prolonged exposure to heat stress in rabbits can cause alterations in their biological, physiological, and biochemical parameters, resulting in reduced growth performance (Ayyat *et al.*, 2018; Dahmani *et al.*, 2022). A study by Dahmani *et al.* (2022) investigated the effects of heat stress on local Algerian growing rabbits. The results showed that rabbits exposed to high ambient temperatures (30.5±1.82°C) had decreased daily gain, body weight and feed intake compared to those in a controlled environment (21.8±1.3°C). FCR was also significantly higher in the heat stress group.

***Growth performance traits*:**

Table 3 and Figure 1 record data of the growth performance of growing rabbits when their diets supplemented with different sources of dietary zinc: Zinc EDTA, ZnO, and a control group without added zinc. The results indicate significant differences between the groups, suggesting that the form of zinc supplementation can affect the growth performance of rabbits. There were no significant differences between the groups at the beginning of the experiment. On the other hand, body weight at 9 or 13 weeks of age during the experimental period showed that rabbits supplemented with Zinc EDTA had the highest body weight, followed by ZnO, but the control group had the lowest weight, with the differences being highly significant ($P<0.01$). The highest daily weight gain at 5-9 and 5-13 weeks of age was seen in the Zinc EDTA group, followed by ZnO, then the control group, with highly significant differences ($P<0.01$). While, at 9-13 weeks there were no significant differences.

Also, Zinc EDTA showed the highest relative growth rate (%), followed by ZnO, and control, with highly significant ($P<0.01$) and significant ($P< 0.05$) differences at 5-9 and 5-13 weeks of age, respectively. This analysis highlights the benefits of supplementing rabbit diets with Zinc EDTA, demonstrating improved growth performance and feed efficiency (Figure 1). Both Zinc EDTA and ZnO treatments show a higher final weight and gain weight compared to the control group. This suggests that zinc supplementation has a positive impact on the weight gain of the animals.

Dietary zinc supplementation, particularly in the form of organic zinc, can significantly enhance the growth performance of rabbits under heat-stress conditions. This improvement may attribute to the antioxidant properties of zinc and its role in enhancing immune function. In El-Sawy *et al.* (2017) study, growing rabbits received a dietary supplement with 100 mg of zinc per one kg diet during the warm season. The findings demonstrated substantial elevations in final body weight and weight gain relative to the control group. Research conducted by Meshreky *et al.* (2015) shown that zinc methionine at a dosage of 200 mg/kg diet markedly enhanced growth performance and nutrient digestibility in comparison to zinc sulfate. Abdel Hakeam *et al.* (2023) demonstrated that supplementation with chelated organic zinc amino acids enhanced average body weight, weight increase, and the digestibility of crude protein and other nutrients. It additionally improved slaughter weight, hot carcass weight, and antioxidant levels.

Table 3. Growth performance traits of growing male NZW rabbits as affected by dietary diary zinc sources supplementation# from 5-13 weeks of age

Parameters	Experimental groups			Sig.
	Control	Zinc EDTA	ZnO	
Body weight, g				
5 weeks (Initial)	621.1±4.23	630.0±5.59	628.8±3.51	NS
9 weeks	1233.7^{c}±7.92	1459.2^{a}±7.49	1384.4^{b}±12.0	**
13 weeks	1840.0^{c}±17.30	2117.7^{a}±1.13	2036.1^{b}±10.3	**
Daily weight gain, g				
5-9 weeks	21.87^{c}±0.14	29.62^{a}±0.38	26.98^{b}±0.45	**
9-13 weeks	21.66±0.35	23.52±0.85	23.27±0.48	NS
5-13 weeks	21.77^{c}±0.40	26.57^{a}±0.41	25.13^{b}±0.41	**
Relative growth rate, g				
5-9 weeks	66.06^{b}±1.93	79.38^{a}±1.50	75.06^{a}±2.02	**
9-13 weeks	39.45±0.35	36.82±1.15	38.11±0.83	NS
5-13 weeks	99.55^{b}±1.61	108.29^{a}±1.32	105.62^{ab}±1.79	*
Daily feed intake, g				
5-9 weeks	85.00±1.40	89.33±1.09	85.00±2.58	NS
9-13 weeks	107.0^{a}±0.37	97.33^{b}±1.83	109.11^{a}±0.84	**
5-13 weeks	96.11^{ab}±0.77	93.33^{b}±1.15	97.00^{a}±1.14	**
Feed conversion, g feed/ g gain				
5-9 weeks	3.89^{a}±0.07	3.02^{b}±0.06	3.15^{b}±0.09	**
9-13 weeks	4.94^{a}±0.09	4.14^{b}±0.16	4.60^{a}±0.07	**
5-13 weeks	4.42^{a}±0.06	3.52^{c}±0.06	3.82^{b}±0.05	**
Protein efficiency ratio (g gain /g protein)				
5-9 weeks	1.390^{b}±0.03	1.790^{a}±0.03	1.718^{a}±0.04	**
9-13 weeks	1.090^{b}±0.02	1.304^{a}±0.04	1.151^{b}±0.01	**
5-13 weeks	1.222^{c}±0.02	1.535^{a}±0.02	1.397^{b}±0.02	**

