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IMPROVING PRODUCTIVE PERFORMANCE AND IMMUNITY RESPONSE OF BROILER CHICKS BY DIETARY ADDIITION OF NANO ZINC AND SPIRULINA

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ABSTRACT: To investigate the effects of nano-oxide zinc (ZnO NPs), spirulina platensis (SP), and their combination on broiler chickens' growth, carcass traits, blood biochemistry, and redox status. A total of 270 Cobb broiler chicks that were one-day-old were allocated into nine equal groups at random. The first group was given a basal diet and functioned as a control group. The other groups were given the basal diet supplemented ZnONPs with 30 or 60 mg/kg diet (groups 2 and 3) or SP with 2 or 4 g/kg diet (groups 4 and 5), and their combination (groups 6 to 9). Results showed that supplementation with ZnONPs and SP, individually or combined improved daily body weight gain (BWG) and live body weight (LBW). This increase in LBW was associated with reduced feed consumption (FC), leading to an improved feed conversion ratio (FCR). The best outcomes were observed with the higher dose of ZnO NPs (60 mg/kg) or its combination with 4 g/kg SP. High doses of ZnONPs and SP significantly ($P \leq 0.05$) reduced abdominal fat and increased relative carcass weight. ZnONPs also improved hemoglobin content and red blood cell count. No significant differences were found in plasma total protein, albumin, globulin, or glucose levels, but liver enzyme activities (AST and ALT) significantly ($P \geq 0.01$) decreased. Plasma total lipids and triglycerides decreased slightly with ZnONPs or SP supplementation. The activity of the antioxidant enzymes total antioxidant capacity (TAC), glutathione peroxidase (GSH-Px), superoxide dismutase (SOD), and catalase (CAT) were increased, while malondialdehyde (MDA) levels showed a slight decrease. serum immunoglobulins (IgA, IgM, IgG, IgD, and IgE) were boosted in treated groups, with significant increases ($P \leq 0.05$) in IgG, IgD, and IgE with the ZnONPs + SP groups. In conclusion, ZnONPs, SP, and their combination enhanced broiler performance, blood biochemical balance, and antioxidant status, with the best results achieved at 60 mg ZnONPs combined with the two studied levels of SP.

Key words: Nano-oxide zinc, spirulina platensis, carcass traits, serum parameters, redox status

INTRODUCTION

As a result of the rapid development in modern broiler chicken breeds, intensive commercial poultry production has introduced numerous challenges and stresses for birds, such as environmental stress, nutritional imbalances, overcrowding from high stocking densities, and frequent disease outbreaks (Abd El-Hack et al., 2020;Abdel-Moneim et al., 2020; Attia et al., 2024). Antibiotics have been used as growth enhancers in chicken feed for more than 60 years without a prescription (Castanon, 2007; Abd El-Hack and Alagawany, 2022). The widespread use of synthetic antimicrobials in poultry diets caused the growth of drug-resistant microbes, affecting human and bird health (Abd El-Hack et al., 2020). As antibiotic bans increase, research is exploring natural alternatives to antibiotics to enhance growth performance, boost immunity, gut health, and decrease oxidative stress (Omar et al., 2022; Abd El-Hack and Alagawany, 2022; Arain et al., 2022; Saeed et al., 2023; El-Kholy et al., 2024).

Spirulina platensis (SP), a filamentous cyanobacterium, is known for its health benefits, therapeutic properties, and various biological activities without adverse effects on performance (Ross and Dominy, 1985). It is considered a concentrated food source of nutraceuticals, antioxidants, and probiotics (Abdel-Daim et al., 2018). Spirulina platensis (SP) is a highly nutrient-dense food that contains important fatty acids, especially gamma-linolenic acid (18%), 15–25% carbs, and 55–70% proteins. Additionally, it is rich in phenolic acids, minerals, vitamins, carotenoids, chlorophyll-a, and phycobiliprotein pigments "phycocyanin, phycoerythrin, and allophycocyanin" (Mariey et al., 2012). Moreover, it is packed with a diverse array of bioactive compounds, including phenolic compounds, polysaccharides, carotenoids, chlorophyll, phycocyanin, and essential minerals and vitamins (Amer, 2018; Farag et al., 2016). Furthermore, spirulina has several health benefits, such as growth parameters, immune stimulation, and hypolipidemic, anti-inflammatory, and antioxidant properties (Deng and Chow, 2010; Hoseini et al., 2013; El-Ratel et al., 2023). The nutritional value of Spirulina platensis (SP), particularly its high quantities of proteins and necessary amino and fatty acids, may be responsible for its pharmacological and therapeutic qualities, according to Abdel-Moneim et al. (2022). Other SP components such as thiamin, riboflavin, ascorbic acid, cobalamin, pyridoxine, and carotenoids are used widely to enhance broilers' flesh quality and its impact on yolk characteristics (Ross and Dominy 1990). Spirulina platensis (SP) has been shown in several studies to enhance carcass yield, daily weight gain, and feed conversion ratios (FCR) when added to broiler diets (Kharde et al., 2012; Kaoud, 2015). Feeding trials with livestock have shown that Spirulina platensis (SP) increase growth rate, egg quality, carcass quality, disease resistance, and strengthens the immune system in poultry, pigs, and rabbits (Sujatha and Narahari, 2011; Evans et al., 2015; Dheeba et al., 2016). Additionally, Alwaleed et al. (2021) and Abdel-Moneim et al. (2022) reported that including 5 or 10 g/kg of SP in the diet can enhance growth performance, parameters of serum biochemistry, and intestinal microbiota in broiler chickens.

The NRC (1994) estimated that the zinc requirement in broilers is 40 ppm, but in field operations, poultry breeders have been adding 100–120 parts per millions of zinc to commercial broiler diets to increase performance (Feng et al. 2010). However, the high levels of zinc residues in the excreta have had a negative impact on the environment (Leeson and Caston 2008). The nanoparticle mineral displays unique physical properties, such as numerous surface-active centers, an extensive specific surface area, great catalytic efficiency, and an excellent adsorption capacity (Wijnhoven et al. 2009). Recently, trace minerals, including zinc, have been commercially produced in nanoparticle form to leverage their enhanced bioavailability and greater efficacy than each organic and inorganic forms (Swain et al., 2015; Gopi et al., 2017). Zinc oxide nanoparticles (ZnONPs) are gaining popularity as an alternative feed supplement for poultry due to their antibacterial and immunostimulant properties, which affect their metabolic activity and overall health (Sagar et al., 2018; Akhavan-

Salamat and Ghasemi, 2019). Many researchers have demonstrated that ZnONPs outperform conventional zinc sources in broiler performance, including production, antioxidant status, and intestinal health, even at the same or lower doses (Zhao et al., 2014; Mohammadi et al., 2015; El-Katcha et al., 2017). Previous research has indicated that ZnONPs as feed additives can enhance meat quality, feed conversion ratio, body weight gain, and egg production (Hafez et al., 2017; El-Katcha et al., 2017; Akhavan-Salamat and Ghasemi, 2019; Fawaz et al., 2019). Adding zinc oxide nanoparticles (ZnONPs) to chicken feed lowered malondialdehyde (MDA) levels while increasing the activity of the enzymes catalase and superoxide dismutase (SOD), according to Hafez et al. (2020). They also observed a significant increase in IgY production compared to inorganic ZnO. They concluded that dietary inclusion of up to 80 mg/kg of ZnONPs is safe for broilers, improving antioxidant defense and cellular immunity. Similarly, Akhavan-Salamat and Ghasemi (2019) found that ZnONP supplementation enhanced growth performance, antioxidant responses, and immunity in commercial broilers exposed to cyclic heat stress conditions.

