Nutritional Evaluation of Nano Zinc Compared with Other Zinc Sources in Broilers

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Abstract

The present study was conducted to evaluate the effects of different dietary zinc sources on carcass traits, mortality, cell-mediated immune response, physiological traits, and economic evaluation of broiler chickens. A total of 156 newly hatched chicks (Ross 308) were randomly distributed into four treatments. The dietary treatment received the basal diet without zinc supplementation (T1) was considered as the control group, the T2 supplemented with 40 mg Zn /kg diet inorganic zinc oxide, T3 supplemented with 40 mg Zn/kg diet organic zinc-lysine, and T4 supplemented with 40 mg /kg diet with a prepared nano zinc oxide (NZnO). The data stated that nano zinc oxide (T4) and zinc lysine (T3) significantly recorded the highest carcass weight and breast muscle weight *($P < 0.05$)* compared to chicks in T1 and T2. Nano zinc oxide (T4) significantly *($P<0.05$)* achieved the highest thigh with drumstick weight compared to T2. None of the different organ indices percentages (internal organs and lymphoid immune organs) were significantly affected *($P > 0.05$)* by different Zn sources. The mortality % was not significantly affected by dietary treatments. Non-significant *($P<0.05$)* differences were observed in the serum aspartate aminotransferase (AST) and alanine aminotransferase (ALT), creatinine, and uric acid levels among treatments. Using NZnO (T4) significantly gave a better selling price compared to T1, T2, and T3. It could be concluded that nano zinc oxide, 40 mg Zn/kg diet, has the highest economical return with no adverse effect physiological status of broilers and can be safely included as a good feed additive in broiler diets.

Keywords

Broilers; Nano zinc oxide; Carcass traits; Physiological traits; Economic Evaluation

Introduction

Zinc (Zn) is a critical trace element essential for normal growth and physiological activities. It has three essential biological functions, categorized as catalytic, structural, and regulatory, participates as a co-factor of over 300 enzymes, which are important for the metabolic function of the body systems ***(Rossi et al., 2007).*** One of these enzymes is the superoxide dismutase (SOD), has an effective role in antioxidant status ***(Bao and Choct, 2009).*** Additionally, dietary zinc impacts bone growth in broiler chickens. This effect could be a result of Zn's direct influence on protein synthesis through hormonal growth mediators, which mainly influences skeletal development ***(Seo et al., 2010).***

Recently, the nanotechnology science revolution has promptly developed in several fields ***(Wijnhoven et al., 2009).*** Hence, the use of nano minerals in animals, especially poultry, is a hopeful application of nanotechnology. The nano mineral sources have a greater bioavailability rate due to their higher area and activity surface, great catalytic efficacy, and more adsorbing capacity ***(Zhang et al., 2022).*** Nano zinc oxide (NZnO) is the third-highest worldwide produced nano material after nano silicon dioxide (SiO_2) and nano titanium dioxide (TiO_2) ***(Sarker, 2019).*** According to ***Tan et al. (2013)***, nano zinc oxide was the first nano mineral used in the industrial and commercial fields. The sudden increase in demand is primarily due to its stronger antibacterial effect than the traditional inorganic zinc oxide (ZnO) ***(Swain et al., 2016).*** NZnO has stronger chemical reactions with several organic complexes compared to inorganic ZnO. It can be more readily absorbed by the digestive tract due to its nano size ***(Feng et al., 2009)***. Also, has anti-inflammatory and antioxidant activity and can be used as a substitute for organic and inorganic zinc sources in animal diets ***(Sizova et al., 2020; Swain et al., 2016)***. Studies evaluating nano zinc oxide as a dietary supplement in broiler diets are scanty. Therefore, the objective of this work was to evaluate the impact of nano zinc oxide compared with the traditional zinc sources (inorganic and organic) on carcass traits, mortality %, cell-mediated immune response, physiological traits, and economic evaluation of broiler chickens.

Materials and methods

This work was conducted and permitted by the policies of the Animal Care and Ethics Agency, Faculty of Veterinary Medicine, Suez Canal University, Egypt [Approval No. 2019040].

