Egyptian Journal of Veterinary Sciences

https://ejvs.journals.ekb.eg/

Impact of Dietary Zinc Sources and Levels on Growth Performance, and Immune Response in Fattening Rabbits

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Abstract

THIS STUDY aimed to assess how different levels and sources of dietary zinc affect the growth performance, carcass characteristics, certain blood parameters, and gene expression in New Zealand White rabbits. Sixty weaned rabbits were randomly assigned to five groups. The first group served as a control (C), while the second and third groups received a basal diet enriched with 10 and 20 mg of Nano-zinc per kg, referred to as 10 NZn and 20 NZn, respectively. The fourth and fifth groups were fed a basal diet supplemented with 20 and 40 mg of organic zinc per kg, labeled as 20 OZn and 40 OZn, respectively. The trial continued until the rabbits reached 14 weeks of age. The findings showed that:

The 20 NZn and 40 OZn groups experienced significant improvements in weight gain and feed conversion ratio (FCR) compared to the control group. No significant differences were observed in the percentages of carcass, head, liver, and heart across the treatments.The rabbits on the 20 NZn diet had the lowest triglyceride levels, while those on the 10 NZn diet showed a reduction in total cholesterol compared to the control group.The 10 NZn group exhibited an over-expression of the IGF-1 gene.In summary, adding either the nano form (20 mg/kg NZn) or the organic form (40 mg/kg OZn) of zinc to the diets of growing rabbits led to enhanced growth performance, as evidenced by increased weight gain and improved FCR. However, these dietary levels did not significantly impact the expression of the IGF-1, GPX1, and MyD88 genes, highlighting the need for additional research to establish the safe levels of nano zinc in livestock feed.

Keywords: nano-zinc, organic zinc, rabbits, gene expression, growth performance.

Introduction

Many natural feed ingredients lack adequate zinc, leading to the supplementation of this trace mineral in animal diets. In poultry nutrition, the most commonly used sources for zinc are inorganic options like ZnO andZnSO4., [1-2] However, when zinc is combined with organic compounds, its absorption in animals improves compared to inorganic sources.[3-4] Organic zinc compounds have been shown to boost growth and overall performance in poultry. [5] .Zinc also plays a vital role in the antioxidant defense system; a deficiency in zinc can lead to oxidative damage from free radicals.[6-7] Additionally, zinc may stimulate the production of metallothionein, a cysteine-rich protein that helps neutralize free radicals. Research by [8] indicated that providing 80 mg/kg of zinc lactate could enhance growth performance, raise liver zinc levels, improve the structure of the duodenum, and lower diarrhea rates in growing rabbits [9] The bioavailability of minerals can be improved by increasing their surface area, yet there has been limited research on the effectiveness of nano minerals. These nano minerals are employed in the livestock sector to enhance mineral bioavailability and can be produced through various methods, including physical, chemical, and biological processes. Their applications include boosting growth, reproductive health, and immunity. For example, supplementation with 20 to 80 mg/kg of nano-zinc oxide has been shown to enhance growth performance, meat quality, and blood biochemical parameters in White New Zealand rabbits.[10] To address these challenges, nanotechnology has been increasingly utilized in animal husbandry to improve the efficiency of trace elements in animal diets. Nano-ZnO represents a promising alternative to traditional zinc sources, potentially enhancing the

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(Received 19 November 2024, accepted 05 January 2025)
DOI: 10.21608/EJVS.2025.337813.2507

performance and health of rabbits. This study aims to explore the effects of different levels and sources of dietary nano-ZnO and ZnO on growth performance, productivity, physiological parameters, and antioxidant status in growing rabb

Material and Methods

The experimental procedures were conducted at a private farm in Giza Governorate, During 2 December 2023 to 27 January 2024 with all methods approved by the Institutional Animal Care and Use Committee at Cairo University (IACUC-CU) under approval number CU II F 53 23.

Preparation of Nano Zinc Oxide (NZn) and Dietary Mixing:

To prepare NZn, 8.615 g of zinc chloride ($ZnCl_2 \cdot 2H_2O$) was dissolved in 100 ml of distilled water. Next, 100 ml of 1M NaOH was added, and the mixture was placed in an ultrasonic water bath for 30 minutes. The resulting white ZnO precipitate was collected via centrifugation, washed with distilled water and ethanol, and dried at 40°C under atmospheric conditions. For synthesizing ZnO nanoparticles, a typical experiment involved preparing 0.45M zinc nitrate ($Zn(NO_3)_2 \cdot 4H_2O$) and 0.9M NaOH solutions in distilled water. The NaOH solution was heated to approximately 55°C, and the $Zn(NO_3)_2$ solution was added dropwise over one hour while stirring vigorously. The mixture was sealed and maintained at this temperature for two hours. The precipitated ZnO nanoparticles were then rinsed with deionized water and ethanol, and dried in air at around 60°C.

