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EFFECTS OF SELENIUM AND ZINC SUPPLEMENTATION ON THE GROWTH, BLOOD PARAMETERS, AND CARCASS TRAITS OF GROWING RABBITS RAISED UNDER SUMMER EGYPTIAN CONDITIONS

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ABSTRACT: This study aimed to evaluate the impact of dietary zinc (Zn) and selenium (Se) supplementation on the growth, blood parameters, antioxidant levels, immune response, and carcass traits of rabbits under summer heat stress in Egypt. Thirty male New Zealand White rabbits, aged 35 days with an average weight of 637.96 ± 15.70 g, were divided into three groups: a control group, a zinc-supplemented group (50.0 mg/kg diet), and a selenium-supplemented group (0.3 mg/kg diet). The results revealed that Zn supplementation led to significant improvements in feed intake, body weight, and feed conversion ratio compared to Se supplementation and the control. Both Zn and Se supplementation increased serum total protein, albumin, superoxide dismutase (SOD), glutathione peroxidase (GPx), lysozyme, and immunoglobulin A (IgA), while decreasing total cholesterol, triglycerides, low-density lipoprotein (LDL), very low-density lipoprotein (VLDL), urea, creatinine, and MDA. However, no significant differences were observed in all hematological parameters, blood contents of high-density lipoprotein (HDL), alanine aminotransferase (ALT), aspartate aminotransferase (AST), or immunoglobulin G (IgG), as well as carcass traits among the experimental groups. In conclusion, supplementing rabbit diets with Se (0.3 mg/kg diet) or Zn (50 mg/kg diet) could ameliorate the adverse effects of heat stress on rabbit growth and health in hot climates of the summer season in Egypt.

Key words: Blood biochemistry, Carcass traits, Growth, Rabbits, Selenium, Zinc.

INTRODUCTION

In recent years, climate change has emerged as a significant stressor confronting the rabbit business, particularly in tropical and subtropical countries during the summer months (**Nardone *et al.*, 2010; Jawhar *et al.*, 2024**). The summer in Egypt is characterized by high ambient temperatures from May to October and high relative humidity (**Habeeb, 2019**). Rabbits exhibit heightened sensitivity to heat stress during this period compared to other farm animal species due to their limited sweat glands and fur-covered bodies, which complicate heat dissipation. This issue is particularly pronounced in open production systems, the predominant farming method in Egypt (**Ebeid *et al.*, 2023**). Therefore, heat stress caused by high ambient temperatures in summer can elevate body temperatures. Furthermore, it can decrease feed intake, disturb mineral balances, enzymatic activities, hormonal secretion, and anti-oxidative properties, leading to impaired immunity (**Goma and Phillips, 2021**). Thus, heat stress presents a considerable challenge to the economic viability of the rabbit industry, particularly in the context of global warming (**Ayyat *et al.*, 2018; Liang *et al.*, 2022**).

Rabbits use various techniques to reduce the negative effects of heat stress, such as decreased feed intake, increased water consumption, modulation of thyroid gland function, and changes in behavior (**El Saidy *et al.*, 2016; Ezzat *et al.*, 2019**). Minimizing the detrimental effects of heat stress on rabbits requires a

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comprehensive approach emphasizing animal nutrition. Implementing nutritional strategies is crucial for mitigating the adverse consequences of heat stress in rabbits (**Al-Sagheer *et al.*, 2017; Liang *et al.*, 2022**). Several studies have shown that modifying the diet of rabbits can help them deal with heat stress. For instance, adding selenium and zinc as feed supplements can increase the rabbits' ability to manage inflammation caused by exposure to hot conditions (**Sheiha *et al.*, 2020; Hassan *et al.*, 2021**).

Feed additives like trace minerals are crucial for optimal animal growth and development (**López-Alonso, 2012**). They also play a vital role in supporting animals' antioxidant systems and immunity responses, especially during heat stress (**Palomares, 2022**). Zinc (Zn) is an essential trace mineral that is supplemented in rabbit diets and contributes to several biological processes (**El-Moghazy *et al.*, 2019**), including normal growth, bone development, biosynthesis of nucleic acids, activity and structure of many enzymes, function of the immune system, and resistance to infection (**Chrastinová *et al.*, 2018; Abd El-Hack *et al.*, 2018**). Furthermore, it plays a critical role in intestinal health by metabolizing carbohydrates, lipids, and proteins, leading to improved feed efficiency (**Sahin *et al.*, 2009**). Additionally, Zn functions as an antioxidant by preventing the oxidation of macromolecules, including DNA and proteins, and by mitigating inflammatory responses during heat stress (**Hassan *et al.*, 2021**).

