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RESEARCH ARTICLE

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Comparison of plant extract-derived nano-zinc particles with different zinc sources and effects of different Zn sources on egg yield and quality traits

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Abstract

This study aimed to compare the zinc (Zn) nanoparticles obtained from plant extracts with different zinc sources and to reveal the effects of different Zn sources on growth performance, egg quality traits and blood serum parameters of laying quail. Treatment groups as follows: control and 3 and 6 mg/kg inorganic, organic, and plant extract-derived nano-Zn particles to quail diet supplementation. Animals were fed on experimental diets for 6 weeks. Different Zn sources supplemented into quail diets did not significantly affect live weights ($P > 0.05$). On the other hand, different Zn sources increased egg yields ($P < 0.05$). Plant extract-derived nano-Zn supplementations into quail diets increased feed consumption, feed conversion ratio, and egg weights ($P < 0.05$). However, 6 mg/kg plant extract-derived nano-Zn supplementations reduced egg weights. Different Zn sources did not have any significant effects on egg yolk weight (g) and egg yolk color L*b* values ($P > 0.05$). For blood serum parameters, 6 mg/kg plant extract-derived nano-Zn supplementations increased blood serum AST, ALT, and Zn values ($P < 0.05$). No adverse effect was observed on the measured values in laying Japanese quails. The findings suggest that plant extract-derived nano-Zn particles could reliably be used in quail feeding.

KEYWORDS
egg, nano-mineral obtained with plant extract, poultry feeding, quail, zinc

1 | INTRODUCTION

Zinc is an essential trace element for animals' biochemical and cellular functions. Zinc is a vital structural and functional integrity trace element with over two thousand transcription factors. Zinc-containing proteins play a critical role in the metabolic pathways of poultry species (Cousins et al., 2006; Kucuk et al., 2008; Ulger & Fidan, 2021; Ulger & Küçük, 2011). It is required for skeletal development, growth, development of skin and other epithelial tissues, adequate resistance to diseases (immunity), appetite, reproduction, and fulfillment of various biochemical functions (including synthesis of metal-containing enzymes, nucleic acids, and proteins and stabilization of membranes) (McNaughton, 1991; Stahl et al., 1989; Underwood & Suttle, 1999). Zinc storage in animal body is limited. Therefore, daily zinc (Zn) supplementations should be made into animal diets (Bao et al., 2009). In practice, zinc is added to poultry diets to meet the needs of animals (Swain et al., 2015). Earlier studies indicated that inorganic mineral salts generally had low bioavailability and retention in broilers compared to organic-based salts (Mwangi et al., 2019; Ulger et al., 2020; Yu et al., 2017). However, although they have greater bioavailability than inorganic mineral salts, producers do not prefer organic chelates as feed additives because they are costly and

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have low zinc content (Sahoo et al., 2014; Zhao et al., 2014). The administration of organic minerals results in greater zinc excretion from the animals, and such a case raises concerns about environmental pollution.

Researchers have recently tried to eliminate nutrient deficiencies in mixed rations of poultry (Ulger, 2019; Ay et al., 2023; Ekizoğlu et al., 2020; Ulger et al., 2023). Deficiencies are primarily encountered in minerals. Minerals play a significant role in vital functions and significantly increase animal performance. Minerals continuously interact with each other, and mineral deficiencies bring about serious health problems (Swain et al., 2015; Ecevit & Olgun, 2019; Ulger & Fidan, 2021; Ulger et al., 2019, 2020). Therefore, it is essential to have enough minerals in animal diets. Organic minerals are more biologically favorable and efficient in poultry nutrition than inorganic minerals (Ulger & Fidan, 2021; Ulger & Küçük, 2011). Using minerals at lower rates without adverse effects on animal performance also reduces production costs.

Instead of inorganic minerals, organic mineral sources are commonly used in poultry diets for active use of mineral supplementations. Today, studies on nano-minerals have attracted significant attention as alternative mineral sources due to their high availability as feed additives (Tatlı et al., 2019).

In this study, zinc nanoparticles obtained from plant extracts were compared with different zinc sources and their effects on live weight change, feed consumption, feed conversion ratio (FCR), egg weight, yolk weight, egg yolk color (L*a*b*), and blood parameters of laying quail were determined.