Experimental birds, diets, and design

A total of 156 newly hatched chicks (Ross 308) were purchased from a private company in Ismailia Province, Egypt. The broiler chicks were housed in a designed battery system with semi-automated feeders and drinkers. The experimental period was five weeks (35 days). The birds were followed at 7 am, 3 pm, and 11 pm for water, feed, and mortality. On days 9 and 24, all the chicks received vaccinations for Newcastle disease; on day 14, they were vaccinated for the infectious bursal disease. All management procedures (lighting program and temperature) were carried out based on the Ross 308 Broiler Management Guide ***(Aviagen, 2018).*** The proximate chemical analysis of the experimental diets and feed ingredients and the zinc analysis are presented in table 1. The chicks were randomly separated into 4 treatments, with 3 repetitions in each treatment and 13 chicks in each repetition. The dietary treatments were: the T1, as a control group, received the basal diet without zinc supplementation. The T2 was supplemented with inorganic zinc oxide (LOBA Chemie, Co. ZnO). The T3 was supplemented with organic zinc-lysine (Availa zinc 170 ®, produced by Multi Vita Co., October City, Egypt). The T4 was supplemented with a prepared nano zinc oxide (NZnO). Following a zinc analysis of the basal (control) diet, the required amount of zinc oxide was added to reach the bird's requirement (40 mg Zn/kg diet), followed by the zinc supplementary level in T2, T3, and T4 by 40 mg Zn/kg diet.

Nano zinc oxide preparation and characterization

Nano zinc oxide has been synthesized as mentioned by ***Beek et al. (2005)*** and ***Pacholski et al. (2002)***: the preparation was done at Nano Gate Co. for Synthesizing of Nanomaterials, Nasr City, Egypt. The nanoparticles were evaluated by X-ray diffraction (XRD) and a transmissible electron microscope (TEM). The XRD and TEM diagrams revealed that the prepared nanoparticles are on the nano scale, a size of about 30 ± 5 nm, and represent uniformity.

Carcass traits

At 35 days of age, two chicks from each repetition were randomly selected to be slaughtered. Birds were left overnight in an isolated place where only water was allowed. Each bird was weighed and then slaughtered; scalded in a water tank at 50°C–65°C for a few seconds; de-feathered; eviscerated; and washed with tap water. The carcass weight (g) and dressing (%) were recorded. The weights and percentages of breast muscle and thigh with drumstick weight were recorded. The internal organs (liver, heart, gizzard, pancreas, abdominal fat, and fat pad) were taken, cleaned, and weighed. The index % of all organs were calculated as a percentage of the final body weight ***(Akhavan-Salamat and Ghasemi, 2019).***

Mortality rate %

Mortality of chicks was daily checked and the mortality rate % for each repetition of treatment was measured and statistically analyzed.

The cell-mediated immune response (lymphoid organ weight index):

After carcass traits were done, the lymphoid organs (spleen, bursa, and thymus) were carefully detached and weighed. The index of bursa of fabricious (BF), spleen, and thymus were calculated as a ratio of the body weight as follow: organ index = (organ weight/live body weight) x 100 with according to ***(El-Haliem et al., 2020)***.

Blood sampling and chemical analysis

The blood samples were collected from the same slaughtered birds. Blood serum was centrifuged at 3000 rpm for 20 min, then kept frozen at - 20ºC until assay for determination of liver and kidney function tests. The serum AST and ALT levels were measured ***(Reitman and Frankel, 1957)*** by using kits (ELI-Tech Co). Determination of creatinine by photometric colorimetric test using commercial kit (Human, Germany) according to ***Henry (1964)***. Uric acid was determined by the enzymatic method using a kit (SPINREACT, Spin) according to ***Friedman and Young (1989)***.

Economic evaluation

The economic efficiency (EE) was calculated according to ***El-Haliem et al. (2020)***. EE = (Net revenue/Total production cost) X 100.

Where: Net revenue = Selling price – Production cost.

Production cost included the price of chicks, diet, and the managemental care.

Statistical analysis

The collected data were analyzed by one-way ANOVA using a statistical software program (IBM SPSS, version 21, USA). Tests of significance for differences among treatments were done according to ***Duncan (1955)*** to display the significance among experimental treatments at *P< 0.05* with: all data were presented as the mean ± standard error.

Results

Carcass traits of broiler chickens

The current data revealed that nano zinc oxide (T4) and zinc lysine (T3), 40 mg/kg diet, significantly achieved the highest weights of carcass and breast muscle *(P <0.05)* compared to chicks in T1 and T2. Also, it was observed that nano zinc oxide achieved the highest thigh with drumstick weight, either significantly *(P<0.05)* compared to chicks in T2 or numerically with T1, and T3 (table 2). However, the internal organ indices percentages were not significantly affected *(P>0.05)* by dietary Zn treatments (table 3).

Mortality % of broiler chickens.

Data presented in table 4 shows the mortality % of chicks in all experimental groups fed on basal diets supplemented with different zinc sources. The mortality % was not statistically different *(P>0.05)* among the experimental treatments. However, the total mortality was within normal limits and did not exceed 3%.

The cell-mediated immune response (lymphoid organ weight index) of broiler chickens.

The results revealed that supplementation of different zinc sources did not have any significant

(P>0.05) effect on lymphoid organ weight and index (Table 5).

Physiological traits of broiler chickens (liver and kidney function tests).