The objective of this study was to examine the effects of adding zinc oxide nanoparticles (ZnONPs) and Spirulina platensis (SP) or their combination in broiler chickens' diets on growth performance, blood biochemical constituents, immune responses and redox status.

MATERIAL AND METHODS

The experimental procedures were approved and undertaken in accordance with the guidelines of the experimental animal care committee ethics of Matrouh University, Egypt.

Experimental design, birds, and diets

The present study was carried out in the poultry experimental unit of the Faculty of Desert and Environmental Agriculture, Matrouh University during the winter season of 2022.

Experimental design:

A total of 270 one-day old of Cobb broiler chicks (Cobb 400 strain) were divided into nine groups and placed 10 chicks per pen with three pens per treatment (30 chicks per treatment). All experimental groups have commenced with a nearly similar an initial live body weight (LBW) which ranged between (328.03 - 331.03 g) and standard error ranged between (4.06- 7.53) with insignificant differences. The experimental treatments were as follows: The 1st group received a basal diet and acted as a control group (C). The 2nd to 9th groups received a basal diet supplemented with ZnO NPs (at levels 30 and 60 mg /kg diet) or SP (at levels 2 and 4 g/kg diet/kg diet) and their combination as shown in Table 1.

Birds, housing management and environment:

Chicks were reared on floor pens in a controlled environmental house under standard management practices with 23:1 light: dark cycle. The environmental temperature was about 32± 2 °C during the first week old and it was gradually reduced by about 2º C weekly until riched 24º C at the fourth week and kept it up to the end of experimental period, and the relative humidity (RH) was 55-60 %. Feed and water were provided *ad libitum* throughout the experimental period (from 1- 38 day of age). Chicks were reared together from day 1st to day 10th and received a pre-starter ration 23% protein and 2900 kcal / kg feed), then at day 11th till day 38th as an experimental period, chicks were distributed to 9 experimental groups and received a growing ration 21.5% protein and 3000 kcal/kg feed supplemented with tested materials. Experimental rations were formulated to be isocaloric–isonitogenus (Table 2). Chicks were vaccinated against Newcastle disease on day 5 and day 28, and on day 14, chicks were vaccinated with Gumboro vaccine against infectious bursal disease.

Source of tested materials:

Zinc nanoparticles were prepared by the company of Nano Tech Egypt for photo-Electronics. Communication center in front of the international school of choueifat, El-wahaat Road, Dream land city, Entrance 3 city of October, Al Giza Egypt. Tests: Size & shape: TEM were performed on JEOL JEM-2100 high resolution transmission electron microscope at an accelerating voltage of 200 kV, respectively. Properties: color: white, form: powder, Solubility: dispersed in water and suspension in

ethanol / Methanol, size (TEM): 30± 5 nm, Shape (TEM): spherical like shape. Spirulina platinsis was growing and prepared in The National Institute of Oceanography and Fisheries, Alexandria, Egypt and the bioactive ingredient in SP are shown in Table 3.

Data collected:

Live body weight (BW) was recorded weekly per each treatment group (as g for each bird) and body weight gain (BWG) was calculated (as g for each bird). Feed consumption (FC) (as g) and feed conversion ratio (FCR) (as g feed intake /g body weight gain) were recorded for each replicate of each treatment. Mortality rate of chicks (MR%) was recorded and determined weekly throughout the experimental period.

Slaughtering traits:

At the end of the experimental period, five birds from each treated group were randomly chosen, fasted overnight and individually weighted. Birds of each treatment were slaughtered by cutting the carotid artery and jugular vein of the neck. After complete bleeding was achieved, the feathers were plucked and then carcasses were eviscerated, then hot carcass and their livers, spleens, kidneys, pancreases and intestine were rapidly weighed separately to the nearest 0.1g. In addition, adrenal, thyroid, bursa, and thymus glands were removed and weighed separately to the nearest 0.1g. The carcasses, organs, and glands weight were measured as relative to live body weight.

Blood hematological and biochemical parameters:

While slaughtering, blood samples were collected from each treatment into dry clean anticoagulant tube. A part of blood samples was diluted 200 times with a physiological saline (0.9% NaCl solution) for counting red blood cells (RBCs, $\times 10^6$) on an Ao bright-line hemocytometer using a light microscope at 400x magnification. The white blood cells (WBCs$\times 10^3$) were counted on an AO Bright line hemocytometer using a light microscope at 100X magnification after diluting blood samples 20 times with a diluting fluid (1% acetic acid solution with a little of Leishman's stain), and their fractions (lymphocyte, neutrophils, monocytes, eosinophils and basophil percentages) were determined according to Altan et al. (2000). Hemoglobin (Hb, mg/dl) was determined by the method of Coles (1986). The reminder of blood samples was centrifuged at 3500 rpm for 20 min to obtain plasma that stored at -20°C. Plasma total proteins (TP, g/dl) concentration was measured by the Biuret method according to Henry et al. (1974), whereas albumin (Alb, g/dl) concentrations was determined by the method of Doumas et al. (1971), and globulin (Glb, g/dl) concentration was determined by subtracting albumin from total protein. Total lipids (TL, g/dl) were measured according to Fringes et al. (1972), while total cholesterol (TC, mg/dl), high-density lipoprotein-cholesterol (HDL-c, mg/dl) and low-density lipoprotein-cholesterol (LDL-c, mg/dl) were determined according to the method of Richmond (1973) and triglycerides (TrGl, mg/dl) was measured according to Sugiura et al., (1977). As well as liver enzymes activities (aspartate aminotransferase (AST, U/l) and alanine aminotransferase (ALT, U/l)) were determined by the method of Reitman and Frankel (1957) using specific kit (Diamond Diagnostic Company, USA). Plasma glucose concentration was estimated according to Trinder (1969) using the instructions of specific kit (Diamond Diagnostic Company, USA). Total antioxidant capacity (TAC, µmol/ml) was measured according to Erel (2004). The antioxidant enzymes such as glutathione peroxidase (GPx, µmol/ml) activity, superoxide dismutase activity (SOD, U/ml) and catalase (U/ml) activity were determined according to Chiu et al. (1976), Misra and Fridovich (1972) and Tome et al., (2001) respectively. Lipid peroxidation biomarkers such as malondialdehyde (MDA, µmol/ml) was assayed in the blood plasma according to Tappel and Zalkin (1959). Different types of immunoglobulins (IgG, IgM, and IgA) in blood serum were determined using commercial ELISA kits (Kamiya Biomedical Company, USA)

Statistical analysis:

Data were statistically analyzed according to SPSS 26.0 (2019) program using General Linear Model (GLM) procedure.

Mean differences (mean ±S.E.) were tested by Duncan's (1955) New Multiple Range test at ($P \leq 0.05$).

The model used is:

$Y_{ij} = \mu + T_i + e_{ij}$

Where:

Y_{ij}=Observed value in the treatment.