Selenium (Se) is one of the important trace minerals for farm animals. It is essential for numerous biological and physiological functions (**Lochi *et al.*, 2023**). Studies have revealed that supplementing rabbit diets with Se enhances growth performance, carcass characteristics, antioxidant status, and immune response during the summer season in growing rabbits. It is therefore, important to ensure that rabbits receive an adequate amount of selenium in their diet to support their antioxidant and immune functions (**Ayyat *et al.* 2018; Abu Hafsa *et al.*, 2024**). Thus, the present study aims to investigate the potential effects of zinc and selenium dietary supplements in experimental diets on growth performance, feed efficiency, blood parameters, and carcass traits during the summer season under heat stress.

MATERIALS AND METHODS

Animals and Experimental Design

This work was performed at the Rabbit Research Farm and laboratories of the Animal Production Department, Faculty of Agriculture, Zagazig University, Zagazig, Egypt, from July to September 2023. This study aimed to assess the impact of zinc and selenium on growth performance, feed efficiency, hematological parameters, blood biochemistry, antioxidant levels, immunological indices, and carcass characteristics of New Zealand White (NZW) growing rabbits under hot climatic conditions throughout the summer in Egypt. Thirty male NZW rabbits, aged 35 days and with comparable initial live body weights (637.96 $\pm$15.70), were utilized for a duration of eight weeks. The rabbits were randomly assigned to three groups, each comprising 10 replicates, with two rabbits per replicate (cage). The experimental groups consisted of: (1) a basal diet without zinc and selenium addition, (2) a basal diet supplemented with zinc at 50.0 mg/kg, and (3) a basal diet supplemented with selenium at 0.3 mg/kg. Zinc oxide was supplied by El-Nasr Pharmaceutical Chemicals Company (Gesr El Suez, Cairo, Egypt), while selenium selenite was procured from Chemajet Company (Borg El-Arab, Alexandria, Egypt). The trial was conducted in accordance with the ethical guidelines established by the Animal Use in Research Committee (ZU-IACUC) at Zagazig University (Approval Number: ZU-IACUC/2/F/67/2019).

Animal Management

Animals were raised under conditions with artificial lighting and natural ventilation. The light-dark cycle was set at 12 hours of light followed by 12 hours of darkness during the experimental period. All animals were acclimatized for one week before starting the experiment and fed on the control diet without additives until the start of the trial. The rabbits were housed two rabbits in stainless steel cages (galvanized wire, $35 \times 50 \times 40$ cm) equipped with automatic nipple drinkers and feeders. Urine and feces were removed from the floor each morning. Fresh water and diets were supplied and replenished daily at 9:00 am and 3:00 pm. The experimental pelleted diets were formulated to meet the nutrient requirements for growing rabbits as outlined by **NRC (1977)**. The chemical analysis and formulation of the basal diet provided to rabbits are presented in Table 1. Each feed additive was mixed with one kilogram of diet prior to final pelleting.

Temperature Humidity Index (THI)

Indoor ambient temperature (ºC) and relative humidity (%) values were recorded daily in the morning (9.00 A.M) and afternoon (2.00 P.M). The averages are shown in Table 2. The calculation of temperature-humidity index (THI) values was performed utilizing the equation modified by **Marai *et al.* (2001)** as follows:

$$\mathrm{THI} = \mathrm{db}\,^{\circ}\mathrm{C} - [(0.31 - 0.31\,\mathrm{RH})(\mathrm{db}\,^{\circ}\mathrm{C} - 14.4)].$$

Where, db°C is dry bulb temperature in Celsius degrees, and RH is the relative humidity as a percentage. The calculated THI values were subsequently classified as <27.8= absence of heat stress, 27.8–28.9°C = moderate heat stress, 28.9–30°C = severe heat stress and above 30°C and more = very severe heat stress.