Results presented in table 6 results showed no statistically significant *(P<0.05)* differences in the serum ALT, AST, and creatinine level or serum uric acid concentration between the experimental treatments.

Economic evaluation.

Results of the economic efficiency (EE) evaluation of the incorporation of ZnO, zinc lysine and nano zinc oxide in broiler diets are displayed in (Table 7). Supplementation of nano zinc oxide (T4, 40 mg Zn/kg diet) gave the highest significant selling price *(P<0.05)* compared with chicks fed T1, T2, and T3. Similarly, zinc lysine (T3, 40 mg Zn/kg diet) significantly gave the better selling price *(P<0.05)* compared with chicks fed T1 and numerically with chicks fed T2. There was a considerable, significant cost saving *(P<0.05)* with the inclusion of 40 mg nano zinc oxide or zinc lysine as compared with the ZnO and control, where the net revenue was 48.66 and 48.21 L. E in T4 and T3 respectively, compared to 45.13 and 43.31 L. E in T1 and T2, respectively. However, EE was 106.85, 102.31, 99.38 and 90.41 for T3, T4, T1 and T2, respectively.

Table (1): *The basal (control) diets composition and calculated chemical analysis [a].*

Ingredients%	Starter diet (0-10 day of age)	Grower diet (11-24 day of age)	Finisher diet (25-35 day of age)
Yellow corn (8.7% CP) [b]	55.592	58.9	64.212
Soya bean meal (45.3 % CP) [b]	32.36	28.2	22.292
Corn gluten (63.7% CP) [b]	5.5	5.708	5.99
Soybean oil	2.63	3.56	4.10
Dical. Phosphate (22%Ca&19%P)	1.494	1.30	1.15
Limestone (38% Ca)	1.363	1.27	1.20
L – Lysine (purity 99%)	0.30	0.318	0.33
DL – Methionine (purity 99%)	0.161	0.144	0.126
Mineral & Vitamins premix [c]	0.30	0.30	0.30
Iodized sodium chloride	0.30	0.30	0.30
Total	100	100	100
Calculated composition			
Crude protein (%)	23	21.5	19.5
ME (Kcal per kg)	3000	3100	3200
Calorie/Protein ratio (C/P)	130.43	144.18	164.10
Calcium (%)	0.96	0.87	0.79
Phosphorus (%) [d]	0.30	0.435	0.395
Zn mg/kg [e]	18.03	10.65	12.81
Still need Zn (mg)/kg [f]	21.97	29.35	27.19
Added amount of ZnO (mg) /kg [g]	27.35	36.53	33.84

[(a)] *Nutrient specification of Ross* ***(Aviagen, 2019).***

[(b)] *Chemical analysis according to* ***(AOAC, 2002).***

[(c)] *Each 3 kg of premix contains: Vit. A 12 mIU, vit. D_3 2 mIU, vit. E 10000 mg, vit. k_3 2000 mg, vit. B_1 1000 mg, vit. B_2 5000 mg, vit. B_6 1500 mg, vit. B_{12} 10 mg, biotin 50 mg, pantothenic*

acid 10000 mg, nicotinic acid 30000 mg, folic acid 1000 mg, manganese oxide 60000 mg, zinc oxide 50000 mg, iron sulphate 30000 mg, copper sulphate 10000 mg, potassium iodide 1000 mg, sodium selenate 100 mg, cobalt sulphate100 mg, carrier ($CaCO_3$) to 3kg. (Avimix for broilers premix- AGRIVET Co, Elasher Egypt. patch No. 2321, production 25-4-2021).
(d) Available phosphorus.
(e) Analysis was carried out at the Central lab, Faculty of Veterinary Medicine, Zagazig University, Egypt.
(f) The amount of zinc required to meet broiler zinc requirement (40 mg Zn/kg diet).
(g) The calculated amount based on each 100 mg zinc oxide containing 80.34 mg of zinc.

Table 2: *Carcass traits and carcass cut-up of broiler chickens at 35 days of age.*

Treatment / Parameter	T1	T2	T3	T4
Live body weight (g)	2285.66 ^{c} ± 24.90	2301.60 ^{bc} ± 10.15	2354.06 ^{b} ± 18.34	2428.66 ^{a} ± 8.40
Carcass weight (g)	1691.00 ^{b} ± 24.17	1703.00 ^{b} ± 10.06	1758.66 ^{a} ± 19.16	1809.66 ^{a} ± 4.91
Dressing %	73.97 ^{a} ± 0.37	73.99 ^{a} ± 0.12	74.70 ^{a} ± 0.22	74.51^{a} ±0.08
Breast muscle Wt.(g)	415.00 ^{c} ± 3.00	425.00 ^{c} ± 3.21	452.00 ^{b} ± 1.52	466.33 ^{a} ± 4.97
Breast muscle Wt. %	18.15 ^{b} ± 3.00	18.15 ^{b}± 3.21	19.20 ^{a} ± 1.52	19.20 ^{a} ± 4.97
Thigh with drumstick Wt.	332.33 ^{ab} ± 3.38	319.00 ^{b} ± 10.58	339.00 ^{ab} ± 1.52	357.00 ^{a} ± 9.60
Thigh with drumstick Wt. %	14.54 ^{a} ± 0.07	13.85 ^{a} ± 0.41	14.40 ^{a} ± 0.08	14.69 ^{a} ± 0.35