μ=Overall mean.

T_i=Treatment effect (i=1to 9).

e_{ij}= Residual error.

RESULTS

It is worth mentioning that all tested groups have commenced with a nearly similar initial LBW which ranged between 328.03 and 331.03 g with insignificant differences. This confirms that the randomization process is appropriate for assessing dietary treatments' impact on the broilers' performance in this experiment.

From the results shown in Table 4, the application of Duncan's test shows that including ZnONPs, SP, or their combination in broiler rations led to an increase ($P \geq 0.01$) in final LBW compared to the control group. This increase was statistically significant with the high dose of ZnONPs (60 mg/kg feed), as well as the groups fed the mixture of ZnONPs + SP except for the group that received the low dose of ZnONPs + SP. Likewise, the data of BWG showed, there was an increase ($P \geq 0.01$) in total BWG at the end of experimental period due to include ZnONPs and SP separately or their mixture in chick broilers' rations compared to the control group with preference for using the high dose of ZnONPs (60 mg/kg feed) or its combination with the high dose of SP (4 g/kg feed) that showed a significant effect on this measurement. Daily FC was decreased ($P \geq 0.01$) due to the addition of ZnONPs or SP and their mixture in the broilers' rations compared to the control group. This decrease was significant ($P \geq 0.01$) for the two doses of ZnONPs or their mixture with the low dose of SP (2 g/kg feed). The increase in daily BWG and decrease in daily feed consumption were reflected on the FCR results, as increasing body weight with decreasing FC in the ZnONPs and SP groups, as well as, their mixture led to a significant improvement ($P \geq 0.05$) in FCR compared to the control group. Generally, our results showed that there is an advantage of using ZnONPs and SP separately or in a combination in broiler chicks' diets on increasing LBW and daily BWG.

The data in Table 5 clearly shows the results of relative carcass weight due to feed chicks on different levels of ZnONPs, SP and their mixture. All tested groups showed significantly higher relative carcass weight ($P \geq 0.05$) compared to the control group; however, this increase was statistically significant ($P \geq 0.05$) with the high doses of ZnONPs, SP, or their combination, except for the group that received 30 mg ZnONPs + 2 g SP. Relative Abdominal fat weight revealed a nonsignificant decrease due to inclusion ZnONPs or SP and their mixture in broiler chick's rations as compared to the control, Furthermore, the mixture of ZnONPs and SP had a greater effect on reducing abdominal fat than either one alone. From Table (5) data of the relative liver, intestine and spleen weight and intestine length showed that adding ZnONPs at a low or high dose to chick diets or their mixture with SP resulted in an increase in these three measurements compared to the groups that received diets containing SP alone, which was higher than the control group, but these differences were nonsignificant. The inclusion of ZnONPs or SP at any tested dose in chick diets increased the relative weight of the pancreas compared to the control group, with a preference for SP alone or its combination with ZnONPs. Also, in Table 5 it could be noticed that there was a nonsignificant improvement in relative weight of thyroid, adrenal, thymus and fabricius glands as a result of including ZnONPs or SP alone in the chicks' diets compared to the control group. This effect was dose-dependent, with the improvement being more pronounced in the groups that received SP or its combination with ZnONPs, compared to those that received ZnONPs alone.

Separate inclusion of ZnONPs in growing broiler rations (Table 6) increased all tested groups showed significantly higher relative carcass weight ($P \geq 0.05$) compared to the control group RBCs and Hb in compared to the control group. The addition of ZnONPs had statistically

significant effect (P≥ 0.01) on Hb content only, while, SP supplementation and their mixture with ZnONPs had a moderate effect on these measurements. On the other hand, the WBCs did not differ among treatment groups due to the addition of ZnONPs, SP and their mixture to broiler diets.

Changes in plasma TP, Alb, Glb, glucose concentrations, and liver enzyme activities (AST and ALT) due to the inclusion of ZnONPs and SP, either separately or in combination, in broiler chicks' diets are presented in Table 7. Putting broiler chicks on rations containing different levels of ZnONPs, SP and their mixture did not affect plasma total protein, albumin, globulin and glucose concentrations, whereas, the results revealed no significant differences between treatment groups and control group regarding these parameters. The data of AST and ALT showed there was a reduction in AST and ALT activities of treatment groups in compared to the control group, but this decrease was significant with ALT only. The data in Table 7 confirmed that there were no significant differences between the treatment groups regarding plasma total lipids, triglycerides, and cholesterol levels as a result of feeding broiler chick diets containing different levels of ZnONPs, SP, or their mixture. On the other hand, a slight dose-dependent decrease in plasma total lipid and triglyceride concentrations was observed in the groups treated with ZnONPs or SP separately, compared to the control group. However, this effect was absent in the groups that received the ZnONPs + SP mixture diet. Plasma cholesterol, LDL and HDL cholesterol concentration in treated groups did not differ than the control group, in spite of the HDL was tendency decreased due to inclusion tested material (ZnONPs, SP and their mixture) in broilers diet especially the ZnONPs 60mg+ SP 4gm treatment.

Inclusion ZnONPs or SP with different studied levels in broiler chicks' diet resulted in an increase significaly (P ≥ 0.05) in TAC (Table 8) and this increase was significant with ZnONPs and its mixture with SP only. Otherwise, there was a slightly decrease in MDA concentration in groups fed ration containing ZnONPs, SP or their mixture especially the two groups fed ZnONPs 60mg+ 2 or 4mg SP. The inclusion of ZnONPs, SP, and their mixture at the studied levels in the chicks' diets enhanced the activity of antioxidant enzymes (GSH-Px, SOD, Catalase). There was an increase in the activity of these enzymes compared to the control group, with the increase being statistically significant for GSH-Px and Catalase enzymes only. Serum immunoglobulins (IgA, IgM, IgG, IgD, and IgE) were elevated in chicks fed diets supplemented with ZnONPs, SP, or their mixture. This effect was particularly significant in the ZnONPs+SP mixture groups, with notable increases in IgG, IgD, and IgE levels.

DISCUSSION

Zinc is an important member of the essential minerals group, playing a key role in the regulation of bird biology. According to Jarosz et al. (2017) and Torres and Korver (2018), Zinc is an essential component of more than 300 metalloenzymes, which are enzymes involved in the metabolism of proteins. Additionally, ZnONPs have an impact on the genes for growth hormone and insulin-like growth factor, leading to improved metabolism in broilers (Ibrahim et al., 2017). From previous studies, zinc deficiency leads to decreased appetite, growth inhibition and skin abnormalities (Petrovic et al., 2010) so zinc is regularly added to animal rations to meet functional requirements (Swain et al., 2016). On the other side, SP is considered a food source of nutraceuticals, antioxidants, and probiotics (Abdel-Daim et al. 2018), In addition, it is rich in phycobiliprotein pigments, phenolic acids, minerals, vitamins, proteins, carbs, and vital fatty acids (Mariey et al., 2012). There have also been reports of numerous therapeutic potentials and medicinal qualities (Mendiola et al., 2007), including immunity stimulation, growth promotion, and hypolipidemic, anti-inflammatory, and antioxidative activities (Deng et al., 2010; Hoseini et al., 2013). The improved performance indexes that were obtained in our results due to adding different levels of ZONPs or SP and their combination were in accordance with that of Zhao et al. (2014), found that ZnONPs at 20 and 60 mg/kg enhanced BWG and

