Egypt. Poult. Sci. Vol. (44) (IV): (377-391)(2024) (2409-1303)

Egyptian Poultry Science Journal

http://www.epsj.journals.ekb.eg/

ISSN: 1110-5623 (Print) – 2090-0570 (Online)

IMPACTS OF NANO-HYDROXYAPATITE REPLACEMENT FOR DICALCIUM PHOSPHATE ON GROWTH PERFORMANCE, CARCASS TRAITS AND IMMUNE ORGANS OF BROILER CHICKS

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Received: 09/08/2024 Accepted: 30 /09 /2024

ABSTRACT: Replacing traditional di-calcium phosphate (DCP) with nano-hydroxyapatite (NHA) was investigate as a potential strategy to enhance mineral bioavailability and reduce feed costs. This study explored the impact of varying levels of dietary NHA on broiler chicks' growth performance, carcass traits, digestive tract measurements, and immune organs. A total number of 1080 unsexed one-day-old "Cobb 500" broiler chicks were distributed in a completely randomized design of six treatments with three replicates (60 chicks each). The control group (T1) contained 100% DCP of diet, treatments two (T2) to six (T6) were supplemented with NHA, which represent replacement rates of 100, 80, 60, 40 and 20% of DCP in the basal diet, respectively. The results indicate that broilers fed with 100% DCP demonstrated superior growth performance and carcass weight ($P \leq 0.05$) compared to those receiving lower NHA dosages. Specifically, the 100% DCP group achieved higher carcass weight ($P \leq 0.05$), while diets containing 80% NHA substitution for DCP resulted in higher carcass percentages. In contrast, birds on lower NHA diets (60 and 40%) exhibited higher giblet percentage ($P \leq 0.05$), and lower ($P \leq 0.05$) abdominal fat weights were observed at 40% NHA levels. The control group with 100% DCP had a significantly higher ($P \leq 0.05$) relative gut weight compared to other treatments. The spleen percentage was notably highest in the group receiving 100% NHA and NHA significantly increased thymus weight and percentage, especially T4, with similar improvements in groups T3, T4, T5, and T6. Additionally, birds fed 40% NHA showed a notable increase in the relative weight and percentage of the bursa compared to other groups. In conclusion, while NHA offer potential benefits in broiler chicken nutrition; further research are needed to determine the optimal dosage, specific conditions, sustainable and environmentally friendly options for incorporating these nanoparticles into broiler chicken feed.

Keywords: Broiler, nano-hydroxyapatite, growth performance, carcass traits, immunity.

INTRODUCTION

Nano materials have potential in a range of environmental applications owing to their extremely small particle size, large surface area, and high reactivity (Huang *et al.,* 2015). The utilization rate of nano minerals is much higher than that of conventional inorganic and organic minerals because nanoparticles can enter the animal body through direct penetration (El-Sheikh, 2017). Consequently, nano minerals can be absorbed and distributed into blood, and internal organs of animals such as the brain, heart, lung, kidney, liver, and spleen (Hillyer and Albrecht, 2001).

In recent years, nanotechnologies have increasingly applied in the field of animal and poultry husbandry. Nanotechnology is gaining ground in animal sciences by providing nanoscale solutions that are vital for living organisms. The positive effects of using nanotechnology on productive performance of animal/poultry related to improvements in appetite, daily gain, feed conversion ratio (FCR), and immunity. On other hand, the odor of poultry manure was reduce, which is conducive to bring environment improvement for instance products (Chen and Yada, 2011).

To achieve optimal growth and production potential in modern broilers, poultry diets must be formulate to provide birds with all required nutrients in adequate amounts (Daghir, 2009). It well known that, under intensive production conditions, yellow corn and soybean meal are the major feed sources of broiler diets. Up to 60-70% of the total phosphorus (P), requirements were bound up as phytate-P (Myoinositol hexaphosphate) and less availability to poultry (Nelson *et al.,* 1968). This leads to the use of inorganic sources such as mono, di or tri calcium phosphate (Ca P) and bone meal to meet the P and calcium (Ca) requirements of poultry diets (Hermes *et al.,* 1983 and NRC 1994).