Values within a same row with dissimilar superscript vary significantly $P < 0.05$.
T1: control diet only.
T2: control diet + 40 mg Zn oxide /kg diet.
T3: control diet + 40 mg Zn lysine /kg diet.
T4: control diet + 40 mg nano Zn oxide /kg diet.

Table 3: *Internal organs weight and index % of broiler chickens at 35 days of age.*

Treatment / Parameter	T1	T2	T3	T4
Liver weight (g)	48.67 ^{a} ± 2.03	47.38 ^{a} ± 3.69	47.30 ^{a} ± 4.33	47.98 ^{a} ± 3.71
Liver index %	2.12 ^{a} ± 0.08	2.06 ^{a} ± 0.16	2.01 ^{a} ± 0.19	1.97 ^{a} ± 0.15
Heart weight (g)	9.99 ^{a} ± 0.17	9.15 ^{a} ± 0.20	10.64 ^{a} ± 0.79	9.63 ^{a} ±1.11
Heart index %	0.43 ^{a} ± 0.003	0.39 ^{a} ± 0.008	0.45 ^{a} ± 0.03	0.39 ^{a} ± 0.04
Gizzard weight (g)	32.88 ^{a} ± 3.73	33.84 ^{a} ± 1.32	37.40 ^{a} ± 0.49	37.64 ^{a} ± 4.02
Gizzard index %	1.43 ^{a} ± 0.16	1.47 ^{a} ± 0.06	1.58 ^{a} ± 0.02	1.55 ^{a} ± 0.16
Giblets weight (g)	91.55 ^{a} ± 5.69	90.38 ^{a} ± 5.10	95.34 ^{a} ± 4.53	95.26 ^{a} ± 6.52
Giblets weight index%	4.00 ^{a} ± 0.24	3.92 ^{a} ± 0.23	4.05 ^{a} ± 0.20	3.92 ^{a} ± 0.27
Pancreas weight (g)	5.04 ^{a} ± 0.35	5.01 ^{a} ± 0.33	4.60 ^{a} ± 0.08	5.47 ^{a} ± 0.55
Pancreas index %	0.22 ^{a} ± 0.013	0.21 ^{a} ± 0.014	0.19 ^{a} ± 0.003	0.22 ^{a} ± 0.02
Abdominal Fat Wt. (g)	7.78 ^{a} ± 0.63	8.12 ^{a} ± 0.22	6.81 ^{a} ± 0.46	7.84 ^{a} ± 0.36
Abdominal Fat index%	0.34 ^{a} ± 0.03	0.35 ^{a} ±0.009	0.28 ^{a} ± 0.01	0.32 ^{a} ± 0.01
Fat pad Wt.(g)	9.41^{a} ± 0.43	8.74 ^{a} ± 0.62	10.12 ^{a} ± 0.35	9.94 ^{a} ± 0.36
Fat pad index %	4.00 ^{a} ± 0.41	3.92 ^{a} ± 0.38	4.05 ^{a} ± 0.43	3.92 ^{a} ± 0.40

Values within a same row with dissimilar superscript vary significantly $P < 0.05$.
T1: control diet only.
T2: control diet + 40 mg Zn oxide /kg diet.
T3: control diet + 40 mg Zn lysine /kg diet.
T4: control diet + 40 mg nano Zn oxide /kg diet.

Table 4: *Mortality% in the experimental groups.*

Treatment	(0-35) days	Mortality %
T1	1.0	2.56 ^{a} ± 4.44
T2	0.0	0.0 ^{a} ± 0.00
T3	1.0	2.56 ^{a} ± 44.4
T4	1.0	2.56 ^{a} ± 4.44

Values within a same column with dissimilar superscript vary significantly P < 0.05.
T1: control diet only.
T2: control diet + 40 mg Zn oxide /kg diet.
T3: control diet + 40 mg Zn lysine /kg diet.
T4: control diet + 40 mg nano Zn oxide /kg diet.