2 | MATERIAL AND METHOD

2.1 | Animal material

Experiment were conducted at the Quail Breeding Unit of Erciyes University. The animals to be used were obtained from the same breeding unit. In the present experiments, 175 quail at 8 weeks old were used as animal material. Before the experiments, animals were subjected to a 14-day pre-adaptation diet.

2.2 | Treatment groups

Animals were weighed at the beginning of experiments and distributed to experimental groups homogeneously with a minimum difference in live weights. Each cage had five quail, and each treatment group comprised 25 laying quail (5 replications × 5 cages) (Table 1). The nutritional compositions of the feeds were at the levels specified in feeding standards. Zinc was also supplemented into the compound feed of the experimental groups. The zinc content of the concentrated feed was also analyzed. All feeds were prepared isonitrogenically and isocalorically. Inorganic, organic, and plant extract nano-zinc were added to the mixed rations of the treatment groups at 3 and 6 mg/kg levels, and animals were fed for 56 days. Commercial companies supplied inorganic and organic zinc sources.

2.3 | Zn supplementation into animal feeds

As the animal material of the experiment, 175 Japanese quail (*Coturnix coturnix* Japonica) at the age of 8 weeks were randomly divided into seven experimental groups consisting of five replicates with five birds each. During the laying period, quails were fed with mixed feeds prepared according to the norms recommended by NRC (1994). Inorganic, organic and plant extract nano-zinc was added to the mixed feeds of the treatment groups at levels of 3 and 6 mg/kg and fed for 56 days. Necessary heating and lighting were provided throughout the experiments, and feed and water were provided as desired.

2.4 | Feed analyses and preparation of mixed rations

Dry matter, crude ash, crude oil, crude protein, and crude cellulose analyses of the rations were determined following the Weende analysis method, sugar analysis following Zoll's rule, and starch analysis following the polarimetric method as specified in at the Feeds and Animal Nutrition laboratories of Animal Science Department of Erciyes University.

TABLE 1 Treatments groups.

Groups	Feed composition	Number	Total
1	Control group without Zn supplementation into the rations	5 × 5	25
2	3 mg/kg inorganic Zn-supplemented group	5 × 5	25
3	6 mg/kg inorganic Zn-supplemented group	5 × 5	25
4	3 mg/kg organic Zn-supplemented group	5 × 5	25
5	6 mg/kg organic Zn-supplemented group	5 × 5	25
6	3 mg/kg plant-extract nano-Zn-supplemented group	5 × 5	25
7	6 mg/kg plant-extract nano-Zn-supplemented group	5 × 5	25
Total			175

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Metabolic energy (ME) values were calculated in accordance with the WPSA method (Vogt et al., 1984).

$$\mathrm{ME(kcal/kg)} = (3.69 \times \%\text{crude protein} + 8.18 \times \%\text{crude oil} + 3.99 \times \%\text{starch} + 3.17 \times \%\text{sugar}) \times 10$$

A basal ration was prepared (Table 2), and zinc levels were determined. Then, the remaining zinc quantities were supplemented into treatment groups specified in Table 1. Experimental rations were prepared in the feed unit of the ERU Research and Application Farm. Feed raw materials were weighed, ground in the required quantities, and given to the mixer. Vitamin and mineral premixes were given to the mixer as anticoccidial, DL-methionine, L-lysine, limestone, dicalcium phosphate, and vitamin E, and then selenium sources were added in the required quantities. Feed consumption and egg yields were monitored daily, and FCR were calculated (Table 3).

TABLE 2 Composition of concentrated feed to be used in present experiments.

Feed materials	%
Corn	52.21
Soybean meal	40.79
Corn gluten	3.09
Vegetable oil	1
Marble powder	1.20
Dicalcium phosphate	0.78
Lysin	0.05
Methionine	0.13
Vitamin–mineral premix[a]	0.50
Salt	0.25

[a]Each 2.5 kg of vitamin–mineral premix includes vitamin A 12,000,000 IU, vitamin D3 2,400,000 IU, vitamin E 20,000 mg, vitamin K3 4000 mg, vitamin B1 3000 mg, vitamin B2 7000 mg, niacin 25,000 mg, calcium D pantothenate 10,000 mg, vitamin B6 5000 mg, vitamin B12 15 mg, D biotin 75 mg, folic acid 1000 mg, choline chloride 125,000 mg, manganese 100,000 mg, iron 60,000 mg, zinc 60,000 mg, copper 5000 mg, cobalt 200 mg, and iodine 1000 mg.