Body Weight and Daily Weight Gain

Live body weight (LBW) was individually mewsured at the start of the growth trial and then every week in grams in the morning at a fixed time before being given access to feed and water; the average daily weight gain (DWG) was calculated individually.

Feed Intake and Feed Conversion Ratio Calculation

The amount of feed intake (FI) was measured weekly by calculating the difference between the initial weight of the provided feed and the final weight of the residual feed after each week. The feed conversion ratio (FCR) was calculated according to the follows:

$$\text{Feed conversion ratio (FCR)} = \frac{\text{(feed intake)}}{\text{body weight gain}}$$

Carcass Characteristics

At the end of the growth experimental period, four rabbits from each group were selected at random. Rabbits were subjected to a 12-hour fasting period prior to slaughter and were individually weighed to determine pre-slaughter weight. Rabbits were euthanized by severing the jugular veins in the neck. After complete bleeding, the carcasses were processed by removing the skin, paws, genital organs, feet, urinary bladder, and digestive tract.

According to **Blasco *et al.* (1993)**, the carcasses and some parts of the carcass (head, kidneys, liver, heart, lungs, fat, and other edible parts) were weighed. The weight of carcass parts was recorded and expressed in grams/kg live weight before slaughter. Then, the carcass was cut into three parts (front, middle, and back parts), and their weights were also recorded based on live pre-slaughtering weight. The dressing percentage was calculated by dividing the carcass weight by the pre-slaughter weight and expressing it as a percentage.

$$\text{Dressing perecentage} = \frac{\text{(carcass weight)} \times 100}{\text{(live body weight)}}$$

Blood Samples

Following the trial's feeding period, blood samples were obtained from four rabbits at the time of slaughtering to assess blood variables. Two blood specimens were obtained from each slaughtered rabbit. Two milliliters of blood were collected in an EDTA tube for hematological assessment. A 10 ml secondary sample was collected in a glass tube (without EDTA) and allowed to coagulate at room temperature for 20 minutes. The sample was subsequently centrifuged at 1500×g in a cooled centrifuge (BOECO centrifuge C-28 A, Hamburg, Germany) for 10 minutes, and the resulting serum was stored at -20°C until utilized in the biochemical analyses detailed below.

Hematological Parameters

Whole blood samples were utilized directly to assess hematological parameters including hemoglobin (Hb), red blood cells (RBCs), platelet count (PLT), mean corpuscular volume (MCV), hematocrit (Hct), mean corpuscular hemoglobin concentration (MCHC), mean corpuscular hemoglobin (MCH), and white blood cells (WBCs). Measurements were obtained utilizing a Hema screen 18 automated hematology analyzer (Hospitex Diagnostics, Sesto Fiorentino, Italy) in accordance with the procedure outlined by **Conrado (2022)**.

Table 1. Formulation and chemical analysis of the experimental basal diet for growing rabbits

Ingredients	(%)
Soybean meal	10
Yellow corn	8
Barley	12
Wheat bran	30
Alfalfa hay	35
Molasses	3
Dicalcium phosphate	1
Sodium chloride salt	0.5
Vitamin and mineral premix*	0.5
Chemical analysis:	
Crude protein %	15.87
Crude fiber %	15.04
Digestible energy MJ/kg***	10.401

- **Each kilogram contains:** Vit. A 12000 IU, Vit. D3 2200, Vit. E 10.0 mg, Vit. K 2.0 mg, Vit. B1 4.0 mg, Vit. B2 1.5 mg, Vit. B5 6.3 mg, Vit.6 1.7 mg, Vit. B12 0.03 mg, Biotin 3.3 mg, Folic acid 0.83 mg, Cholin 200 mg, Zn 11.79 mg, Mn 5.00 mg, Fe 12.5 mg, I 0.33 mg, Se 0.65 mg and Mg 66.79 mg.