Hassan *et al.* (2016) found that incorporating nano-dicalcium phosphate (NDCP) into broiler diets effectively reduced the need for dietary conventional di-calcium phosphate (CDCP) by 75%. Diets containing only 25% of the required non-phytate phosphorus in the form of NDCP were used as a viable alternative to diets containing 100% CDCP. Calcium can be effectively supplied using low-cost sources like clam shells or limestone. To ensure adequate dietary phosphorus for optimal chicken growth and development, inorganic phosphorous are used (Williams *et al.,* 2000). The inorganic phosphorous sources are relatively expensive, which encouraged the use of exogenous phytases to improve phytate P utilization in cereals and oilseed meals (Slominski, 2011 and Romano and Kumar, 2018). More recently, Sohair *et al.* (2017) reported that supplementation of 6% of NDCP practiced instead of the conventional in broiler diet. This suggests that the nano form's ability to reduce the required mineral quantity in the diet could significantly lower feed costs. Vladimir (2010) found that nano-organized calcium phosphate absorbed by 100% by animals and poultry compared with those fed traditional di-calcium phosphate (DCP). Vijayakumar and Balakrishan (2014a) reported that supplementation of 50% of (CPN) can be practiced instead of the conventional practice of DCP incorporation in broiler diet. Thus, it postulated that the usefulness of nano form in reducing the mineral quantity to 50% in the diet reduce the cost of feeding in industrial level. Hassan *et al.* (2016) concluded that using NDCP in broiler diets were successfully reduced the dietary DCP by 75%. In the same manner, using DCP in nanoparticle size allow to reduce the excreted Ca and P by about 50% which reduce the impact of poultry on environmental pollution.

The lack of information regarding the use of nanotechnology in poultry nutrition, particularly for major elements, calls for further investigation. Therefore, the present study curried out to investigate the effects of using different levels of nano-hydroxyapatite (NHA) instead of traditional dicalcium phosphate on productive performance and immune organs under intensive production of broiler chicks.

MATERIALS AND METHODS:

1-Sourse of di-calcium phosphate nanoparticles (NHA):

Di-calcium phosphate nanoparticles obtained from one of the companies specialized in this field (Nano Tech, Cairo/Egypt) in the form of NHA in quantities appropriate to the research plan. All necessary tests conducted by a specialized agency before the start of the study to assess the purity, morphology, size of di-calcium phosphate nanoparticles (nano hydroxyapatite form).

2. Birds and management:

This study conducted at the Misr/Ismailia Poultry Company in Ismailia, Egypt. One thousand and eighty Cobb 500 broiler chicks obtained from a commercial hatchery of the same company. One-day-old, unsexed chicks were individually weighed and randomly distributed into 6 groups, three replicates, of one hundred eighty chicks each. The average of the live body weight (LBW) for each group was comparable, with an overall mean of 40.61g ± 0.03. Chicks raised in a floor-closed system under controlled management conditions. Feed and water were supplied *ad-libitum*. The artificial light supplied daily (23 hours light + 1 hour dark). The ambient temperature maintained at 34-35°C during the first week of the experiment and then gradually decreased by 2-3°C per week. All chicks kept under the same management, hygienic (Vaccinated against the common poultry diseases), and environmental conditions during the experimental period, which lasted for 5 weeks. Birds observed daily for rickets and mortality.