TABLE 3 Nutritional values of concentrated feed to be used in present experiments.

Calculated nutrients[a]	Value
Metabolic energy, kcal/kg	2910
Dry matter, %	89.90
Crude protein, %	24.00
Calcium, %	0.80
Phosphorus, %	0.32
Sodium, %	0.12
Lysin, %	1.30
Methionine + cysteine, %	0.89

Note: Each 2.5 kg of vitamin–mineral mixture includes vitamin A, 12,500,000 IU; vitamin D3, 3,000,000 IU; vitamin E, 20,000 mg; vitamin K3, 3000 mg; vitamin B1, 2.500 mg; vitamin B2, 7000 mg; vitamin B6, 5000 mg; vitamin B12, 20 mg; niacin, 20,000 mg; Cal-D-Pan, 15,000 mg; folic acid, 1000 mg; biotin, 20 mg; vitamin C, 50,000 mg; choline chloride, 300,000 mg; manganese, 80,000 mg; iron, 70,000 mg; zinc, 50,000 mg; copper, 6250 mg; iodine, 1250 mg; cobalt, 200 mg; selenium, 150 mg; canthaxanthin, 0 mg; apo-carotenoicacidest., 0 mg; and lasolosid sodium, 90,000 mg.

[a]Except for dry matter, values were calculated from NRC (1994) tables.

2.5 | Live weight and weight gains

Live weights of the animals were determined by weighing them using precision scales (± 0.01 g) at the beginning and end of the experiment. The subsequent weighing differences were calculated as live weight gain (LWG).

2.6 | Feed consumption and FCR

The weekly feed consumption of each subgroup was measured by subtracting the amount of feed remaining in feeders for six consecutive weeks from the total amount of feed given to each subgroup at the beginning of the same week. Weekly feed consumption was then divided by the number of animals in each subgroup, and weekly feed consumption was calculated as the average of subgroups and groups. Feed consumption was divided by LWG between subsequent weighing to get the feed conversion ratio.

2.6.1 | Egg internal quality traits

Egg weight was determined in 75 eggs collected every 14 days from each treatment group. Then, the egg yolk was separated from the albumen, and the yolk weight was determined using a precise scale (± 0.01 g). Color parameters of (L*, brightness; a*, redness; b*, yellowness) were measured with a Minolta CR-400 (Minolta Co., Japan) colorimeter.

2.7 | Serum biochemical parameters

On the 56th day of the experiments, during the slaughter of the animals, blood samples were taken from 12 animals from each experimental group, and samples were centrifuged to separate the serums. Serums were kept in a deep freezer at −20°C until analysis. Serum CAT, SOD, MDA, GSH-Px, total protein, total cholesterol, HDL, LDL, and Zn levels were determined by using commercial kits.

2.8 | Statistical analysis

Animals were placed into cages in randomized plots design. Statistical analyses were conducted using SAS (1985) statistical analysis

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TABLE 4 Live weight, live weight gains and weekly average live weights of treatment groups.

Parameter	Control	3 mg/kg inorganic Zn-supplemented group	6 mg/kg inorganic Zn-supplemented group	3 mg/kg organic Zn-supplemented group	6 mg/kg organic Zn-supplemented group	3 mg/kg plant extract nano-Zn-supplemented group	6 mg/kg plant extract nano- Zn-supplemented group	SEM	*P*
Initial live weight, g	204.92	203.76	204.04	205.24	205.32	203.60	206.40	0.659	0.921
Final live weight, g	235.40	235.16	234.80	235.28	235.32	235.96	235.60	0.688	0.999
Change in live weight, g	30.48^{abc}	31.40^{ab}	30.76^{abc}	30.04^{bc}	30.00^{bc}	32.36^{a}	29.20^{c}	0.251	0.021
Egg yield, number/day/25 quail	21.07^{c}	23.62^{b}	23.43^{bc}	23.71^{b}	23.43^{c}	24.03^{a}	24.04^{a}	0.189	<0.001
Egg yield, %	84.29^{c}	94.49^{ba}	93.72^{b}	94.85a	93.71^{b}	96.13^{a}	96.15^{a}	0.754	<0.001

Note: The means indicated with different letters (a–c) in the same row are significantly different.
Abbreviations: P, significance level; SEM, standard error of the mean; Zn, zinc.

software following randomized plots design. Significant means were compared with the use of Duncan's test. The significance level was taken as 5% ($P < 0.05$) (SAS Institute, 1985).