FCR compared to 60 mg/kg ZnO. However, levels higher than 60 mg/kg (specifically 100 mg/kg ZnONPs) may have a toxic effect, inhibiting broiler growth and negatively impacting BWG and FCR. Fawaz et al. (2019) also observed that ZnONPs improved the performance and health of laying hens. According to Hafez et al. (2020), broiler BWG and FCR significantly increased when 40 and 80 mg/kg ZnONPs were added to the diet, while feed intake (FI) did not significantly differ. In the same context, the level above 60 mg/kg ZnONPs reduced FI and FCR (Kumari et al. 2019). Similarly, Akhavan-Salamata and Ghasemi (2019), found that both organic and nanoparticle forms of zinc enhance growth performance and immune response in broilers under heat stress. The improved performance indices observed in our results may be attributed to the inclusion of ZnONPs in broiler diets, which can enhance mineral deposition due to their superior bioavailability than inorganic sources (Ibrahim et al., 2017). Furthermore, ZnONPs play a role in enhancing intestinal absorptive capacity by increasing mucosal length as well as villi width and length (Hafez et al., 2017). Additionally, Spirulina's beneficial effects on growth performance may be attributed to the physiological roles of its bioactive ingredients, which include phenolic compounds, carotenoids, vitamins, minerals, and other components (Agustini et al., 2015). Previous studies have shown that including 1 or 2 g/kg of spirulina to diets that contain both vegetable and animal protein enhances Japanese quail growth performance without compromising the quality of the meat or the gut flora of the birds fed diets primarily on vegetable protein. But with diets based on animal protein, no such effect was seen (Yusuf et al., 2016). In the current study, the dietary supplementation with different levels of SP resulted in a nonsignificant improvement in LBW, BWG, and FCR in broilers. However, Hajati and Zaghari (2019) reported that SP at 3 and 5 g/kg feed significantly increased BWG and production efficiency in Japanese quails. This improvement may be attributed to the nutrient composition and physiological roles of spirulina, which could positively influence the metabolic systems of broilers (Park et al., 2018). Adding 1% Spirulina platensis to broiler rations raised villi height, which improved the broiler intestines' ability to absorb nutrients, according to Shanmugapriya et al. (2015). Additionally, Kaoud (2015) discovered that LBW and BWG were significantly increased by the dietary Spirulina platensis supplementation. This significant influence might be due to improving the feed utilization efficiency. Alaqil and Abbas (2023) found that the broilers supplemented with SP expressed a significant resistance to the reduction in their performance when challenged by E. coli infection, thus, this improvement could be attributed to the contribution of SP to increase the high-quality protein content of the diets. The beneficial effects of SP's components on feed utilization and nutrient absorption may be the cause of the enhanced growth performance of birds fed these supplements. In contrast, spirulina is a complete protein that contains all of the essential amino acids and has a sufficient amount of metabolisable energy (Tavernari et al., 2018; Alwaleed et al., 2021). Additionally, the protein found in spirulina has highly digestible amino acids.

The addition of ZnONPs, SP, or their combination to broilers' diets positively affected the eviscerated carcass yield. This increase was significant with 60 mg/kg ZnONPs alone or in combination with SP compared to the control group. On the other hand, the inclusion of ZnONPs, SP, or their mixture in broiler rations did not have a significant effect on the relative weight of organs, which slightly increased compared to the control, especially in ZONPs+SP mixture groups. From our results, it could be noticed that there was a correlation between decreased relative weight of abdominal fat deposit tissues and the nonsignificant decrease of blood total lipids and triglycerides. This result was in line with earlier studies that shown that at doses ranging from 40 to 90 ppm, dietary ZONPs significantly raised dressing %, carcass production, and carcass weight (Lina et al., 2009; ElKatcha et al., 2017; Khah et al., 2015). Increased zinc residue in tissue, zinc's impact on

antioxidant status, and oxidative enzymes, particularly the muscle's antioxidant activity, could all be contributing factors to the changes in carcass features (Liu et al. 2011; Selim et al. 2014; Zhao et al. 2014; Fathi et al. 2016; Ramiah et al. 2019). Another study by Mohammadi et al. (2015) suggested that dietary ZnO-NPs at 80 mg/kg significantly improved carcass yield and increased the relative weight of the digestive and lymphoid organs in broilers. Moreover, Mohammadi et al. (2015) found that dietary ZnO-NPs at 80 mg/kg raised the relative weight of the broiler's lymphoid and digestive organs and significantly increased carcass yield. Furthermore, ZnONPs raised ($P<0.05$) the relative weight of immunological organs (spleen, bursa, and thymus), according to Ahmadi et al. (2013) and Sagar et al. (2018). This could be explained by ZnONPs' antibacterial qualities, which might lower the impact of the pathogenic microbes and enhance gut health (Sahoo et al., 2014). These findings agree with those of Ahmadi et al. (2013), Mohammadi et al. (2015), and ElKatcha et al. (2017). According to several research, feeding Spirulina (SP) increased the carcass percentage in Japanese quails (Hajati and Zaghari, 2019) and broiler chicks (Raju et al., 2004; Kaoud, 2012; Mariey et al., 2014). Furthermore, it was shown that SP supplementation increased the carcass % in broiler chicks by Kaoud (2015), Mariey et al. (2012), and Jamil et al. (2015). However, Sugiharto et al. (2018) found no association between SP and broiler carcass characteristics, regardless of feeding duration. The study by Ibrahim et al. (2018) showed that adding 0.5, 1, and 2 g/L of spirulina to broiler drinking water for four weeks significantly increased carcass and internal organ weights while decreasing abdominal fat. This finding is consistent with our results and can be explained by the medicinal properties and therapeutic potential of spirulina, which possess hypolipidemic effects and antioxidative activities (Deng et al., 2010; Hoseini et al., 2013). Mariey et al. (2014), there was a strong correlation between the carcass weight and the live body weight of broilers. In current study, the greater final live body weight of the broilers was linked to higher carcass weight and total digestible components, and vice versa. The enhanced growth performance of supplemented birds may be the reason for Abdel-Moneim et al.'s (2022) demonstration of the beneficial impact of dietary spirulina (SP) on carcass yield and dressing %. This improvement is associated with improved protein synthesis and amino acid nutrition digestibility (Evans et al., 2015). The findings of Abdel-Moneim et al. (2022), who demonstrated that dietary supplementation with a combination of SP and SeNPs enhanced the relative weight of the thymus and spleen compared to the control diet, are consistent with the rise in immune organs in the SP groups of our investigation. Furthermore, SP may enhance heat-stressed broiler chickens' immunological responses, including their anti-inflammatory and antioxidant properties.