Means in a row different superscripts differ significantly (P≤0.5), NS=Not significant, * P< 0.05, ** P< 0.01

Supplemented zinc dose was 50 mg/ kg diet for both sources of Zinc EDTA and ZnO.

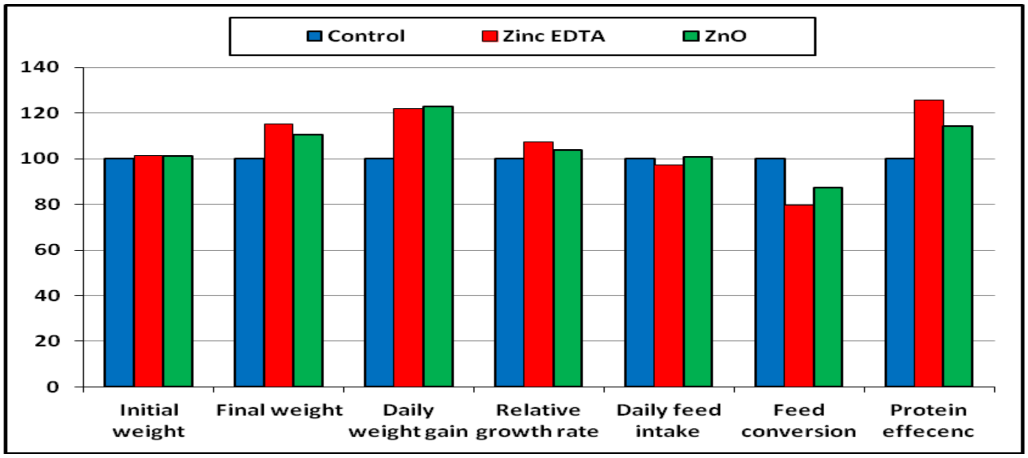

Figure 1. Growth performance index of male NZW rabbits as affected by dietary diary zinc source supplementation when considering the control values as 100%,

Supplemented zinc dose was 50 mg/ kg diet for both sources of Zinc EDTA and ZnO.

Feed efficiency:

At 9-13 and 5-13 weeks of age, control group and ZnO group had the highest feed intake, followed by Zinc EDTA group, with highly significant differences (P<0.01). Zinc EDTA group had the most efficient feed conversion ratio, followed by ZnO and control, with highly significant differences (P<0.01) during the all-experimental periods. The same tend was observed respect protein efficiency ratio. The Zinc EDTA group showed the highest protein efficiency ratio, followed by ZnO and control, with highly significant differences (P<0.01) as shown in Table 3 and Figure 1.

Zinc supplementation improved feed conversion ratios, meaning rabbits converted feed into body mass more efficiently. This was observed with both inorganic and organic forms of zinc. Zinc supplementation also enhanced the digestibility of nutrients. Rabbits fed diets with zinc had better digestibility coefficients for various nutrients, including sodium, potassium, iron, manganese, and zinc itself (Meshreky *et al.*, 2015). El-Sawy *et al.* (2017) reported that heat stress can negatively affect rabbits by reducing feed efficiency, feed intake, and causing disturbances in water metabolism, mineral, energy, and protein balances. Zinc supplementation helps mitigate these effects by enhancing antioxidant capacity and improving immune responses.