3 | RESULTS

3.1 | Live weight and egg yield parameters

The average values for live weight (LW) are presented in Table 4. Zn supplementations did not generate significant differences in the LWG of the groups ($P > 0.05$). The highest change in LWG was seen in 3 mg/kg plant extract nano-Zn-supplemented groups, and the lowest was in 6 mg/kg plant extract nano-Zn-supplemented groups ($P < 0.05$). The highest egg yield (number and %) was obtained from 3 and 6 mg/kg plant extract nano-Zn-supplemented groups, and the lowest egg yield was obtained from the control group. Supplementation of different zinc sources into quail rations increased egg yields ($P < 0.05$).

3.2 | Feed consumption and FCR

The feed consumption and feed conversion ratios increased significantly at weekly intervals ($P < 0.05$) (Table 5). The application of 6 mg/kg nano-Zn provided the highest feed consumption, while the lowest was detected in the 3 mg/kg inorganic Zn-supplemented group in the first week and in control groups in the second to sixth weeks ($P < 0.05$). The highest FCR was obtained from applying 6 mg/kg of plant extract nano-Zn-supplemented group for all periods except for the first week. The lowest FCR values were generally obtained from the 6 mg/kg inorganic Zn-treated group except for the third week (Table 5).

3.3 | Egg weight (g)

The weekly egg weights of the treatment groups are given in Table 6. The highest egg weight in the first to sixth weeks was detected in the 6 mg/kg inorganic Zn-supplemented group, and the lowest egg weight was detected in the control group in the first week and 6 mg/kg plant extract nano-Zn-supplemented groups in the second to sixth weeks ($P < 0.05$).

3.4 | Yolk weight (g)

Weekly and overall yolk weights (g) of the treatment groups are provided in Table 7. In the first to sixth weeks, no significant difference was detected in yolk weights ($P > 0.05$).

3.5 | Egg yolk color parameters (L*, a*, b*)

Egg yolk color (L*, a*, b*) parameters of the treatment groups are given in Table 8. Different zinc sources did not have significant effects

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TABLE 5 Weekly and overall feed consumption and feed conversion ratios of the treatment groups.

Period	Parameter	Control	3 mg/kg inorganic Zn-supplemented group	6 mg/kg inorganic Zn-supplemented group	3 mg/kg organic Zn-supplemented group	6 mg/kg organic Zn-supplemented group	3 mg/kg plant extract nano-Zn-supplemented group	6 mg/kg plant extract nano- Zn-supplemented group	SEM	P
1st week	Feed consumption, g	38.81^{b}	38.61^{b}	38.75^{b}	38.89^{b}	39.33^{a}	38.94^{b}	39.48^{a}	0.056	<0.001
	FCR, g/g	3.36^{a}	3.24^{ab}	3.03^{c}	3.10^{bc}	3.33^{a}	3.25^{ab}	3.28^{ab}	0.028	0.010
2nd week	Feed consumption, g	38.02^{c}	38.72^{b}	39.24^{a}	39.25^{a}	39.49^{a}	39.31^{a}	39.49^{a}	0.076	<0.001
	FCR, g/g	3.11^{bc}	3.11^{bc}	3.02^{c}	3.03^{c}	3.15^{b}	3.20^{b}	3.41^{a}	0.025	<0.001
3rd week	Feed consumption, g	38.32^{c}	38.75^{ab}	39.85^{a}	39.67^{b}	39.67^{b}	39.74^{ab}	39.86^{a}	0.099	<0.001
	FCR, g/g	3.24^{abc}	3.15^{bc}	3.12^{c}	3.14^{bc}	3.10^{c}	3.34^{ab}	3.40^{a}	0.028	0.016
4th week	Feed consumption, g	38.34^{c}	39.09^{b}	39.80^{a}	39.74^{ab}	39.75^{ab}	39.83^{a}	39.89^{a}	0.096	<0.001
	FCR, g/g	3.18^{bc}	3.39^{ab}	3.15^{c}	3.17^{bc}	3.18^{bc}	3.39^{ab}	3.46^{a}	0.031	0.012
5th week	Feed consumption, g	38.36^{c}	39.12^{b}	39.83^{a}	39.77^{ab}	39.76^{ab}	39.82^{ab}	39.93^{a}	0.096	<0.001
	FCR, g/g	3.07^{c}	3.18^{b}	3.05^{c}	3.13^{bc}	3.12^{bc}	3.29^{ab}	3.35^{a}	0.025	0.007
6th week	Feed consumption, g	38.44^{c}	39.23^{bc}	39.84^{ab}	39.80^{b}	39.82^{b}	39.89^{ab}	40.03^{a}	0.095	<0.001
	FCR, g/g	3.15^{bc}	3.26^{bc}	3.08^{c}	3.13^{bc}	3.09^{c}	3.30^{ab}	3.46^{a}	0.027	<0.001