Table 2. Effect of dietary supplementation with zinc and selenium on the growth performance of New Zealand White rabbits exposed to heat stress conditions

Parameters	**Experimental groups**			**Significance**
	Control	**Zn**	**Se**	
Body weight (g)				
Initial weight	638.30±11.40	636.80±21.70	632.78±14.00	NS
4 weeks	1152.10^{b}±13.55	1218.50^{a}±23.86	1130.44^{b}±18.69	**
8 weeks	1725.30^{b}±21.71	1858.00^{a}±22.50	1748.67^{b}±25.09	***
Daily weight gain (g / rabbit)				
0-4 weeks	18.35^{b}±0.45	20.77^{a}±0.72	17.77^{b}±0.81	**
4-8 weeks	20.47^{b}±0.53	22.84^{a}± 0.48	22.08^{a}±0.58	*
0-8 weeks	19.41^{b}±0.30	21.81^{a}±0.39	19.93^{b}±0.43	***
Daily feed intake (g / rabbit)				
0-4 weeks	51.18^{b}±0.88	57.25^{a}±0.69	51.02^{b}±0.55	***
4-8 weeks	104.75^{b}±0.63	123.08^{a}±1.22	106.76^{b}±0.55	***
0-8 weeks	77.96^{b}±0.56	90.16^{a}±0.94	78.89^{b}±0.53	***
Feed conversion (g feed / g gain)				
0-4 weeks	2.80±0.08	2.78±0.09	2.92±0.14	NS
4-8 weeks	5.15^{ab}±0.13	5.41^{a}±0.14	4.86^{b}±0.12	*
0-8 weeks	4.03±0.07	4.15±0.08	3.97±0.08	NS

- [a,b] Means of each column followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

- NS indicate not significant - * indicate significance at $P \leq 0.05$ - ** indicate high significance at $P \leq 0.01$.

Blood Biochemical Parameters

The serum albumin (ALB), total protein (TP), aspartate aminotransferase (AST), alanine aminotransferase (ALT), triglycerides (TG), total cholesterol (TC), low density lipoprotein (LDL), high density lipoprotein (HDL), very low density lipoprotein (VLDL), creatinine, and urea were measured colorimetrically using commercial kits (Diamond Diagnostic, Dokki, Giza, Egypt) in accordance with the guidelines provided by the manufacturer. Globulin levels determined by subtracting albumin from total protein.

Antioxidants and Immunological Assays

Immunoglobulin's (IgA and IgG) were measured using on the method described by **Akiba *et al.* (1982)**. The activities of antioxidants parameters were measured including: superoxide dismutase (SOD), malondialdehyde (MDA), glutathione peroxidase (GPx), and lysozyme (LZM) were estimated in serum samples using commercial kit (Bio Diagnostic Company, Giza, Egypt) according to the instructions provided by the manufacture.

Statistical Analysis

Data analysis was done by one-way ANOVA using the general linear model procedure (**SAS, 2002**) with dietary trace minerals (Se and Zn) as fixed factors. Model (1) was used; $Y_{ij} = \mu + Mi + \varepsilon_{ij}$, where Y_{ijk} = the dependent variable, μ= the overall mean, Mi = the fixed effect of supplementation, and ε_{ij} = the overall error term. The data of carcass characteristics were statistically analyzed considering pre-slaughter weight as a covariate variable based on Model (2) as follows: $Y_{ij} = \mu + Mi + b(X-x) + \varepsilon_{ij}$, where Mi, and ε_{ij} are defined in Model (1), and b(X−x) is the covariate variable. Tests of significance for differences among treatments were done according to **Duncan (1955)**.

RESULTS AND DISCUSSION

Temperature Humidity Index (THI)

During the current experiment, the recorded daily ambient temperature fluctuated between 29.00°C and 38.00°C, with an average of 33.86°C. The relative humidity varied from 56% to 81%, with an average of 69.58%. As a result, the calculated values of THI ranged from 27.60 to 36.24, with an overall THI of 32.01, indicating that the rabbits were exposed to severe heat stress (**Marai *et al.*, 2001**).

Growth Performance

Table 2 shows the effects of zinc and selenium supplementation on the growth performance of growing NZW rabbits under heat stress conditions. The findings indicate that rabbits receiving zinc-supplemented diet showed a significant increase in body weight and body weight gain (BWG) at both 4 weeks ($P < 0.01$) and 8 weeks ($P<0.001$) of the experimental period. Compared to those of selenium-supplemented or control diets. Additionally, both Zn and Se supplementation significantly ($P<0.05$) increased BWG in the 4-8 weeks compared to the control group. Rabbits fed a zinc-supplemented diet had a significantly higher ($P<0.001$) feed intake (FI) throughout the experiment period compared to those of selenium-supplemented or control diets. Rabbits supplemented with either Zn or Se had a significantly higher ($P < 0.05$) feed conversion ratio (FCR) during weeks 4-8 compared to the control group. However, Zn or Se supplementation did not significantly affect the FCR during the 0-4 week or 0-8 week periods in growing NZW rabbits.