Blood hematological measurements are good indicator of animal health and physiological status. Our results indicated that blood haematological parameters (Hb, RBC, and WBC) were positively impacted by the addition of ZnONPs to the broiler diet, however there were no significant differences in these parameters when SP supplementation was applied in comparison to the control group. Regarding ZnONPs supplements, our results contradict the finding of Reda et al. (2021) revealed that when growing Japanese quail were given ZnONPs supplementation, no significant differences were found in blood cell differential counts, lymphocytes, granulocytes, haemoglobin concentration, or platelet count. A small quantity of SP enhances both the humoral and cellular mechanisms of the immune system in chickens, thereby improving immune function and growth (Qureshi et al., 1996; Khan et al., 2005). Regarding the effect of SP supplements on blood hematological parameters, the present results explain that despite SP did not increase Hb, RBC, and WBC values, it did not have a negative effect on these measurements and kept them slightly above the control value. Dietary supplementation with SP increased the Hb and RBC counts in chickens fed 0.1, 0.2, and 0.3 g SP/kg diet compared to the control group. Additionally, the

0.3 g SP/kg diet level elevated the WBC count (Mariey et al., 2012). Broiler chicks supplemented with SP have been shown to have higher levels of leukocytes, Hb, and erythrocytes (Jamil et al., 2015; Lokapirnasari et al., 2016). SP is well-known for its antioxidant properties, which protect platelets, lymphocytes, and white blood cells from the harmful effects of reactive oxygen species and help in preventing RBC haemolysis (Elmalawany et al., 2014). Additionally, SP has a high iron content (90 mg/100 g), which is sufficient for the production of red blood cells (Nasirian et al., 2017). In contrast, feeding SP to broilers resulted in lower values of erythrocytes, hemoglobin, leukocytes, and lymphocytes (Sugiharto et al., 2018).

Blood biochemistry parameters serve as key indicators of a chick's physiological status. Our results demonstrated that ZnONPs and SP did not produce a disturbance in the balance of blood biochemical measurements. The present findings are in line with those of Reda et al. (2021), who discovered that supplementing with ZnONPs had no effect on plasma total protein and albumin levels. Furthermore, they noticed a positive effect on ALT and AST activity. Regarding SP treatment, the present results were in according to Mariey et al. (2012), broiler diets supplemented with SP showed slightly higher levels of blood total protein, albumin, and globulins than the control group. According to Zahir et al. (2019), adding 0.5%, 1%, and 1.5% of SP to broiler chickens' diets improved their serum levels of total proteins, albumin, total globulins, and growth hormone thyroxine hormone, but it had no effect on their glucose levels (Ruth et al., 2013). Similarly, Omar et al. (2022) found that a higher dose of SP phycocyanin supplementation resulted in a linear increase in serum levels of albumin, globulins, and total proteins. Additionally, SP phycocyanin elevated thyroxine hormone levels without affecting serum glucose.

Regarding the lipid profile, the present data showed that the blood content of total plasma lipids, total cholesterol and triglycerides tended to decrease in the groups treated with ZnONPs or SP separately, which was dose dependent, but this effect disappeared in the groups that received the ZnONPs + SP mixture diet. On the other hand, LDL cholesterol exhibited a non-significant decrease across all treated groups compared to the control group. Notably, the groups receiving the ZnONPs + SP mixture showed a slight increase in HDL levels compared to both the control group and the groups treated with either ZnONPs or SP alone. These findings are consistent with previous studies, which reported that the inclusion of ZnONPs or SP in broiler diets positively influenced the lipid profile, resulting in reduced total blood lipids, triglycerides, and total cholesterol levels compared to untreated groups. Additionally, nano zinc supplementation has been shown to lower LDL cholesterol levels in Japanese quails, while increasing HDL cholesterol (ZnONPs: Ibrahim et al., 2017; Mahmoud et al., 2020; Reda et al., 2021; SP: Ibrahim et al., 2018; Mobarez et al., 2018; Mirzaie et al., 2018; Moustafa et al., 2021; Abdel-Moneim et al., 2022; Omar et al., 2022). The observed effects of ZnONPs and SP on the lipid profile in our study may be attributed to zinc's role as an essential component of enzymes involved in lipid metabolism (Al-Daraji and Amen, 2011). Furthermore, SP has demonstrated hypocholesterolemia activity in rats, potentially due to its polyunsaturated fatty acids, which aid in reducing serum lipid levels (Hajati and Zaghari, 2019). Mariey et al. (2012) also suggested that SP supplementation in broiler diets may reduce cholesterol absorption and synthesis in the gastrointestinal tract.

Dietary supplementation with ZnONPs, SP, and their combination positively influenced total antioxidant capacity (TAC), superoxide dismutase (SOD), glutathione peroxidase (GPX), catalase (CAT), and malondialdehyde (MDA) levels. Antioxidant enzyme activities (GPX, SOD, CAT) showed a numerical increase in the treated groups compared to the untreated group, particularly in those receiving ZnONPs or its combination with SP, which was reflected in higher TAC levels. According to Yigit et al. (2014), GSH-Px and SOD are crucial components of the first line of antioxidant defense. The observed increase in antioxidant enzyme activities may be attributed to zinc’s role

as an essential component of over 300 enzymes (Jarosz et al., 2017; Torres and Korver, 2018). Zinc is a vital element of Cu-zinc-SOD, a key player in protecting cells from oxidative stress (Zago and Oteiza, 2001). Additionally, Tate et al. (1999) highlighted zinc's ability to enhance antioxidant activity by reducing free radical production. Furthermore, Bhat et al. (2000) and Khan et al. (2005) reported that SP exhibits potent antioxidant properties. Thus, our data showed a synergistic effect between ZnONPs and the active antioxidant components in SP, resulting in increased antioxidant enzyme activity in the ZnONPs+SP mixture groups compared to those that received ZnONPs and SP separately. On the other hand, the increase in TAC that occurred in the treated groups was associated with a decrease in serum MAD level resulting from lipid oxidation. Our results align with those of Hafez et al. (2020), who found that the addition of ZnONPs to chicken feed led to increased activity of SOD and CAT enzymes, along with a reduction in malondialdehyde (MDA) concentration. Similar results were reported by Akhavan-Salamata and Ghasemi (2019), who found that ZnONPs supplementation increased SOD activity and reduced MDA in commercial broiler chickens raised under cyclic heat stress conditions. Consistent with the findings of Omar et al. (2022), TAC, CAT, and SOD levels increased both linearly and quadratically, while malondialdehyde (MDA) levels decreased linearly with higher levels of SP-phycocyanin supplementation. SP effectively enhances the activity of antioxidant enzymes by scavenging free radicals and preventing lipid oxidation and DNA damage (Abdelkhaleq et al., 2015).

Because zinc is an essential part of the cell integration process, which is crucial to the immune response, the serum immunoglobulin levels in chicks treated with ZnONPs, SP, and their mixture were higher than in the untreated group (Dardenne et al., 1985). Zinc deficiency in broilers has been shown to limit the development of lymphoid organs and the maturation of T lymphocytes in the blood (Cui et al., 2004). However, supplementing a zinc-deficient diet with zinc increases poultry antibody production (Beach et al., 1980; Burns, 1983). Similarly, Hidayat et al. (2021) found that adding zinc to broiler diets improved their health by enhancing immunity. Furthermore, Spirulina is abundant in natural antioxidants such as phenolic compounds, polypeptide pigments, β-carotene, selenium, and tocopherol (Abdel-Moneim et al., 2022). Additionally, the antioxidant qualities of Spirulina platensis help reduce RBC haemolysis and protect platelets, lymphocytes, and white blood cells from harm brought on by reactive oxygen species (Elmalawany et al., 2014).