Note: The means indicated with different letters (a–c) in the same row are significantly different.
Abbreviations: FCR, feed conversion ratio; P, significance level; SEM, standard error of the mean; Zn, zinc.

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TABLE 6 Weekly and overall average egg weights of the treatment groups (g).

Period	Parameter	Control	3 mg/kg inorganic Zn-supplemented group	6 mg/kg inorganic Zn-supplemented group	3 mg/kg organic Zn-supplemented group	6 mg/kg organic Zn-supplemented group	3 mg/kg plant extract nano-Zn-supplemented group	6 mg/kg plant extract nano-Zn-supplemented group	SEM	*P*
1st week	Egg weight, g	11.67^{c}	11.98^{bc}	12.93^{a}	12.55^{ab}	11.84^{bc}	11.99^{bc}	12.08^{bc}	0.102	0.012
2nd week	Egg weight, g	12.26^{bc}	12.54^{ab}	13.10^{a}	12.97^{ab}	12.58^{ab}	12.30^{bc}	11.62^{c}	0.099	<0.001
3rd week	Egg weight, g	11.89^{bc}	12.35^{abc}	12.84^{a}	12.69^{ab}	12.93^{a}	11.95^{bc}	11.78^{c}	0.111	0.010
4th week	Egg weight, g	12.14^{abc}	11.62^{c}	12.72^{a}	12.56^{ab}	12.58^{ab}	11.82^{bc}	11.60^{c}	0.108	0.007
5th week	Egg weight, g	12.52^{abc}	12.39^{bc}	13.15^{a}	12.75^{ab}	12.77^{ab}	12.17^{bc}	11.92^{c}	0.096	0.011
6th week	Egg weight, g	12.24^{bc}	12.08^{bc}	13.01^{a}	12.72^{ab}	12.95^{a}	12.12^{bc}	11.63^{c}	0.097	<0.001

Note: The means indicated with different letters (a–c) in the same row are significantly different.
Abbreviations: P, significance level; SEM, standard error of the mean; Zn, zinc.

TABLE 7 Weekly and overall yolk weights of the treatment groups.

Period	Parameter	Control	3 mg/kg inorganic Zn-supplemented group	6 mg/kg inorganic Zn-supplemented group	3 mg/kg organic Zn-supplemented group	6 mg/kg organic Zn-supplemented group	3 mg/kg plant extract nano-Zn-supplemented group	6 mg/kg plant extract nano-Zn-supplemented group	SEM	*P*
1st week	Yolk weight, g	3.67	3.81	3.54	3.43	3.63	3.50	3.80	0.083	0.863
2nd week	Yolk weight, g	3.73	3.98	3.96	3.95	3.85	3.56	3.70	0.056	0.339
3rd week	Yolk weight, g	3.75	4.00	3.56	3.65	3.79	3.86	3.80	0.074	0.794
4th week	Yolk weight, g	3.78	3.62	3.81	3.83	3.78	3.32	3.62	0.058	0.229
5th week	Yolk weight, g	3.97	3.95	4.06	3.88	4.02	3.93	3.85	0.037	0.777
6th week	Yolk weight, g	3.58	3.70	3.96	3.80	3.97	3.55	3.67	0.054	0.200

Note: The means indicated with different letters (a–c) in the same row are significantly different.
Abbreviations: P, significance level; SEM, standard error of the mean; Zn, zinc.