In a stoppered cuvette, 3 ml of SDS (10–2 M) and 50 ml of methylene blue (MB, 0.5 × 10–3 M) were combined with 15–75 mg of arsenic (in either arsenate or arsenite form). Finally, 100 ml of $NaBH_4$ (10–1 M) was added. After 3 minutes, the decrease in absorbance at 660 nm was measured, indicating the amount of arsenic present based on the bleaching of the dye [11] To prepare the experimental diets and ensure accurate mixing of NZn with the basal diet, the required amount of NZn for each experimental level was removed, and then it was mixed into a five kg batch of the basal diet.

Organic Zinc:

Organic zinc, chelated with lysine (OZn), has a purity of 50%, featuring a 100% chelation rate, with a composition of 17% zinc and 19% lysine.

Experimental Animals, Design, and Management:

A total of 60 six-week-old New Zealand white rabbits were housed in clean, fumigated wire-floored cages in an open system. The rabbits were randomly assigned to five groups, each consisting of 12 rabbits divided into four replicates of three rabbits each. The groups were designated as follows:

-T1: Basal diet without supplementation (control).

-T2: Basal diet supplemented with 10 mg/kg nano-zinc oxide (10 NZn).

-T3: Basal diet supplemented with 20 mg/kg nano-zinc oxide (20 NZn).

-T4: Basal diet supplemented with 20 mg/kg zinc glycine (20 OZn.(

-T5: Basal diet supplemented with 40 mg/kg zinc glycine (40 OZn).

Throughout the 8-week experimental period, all groups received iso-caloric (2510 DE kcal/kg) and iso-nitrogenous (17.00%) diets, formulated according to the guidelines in [12] (see Table 1). Fresh water and pellet feed were provided *ad libitum*.

The rabbits were weighed at the beginning (6 weeks) and end (14 weeks) of the growth trial, with weekly monitoring of feed intake. Weight gain and feed conversion ratio (grams of feed per gram of gain) were calculated. At the end of the trial, four rabbits from each group were fasted overnight and then evaluated for carcass weight and giblet weights (heart, liver, and kidney) as a percentage of live weight at slaughter.

Twenty blood samples were collected in tubes without anticoagulant, centrifuged at 3000 rpm for 15 minutes to obtain serum, which was stored at -20°C until analysis. Various parameters, including total protein (TP; g/dl), albumin (g/dl), globulin (g/dl), total cholesterol (mg/l), triglycerides (mg/l), creatinine (mg/dl), urea (mg/dl), aspartate aminotransferase (AST; u/l), and alanine aminotransferase (ALT; u/l), were measured using commercial kits from Biodiagnostic Company.

RNA Extraction:

For gene expression analysis, liver tissue samples (three from each treatment) were quickly frozen in dry ice and stored at -80°C until use. Total RNA extraction was performed on three independent replicates per treatment using the GeneJET RNA Purification Kit (Thermo Scientific, USA), following the manufacturer's guidelines. RNA purity and concentration were assessed using a NanoDrop spectrophotometer (Thermo Scientific, USA). The extracted mRNA was then converted to complementary DNA (cDNA) using RevertAid™ H Minus Reverse Transcriptase and Oligo (dT)18 primer (Thermo Scientific, USA)(

Quantitative Real-Time PCR

The expression levels of four specific genes were measured using the AriaMxe Real-Time PCR machine (Agilent Technologies, USA). The reaction mixture consisted of 25 µl, including 15 µl of SYBR® Green master mix, 8 µl of cDNA, and 1 µl each of forward and reverse primers, with primer sequences provided in Table 5. Quantitative real-time PCR (qRT-PCR) was conducted under the following cycling

conditions: an initial activation step at 95°C for 15 minutes, followed by 40 cycles of 95°C for 15 seconds (denaturation), 60°C for 15 seconds (annealing), and 72°C for 15 seconds (extension). A melting curve analysis was performed to confirm the specificity of the PCR amplification.