Biochemical blood parameters

Table 4 illustrated the impact of dietary zinc source supplementation on diverse blood parameters (with in normal range) in developing rabbits. Zinc

Table 4. Blood parameters with in normal range of growing male NZW rabbits as affected by dietary diary zinc source supplementation# at 13 weeks of age

Parameters	Experimental groups			Sig.
	Control	Zinc EDTA	ZnO	
Total protein (g/dl)	5.92^c±0.03	6.71^a±6.72	6.37^b±0.02	**
Albumin (g/dl)	3.71±0.01	3.72±0.25	3.69±3.69	NS
Globulin	2.20±0.05	2.99±0.34	2.67±0.08	NS
Cholesterol (mg/dl)	107.35±1.71	105.12±0.43	106.03±0.91	NS
Triglyceride (mg/dl)	153.68±6.65	141.25±2.95	148.80±4.49	NS
ALT (U/L)	42.48^a±3.03	31.42^b±3.30	32.0^b±0.59	*
AST (U/L)	24.29^a±0.61	21.48^b±0.35	23.03^a±0.04	**
Urea (mg/dl)	32.84^a±0.41	29.05^b±0.23	29.54^b±0.34	**
Creatinine (mg/dl)	0.87±0.05	0.72±0.04	0.86±0.02	NS

Means in a row different superscripts differ significantly (P≤0.5), NS=Not significant,
* P< 0.05, ** P< 0.01.

Supplemented zinc dose was 50 mg/ kg diet for both sources of Zinc EDTA and ZnO.

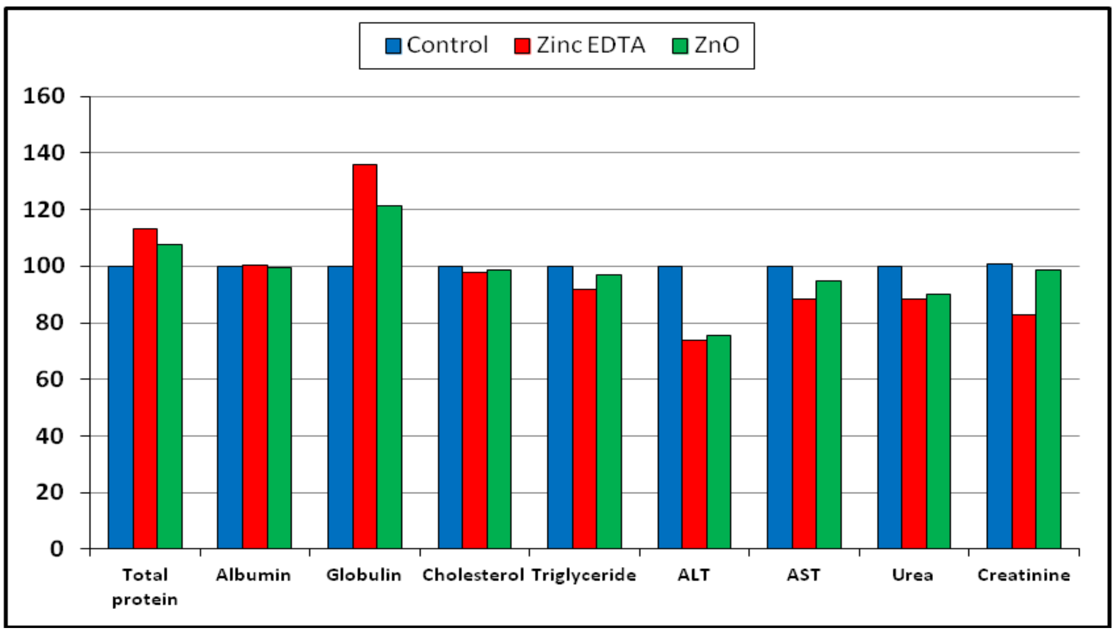

Figure 2. Blood components index of male NZW rabbits as affected by dietary diary zinc source supplementation when considering the control values as 100%.

Supplemented zinc dose was 50 mg/ kg diet for both sources of Zinc EDTA and ZnO.

EDTA supplementation markedly elevated serum total protein levels relative to the control group ($P<0.01$). Zinc EDTA and ZnO supplementations markedly decreased serum ALT levels in comparison to the control group ($P<0.05$). Zinc EDTA supplementation markedly decreased serum AST levels comparing to the control group ($P<0.01$). Supplementation with Zinc EDTA or ZnO markedly decreased serum urea levels in comparison to the control group ($P<0.01$). No significant difference was observed in albumin, globulin, cholesterol, triglyceride and creatinine levels among the all groups. These findings suggest that Zinc EDTA supplementation has a more pronounced effect on total protein, indicating potential benefits for protein metabolism and immune response. Zinc EDTA and ZnO supplementations appear to be more effective in improving liver function, as indicated by the lower ALT levels (Figure 2).