These findings of the current study align with those of Abdel **Hakeam *et al.* (2023)**, who reported that the addition of Zn to the diets of weaned V-line rabbits resulted in increased weight gain, final body weight, FI, and FCR compared to the control group. Similarly, dietary supplementation with Zn or Se has been shown to significantly increase the body weight and FI of rabbits under heat stress (**Yan *et al.*, 2017; Kamel *et al.*, 2020**). Furthermore, **Ebeid *et al.* (2012)** observed that Se supplementation significantly improved body weight and BWG in growing rabbits compared to the control group. In the same line, **Al-Sagheer *et al.* (2020)** reported that a diet supplemented with 100 mg Zn/kg improved both body weight and FCR in growing NZW male rabbits over an 8-week period. **Zeweil *et al.* (2016)** reported that adding different sources of Se to rabbit diets significantly enhanced FCR. The significant improvement in growth performance observed in the current study may be related to the vital role of Zn and Se for good biological functions for animal growth, and physiological activities (**Marai *et al.*, 2003; Bao *et al.* 2007**). Also, Zinc and selenium are crucial for several biological functions in rabbits, including the regulation of RNA and DNA, cell division, and gene expression (**Prasad, 1991**). These trace minerals also influence the structure and activity of various enzymes, which in turn enhance the antioxidant and immune system functions in animals (**Zhao *et al.*, 2014**). Additionally, Zn and Se are vital for protein synthesis as well as carbohydrate and lipid metabolism (**Chrastinová *et al.*, 2015**). Zinc, in particular, plays a key role in maintaining the structure of metalloproteins, including growth factor, growth hormone, and insulin (**Midilli *et al.*, 2014**).

Blood Biochemical Hematological Parameters

Hematological traits are important parameters for evaluating the health and physiological status of rabbits (**Etim *et al.*, 2013**). The results revealed that supplementing the diets of weaned NZW rabbits with Zn and Se did not lead to significant changes in blood hematological parameters by the end of the experimental period (Table 3). This suggests that the supplemental levels of Zn and Se used in the study maintained normal hematopoietic function in the rabbits.

Table 4 presents the biochemical results of heat stressed NZW rabbits as affected by Zn and Se supplementation. Both Zn and Se significantly elevated total protein and albumin levels compared to the control group. However, no significant changes in serum globulin levels or the albumin/ globulin ratio in rabbits treated with either Zn or Se by the end of the trial period. The current findings align with those of **Khan *et al.* (2023)**, who reported that broiler chicks receiving Se supplementation exhibited increased total protein and globulin levels. Similarly, **Fawzy *et al.* (2016)** found that adding Zn and Se to the diets of broiler chicks led to higher total protein and albumin levels. **Ayyat *et al.* (2018)** also noted that dietary Se supplementation for growing rabbits in the summer significantly enhanced total protein and globulin. On the other hand, **El-Moustafa *et al.* (2024)** discovered that various forms of Se supplementation in rabbit diets did not significantly impact globulin or the albumin/globulin ratio. Likewise, **Kamel *et al.* (2020)** reported that ZnO supplementation in the diets of growing APRI rabbits under heat stress did not significantly alter globulin levels or the albumin/globulin ratio.