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TABLE 8 Weekly and overall egg yolk color parameters of the treatment groups.

Period	Parameter	Control	3 mg/kg inorganic Zn-supplemented group	6 mg/kg inorganic Zn-supplemented group	3 mg/kg organic Zn-supplemented group	6 mg/kg organic Zn-supplemented group	3 mg/kg plant extract nano-Zn-supplemented group	6 mg/kg plant extract nano-Zn-supplemented group	SEM	P
1st week	L*	69.17	67.99	52.83	59.76	66.48	54.09	67.24	1.847	0.057
	a*	8.46	8.58	7.41	6.88	8.30	6.01	8.87	0.296	0.088
	b*	63.91^{ab}	64.36^{ab}	51.50^{bc}	57.23^{abc}	64.58^{ab}	47.05^{c}	67.26^{a}	1.930	0.029
2nd week	L*	64.02	57.49	62.29	60.54	59.47	57.82	59.45	1.061	0.662
	a*	7.66^{ab}	6.92^{bc}	7.98^{a}	7.40^{a}	7.33^{ab}	6.99^{b}	5.18^{c}	0.227	0.027
	b*	60.20	53.77	57.48	58.17	56.33	56.16	54.16	1.003	0.648
3rd week	L*	64.31	68.86	60.77	58.93	68.04	67.62	67.76	1.264	0.210
	a*	6.38	6.64	5.72	5.35	6.98	6.05	6.84	0.198	0.239
	b*	62.65	63.83	58.17	56.66	66.99	66.02	64.75	1.193	0.158
4th week	L*	65.93	65.07	66.64	66.45	67.21	61.03	64.91	0.949	0.681
	a*	6.26	5.99	6.30	6.17	6.73	5.65	7.15	0.169	0.305
	b*	65.67	63.62	64.87	65.16	64.06	59.82	61.71	0.915	0.622
5th week	L*	65.37	64.92	66.02	65.01	64.97	64.91	64.06	0.511	0.982
	a*	6.81	6.10	6.58	5.98	6.15	5.91	6.82	0.165	0.583
	b*	61.30	63.51	61.40	62.46	64.46	64.49	65.54	0.471	0.103
6th week	L*	65.35	64.89	64.19	64.26	65.14	58.16	64.57	0.917	0.378
	a*	7.03^{ab}	6.18^{bc}	5.20^{c}	7.61^{ab}	7.59^{ab}	7.44^{ab}	7.94^{a}	0.203	<0.001
	b*	65.16	63.32	63.11	62.35	66.96	62.29	68.27	0.959	0.529

Note: The means indicated with different letters (a–c) in the same row are significantly different.
Abbreviations: P, significance level; SEM, standard error of the mean; Zn, zinc.

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TABLE 9 Blood serum parameters of the treatment groups.

Parameter	Control	3 mg/kg inorganic Zn-supplemented group	6 mg/kg inorganic Zn-supplemented group	3 mg/kg organic Zn-supplemented group	6 mg/kg organic Zn-supplemented group	3 mg/kg plant extract nano-Zn-supplemented group	6 mg/kg plant extract nano-Zn-supplemented group	SEM	*P*
Total protein	2.38	2.56	2.82	2.48	2.52	2.63	2.70	0.597	0.559
Total glyceride	244.22	235.18	231.05	228.31	233.07	249.84	259.55	3.435	0.143
AST	187.54^{ab}	162.72^{c}	167.55^{bc}	171.56^{bc}	173.26^{bc}	181.56^{bc}	207.79^{a}	3.141	*<0.001*
ALT	9.71^{ab}	7.80^{b}	7.58^{b}	9.12^{b}	9.48^{ab}	9.85^{ab}	12.13^{a}	0.353	*0.011*
Glucose	328.76	324.12	319.23	328.76	312.32	305.92	315.96	4.159	0.738
Total cholesterol	223.85	236.63	244.40	252.05	255.03	221.22	259.71	4.054	0.055
Zn	2.66^{c}	3.15^{b}	3.29^{b}	3.32^{b}	3.18^{b}	3.86^{a}	3.21^{b}	0.058	*<0.001*