CONCLUSION

From this study, it can be concluded that dietary supplementation with ZnONPs and Spirulina (SP), either separately or in combination, has a positive effect on the physiological and immune status of broiler chickens. The supplementation enhanced antioxidant enzyme activity, improved serum immunoglobulin levels, and positively influenced the lipid profile. Additionally, the synergistic effect of ZnONPs and SP resulted in greater antioxidant activity and immune support compared to when either component was used alone. These findings highlight the potential benefits of ZnONPs and Spirulina in improving broiler health and performance, especially the dose of 60 mg ZnONPs with the two studied levels of SP.

Geolocation information:

This study was carried out at the Poultry Farm, Department of Animal and Poultry Production, Faculty of Desert and Environmental Agriculture, Matrouh University, Marsa Matrouh governorate, Egypt.

Declaration of interest statement:

The authors declare that there is no known conflict of interest associated with this publication.

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Data availability statement:

Not applicable. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Table (1): The experimental treatments design.

Treatments	Basal diet	ZnO NPs (30 mg/kg feed)	ZnO NPs (60 mg/kg feed)	SP (2 g/kg feed)	SP (4 g/kg feed)
Control (C)	+				
T1 (ZN 30)	+	+			
T2 (ZN 60)	+		+		
T3 (PS 2)	+			+	
T4 (PS 4)	+				+
T5 (ZN30+PS 2)	+	+		+	
T6 (ZN30+PS 4)	+	+			+
T7 (ZN60+PS 2)	+		+	+	
T8 (ZN60+PS 4)	+		+		+

Table (2): The composition and calculated analysis of the basal diet used throughout the experiment.

Ingredients	Starter (0 to 21 days)	Grower (22 to 38 days)
Maize	53.20	61.50
Soybean meal (44%)	35.0	29.00
Corn gluten meal (60%)	5.5	2.5
Vegetable oil	1.8	3.00
Dicalcium Phosphate (DCP)	2.0	1.60
Limestone Powder (LSP)	1.41	1.25
Salt (NaCl)	0.30	0.30
Vitamin premix[1]	0.30	0.30
D L-Methionine	0. 25	0.20
L-Lysine	0.20	0.25
Toxin binder	0.05	0.05
Coccidiostat	0.05	0.05
Choline HCl	0.15	0.15
Total	**100**	**100**
Calculated analysis		
Crude Protein (%)	23.00	21.5
Metabolizable energy (kcal/kg)	2940	3140
C/P ratio	127.82	146.04
Crude fiber (%)	3.27	
Crude fat (%)	4.35	
Calcium (%)	1.01	1.09
Lysine (%)	1.39	1.31
Methionine (%)	0.59	0.55

[1]Vitamin premix: each kg contain vit.A(12M.I.U), vit.D3 (2U.IU) ,vit E(10g),vit. K2 (1g), vit.B1 (1g),vit.B2 (4g), vit.B6(1.5g), vit. B12(10g), pantathenic acid (10g), Nicotinic acid (20g), Folic acid (100mg), Bidin (50g), Cholin chloride (500g).

Table (3): Proximate composition of Spirulina platensis

Proximate composition, g.kg DM-1	Spirulina platensis
Crude protein	565.0
Crude fat	10.5
Crude fiber	35.6
B-Carotene (vit. A), µg.kg DM-1	982.4
Riboflavin (vit. B2), µg.kg DM-1	24000
Fatty acids (FAs, %)	
Σ Saturated FAs	63.43
Σ Monounsaturated FAs	9.40
Σ Polyunsaturated FAs	26.06
Σ Unsaturated FAs	35.46
PUFAs/SFAs	0.41
UFAs/SFAs	0.56
MUFAs/PUFAs	0.36

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Table (4): Effects of dietary ZnONPs and SP supplementation on productive performance in broiler chickens

Measurement[1]	Treatments[2]									
	Control	**ZnONPs 30 mg**	**ZnONPs 60 mg**	**SP 2 gm**	**SP 4 gm**	**ZnONPs 30 mg+ SP 2 gm**	**ZnONPs 30 mg+ SP 4 gm**	**ZnONPs 60 mg+ SP 2 gm**	**ZnONPs 60 mg+ SP 4 gm**	**P-value**
IBW	328.63± 4.88	330.63± 7.02	328.03± 5.14	329.37± 6.08	328.67± 7.53	329.60± 4.88	329.50± 4.06	329.77± 5.37	331.03± 4.06	0.73
LBW	2326.50^{b}± 31.43	2596.70^{ab}± 41.83	2749.63^{a}± 38.26	2556.4^{ab}± 48.78	2549.8^{ab}± 50.659	2546.36^{ab}± 44.67	2682.80^{a}± 60.00	2686.60^{a}± 49.07	2760.30^{a}± 63.22	0.001
BWG	1997.87^{d}± 67.15	2266.07^{bc}± 41.73	2421.60^{a}± 37.87	2227.10^{cd}± 48.79	2221.13^{cd}± 50.45	2216.77^{cd}± 44.36	2353.30^{ab}± 60.18	2356.83^{abc} ±48.36	2429.27^{a}± 63.34	0.001
FI	119.78^{a}± 15.27	85.70^{b}± 6.81	90.86^{b}± 2.23	95.19^{ab}± 1.80	95.32^{ab}± 3.14	88.22^{b}± 3.25	95.85^{ab}± 2.70	92.62^{b}± 2.80	101.83^{ab}± 16.18	0.001
FCR	1.67^{a}± 0.22	1.06^{b}± 0.10	1.05^{b}± 0.12	1.19^{b}± 0.11	1.12^{b}± 0.12	1.11^{b}± 0.08	1.14^{b}± 0.10	1.10^{b}± 0.07	1.17^{b}± 0.14	0.034

Means within the same row carrying different superscripts were significantly different at $P \leq 0.05$.
1IBW: initial body weight, LBW: live body weight (g), BWG: body weight gain (g), FI: feed intake, and FCR: feed conversion ratio.
2ZnONPs: Nano-oxide zinc, SP: Spirulina platensis

Table(5): Effects of dietary ZnONPs and SP supplementation eviscerated carcass and organs relative weight in broiler chickens