Gene Expression Data Analysis

The relative mRNA levels of the target genes were calculated using the comparative 2−ΔΔCt method [13],(One of the most common approaches used in qPCR analysis is the ΔΔCT method – pronounced "delta-delta-C-T," and sometimes abbreviated ddCt for convenience.) normalizing against the GAPDH (glyceraldehyde-3-phosphate dehydrogenase) gene as a housekeeping reference. Data analysis was carried out following the methodology from the referenced study [14], and gene expression graphs were generated using the ggplot package in R(ggplot2 is a popular R package that lets you create graphics using the Grammar of Graphics.).

Statistical Analysis

Data from all response variables were subjected to one - way analysis of variance (SAS, 1994). Variables having a significant F-test ($P<0.05$) were compared using Duncan's Multiple Range Test (Duncan, 1955).

Model:

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

Where:

$\mathbf{Y_{ij}}$ = observations

$\boldsymbol{\mu}$ = Overall mean of Y_{ij}

$\mathbf{T_i}$ = experimental treatments (i = 1.2 unit)

$\mathbf{e_{ij}}$ = Random error [15]

Results

Table 2 summarizes the effects of different treatments on growth performance parameters. It is clear that the final weight significantly increased in the 20 NZn, 40 OZn, and 20 OZn groups compared to the control and 10 NZn groups.

For overall weight gain, the 20 NZn and 40 OZn groups exhibited significantly higher increases than the control and 10 NZn groups. Additionally, feed intake was significantly higher in the 20 NZn and 40 OZn groups, while the control group had the lowest intake; the 10 NZn and 20 OZn groups had intermediate values.Regarding the feed conversion ratio (FCR), the 40 OZn group achieved the best ratio at 3.26, closely followed by the 20 NZn group at 3.30. The 20 OZn and 10 NZn groups recorded FCRs of 3.67 and 4.90, respectively, with the control group showing the lowest at 5.43.

Carcass Characteristic:

Table 7 presents the impact of dietary zinc sources and levels on carcass characteristics. All carcass parameters (carcass %, heart %, liver %, spleen %, and head %) were unaffected by the treatments. However, the kidney percentage exhibited significant differences, with the control group having the highest percentage (0.98%), followed by 10 NZn (0.77%), 20 NZn (0.86%), and 40 OZn (0.83%), while the 20 OZn group had the lowest at 0.73%.

Blood Constituents:

Table 9 outlines the effects of various treatments on blood parameters. For total protein, rabbits fed 10 NZn or 20 OZn did not show significant differences from the control group . The 40 OZn group had the lowest total protein level. Albumin levels were not significantly affected by any treatment, while globulin levels improved across all groups, , 10 NZn, 20 NZn, and 20 OZn, respectively. The lowest globulin value was in the 40 OZn group Regarding lipid profiles, rabbits on a 20 NZn diet had the lowest triglyceride levels , while the 40 OZn group had the highest . The 10 NZn group experienced a decrease in total cholesterol , while the 20 NZn group saw an increase .

In terms of kidney function, as shown in Table 9, the 40 OZn group had elevated urea and creatinine levels compared to the 10 NZn group . A similar trend was observed for liver function, where the 40 OZn group recorded higher ALT and AST values than the 10 NZn group; nonetheless, all kidney and liver function measurements remained within normal limits.

Gene Expression

Fig.1, illustrates the findings from the gene expression analysis. For the glutathione peroxidase 1 (GPX1) gene, no differences in expression were noted between the Nano zinc 10 and organic zinc 20 treatments. However, the Nano zinc 20 treatment led to a down-regulation of this gene, indicating increased oxidative stress associated with the supplementation. In contrast, organic zinc 40 resulted in the up-regulation of the GPX1 gene.

The expression of the Insulin-Like Growth Factor 1 (IGF-1) gene showed distinct patterns from GPX1. Nano zinc supplementation led to an increase in IGF-1 expression, peaking with Nano zinc 10, while a higher dose of 20 reduced the expression. Organic zinc 20 had no effect on IGF-1 expression, but organic zinc 40 caused a significant decrease.For the Myeloid differentiation primary response 88 (MYD88) gene, organic zinc 40 did not influence its expression level, while all other treatments resulted in a down-regulation of MYD88 transcriptionThe most substantial reductions in MYD88 expression were observed with Nano zinc supplementation at both 10 and 20.