In addition, the data in Table 4 indicate that rabbits receiving Zn or Se supplementation had a significant ($p<0.01$) decrease in total cholesterol, triglycerides, LDL, and VLDL levels compared to the control group. However, neither Zn nor Se supplementation significantly affected HDL levels in growing NZW rabbits. These results are consistent with findings from **Tag-El Din (2019),** who reported reduced triglycerides and total cholesterol levels in rabbits fed diets supplemented with 30 mg of Nano-Zn and 0.1 mg of Nano-Se/kg diet compared to control diets. Similarly, **Saleh *et al.* (2018)** found that supplementing broiler chicken diets with Zn at high ambient temperatures led to decreased total cholesterol, triglycerides, and LDL cholesterol, while HDL levels remained unchanged. The reduction in total cholesterol, triglycerides, and LDL cholesterol in rabbits on zinc-supplemented diets may be linked to zinc's role in enzyme activity. Zinc is a critical component of various metalloenzymes involved in fat digestion and absorption, which may inhibit lipolysis in adipose tissue and subsequently reduce the release of free fatty acids into the bloodstream. This process can limit the availability of fatty acids to the liver and help prevent excessive lipoprotein synthesis (**Dick *et al.*, 2005; Al-Daraji and Amin, 2011**). Additionally, both Zn and Se play important roles in maintaining the structural integrity of proteins and combating oxidative stress in rabbits. Their antioxidant properties may reduce lipid oxidation in the bloodstream, contributing to lower blood lipid levels. Furthermore, the anti-inflammatory properties of zinc and selenium may help mitigate dyslipidemia, characterized by abnormal lipid levels, including elevated cholesterol and triglycerides (**Chrastinova *et al.*, 2018**).

Regarding liver and kidney function, the data in Table 4 show that rabbits receiving Zn or Se supplementation had a significant ($P<0.05$) reduction in urea levels compared to the control group. Additionally, serum creatinine levels were significantly lower ($P < 0.01$) in rabbits fed a zinc-supplemented diet compared to those fed

Table 3. Effect of dietary supplementation with zinc and selenium on hematological parameters of New Zealand White rabbits exposed to heat stress conditions

Parameters	Experimental groups			Significance
	Control	Zn	Se	
RBCs (10^6/ml)	4.58±0.40	5.06±0.22	5.00±0.14	NS
HGB (g/dl)	9.87±0.28	10.45±0.54	10.98±0.14	NS
HCT (%)	34.61±1.02	35.71±1.05	36.56±0.22	NS
MCV (fL)	77.89±9.03	71.17±4.84	73.26±2.02	NS
MCH (pg/dl)	22.20±2.53	20.91±2.01	22.01±0.86	NS
MCHC (g/dl)	28.53±0.14	29.23±0.91	30.02±0.39	NS
PLT (10^3/ml)	179.25±40.10	161.75±24.31	155.75±16.69	NS
WBCs (10^3/ml)	9.95±0.61	8.56±0.93	8.69±0.37	NS

- **RBC**s, red blood cells; **HGB**, Hemoglobin; **HCT**, hematocrit; **MCV**, Mean Corpuscular Volume; **MCH**, Mean Corpuscular Hemoglobin; **MCHC**, The mean corpuscular hemoglobin concentration; **PLT**, platelets count; **WBC**, white blood cell.
- NS indicate not significant

Table 4. Effect of dietary supplementation with zinc and selenium on serum biochemical parameters of New Zealand White rabbits exposed to heat stress conditions

Parameters	Experimental groups			Significance
	Control	Zn	Se	
Total protein (g/dl)	5.49^b±0.16	6.11^a±0.12	6.39^a±0.05	**
Albumin (AL) (g/dl)	3.01^b±0.06	3.51^a±0.16	3.67^a±0.06	*
Globulin (GL) (g/dl)	2.49±0.09	2.60±0.16	2.73±0.12	NS
AL⁄GL ratio	1.21±0.02	1.36±0.13	1.35±0.08	NS
Total cholesterol (mg/dl)	224.99^a±14.15	117.99^c±15.20	171.85^b±8.90	**
Triglycerides (mg/dl)	165.52^a±7.87	96.39^c±8.76	127.03^b±9.07	**
HDL (mg/dl)	50.23±0.60	48.92±0.68	47.41±0.98	NS
LDL (mg/dl)	141.65^a±12.95	49.79^b±16.78	99.04^a±6.42	**
VLDL (mg/dl)	33.10^a±1.57	19.27^c±1.75	25.40^b±1.81	**
Urea (mg/dl)	17.91^a±2.10	10.49^b±1.27	10.77^b±1.68	*
Creatinine (mg/dl)	0.88^a±0.07	0.45^b±0.04	0.85^a±0.07	**
ALT (u/l)	43.97±2.02	35.49±3.78	35.37±3.77	NS
AST (u/l)	31.82±3.42	31.85±1.85	28.85±0.62	NS
SOD (mmol/l)	35.62^c±3.99	153.94^a±5.37	106.04^b±9.14	***
MDA (mmol/l)	9.39^a±0.39	4.797^b±0.21	2.89^c±0.23	***
GPx (mmol/l)	45.94^b±4.68	134.66^a±14.02	99.65^a±12.25	**
LZM (u /ml)	0.68^c±0.05	5.59^a±0.28	4.06^b±0.29	***
IgG (ng/ml)	242.79±37.04	319.54±42.096	364.32±31.67	NS
IgA (ng/ml)	201.51^b±11.52	256.44^{ab}±24.65	311.85^a±12.22	*