These results suggest that zinc supplementation, particularly with Zinc EDTA, can positively affect several blood parameters in growing rabbits, potentially indicating improved metabolic health and liver function. Our findings regarding zinc's role align with those of Ahmed *et al.* (2020), who showed that rabbits administered Nano-zinc oxide experienced notable enhancements in serum ALT, AST, urea, and creatinine levels. Boiko *et al.* (2020) found that weaning rabbits consuming different levels of zinc citrate improved total protein content and liver enzyme activity in the blood, and the most significant effect was observed in total protein levels and the activity of ALT and alkaline phosphatase enzymes in animals that ingested the lowest amount of zinc citrate. Zeweil *et al.* (2017) reported that zinc supplementation can increase blood plasma total protein and albumin concentrations. This is indicative of improved nutritional status and liver function. Also, zinc supplementation has been found to reduce the levels of liver enzymes of ALT and AST. This suggests improved liver health and reduced liver damage. Zinc supplementation can also affect kidney function markers such as urea and creatinine. Studies have shown that zinc supplementation can reduce urea levels, indicating better kidney function. Zinc supplementation positively impacts various blood components in growing rabbits, enhancing their overall health and immune response.

Physiological indicators:

Table 5 presented effects of dietary zinc source supplementation on physiological indicators in growing rabbits. No significant difference was observed in rectal temperature and pulse rate among the tested groups. On the other hand, zinc EDTA and ZnO supplementation significantly increased the respiration rate compared to the Control group ($P<0.01$).

Table 5. Physiological indicators of growing male NZW rabbits as affected by dietary diary zinc source supplementation# at 9 weeks of age.

Parameters	Experimental groups			Sig. test
	Control	Zinc EDTA	ZnO	
Rectal temperature(C^0)	37.94±0.38	37.38±0.14	37.24±0.09	NS
Respiration rate	98.40^b±1.08	110.8^a±1.4	110.0^a±0.71	**
Pulse rate	109.2±0.86	110.8±1.77	111.2±1.46	NS

Means in row different superscripts differ significantly (P≤0.5),
NS=Not significant, ** P< 0.01.
# Supplemented zinc dose was 50 mg/ kg diet for both sources of Zinc EDTA and ZnO.

The pulse rate refers to the frequency of aggressive behaviors or pulling among rabbits. While there is limited specific research directly linking zinc supplementation to pulse rate, zinc is known to play a role in improving overall health and reducing stress, which could indirectly influence aggressive behaviors (El-Gindy *et al.*, 2023). El-Kholy *et al.* (2020) reported that zinc supplementation has been shown to help alleviate heat stress in rabbits. For instance, a study on New Zealand White rabbit bucks found that dietary zinc supplementation reduced heat stress-related increases in rectal temperature. All forms of zinc (zinc sulphate, zinc picolinate, and zinc methionine) helped in maintaining lower rectal temperatures under heat stress conditions. Also, Abdel-Waretha *et al.* (2024) indicated that zinc supplementation can positively impact the respiration rate of rabbits. A study involving zinc oxide nanoparticles showed that dietary supplementation with this mineral improved the respiration rate among growing rabbits. The rabbits that received zinc oxide nanoparticles had lower respiration rates compared to the control group.

Slaughter test:

Table 6 illustrates the impact of dietary zinc source supplementation (Zinc EDTA and ZnO) on weights of internal organs and carcass components of male NZW growing rabbits. No significant differences in slaughter weight were observed among Zinc EDTA, ZnO and the control groups.

Additionally, results showed that dietary zinc supplementation, including Zinc EDTA and ZnO, significantly enhanced carcass weight and carcass percentage defined as carcass weight relative to slaughter weight, as well as intermediate part and hind part weights in growing rabbits as compare to control group. While, no significant differences were observed in liver, kidney, head and fore part weights across all the tested groups. However, previous study of Elsisi *et al.*, (2017) reported that zinc supplementation can

Table 6. Internal organs weight and carcass parts of growing male NZW rabbits as affected by dietary zinc source supplementation# at 13weeks of age