Discussion

Growth Performance:

This study examined the impact of various zinc sources and levels in the diets of growing rabbits on physiological and productive parameters. The

improvement in growth performance observed at higher levels of nano-zinc (20 mg/kg) and organic zinc (40 mg/kg) may be attributed to the unique physico-chemical properties of nano-zinc[16]. . The increase in live weight could be linked to enhanced digestion and nutrient absorption in the gastrointestinal tract, likely due to the greater bioavailability of zinc in its nanoparticle [17]. form. Additionally, the benefits of chelated organic zinc as a growth factor may also play a role. These findings are consistent with previous research indicating that rabbits fed diets containing 80 mg Zn/kg (in the form of ZnSO4 versus Zn-Met) [18] exhibited improved daily weight gains. Furthermore, several studies have reported enhanced weight gain in rabbits fed various levels of nano-zinc oxide. For example, adding 50 mg/kg of nano-zinc oxide also resulted in improved weight gain[19]. . Similarly, noted increased body weight gain with organic zinc levels of 150, 300, and 450 mg/kg. Our results align with findings that show feed intake in rabbits increases linearly with zinc oxide nanoparticle supplementation.[20]. [19] noted improvement in rabbits FCR which fed dietary 50 mg/kg nano zinc oxide.

Carcass Characteristics:

Some groups (10 NZn and 20 OZn) displayed a numerical increase in carcass percentage, possibly due to better zinc absorption from nano-zinc and the advantages of its nano size. Nano-sized zinc oxide exhibits distinct properties compared to bulk zinc oxide [22] noted improvement in rabbits FCR which fed dietary 50 mg/kg nano zinc oxide; smaller particle sizes enhance chemical reactivity. The positive charge of nano-sized ZnO facilitates greater cellular uptake due to its strong interaction with the negatively charged plasma membrane[23]. . This aligns with[20] noted improvement in rabbits FCR which fed dietary 50 mg/kg nano zinc oxid. Findings that indicated no significant differences in carcass characteristics among rabbits fed different levels of nano-zinc[17].

Blood Constituents:

The study showed an increase in total protein and albumin, supporting earlier findings that noted improvements in these parameters with dietary zinc amino acids [17].

Lipid Profile:

Our results correlate with earlier studies such as Eder and Kirchgessner [25] indicating that zinc deficiency can lead to triacylglycerol accumulation in the liver. Zinc plays a crucial role in regulating lipid metabolism and is necessary for the expression of genes involved in lipid breakdown. Additionally, our findings are consistent with [34, 45] research that demonstrated a significant reduction in serum cholesterol levels when zinc nanoparticles were included in the diet[9].

Kidney Function:

Creatinine and urea levels were lower in rabbits fed various levels of nano-zinc oxide compared to controls, which is supported by prior research such as [17] . However,-[31].found no significant differences in kidney function between groups fed organic zinc and controls.

Liver Function:

Similar findings were reported regarding the liver enzymes ALT and AST [16], with lower levels observed in rabbits receiving nano-zinc oxide. Conversely, other research [27]), indicated no significant changes in these liver function markers with dietary zinc amino[27]

Gene Expression:

In this study, we examined the expression of three genes with distinct biological functions. The first gene, GPX1, encodes the enzyme glutathione peroxidase 1, which is crucial for eliminating hydrogen peroxide and organic peroxides from the body [28, 29]. By doing so, this enzyme protects cells from oxidative stress and associated damage .

The second gene, IGF1, encodes insulin-like growth factor 1, a key protein involved in cell growth, development, and metabolism [30]. Structurally similar to insulin, IGF1 acts as a mediator of growth hormone effects and plays a critical role in regulating cell proliferation, differentiation, and apoptosis. It is essential for normal growth, muscle development, and metabolic processes throughout life [31, 32].

The third gene analyzed, MYD88, encodes a protein central to the innate immune response [33]. MYD88 serves as an adaptor protein in the signaling pathways of various pattern-recognition receptors. It facilitates the activation of nuclear factor-kappa B (NF-κB) and mitogen-activated protein kinase signaling pathways, which lead to the production of inflammatory cytokines and the initiation of immune responses against pathogens [34, 35].