Measurement	Treatments[1]									
	Control	ZnONPs 30 mg	ZnONPs 60 mg	SP 2 gm	SP 4 gm	ZnONPs 30 mg+ SP 2 gm	ZnONPs 30 mg+ SP 4 gm	ZnONPs 60 mg+ SP 2 gm	ZnONPs 60 mg+ SP 4gm	P-value
Relative carcass weight	72.20^{b}± 1.12	73.63^{ab}± 0.11	75.10^{a} ± 0.91	73.94^{ab}± 0.46	75.33^{a}± 0.21	73.46 ^{ab} ± 0.16	75.38 ^{a} ± 0.55	74.24 ^{a} ± 0.50	75.51 ^{a} ± 0.62	0.030
Abdominal fat	1.40± 0.26	1.21± 0.21	1.12± 0.19	1.15± 0.18	0.90± 0.04	0.84± 0.04	0.88± 0.15	0.83± 0.08	0.85± 0.10	0.195
Liver	1.97± 0.03	2.24± 0.07	2.23± 0.46	2.09± 0.12	2.07± 0.15	2.19± 0.08	2.20± 0.08	2.23± 0.19	2.34± 0.24	0.467
Intestinal length	183.33± 6.65	205.66± 9.13	212.66± 13.87	199.00± 13.11	198.33± 11.31	209.33± 5.69	202.33± 16.9	230.66± 18.49	240.00± 30.55	0.277
Intestinal weight	2.76± 0.14	3.18± 0.13	3.40± 0.40	2.88± 0.14	2.81± 0.01	3.64± 0.26	3.40± 0.14	3.80± 0.40	3.85± 0.46	0.071
Pancreas	0.16± 0.01	0.17± 0.01	0.18± 0.00	0.18± 0.01	0.19± 0.02	0.19± 0.01	0.22± 0.01	0.24 ± 0.00	0.22 ± 0.03	0.056
Spleen	0.10± 0.01	0.10± 0.01	0.10± 0.00	0.10± 0.01	0.11± 0.01	0.11± 0.01	0.11± 0.01	0.12± 0.00	0.12± 0.02	0.408
Thyroid gland	0.0067± 6.81	0.0081± 0.01	0.0089± 8.54	0.0113± 0.00	0.0139± 0.01	0.0105± 3.72	0.0109± 0.00	0.0119± 0.01	0.0149± 0.01	0.114
Adrenal gland	0.0057± 0.01	0.0057± 6.87	0.0065± 0.01	0.0088± 0.01	0.0095± 0.01	0.0071± 5.66	0.0074± 0.01	0.0076± 6.76	0.0084± 8.23	0.248
Fabricius	0.109± 0.02	0.131± 0.01	0.161± 0.03	0.124± 0.02	0.138± 0.04	0.136± 0.02	0.140± 0.02	0.162± 0.01	0.212± 0.01	0.156
Thymus gland	0.338± 0.07	0.375± 0.06	0.377± 0.01	0.420± 0.04	0.444± 0.02	0.408± 0.04	0.418± 0.03	0.401± 0.01	0.482± 0.02	0.140

Means within the same row carrying different superscripts were significantly different at $P \leq 0.05$. [1]ZnONPs: Nano-oxide zinc, SP: Spirulina platensis.

Table (6): Effects of dietary ZnONPs and SP supplementation on Hb content, RBCcount and WBC count in broiler chickens

Measurement1	Treatments2									
	Control	**ZnONPs 30 mg**	**ZnONPs 60 mg**	**SP 2 gm**	**SP 4 gm**	**ZnONPs 30 mg+ SP 2 gm**	**ZnONPs 30 mg+ SP 4 gm**	**ZnONPs 60 mg+ SP 2 gm**	**ZnONPs 60 mg+ SP 4 gm**	**P-value**
Hb(g/dl)	12.38^{b}± 0.200	13.44^{a}± 0.03	13.35^{a}± 0.100	12.69^{b}± 0.100	12.57^{b}± 0.17	12.45 ^{b}± 0.200	12.88 ^{ab}± 0.06	13.08 ^{ab}± 0.08	12.71 ^{ab}± 0.27	0.001
RBC(x6/mm3)	2.08± 0.05	3.07± 0.21	3.69± 0.06	2.66± 0.08	2.84± 0.19	2.70± 0.16	3.28± 0.03	3.04± 0.02	3.20± 0.04	0.180
WBC(x3/mm3)	24.89± 0.40	26.09± 0.33	27.28± 0.19	25.91± 0.45	26.64± 0.38	26.46± 0.44	26.52± 1.14	26.40± 0.36	26.23± 0.38	0.163

Means within the same row carrying different superscripts were significantly different at $P \leq 0.05$. 1Hb: hemoglobin; RBCS: red blood cell count; WBCs white blood cell count. 2ZnONPs: Nano-oxide zinc, SP: Spirulina platensis.

Table (7): Effects of dietary ZnONPs and SP supplementation on blood biochemical constituent in broiler chickens

Measurement[1]	Treatment[2]									
	Control	**ZnONPs 30 mg**	**ZnONPs 60 mg**	**SP 2 gm**	**SP 4 gm**	**ZnONPs 30 mg+ SP 2 gm**	**ZnONPs 30 mg+ SP 4 gm**	**ZnONPs 60 mg+ SP 2 gm**	**ZnONPs 60 mg+ SP 4 gm**	**P-value**
Total Protein (g/dl)	5.35± 0.11	5.57± 2.62	5.46± 1.50	5.73± 0.51	5.62± 1.16	5.84± 1.28	5.61± 2.89	5.86± 3.78	5.62± 0.44	0.692
Albumin (g/dl)	2.71± 0.69	2.65± 0.72	2.55± 1.89	2.64± 2.36	2.91± 0.69	2.34± 2.10	2.60± 2.19	2.89± 0.73	2.40± 1.45	0.227
Globulin (g/dl)	2.64± 0.62	2.91± 2.36	2.90± 0.40	3.08± 2.50	2.71± 1.71	3.49± 2.73	3.00± 4.11	2.97± 4.03	3.21± 1.76	0.202
Glucose(mg/dl)	79.68± 0.29	78.11± 3.46	76.67± 2.48	80.89± 1.19	82.14± 1.22	76.12± 2.91	79.98± 3.38	78.11± 3.46	79.68± 0.29	0.732
AST(U/L)	59.81± 0.35	53.85± 2.65	57.05 ± 1.84	52.77± 0.82	57.35 ± 1.78	54.13± 2.93	51.22± 0.04	56.76± 2.81	54.39± 2.22	0.145
ALT(U/L)	69.14^{a}± 1.15	65.77^{b}± 0.35	65.85^{b}± 0.88	65.06^{b}± 0.48	65.88^{b}± 0.89	66.29^{b}± 1.03	67.02^{ab}± 0.55	65.39^{b}± 0.19	65.89^{b}± 1.18	0.019
Total lipids (mg/dl)	640.53± 3.50	580.12± 5.82	548.10± 4.11	612.31± 3.75	573.53± 5.55	602.21± 4.41	610.30± 3.42	623.12± 1.17	622.21± 1.11	0.341
Triglycerides (mg/dl)	184.34± 5.19	178.72± 3.84	173.51± 1.06	177.01± 1.68	170.97± 2.82	181.12± 2.91	181.22± 7.46	182.32± 4.16	187.91± 2.96	0.376
Cholesterol (mg/dl)	135.81± 2.50	131.90± 2.66	127.68± 2.98	129.39± 2.06	129.63± 4.14	130.35± 2.33	129.69± 3.09	129.26± 2.31	125.95± 2.55	0.202
HDL(mg/dl)	38.03± 1.59	38.30± 0.61	38.60± 0.89	38.08± 1.22	39.61± 1.87	39.95± 2.94	40.66± 2.45	40.35± 2.99	40.00± 1.92	0.819
LDL(mg/dl)	97.96± 1.29	93.60± 2.20	90.60± 2.37	91.31± 3.66	90.02± 3.32	89.08± 2.05	89.03± 5.08	88.91± 2.63	85.95± 3.35	0.335

Means within the same row carrying different superscripts were significantly different at $P \leq 0.05$.
[1]AST: aspartate aminotransferase; ALT: alanine aminotransferase; HDL: high-density lipoprotein cholesterol; LDL: low-density lipoprotein cholesterol.
[2]ZnONPs: Nano-oxide zinc, SP: Spirulina platensis.