Table 5: *Lymphoid organs weight of broiler chickens at 35 days of age.*

Group / Parameter	G1	G2	G3	G4
Spleen weight (g)	2.60 ^{a} ± 0.60	2.65 ^{a} ± 0.95	2.14 ^{a} ± 0.29	1.91^{a} ± 0.45
Spleen index %	0.114 ^{a} ± 0.02	0.116 ^{a} ± 0.04	0.091^{a} ± 0.01	0.078 ^{a} ± 0.01
Bursa of fabricious wt.(g)	4.73 ^{a} ± 1.26	4.29 ^{a} ± 0.14	4.46 ^{a} ± 0.19	2.85 ^{a} ± 0.35
Bursa index %	0.206^{a} ± 0.05	0.186 ^{a} ± 0.005	0.189 ^{a} ±0.006	0.117 ^{a} ± 0.01
Thymus weight (g)	8.17 ^{a} ± 0.88	7.38 ^{a} ± 0.47	10.70 ^{a} ± 1.48	7.89 ^{a} ± 0.90
Thymus index %	0.358 ^{a} ± 0.04	0.321 ^{a} ± 0.02	0.455 ^{a} ± 0.06	0.325 ^{a} ± 0.03

Values within a same row with dissimilar superscript vary significantly P < 0.05
T1: control diet only.
T2: control diet + 40 mg Zn oxide /kg diet.
T3: control diet + 40 mg Zn lysine /kg diet.
T4: control diet + 40 mg nano Zn oxide /kg diet.

Table 6: *Impact of dietary zinc treatment on liver and kidney functions tests.*

Treatment / Parameter	T1	T2	T3	T4
ALT(U/L)	19.33 ^{a} ± 7.83	30.66 ^{a} ± 7.96	30.33 ^{a} ± 8.08	36.66 ^{a} ± 4.91
AST(U/L)	295.33 ^{a} ± 37.35	242.33 ^{a} ± 50.96	228.33 ^{a} ± 24.91	272.33^{a} ± 50.91
Creatinine (mg/dl)	0.16 ^{a} ± 0.03	0.13 ^{a} ± 0.03	0.13 ^{a} ± 0.03	0.16 ^{a} ± 0.03
Uric acid (mg/dl)	8.26 ^{a} ± 2.42	5.96 ^{a} ± 0.31	5.43 ^{a} ± 0.96	7.10 ^{a} ± 0.85

Values within a same row with dissimilar superscript vary significantly P < 0.05.
T1: control diet only.
T2: control diet + 40 mg Zn oxide /kg diet.
T3: control diet + 40 mg Zn lysine /kg diet.
T4: control diet + 40 mg nano Zn oxide /kg diet.

Table 7: *The economical evaluation of broiler chickens as affected by different dietary treatments.*

Treatment / Parameter	T1	T2	T3	T4
Number of chicks	39	39	39	39
Price/chick (LE)	8.00	8.00	8.00	8.00
Final wt. (g)	2263.66 ^{c} ± 26.73	2280.93 ^{bc} ± 10.79	2333.46 ^{b} ± 18.66	2406.00 ^{a} ± 7.69
Feed intake /chicks (g)	3240.97 ^{a} ± 32.42	3118.13 ^{b} ± 32.49	3088.01^{b} ± 37.58	3033.16 ^{b} ± 35.91
Feed cost* /chicks (LE)	32.40 ^{a} ± 0.32	31.18 ^{b} ± 0.32	30.88 ^{b} ± 0.37	30.33 ^{b} ± 0.35
management /chicks (LE)	5.00	5.00	5.00	5.00
Feed additive cost /chicks	00 ^{d} ± 0.00	3.74 ^{b} ± 0.03	1.23 ^{c} ± 0.01	4.24 ^{a} ± 0.05
Total cost /chick (LE)**	45.40 ^{b} ± 0.32	47.92 ^{a} ± 0.36	45.12 ^{b} ± 0.39	47.57 ^{a} ± 0.40
Selling price (LE)	90.54 ^{c} ± 1.06	91.23 ^{bc} ± 0.43	93.33 ^{b} ± 0.74	96.24 ^{a} ± 0.30
Net revenue* (LE)**	45.13 ^{b} ± 0.74	43.31 ^{b} ± 0.77	48.21 ^{a} ± 0.36	48.66 ^{a} ± 0.68
Economic efficiency (EE)******	99.38 ^{b} ± 0.95	90.41 ^{c} ± 2.28	106.85 ^{a} ± 0.29	102.31 ^{ab} ± 2.32

Values within a same row with dissimilar superscript vary significantly P < 0.05.
T1: control diet only.
T2: control diet + 40 mg Zn oxide /kg diet.
T3: control diet + 40 mg Zn lysine /kg diet.
T4: control diet + 40 mg nano Zn oxide /kg diet.
** Price of one kg of feed = 10.00 LE.*
*** = price of chick + management + feed cost + additive.*
**** = selling price – total cost.* ********** *= Net revenue / total cost X 100.*