Conclusion

In summary, incorporating higher levels of zinc-either in nano form (20 mg/kg NZn) or organic form (40 mg/kg OZn)—in the diets of growing New Zealand white rabbits can enhance growth performance, reflected in increased weight gain and improved feed conversion ratios. However, these elevated zinc levels did not significantly alter the expression of key genes (IGF-1, GPX1, and MYD88), indicating a need for further research to establish safe levels of nano-zinc in livestock diets.

*Acknowledgments:*Not applicable.

Funding statement:

This study didn't receive any funding support

Declaration of Conflict of Interest:

The authors declare that there is no conflict of interest.

TABLE 1. Ingredients and calculated analysis of the basal diet

Ingredient	%	Calculated chemical analysis**	
Wheat bran	20.54	Crude protein (%)	17.00
Soybean meal (44%)	15.64	Digestible energy (kcal/kg)	2510
Clover hay (15%)	30.00	Crude fiber (%)	11.72
Yellow corn	27.33	Ether extract (%)	2.76
Molass	3.00	Calcium (%)	1.20
Limestone	0.80	Total phosphorus (%)	0.80
di-Calcium phosphate	1.84	Lysine (%)	0.82
NaCl	0.35	Methionine + cysteine	0.74
Vitamins and menial premix*	0.30		
Dl- Methionine	0.20		
Total	100		

*Each 3 kg contain: 6000000 IU Vit. A; 900000 IU Vit. D3; 40000 mg Vit. E; 2000 mg Vit. K3; 2000 mg Vit. B1; 4000 mg Vit. B2; 2000 mg Vit. B6; 10 mg Vit. B12; 50 mg Biotin; 10000 mg Pantothenic acid; 50000 Niacin; 3000 mg Folic acid; 250000 mg Choline; 8500 mg Mn; 50000 mg Zn; 50000 mg Fe; 200 mg I; 100 mg Se, 5000 mg Cu, and 100 mg Co.According to NRC (1977)

TABLE 2. Effect of different treatments on rabbit's growth performance during overall period.

	T1 Control	T2 10 NZn	T3 20 NZn	T4 20 OZn	T5 40 OZn	Sig	± SEM
IW (g)	1238	1210	1357	1350	1233	NS	72.3
Final weight (g)	2094^{b}	2178^{b}	3319^{a}	2915^{a}	3054^{a}	*	162.8
Weight gain (g)	856^{c}	968^{c}	1962^{a}	1565^{b}	1821^{ab}	*	91.6
Feed intake (g)	4644^{c}	4740^{bc}	6465^{a}	5740^{ab}	5942^{a}	*	323.8
FCR	5.43^{a}	4.90^{b}	3.30^{d}	3.67^{c}	3.26^{e}	*	0.007

a ,b, c, d and e mean within some rows with differing superscript are significantly differ (P<0.05).
T1: Control, T2(10 NZn): 10mg/kg Nano-Zn, T3(20 NZn): 20 mg/kg Nano-Zn, T4(20 OZn): 20 mg/kg organic-Zn, T5 (40 OZn): 40 mg/kg organic-Zn.

TABLE 3. Effect of different treatments on carcass characteristics

	T1 Control	T2 10 NZn	T3 20 NZn	T4 20 OZn	T5 40 OZn	Sig	± SEM
Carcass (%)	51.48	54.82	51.22	57.68	51.08	NS	2.94
Heart (%)	0.38	0.28	0.34	0.36	0.34	NS	0.04
Liver (%)	3.22	3.20	3.12	2.96	3.17	NS	0.20
Spleen (%)	0.10	0.09	0.08	0.08	0.08	NS	0.01
Kidney (%)	0.98^{a}	0.77^{ab}	0.86^{ab}	0.73^{b}	0.83^{ab}	*	0.07
Head (%)	1.09	1.08	0.99	1.04	0.92	NS	0.08

a and b mean within some rows with differing superscript are significantly differ (P<0.05).
T1: Control, T2(10 NZn): 10mg/kg Nano-Zn, T3(20 NZn): 20 mg/kg Nano-Zn, T4(20 OZn): 20 mg/kg organic-Zn, T5 (40 OZn): 40 mg/kg organic-Zn.

TABLE 4. Effect of different treatments on some blood parameters.