Note: The means indicated with different letters (a–c) in the same row are significantly different.
Abbreviations: P, significance level; SEM, standard error of the mean; Zn, zinc.

on egg yolk color L* (brightness) values ($P > 0.05$). Effects of Zn sources on egg yolk color a* (red-green) values were found to be significant in the second and sixth weeks ($P < 0.05$) but insignificant in the other weeks ($P > 0.05$). Except for the first week, effects of Zn sources on egg yolk color b* (yellow-blue) values were not found to be significant ($P > 0.05$).

3.6 | Blood serum parameters

Applying 6 mg/kg plant extract nano-Zn significantly increased the AST and ALT values and provided the highest AST and ALT values ($P < 0.05$). However, the highest Zn value was found in the 3 mg/kg plant extract nano-Zn-supplemented group (Table 9).

4 | DISCUSSION

In this study, different Zn sources were supplemented (3 and 6 mg/kg) into quail rations, and the effects of different Zn sources on live weight, live weight change, egg yield, feed consumption, FCR, egg quality traits, and serum biochemical parameters were investigated.

Different Zn sources did not have any significant effects on live weights. The findings of this study agree with the results of previous studies conducted with Zn supplementations (Barzegar et al., 2020; Cufadar et al., 2020; Sahin et al., 2005; Sevim & Olgun, 2021; Zhao et al., 2014). Reda et al. (2021) indicated that biological nano-mineral increased live weights. In this study, Zn supplementations increased egg yields. Torki et al. (2015) reported that Zn supplementations into poultry diets increased egg yields. It was reported that Zn supplementations into quail diets increased egg yields (Abbasi et al., 2022). However, another study reported that Zn supplementations did not significantly affect egg yields (Karimi et al., 2018; Tabatabaie et al., 2007). In this study, plant extracts nano-Zn supplementations increased feed consumption and conversion ratios. In contrast to our results, earlier studies stated that the feed consumption of quail was not affected by different Zn sources (Cufadar et al., 2020; Tatlı et al., 2019). Darmiyan et al. (2020) reported that different zinc sources decreased feed consumption but increased feed conversion ratio and live weight of quail. In this study, 6 mg/kg plant extract nano-Zn supplementations decreased the egg weight. Torki et al. (2015) reported that 40 mg/kg Zn supplementation into basal diets of laying hens led to an increase in egg yield and weight, similar to our findings. It was reported in a previous study that nano-ZnO supplementations in laying hen diets did not affect egg yolk weight (Abedini et al., 2018a). The findings indicate that different zinc sources did not affect the egg yolk color L* b* values of layer quail.

Different Zn sources resulted in significant differences in egg yolk color a* (red-green) values in the second and sixth weeks. Similar to the present findings, previous studies report that nano-Zn supplementations did not affect the internal quality traits of eggs (Abedini et al., 2018b; Idowu et al., 2011; Mao & Lien, 2017). It was observed in this study that 6 mg/kg plant extract nano-Zn supplementations

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into quail diets increased blood AST and ALT values. Reda et al. (2021) supplemented quail diets with biological nano-minerals and reported similar findings to the present study. In this study, the effects of different zinc sources on total protein, glyceride, glucose, and cholesterol values were insignificant. Abbasi et al. (2022) conducted a study on quail and reported that Zn supplementations did not change the serum glucose, cholesterol, triglyceride, calcium, and phosphorus contents. Consistent with the present findings, Jenner et al. (2007) reported that zinc supplementations in rabbit diets did not change serum cholesterol concentrations.

5 | CONCLUSION

Present findings revealed that different Zn sources supplemented into quail diets increased egg yields, feed consumption, and conversion ratios. The 3 and 6 mg/kg plant extract nano-Zn supplementations into quail diets did not cause a toxic effect on quail and had no adverse effects on animal performance or other investigated parameters. However, high doses of nano-Zn particles from plant extracts may adversely affect yield parameters. In addition, current findings on quail may also have similar effects on other poultry species. Therefore, further research is required to reveal the effects of different Zn sources on other poultry species' growth performance and egg quality parameters.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

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