Discussion

The improvement in the carcass weight and carcass cut-up (breast and thigh with drumstick) yield in zinc lysine and nano zinc oxide supplemented groups may be due to the significant improvement in final body weight as a result of proper feed utilization efficiency. Besides, zinc is a crucial microelement of > 300 enzymes contributing to nucleic acid and protein metabolism regulation ***(Jarosz et al., 2017).*** These positive effects were more prominent with nano zinc oxide than with zinc lysine due to the higher bioavailability of nanoparticles. Furthermore, NZnO can control the broiler's metabolism by upregulating the insulin and growth hormone genes ***(Ibrahim et al., 2017).*** Regarding the significant effect of nano zinc oxide followed by zinc lysine comparing with zinc oxide and control group on carcass and cut-up weights, this could be reflected positively in the broiler industry's processing practice due to the increase in the carcass yield. Because poultry meat is now typically consumed as cuts or processed products rather than whole carcasses, the technological quality of poultry meat is becoming increasingly important ***(Kumar et al., 2022).*** These findings corroborate those of ***Tronina et al. (2007)*** who noted that the group of broilers receiving Zn-glycine from feed led to an increasing breast and leg muscles yield. It was found that organic zinc supplementation, at a level of 40, 80, and 120 mg/kg diet, had positive effects on carcass and breast muscle weight yield ***(Jahanian et al., 2008)***. Likewise, ***Olukosi et al. (2018)*** stated that chickens receiving a diet enriched with hydroxychloride Zn and Cu had a higher *(P<0.05)* breast muscle percentage compared to birds receiving inorganic Zn and Cu sulfate. These data were also previously stated by ***Lina et al. (2009a)***, who found that a higher slaughter percentage of broilers supplemented with NZnO, 40 mg/kg diet, than the control group *(P< 0.01)* at 42d. Also, ***Ebrahimnezhad et al. (2013)*** mentioned that Ross 308 chicks offered a diet containing 60 or 90 mg NZnO/kg diet significantly have a greater breast and thigh muscle weight. Different trends were informed by other investigators. ***Hess et al. (2001)*** indicated that a non-significant effect was noticed when chickens provided a diet with 40 mg Zn/kg diet from zinc methionine, zinc lysine, or their mixture for total carcass and carcass cut-up yields. ***Rossi et al. (2007)*** cited that the breast and thigh with drumstick yields of broilers were not statistically influenced by the gradual increasing dose of organic zinc. Likewise, ***Bami et al. (2020)*** noted the relative weights of carcass and breast muscle were not influenced by the adding of 25 and 50 mg NZnO/kg of diet. Reasons for explaining incoherence may be related to form, type, experimental period, and a level of zinc oxide nanoparticles ***(Khah et al., 2015).***

Different zinc sources have a non-significant influence on internal organ index percentages under the experimental conditions. In the same context, ***Zakaria et al. (2017)*** reported that fat pad and internal organ (liver, heart, and gizzard) yields were not influenced by Zn source (ZnO and Zn-amino acid complex) in broilers. Also, ***Ahmadi et al. (2013)*** found that none of the internal organs (pancreas, gizzard, proventriculus, and heart) of broilers were significantly affected by NZnO supplementation at a level of 60 or 90 mg/kg diet. ***Akhavan-Salamat and Ghasemi (2019)*** revealed that none of the carcass traits, including dressing percent as well as the internal organs index (liver, heart, and abdominal fat), were influenced by zinc sources (ZnO, Zn-Methionine, and nano zinc oxide) and content of zinc administration at a level of 20, 40, and 80 mg/kg diet. In contradiction to the present finding, ***Mohammadi et al. (2015)*** recorded a rise in the relative weight of internal organs of broilers fed ZnO-NPs containing dry diets at the level of 100 mg Zn/kg compared to wet diets. ***Bami et al. (2020)*** showed that the liver weight was significantly reduced in broilers fed with 50 mg/kg diet of NZnO compared with 100 mg/kg diet of ZnO. As well, ***Eskandani et al. (2021)*** conveyed that the heart index % was significantly high in the 50 mg Zn-NPs treatment and non-supplemented groups, but the lowest weights were recorded in the 30 and 90 mg Zn-NPs treatments. In view of the above findings, we could indicate that the supplementation of nano zinc oxide as well as zinc lysine significantly improved carcass weight and could support cut-part characteristics without negative effects on internal organs and other carcass parameters of broiler chickens.