Parameters	Experimental groups			Sig.	LW-*Sig*
	Control	Zinc EDTA	ZnO		
Slaughter weight (g)	1865±46.27	1974±82.42	2017±26.90	NS	----
Carcass weight (g)	1021^{b}±12.01	1216^{a}±51.34	1251^{a}±15.89	**	**
Carcass weight (%)	54.75^{b}±0.87	61.60^{a}±0.06	62.02^{a}±0.25	**	----
Liver weight (g)	61.88±7.88	53.76±6.30	55.96±5.01	NS	NS
Kidneys weight (g)	15.07±1.71	16.10±0.60	15.92±1.68	NS	NS
Head weight (g)	120.0±1.15	115.3±1.20	117.0±3.51	NS	NS
Fore part weight (g)	244.3^{b}±7.44	275.0^{a}±7.63	276.3^{a}±2.96	NS	NS
Intermediate part weight (g)	250.0^{b}±8.66	315.0^{a}±10.40	306.6^{a}±6.01	**	NS
Hind part weight (g)	328.3^{b}±8.82	438.3±^{a}30.59	476.6^{a}±11.66	**	**

Means in the same row within each classification with different superscripts letters differ significantly (P≤0.5).

NS=Not significant, * P< 0.05, ** P< 0.01, Sig.: Significance, LW-*Sig*= life body weight significance.

Supplemented zinc dose was 50 mg/ kg diet for both sources of Zinc EDTA and ZnO.

improve carcass percentage and weights and internal of various organs (liver, kidney, heart and lungs), and such effects can vary depending on protein level in the used diet.

Economic efficiency:

Dietary zinc supplementation, whether through Zinc EDTA or ZnO, groups improves the economic efficiency of growing rabbits by increasing total gain and return of gain while reducing feed intake and its cost. Zinc EDTA demonstrated a marginally greater advantage regarding feed efficiency and profit margin (Table 7 and Figure 3).

The feed cost for the Zinc EDTA group was marginally lower than that of the control and ZnO groups. Conversely, both the Zinc EDTA and ZnO groups exhibited a greater return on total gain relative to the control group. The profit margin for both Zinc EDTA and ZnO groups was higher than that of the control group, with Zinc EDTA exhibiting the highest margin. However, previous results of Helal *et al.* (2018) found that dietary zinc supplementation caused increasing in feed costs, but resulted in higher income from weight gain per rabbit, and improved the final margins.

Table 7. Profit analysis of growing male NZW rabbits as affected by dietary zinc source supplementation

Parameters	Experimental groups		
	Control	Zinc EDTA	ZnO
Total gain (g)	1219.12	1487.92	1499.68
Total feed intake (g)	5382.16	5226.48	5432.00
Cost of 1kg of feed	17.00	17.095	17.090
Total feed cost (EGP /rabbit)	91.50	89.35	92.86
Revenue from weight gain (EGP/ rabbit)	109.72	133.91	134.97
Profit margin (EGP/rabbit)	18.22	44.56	42.11

Cost of 1kg of feed (control group) was set at 17 Egyptian pounds (EGP), while cost of 1kg of Zinc EDTA was190 EGP, Cost of 1kg of ZnO was 180EGP, respectively
The market price of one kilogram of live rabbit body weight was 90 EGP.