Table (8): Effects of dietary ZnONPs and SP supplementation on serum TAC, MDA, antioxidant enzymes (GSH-Px. SOD and CAT) and immunoglobulin in broiler chickens

Measurement[1]	Treatments[2]									
	Control	**ZnONPs 30 mg**	**ZnONPs 60 mg**	**SP 2 gm**	**SP 4 gm**	**ZnONPs 30 mg+ SP 2 gm**	**ZnONPs 30 mg+ SP 4 gm**	**ZnONPs 60 mg+ SP 2 gm**	**ZnONPs 60 mg+ SP 4 gm**	**P-value**
GSHPx (µmol/ml)	938.21^{c}± 3.97	946.54^{bc}± 5.68	952.91^{bc}± 3.75	939.35^{c}± 4.03	946.57^{bc}± 8.79	946.57^{bc}± 5.68	949.27^{bc} ±3.81	970.44^{ab} ±9.46	981.30^{a}± 8.79	0.025
SOD (U/ml)	3115.41± 1.74	3126.25± 9.20	3127.32± 7.29	3122.36± 6.05	3134.01± 5.20	3128.52± 9.08	3137.30± 5.39	3129.92± 8.95	3144.30± 1.74	0.194
CAT (U/ml)	35.89^{b}± 0.23	38.82^{a}± 0.21	39.48 ^{a}± 1.24	38.88^{a}± 0.44	38.65^{a}± 1.25	38.94^{a}± 1.31	39.13^{a}± 0.41	39.95^{a}± 0.45	40.78^{a}± 0.32	0.025
TAC (µmol/ml)	415.02^{b}± 1.63	428.03^{a}± 3.58	429.79^{a}± 1.61	422.5^{ab}± 4.83	424.57^{ab}± 2.90	431.83^{a}± 2.42	435.75^{a}± 4.07	428.72^{a}± 3.44	429.24^{a}± 4.02	0.050
MDA (µmol/ml)	11.21± 0.14	11.15± 0.59	10.94± 0.13	10.60± 0.69	10.97± 0.32	10.61± 0.65	10.59± 0.66	9.94± 0.33	9.25± 0.01	0.153
IgM	244.34± 4.43	257.46± 3.59	265.79± 5.92	250.46± 5.33	257.22± 3.28	251.34± 5.11	258.46± 5.83	259.12± 6.22	265.46± 5.98	0.876
IgA	78.77± 1.22	82.65± 3.59	83.32± 1.66	82.65± 2.26	84.32± 4.16	81.21± 0.61	81.99± 2.79	81.32± 2.71	84.10± 1.23	0.140
IgG	988.65^{c}± 3.17	994.88^{bc}± 0.11	995.20^{bc}± 0.67	991.32^{bc}± 3.02	996.2^{bc}± 0.44	997.99^{bc}± 4.53	1013.18^{a} ±3.42	1006.54^{ab} ±6.44	1014.10^{a} ±1.25	0 .001
IgD	10.65^{b}± 0.14	11.55^{ab}± 0.03	12.77^{a}± 0.03	11.78^{ab}± 0.26	11.50^{ab}± 0.45	12.00^{a}± 0.30	12.66^{a}± 0.62	13.02^{a}± 0.02	13.04^{a}± 0.35	0.001
IgE	6.58^{b}± 0.60	8.93^{ab}± 0.64	9.15^{ab}± 0.69	8.7^{ab}± 0.58	8.67^{ab}± 0.56	9.00^{ab}± 0.58	9.00^{ab} ± 0.78	9.00^{ab}± 0.23	9.65^{a}± 0.28	0.05

Means within the same row carrying different superscripts were significantly different at $P \leq 0.05$. [1]GSH: glutathione peroxidase; TAC: total antioxidant capacity; CAT: catalase; SOD: superoxide dismutase; MDA: malondialdehyde; IgM: immunoglobulin M; IgA: immunoglobulin A; IgG: immunoglobulin G; IgD: immunoglobulin D; IgE: immunoglobulin E. [2]ZnONPs: Nano-oxide zinc, SP: Spirulina platensi

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الملخص العربى

تحسين الأداء الإنتاجي والاستجابة المناعية لبداري التسمين بالإضافة الغذائية بالنانو زنك والاسبيرولينا

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تهدف الدراسة إلى تقييم تأثير الإضافة الغذائية بأكسيد النانو زنك (ZnO NPs) والاسبيرولينا بلاتنسيس (SP) وخليطهما على دجاج التسمين، وخصائص الذبيحة، ومؤشرات سيرم الدم، وحالة إنزيمات مضادات الأكسدة. تم استخدام 270 كتكوتا من دجاج تسمين (كب) بعمر يوم واحد ووزعت عشوائيا على تسع معاملات غذائية، تلقت المجموعة الضابطة نظامًا غذائيًا أساسيًا دون أضافات. بينما تلقت المجموعات الأخرى النظام الغذائي الأساسي المضاف إليه أكسيد النانو زنك ب مستويين30 أو 60 مجم / كجم (المجموعتان 2و3) أو الاسبيرولينا بلاتنسيس بمستويين 2 أو 4 جم / كجم (المجموعتان 4و5)، او مزيج من الاثنين معا (المجموعتان 6الي9). وأظهرت النتائج أن المكملات التي تحتوي على أكسيد النانو زنك، بمفرده أو مع الاسبيرولينا بلاتنسيس، أدت إلى تحسين وزن الجسم الحي للدجاج (LBW) وزيادة معدل النمو اليومي (BWG). رافق ذلك انخفاض استهلاك العلف (FC)، وتحسن في كفاءة تحويل العلف (FCR). أظهرت أفضل النتائج عند استخدام الجرعات العالية من أكسيد النانو زنك (60 مجم / كجم) أو مزيجه مع الاسبيرولينا بلاتنسيس عند مستوي 4 جم / كجم. قللت الجرعات العالية من أكسيد النانو الزنك والاسبيرولينا بلاتنسيس نسبة الدهون في البطن وزادت الوزن النسبي للذبيحة. زادت نسبة الهيموجلوبين وعدد خلايا الدم الحمراء مع أكسيد النانو الزنك. لم تظهر اختلافات ملحوظة في مستويات البروتين الكلي في البلازما، الألبومين، الجلوبولين أو الجلوكوز، انخفضت إنزيمات الكبد (AST وALT)، مع انخفاض كبير في ALT. لوحظ انخفاض طفيف في الدهون الكلية والدهون الثلاثية في البلازما ً. تحسنت أنشطة إنزيمات مضادات الأكسدة (TAC وGSH-Px وSOD وcatalase) وانخفض مستوي المالونديالدهيد (MDA). كما لوحظ ارتفاع مستويات الجلوبيولينات المناعية (IgA وIgM وIgG وIgD وIgE)، مع زيادة ملحوظة في IgG وIgD وIgE.

الخلاصة: إضافة أكسيد النانو زنك والاسبيرولينا بلاتنسيس سواء منفردين او كمزيج، الي علائق دجاج التسمين حسنت الأداء الانتاجي، التوازن الكيميائي الحيوي للدم ونشاط مضادات الأكسدة، وقد كانت أفضل النتائج عند استخدام 60مجم / كجم من أكسيد النانو زنك (ZnO NPs) مع المستويات المدروسة من الاسبيرولينا بلاتنسيس (SP).