The results reported here indicated that total mortality % was not related to the dietary treatments. This was in match with the previous data mentioned by ***Burrell et al. (2004)*** and ***Chand et al. (2020),*** who declared that progressive additions of zinc, either organic or inorganic to the broiler diet did not impact mortality. It was also reported that the increase in organic Zn level (0, 15, 30, 45, or 60 mg/kg diet) in the diet did not statistically affect the mortality of broiler chickens ***(Rossi et al., 2007).*** Additionally, ***Ramiah et al. (2019)*** noted that neither the diet that was supplemented with ZnO-NPs at the levels of 0, 40, 60, and 100 mg/kg diet nor the heat stress condition had a significant impact on mortality percentage of broilers. However, ***Zakaria et al. (2017)*** showed that the mortality rate was significantly lower in broiler chicks' group that included 80 mg of ZnO plus 42 mg of an organic Zn-amino acid complex. Besides, ***Asheer et al. (2018)*** mentioned that the nano zinc substituting inorganic zinc at a level of 25, 50, 75 and 100% resulted in reduced mortality rates of broiler chickens. In current investigation, there was no influence of the zinc levels on the mortality of broilers. However, under practical production conditions, birds may encounter many stressors such as microbial challenges, mycotoxicoses, and oxidative stress. So, zinc supplementation may reduce morbidity and mortality due to its role in supporting immunity and improving antioxidant defense of chickens.

The present results showed that zinc sources had no significant effect on relative weights of immune organs. These immune organs are associated with the ability of immune cells production, but they are also important index for estimating the harmful effects of additives or drugs ***(Kidd, 2004).*** The present data suggest that the supplementation of 40 mg Zn/kg diet of either ZnO, zinc lysine, or NZnO did not have apparent adverse effects on organ development in broiler chickens. The results were in accordance with those obtained by ***Bartlett and Smith (2003),*** who revealed that none of the lymphoid organs were significantly impacted *($P < 0.05$)* by the level of zinc in the diet. Also, ***Eskandani et al. (2021)*** indicated that the relative weight of lymphatic organs of broilers was not affected *(P >0.05)* by different zinc treatments, either $ZnSO_4$ (70 mg/kg diet), Zn amino acid complex (70 mg/kg diet), or NZnO (30, 50, 70, and 90 mg/kg diet).

In a converse trend, ***Mahmoud et al. (2020)*** found that the 10 mg/kg diet of ZnO-NPs significantly elevated the spleen weight, and 20, 30 and 40 mg/kg diet of ZnO-NPs increased bursa weight. Furthermore, dietary NZnO (100, 40, and 20 mg/kg diet) reduced the relative weight of thymus and 60 and 40 mg NZnO/kg of diet improved the relative weight of bursa of Fabricius in comparison with the control ***(El-Haliem et al., 2020).***

The present findings demonstrate that all sources of zinc supplementation (40 mg Zn/kg diet) were safe with respect to liver and kidney function, as indicated by unchanged values of ALT, AST, and concentrations of creatinine and uric acid in the serum of treated birds compared to control. These data were in harmony with ***Salim et al. (2012)***, who revealed that glutamic oxaloacetic transaminase (GOT) was not affected by dietary 25 ppm of organic zinc supplementation. Additionally, serum AST and ALT activity were not significantly changed *(P>0.05)* by addition of 10, 20, and 40 mg NZnO/kg diet ***(Fathi et al., 2016).*** The current results also matched with ***El-Katcha et al. (2017),*** who showed that broiler chicks fed a diet enriched with organic or nano zinc (60, 45, 30, or 15 mg/kg diet) did not reveal significant impact on blood serum uric acid and GOT concentrations when compared with the inorganic zinc enriched group. ***Abdel-Monem et al. (2021)*** illustrated that serum ALT, ALP, AST, uric acid, and creatinine of broiler chicks were not significantly different between groups of ZnO or NZnO, at levels of 40 and 80 mg Zn/kg diet. In contrast, ***Ahmadi et al. (2014)*** cited that dietary 30, 60, 90, or 120 mg of ZnO-NPs/kg diet had significantly decreased *(P<0.05)* serum AST, and ALT enzyme activity of broilers compared with control treatment. As well, the introduction of organic zinc into the diets partially substitute of inorganic sources lead to significantly decline uric acid concentration ***(Jahanian and Rasouli, 2015).*** In addition, it was reported that broilers fed organic or nano zinc , 60, 45, 30, or 15 mg/kg diet, reduced blood serum creatinine concentration ***(El-Katcha et al., 2017).*** Moreover, serum uric acid, creatinine, SGOT, and SGPT levels in nanoparticle-supplemented groups (20, 40, or 60 mg/kg diet) show linearly reducing effects compared to the control group ***(Abdel-Wareth et al., 2022).*** The incompatible results between research studies could be associated with the Zn status of birds, size and form of zinc, level of zinc in the feed ingredients and supplemental level.