3. Treatments and the experimental diets:

The nutritional program of the Misr/Ismailia Poultry Company, including starter, grower, and finisher diets, followed under the conditions of intensive production for the strain used in this study. Six treatments in a completely randomized design applied. The first treatment (control) consisted of a diet containing 100% DCP in its inorganic form, as recommended by the Cobb manual (2018). Treatments two to six supplemented with NHA in which represent replacement rates 100, 80, 60, 40, and 20% the basal diet, respectively, in nanoparticle form. Chicks were fed three types of diets in mash form and were formulated to be iso-caloric and iso-nitrogenous. Starter diet (0 to 8 days of age), grower diet (9 to 18 days of age) and finisher diet (19 to 35 days of age). Chemical analysis of the experimental samples and diets performed in the laboratories of the Nanotechnology Laboratory at the Regional Center for Food and Feed, Agricultural Research Center, Cairo, Egypt, according to the procedures outlined by A.O.A.C (1995). The composition and chemical analysis (calculated and determined) of the experimental basal diets for the starter, grower, and finisher phases presented in Table (1).

4- Growth parameters:

Individual LBW and feed intake (FI) per replicate recorded weekly and then FCR was calculated.

5- Economic Efficiency (EE):

The intake FI during the experimental period for each treatment multiplied by the price per kilogram of the respective experimental diet (Estimated based on local prices at the time of the experiment). Net revenue calculated by subtracting the total feed cost from the revenue generated by the sale of one kilogram of broiler. Economic efficiency (EE) then calculated by dividing the net revenue by the total feed cost.

6- Slaughtered parameters:

At the end of the experimental period (5 weeks of age), eighteen birds from each treatment group, selected to be close to the average body weight slaughtered. After feathering, the head severed close to the skull, and the feet with shanks removed at the hock joint. Carcass evisceration performed by making a posterior ventral cut to remove the visceral organs. The inedible parts (blood, feathers, head, legs, and viscera) separated, and the eviscerated carcass weighed. The proventriculus, intestines, giblets (liver, gizzard, and heart), immune organs (spleen, thymus gland, and bursa of Fabricius), and abdominal fat weighed for each bird. Dressing percentages (carcass plus giblets) calculated for each treatment group. Each carcass eviscerated then divided into two halves, with the right side further portioned into breast and thigh sections. The percentages of carcass, giblets, dressed, abdominal fat and meat yield to live body weight were calculated.

7- Statistical analysis:

Data analyzed for significance using a one-way ANOVA model, appropriate for a completely randomized design, via the General Linear Models (GLM) procedures in SPSS (IBM SPSS Statistics, version 22, USA). The following mathematical model used:

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

Where:

Y_{ij} = the observation on the j^{th} individual from the i^{th} treatment.

μ = the overall mean.

t_i = the fixed effect of the i^{th} treatment.

e_{ij} = the random error associated with the individual ij.

Means comparisons were performed-using Duncan’s multiple range tests (Duncan, 1955). Treatments differences considered significant at $P \leq 0.05$ for all measurements.

RESULTS AND DISCUSSION:

1- Growth performance:

Table (2) illustrates the impact of dietary supplementation with NHA on the growth performance and feed efficiency of broiler chickens. The overall mortality rate was within expected bounds, not exceeding 2.59%, with the number of deceased birds per treatment ranging from one to 10. In the same order, during the experimental period, the birds did not show any cases of rickets. Significant differences ($P \leq 0.01$) observed in the average values of final LBW and total body weight gain (BWG) between treatment groups, while FCR showed notable differences ($P \leq 0.05$). However, no significant variations detected in average FI values across the different treatment doses. Birds fed the 20% NHA diet had the lowest LBW values, whereas those in the 100% DCP treatment group had the highest final LBW and the corresponding values (1674.57 g versus

1971.36 g) as shown in Table (2). The best total BWG (P≤0.01) recorded in the 100% DCP group (1930.7 g, T1), while the lower BWG value observed in group T6 The highest total FI was noted in the T1 (control) group, though without significant differences.