Items	T1 Control	T2 10 NZn	T3 20 NZn	T4 20 OZn	T5 40 OZn	Sig	± SEM
Total Protein (g/dl)	6.70 ^{ab}	7.30^{a}	5.93^{bc}	7.00^{a}	5.17^{c}	*	0.27
Albumin (g/dl)	2.33	2.56	2.13	2.13	2.53	---	0.18
Globulin (g/dl)	4.37^{a}	4.73^{a}	3.73^{ab}	4.87^{a}	2.63^{b}	*	0.43
TRI (mg/l)	70.63^{b}	62.20^{c}	53.73^{d}	66.97^{b}	82.73^{a}	*	1.1
CHO(mg/l)	53.37^{c}	46.50^{d}	74.83^{a}	49.83^{cd}	63.87^{b}	*	1.53
Urea (mg/dl)	22.80^{bc}	17.73^{d}	24.47^{b}	20.10^{cd}	29.80^{a}	*	0.93
Creatinine (mg/dl)	0.68^{bc}	0.54^{d}	0.74^{b}	0.62^{cd}	0.86^{a}	*	0.02
ALT(mg/dl)	18.40^{c}	15.03^{d}	21.0^{b}	16.2^{cd}	23.5^{a}	*	0.75
AST(mg/dl)	29.3^{bc}	22.9^{d}	32.13^{b}	26.0 ^{dc}	38.4^{a}	*	1.20

a ,b, c and d mean within some rows with differing superscript are significantly differ (P<0.05).
T1: Control, T2(10 NZn): 10mg/kg Nano-Zn, T3(20 NZn): 20 mg/kg Nano-Zn, T4(20 OZn): 20 mg/kg organic-Zn, T5 (40 OZn): 40 mg/kg organic-Zn.

TABLE 5. The primer sequences of IGF-1, MyD88 and GPx1 genes.

Gene	Accession number	Primer sequences (5'--3')	Product size (bp)	Reference
IGF-1	NM_001082026.1	F: TGTGATCTGAGGAGGCTGGA R:GAAGCAGCACTCATCCACGAT	181	https://doi.org/10.1080/10495398.2022.2140055
MyD88	XM_008252715.2	F: ATGGTGGTGGTCGTCTCG R: GTGATGAACCGCAGGATACT	161	https://doi.org/10.1007/s12602-018-9476-x
GPx1	NM_001085444.1	F:CAGTTTGGGCATCAGGAGAAC R: GCATGAAGTTGGGCTCGAA	94	https://doi.org/10.1016/j.animal.2021.100339

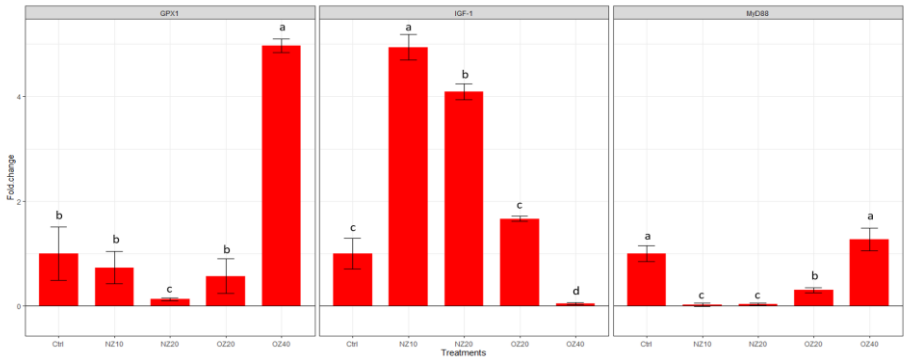

Fig.1. Effect of different treatments on GPx1, IGF-1 and MyD88 genes expressions.

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تأثير مصادر ومستويات الزنك الغذائية على أداء النمو والاستجابة المناعية في أرانب التسمين

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الملخص

تقدم الدراسة التي أجريتها حول تأثيرات مستويات ومصادر مختلفة من أكسيد الزنك النانوي الغذائي والزنك العضوي على أرانب نيوزيلندا رؤى قيمة حول كيفية تأثير هذه المكملات على مختلف معايير النمو والفسيولوجية. فيما يلي ملخص منظم بناءً على النتائج التي حددتها:

ملخص النتائج

- كانت هناك فروق غير مهمة في متوسط وزن الجسم (AV.BW) وزيادة وزن الجسم (BWG) عبر المجموعات المختلفة.

- ومع ذلك، أظهرت المجموعات التي تلقت 20 مجم نانو-زنك و40 مجم زنك عضوي مقاييس أداء أفضل بشكل ملحوظ مقارنة بمجموعات التحكم و10 مجم نانو-زنك.