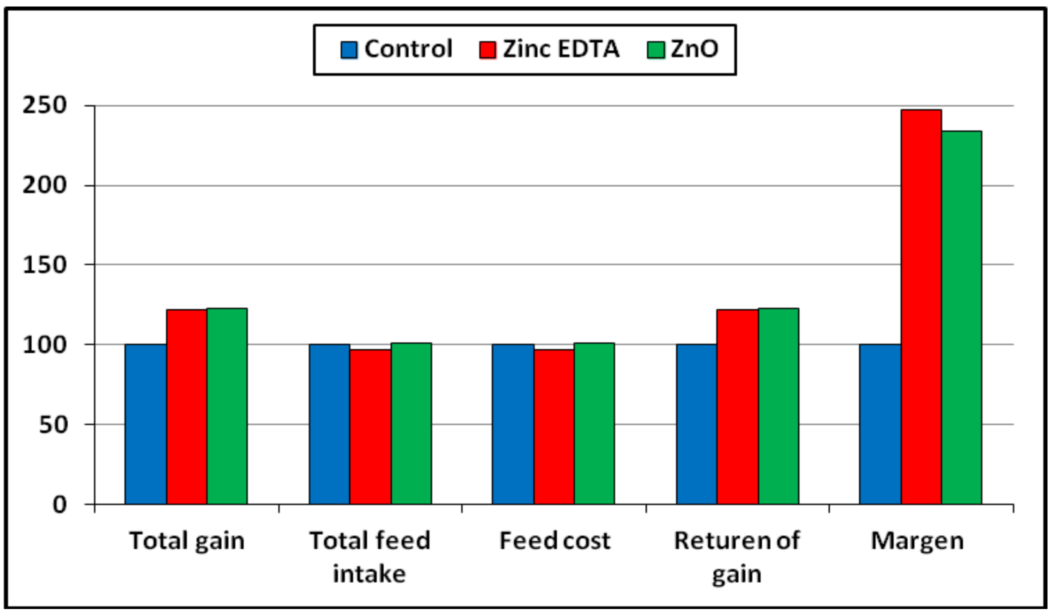

Figure 3. Profit analysis index of growing male NZW rabbits as affected by dietary diary zinc source supplementation when considering the control values as 100%.
[#] Supplemented zinc dose was 50 mg/ kg diet for both sources of Zinc EDTA and ZnO.

Conclusively, dietary zinc supplementation has been shown to enhance the growth performance of growing male NZW rabbits under Egyptian heat stress conditions. This study demonstrates that dietary zinc supplementation enhances body weight gain, final body weight, and feed conversion ratio.

Zinc supplementation also enhances the rabbits' antioxidant capacity and immune response. In summary, zinc supplementation helps rabbits cope better with heat stress, leading to improve growth performance and health outcomes.

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تأثير إضافة الزنك العضوي وغير العضوي إلى الغذاء لتقليل التأثيرات السلبية للإجهاد الحراري على نمو ذكور الأرانب النيوزلندية البيضاء

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يشكل الإجهاد الحراري تحديًا كبيرًا في إنتاج الأرانب، حيث يؤثر سلبًا على النمو وكفاءة التغذية والصحة العامة. تهدف هذه الدراسة إلى تقييم تأثير إضافة الزنك العضوي (زنك-إديتا) والزنك غير العضوي (أكسيد الزنك) في العلف على النمو وكفاءة التغذية والمعايير الدموية والمؤشرات الفسيولوجية وخصائص الذبيحة لذكور الأرانب النيوزلندية البيضاء النامية تحت ظروف الإجهاد الحراري المصرية. تم توزيع ثلاثين أرنبًا ذكراً مفطومًا من سلالة النيوزيلندى البيضاء عشوائيًا على ثلاث مجموعات: مجموعة كنترول، مجموعة زنك-إديتا (٥٠ مجم/كجم علف)، ومجموعة أكسيد الزنك (٥٠ مجم/كجم علف).

أظهرت النتائج أن إضافة الزنك للعلف أدت إلى زيادات معنوية في زيادة الوزن، وزيادة الوزن اليومية، ومعدل النمو النسبي في مجموعتي زنك-إديتا وأكسيد الزنك مقارنة بمجموعة الكنترول .كما كانت مجموعة زنك-إديتا الأكثر كفاءة في التحول الغذائى ومعدل كفاءة البروتين . كما تأثرت قياسات الدم بشكل معنوى بإضافة الزنك: حيث زادت مستويات البروتين الكلي في السيرم في مجموعة زنك-إديتا ، بينما انخفضت مستويات ALTو AST واليوريا في السيرم بشكل معنوي فى كل من مجموعتى زنك-إديتا وأكسيد الزنك .أما بالنسبة لخصائص الذبيحة، فقد أظهرت مجموعتا زنك-إديتا وأكسيد الزنك زيادة معنوية في وزن الذبيحة ونسبة التصافي مقارنة بمجموعة الكنترول . كما تحسنت الكفاءة الاقتصادية، أظهرت مجموعتا زنك-إديتا وأكسيد الزنك تحقيق أعلى عائد من المكاسب وأعلى هامش ربح مقارنة بمجموعة الكنترول، وكان هامش الربح الأعلى في مجموعة زنك-إديتا.

التوصية: توصي هذه الدراسة باستخدام الزنك العضوي (زنك-إديتا) في علائق الأرانب النامية لتحسين أداء النمو، كفاءة التحويل الغذائي، الصحة العامة، والنتائج الاقتصادية لذكور الأرانب النيوزلندية البيضاء المعرضة لظروف الإجهاد الحراري.