- HDL, High density lipoprotein; LDL, Low density lipoprotein; VLDL, Very Low-density Lipoprotein; ALT, alanine aminotransferase; AST, aspartate aminotransferase; IgG, Immunoglobulin G; IgA, Immunoglobulin A; SOD, superoxide dismutase; MDA, Malondialdehyde; GPx, Glutathione peroxidase; LZM, lysozyme.
- [a,b,c] Means of each row followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.
- NS indicate not significant - * indicate significance at P < 0.05; ** indicate high significance at P < 0.01; *** indicate high significance at P <0.001.

selenium or the control diet. However, no significant differences were observed in serum ALT and AST levels among experimental group. The reductions in creatinine, urea, and enzyme activity in rabbits supplemented with Zn and Se suggest that these dietary additives positively impacted kidney and liver function, contributing to overall rabbit health (**El-Moghazy *et al.*, 2019**). Furthermore, Zn and Se are essential trace elements that play important roles in maintaining liver health-selenium enhances the function of antioxidant enzymes, while zinc supports various liver enzymes, together promoting optimal liver function and rabbit well-being.

As shown in Table 4, the results demonstrated that rabbits supplemented with Zn or Se had a significant (p<0.01) increase in SOD, GPx, and LZM levels compared to the control group. Additionally, IgA levels were significantly higher (P<0.05) in rabbits fed zinc- or selenium-supplemented diets than in the control group. In contrast, the supplementation significantly (p<0.001) reduced MDA concentrations, with the lowest levels observed in the Se group. However, Zn or Se supplementation did not significantly affect IgG levels in the rabbits. Enzymatic defense systems such as SOD, GPx, CAT, glutathione transferases, and glutathione reductase play a critical role in protecting mitochondria and DNA from oxidative stress, which helps defend against various diseases. These antioxidant enzymes neutralize free radicals, safeguarding proteins, lipids, and DNA from oxidative damage, thereby improving immune responses and potentially enhancing animal performance and productivity (**Chauhan *et al.*, 2014; Ponnampalam *et al.*, 2022**).

Carcass Characteristics

Slaughter weight and carcass weight were significantly (P < 0.05) impacted in terms of all carcass cuts, carcass weight, and dressing percentage (Table 5). However, no significant

Table 5. Dressing percentage and carcass parts of New Zealand White rabbits as affected by supplemental with zinc and selenium exposed to heat stress conditions

Parameters	Experimental groups			Sig.	LW sig.
	Control	Zn	Se		
Slaughter weight (g)	1756.25[b]±13.05	1868.75[a]±26.64	1759.50[b]±30.40	*	--
Actual carcass weight (g)	1002.25[b]±11.18	1094.50[a]±22.89	1015.25[b]±32.45	*	--
Adjusted carcass weight (g)	1037.99±8.54	1026.02±10.73	1047.99±8.39	NS	***
Dressing (%)	57.80±0.47	57.14±0.59	58.33±0.46	NS	**
		Adjusted carcass parts			
Fore part (g)	352.05±10.697	360.20±13.43	374.25±10.51	NS	*
Intermediate part (g)	219.48±6.11	187.64±7.67	195.37±6.00	*	*
Hind part (g)	354.74±6.899	378.46±8.66	367.29±6.78	NS	**
Head (g)	110.67±3.75	102.01±4.70	106.07±3.68	NS	*
		Adjusted organs parts			
Liver (g)	53.22±4.02	56.61±5.05	51.897±3.95	NS	NS
Heart (g/kg SW)	4.42±0.44	4.41±0.55	5.298±0.43	NS	NS
Kidney (g/kg SW)	9.29±0.84	10.23±1.05	11.34±0.83	NS	NS
Lunges (g/kg SW)	10.96±0.0.78	12.07±0.98	11.18±0.77	NS	NS
Testes (g/kg SW)	4.40±0.60	4.23±0.76	5.05±0.59	NS	NS
Kidney Fat (g/kg SW)	4.699±1.93	4.49±2.42	7.22±1.89	NS	NS