The improvement in economic evaluation parameters was matched with the improvement in feed conversion or decreasing the feed amount required to produce body weight gain. This may be due to the beneficial effects of nano zinc oxide, followed by zinc lysine, on digestion and nutrient absorption in the digestive tract, as well as increased bioavailability of zinc nanoparticles and organic sources ***(Chen et al., 2006)*** and ***(Świątkiewicz et al., 2014).*** These results were in match with ***Abdallah et al. (2009)***, who noted that chicks fed diets supplemented with 50% or 100% of Zn or Mn or Cu as organic minerals of the broiler strain microelement requirements showed better relative economic efficiency than those received diets supplemented with 100% of the requirements for these minerals as inorganic form. The same trend was recorded in the case of zinc nano form. It was found that NZnO has been sustained to improve growth, nutrient utilization, and enhance economic profits in poultry ***(Mishra et al., 2014).*** Also, it provided the best feed efficiency at certain inclusion levels and gave the best economic efficiency of broiler chicks ***(Joshua et al., 2016).*** Besides, ***Swain et al. (2016)*** mentioned that nano Zn, as an alternative to traditional Zn sources, can be a promising feed additive for animal rations and improve performance and economic efficiency. Similarly, ***Zhao et al. (2014)*** observed that compared with ZnO supplementation, 20 mg/kg diet as nano ZnO is the ideal level in broiler diets to give the best growth performance and economic efficiency. Likewise, ***Badawi et al. (2017)*** and ***El-Haliem et al. (2020)*** confirmed that 40-ppm nano ZnO/kg of diet gave the highest return and net profit values in spite of the high cost of nano ZnO feed additive. On the other hand, the cost of production and net profit of NZnO at different levels (0.0, 25, 50, 75, and 100% of replacement level of inorganic zinc by NZnO) of broiler chicken diets were very similar ***(Asheer et al., 2018).***

Conclusion

The addition of nano zinc oxide at a level of 40 mg Zn/kg diet, which exceeds the NRC requirements for zinc in broilers, successfully improved the carcass cuts-up without any harmful effect on internal organs. It has no negative impact on the liver and kidney function. It also gave the highest selling price compared to the traditional zinc source. Finally, it could be recommend using NZnO at a level of 40 mg Zn/kg diet in broiler rations.

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التقييم الغذائي للنانو زنك بالمقارنة بمصادر الزنك الاخري في بداري التسمين

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الملخص العربي

تهدف هذه الدراسة إلى تقييم تأثيرات مصادر الزنك المختلفة على صفات الذبيحة ، نسبة النفوق ، والاستجابة المناعية الخلوية ، والصفات الفسيولوجية ، والتقييم الاقتصادي في بداري التسمين. تم تقسيم كتاكيت التسمين عشوائياً إلى 4 معاملات. كانت المعالجات الغذائية: T1 كمجموعة ضابطة تلقت العليقه الأسياسية بدون اضافة الزنك. تم تزويد T2 بأكسيد الزنك غير العضوي. تم تزويد T3 بالزنك ليسين العضوي. تم تزويد T4 بالنانوأكسيد الزنك المحضر (NZnO). تم امداد T2 و T3 و T4 من مصادر مختلفة من الزنك بمستوى 40 مجم زنك / كجم عليقة. أظهرت النتائج أن نانو أكسيد الزنك (T4) والزنك ليسين (T3) بمستوى 40 مجم / كجم عليقة حققوا أعلى وزن للذبيحة ووزن عضلات الصدر (P <0.05) مقارنة بالكتاكيت في T1 و T2. حقق النانو أكسيد الزنك أعلى وزن للفخذين معنويا (P <0.05) مقارنة بالطيور في T2 أو عدديا مع T1 و T3. لم تتأثر أي من النسب المئوية لمؤشرات الأعضاء المختلفة (الأعضاء الداخلية وأعضاء المناعة الليمفاوية) بشكل كبير (P> 0.05) بمصادر الزنك المختلفة. كما لم تكن هناك فروق معنوية (P> 0.05) في متوسط نسب النفوق بين المعاملات التجريبية. لا توجد فروق ذات دلالة إحصائية (P <0.05) في مستويات ALT و AST والكرياتينين وحمض البوليك في الدم بين جميع المجموعات التجريبية. استخدام النانو أكسيد الزنك بمستوى 40 ملجم زنك / كجم عليقة أعطى أفضل سعر مبيعاً (P <0.05) مقارنة بالطيور في T1 و T2 و T3. يمكن الاستنتاج بأن النانو أكسيد الزنك بمستوى 40 ملجم زنك / كجم عليقة ليس له تأثير سلبي على الحالة الفسيولوجية ويمكن إدراجه بأمان في علائق بداري التسمين.

الكلمات الداله بداري التسمين، أكسيد الزنك، أجزاء الذبيحة، الأعضاء اليمفاوية، الصفات الفسيولوجية، الجدوي الإقتصادية