أظهرت المجموعات التي تلقت مكملات 20 مجم نانو-زنك و40 مجم زنك عضوي تحسنًا في تناول العلف (FI) ونسبة تحويل العلف (FCR) مقارنة بالمجموعة الضابطة والمجموعة 10 مجم نانو-زنك طوال معظم الفترة التجريبية.

لم يتم ملاحظة أي اختلافات كبيرة في خصائص الذبيحة، بما في ذلك نسبة الذبيحة، ونسبة القلب، ونسبة الكبد، ونسبة الطحال، ونسبة الرأس عبر جميع مجموعات العلاج. وهذا يشير إلى أن المستويات المختلفة من مكملات الزنك لم تؤثر على هذه السمات المحددة للذبيحة.

- أظهرت المجموعة التي تلقت 10 مجم نانو-زنك أعلى نسبة هضم لـ CF% بنسبة 47.1%. - أسفرت المعالجات الأخرى عن معدلات هضم أقل

- البروتين الكلي: لم تظهر الأرانب التي تغذت على 10 مجم نانو-زنك (7.30 جم/ديسيلتر) و20 مجم زنك عضوي (7.00 جم/ديسيلتر) أي اختلافات كبيرة مقارنة بمجموعة التحكم (6.70 جم/ديسيلتر).

- سجلت مجموعة الزنك العضوي التي تناولت 40 مجم أدنى قيمة إجمالية للبروتين عند 5.17 جم/ديسيلتر. - الألبومين:- لم يتم ملاحظة أي اختلافات كبيرة في مستويات الألبومين في جميع مجموعات العلاج. - الجلوبيولين:- تحسنت مستويات الجلوبيولين في جميع المجموعات:

- تم العثور على أدنى مستوى للجلوبيولين في مجموعة الزنك العضوي 40 مجم عند 2.63 جم/ديسيلتر.

- الدهون الثلاثية:- حققت مجموعة نانو-زنك 20 مجم أدنى قيمة للدهون الثلاثية عند 53.73 مجم/ديسيلتر.

- تم ملاحظة أعلى قيمة للدهون الثلاثية في مجموعة الزنك العضوي 40 مجم عند 82.73 مجم/ديسيلتر.

- الكوليسترول الكلي: - سجلت مجموعة نانو-زنك 10 ملج انخفاضًا في الكوليسترول الكلي بمقدار 46.50 ملج/لتر.

- أظهرت مجموعة الزنك العضوي 40 ملج قيم يوريا وكرياتينين أعلى (29.80 ملج/ديسيلتر و0.86 ملج/ديسيلتر على التوالي) مقارنة بمجموعة نانو-زنك 10 ملج (17.73 ملج/ديسيلتر و0.54 ملج/ديسيلتر على التوالي).

- أظهرت مجموعة الزنك العضوي 40 ملج قيم ALT وAST أعلى مقارنة بمجموعة نانو-زنك 10 ملج.- كانت جميع معايير وظائف الكلى والكبد ضمن النطاقات الطبيعية.

- كانت قيم بيروكسيداز الجلوتاثيون في مجموعتي 10 ملج نانو-زنك (578.33 وحدة/مل) و20 ملج زنك عضوي (534.67 وحدة/مل) أفضل بشكل ملحوظ مقارنة بمجموعتي 20 ملج زنك عضوي (474.67 وحدة/مل) و40 ملج زنك عضوي (464.67 وحدة/مل).

- مالونديالدهيد (MDA) - تم تسجيل أقل قيم MDA لـ: - المجموعة الضابطة: 1.33 نانومول/مل - سجلت مجموعتا 10 ملج نانو-زنك و20 ملج الزنك العضوي أعلى مستويات IgG وIgM:

- كانت أدنى القيم لكل من IgG وIgM في مجموعة 40 ملج الزنك العضوي (31.67 ملج/ديسيلتر و49.20 ملج/ديسيلتر على التوالي).

- سجلت مجموعة 20 ملج الزنك العضوي أعلى عدد إجمالي للبكتيريا عند 3.3 × 10^12 وحدة دولية. - لوحظ انخفاض في أعداد البكتيريا لباقي المعاملات

الكلمات الدالة: الأرانب النيوزيلندية – أداء النمو – المعايير البيوكيميائية – مكونات المصل – العدد الميكروبي – نانو الزنك (NZn) – الزنك العضوي (OZN) – التعبير الجيني – مضادات الأكسدة.