- [a,b] Means of each row followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

- NS indicate not significant - * indicate significance at P < 0.05; ** indicate high significance at P < 0.01; *** indicate high significance at P <0.001.

differences were observed among treatments for adjusted carcass weight, dressing percentage, or most carcass parts, except for the intermediate part weight. Additionally, Zn or Se supplementation did not significantly affect the adjusted weights of organs such as the liver, heart, kidneys, lungs, testes, or kidney fat. Similarly, **Taj El-Din (2019)** found no significant differences in carcass traits, including the relative weights of organs and edible parts, among rabbits fed nano-zinc and nano-selenium. **Downs *et al.* (2000)** also reported no differences in carcass, breast, or thigh muscle yields in broilers given selenium-enriched diets. Likewise, **Al-Sagheer *et al.* (2020)** found that dietary ZnO had no significant effect on carcass parts, dressing percentage, or organ weights in New Zealand White rabbits.

Conclusions

Based on the obtained results, it could be concluded that dietary supplementation with Zn (50 mg/kg) or Se (0.3 mg/kg) could mitigate the negative impacts of heat stress on growing rabbit performance and health. It is paramount to ensure that growing rabbits receive adequate amounts of selenium and zinc through dietary supplementation. This has positive effects on growth performance, blood biochemistry, oxidative stress, immunity, and carcass characteristics in rabbits reared under hot climatic conditions.

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تأثير إضافة السيلينيوم والزنك على النمو ومقاييس الدم وصفات الذبيحة للأرانب النامية التي تربت تحت ظروف صيف مصر

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أجريت هذة الدراسة لتقييم تأثير إضافة الزنك والسيلينيوم على النمو وبعض مكونات الدم ومستويات مضادات الأكسدة والاستجابة المناعية وخصائص الذبيحة للأرانب تحت تأثير الإجهاد الحرارى في الصيف في جمهورية مصر العربية. تم إستخدام 30 ذكر من أرانب النيوزيلاندي الأبيض، عمر 35 يومًا بمتوسط وزن حوالي 637.96±15.70جم، قسمت إلى ثلاث مجموعات: مجموعة مقارنة ومجموعة غذيت علي عليقة مضاف لها الزنك (50.0 ملجم / كجم من العليقة) ومجموعة غذيت علي عليقة مضاف لها السيلينيوم (0.3 ملجم / كجم من العليقة). أظهرت النتائج أن إضافة الزنك أدت إلى زيادة معنوية في كمية العلف المأكول، وزن الجسم، معدل تحويل الغذاء مقارنة بإضافة السيلينيوم ومجموعة المقارنة. أدى إضافة كلاً من الزنك والسيلينيوم إلى زيادة البروتين الكلي، الألبيومين، فوق أكسيد الديسموتيز (SOD)، الجلوتاثيون بيروكسيديز (GPx)، الليزوزيم، الجلوبيولين المناعي A (IgA)، بينما إنخفض الكوليسترول الكلي، الدهون الثلاثية، البروتين الدهني منخفض الكثافة (LDL)، البروتين الدهني منخفض الكثافة جداً (VLDL)، اليوريا، الكرياتينين، المالون داي الديهايد (MDA). ومع ذلك، لم يلاحظ أي تأثير معنوي علي جميع مكونات الدم، محتوى الدم من البروتين الدهني عالي الكثافة (LDL)، الإنزيم الناقل للأسبارتات (AST)، الإنزيم الإنزيم الناقل للألانين(ALT)، الجلوبيولين المناعي G (IgG)، وكذلك صفات الذبيحة بين المجموعات التجريبية. والخلاصة، فإن إضافة السيلينيوم (0.3 ملجم/كجم من العليقة) أو الزنك (50 ملجم/كجم من العليقة) إلى علائق الأرانب النامية يمكن أن يخفف من الآثار السلبية للإجهاد الحراري على نمو الأرانب وصحتها في المناخ الحار في موسم الصيف في جمهورية مصر العربية.

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