Additionally, the 20% NHA diet group (T6) exhibited significantly the worst FCR values (P≤0.05) at 1.772, while the 100% DCP group showed the best FCR at 1.546. Compared to birds fed diets containing a low dose of NHA (20%), broilers in the control group (100% DCP) exhibited significantly better results in terms of LBW and BWG. This suggests that the low level of NHA (20%) supplementation did not meet the broilers' Ca and P requirements, negatively affecting metabolism. These findings contrast with those of Hassan *et al.* (2016), who reported that broiler chicks fed diets with lower concentrations of Ca-P nanoparticles (0.88 and 0.44%) outperformed those on a control diet. Also, Sohair *et al.* (2017) found that broilers fed a diet supplemented with NHA, replacing 6% of DCP in the basal diet achieved the best BWG and FI values, with even higher performance at 8% supplementation. Furthermore, broilers receiving a 2% NHA diet showed no significant differences in FI values compared to the control group. The various dietary levels of NHA also did not significantly affect FCR results.

In contrast to the current study, Vijayakumar and Balakrishnan (2014a) observed that broiler chicks fed diets containing 50 and 60% calcium phosphate nanoparticles exhibited significantly faster body weight gain than other treatment groups. This suggests that scaling up the industrial production of calcium phosphate nanoparticles (NCP) could potentially reduce the mineral content in broiler diets by half, leading to lower feeding costs. Hassan *et al.* (2016) observed a proportional increase in broiler weight gain as the inclusion rate of nano calcium phosphate rose from 0.44 to 1.75%. The variability in findings among feeding experiments attributed to several factors, including feed types, management practices, inclusion rates of nano-feed supplements, and the size and solubility of the nanoparticle experimental design. While there were substantial changes in FCR, the average feed consumption of each treatment group was not significantly different. The current data are consistent with those reported that broilers given diets supplemented with Ca-P NPs shown to have comparable feed consumption and feed conversion rates (Hassan *et al.*, 2016 and Vijayakumar and Balakrishnan, 2014a).

According to Makola *et al.* (2021a), broiler growth performance enhanced when 40% NDCP substituted for regular DCP in the diet. Furthermore, groups of birds fed diets containing nano-dicalcium phosphate showed faster daily weight gain, FCR and higher final LBW (Mohamed *et al.*, 2016). However, Samanta *et al.* (2019) demonstrated that FI and FCR were unaffected by the administration of Ca phosphate nanoparticles at varying amounts, either alone or in conjunction with conventional Ca phosphate. According to the previous investigation, when diets supplemented with nanoparticles at a 50% concentration, the growth performance of birds was increased. As compared to the control group fed DCP at levels of 2% of the diet, (NHA improved BWG and FI by 6 and 8%, respectively.

Sobhi *et al.* (2020), investigated that birds fed 1% DCP plus 0.1% NHA or 0.5% DCP plus 0.1% NHA had lower final LBW and BWG than that fed the control diet, but comparable to those fed 0% DCP. All treatments consumed the same amount of feed, however the chicks fed 1% DCP + 0.1% NHA (50% DCP) had a greater FCR than the other treatments. In comparison to birds given the control or 0.1% NHA, the mortality rate was numerically greater in those fed 1% DCP plus 0.1% NHA or 0.5% DCP plus 0.1% NHA.

It is important to emphasize that the Ca and P from the NHA were significantly better absorbed and subsequently decreased in excreta (Sohair *et al.,* 2017). In addition, Matuszewski *et al.* (2020) stated that productive performances of broiler chicken less affected by the concentration, source, or particle size of Ca. The decreased bioavailability of the conventional/inorganic DCP explained. Conversely, NHA's smaller size (between 20 and 100 nm) and greater surface area likely enhanced bioavailability and produced similar results as the control group.

The possible impacts of calcium phosphate nanoparticles (NCP) on broiler chicken growth performance investigated. In one work (Vijayakumar and Balakrishnan, 2014a), wet chemical synthesis used to create NCP in the lab, with particle sizes ranging from 20 to 90 nm. Over the course of 28 days, the study fed 70 male Cobb 400 broiler chicks a meal containing NCP in various ratios (50, 60, 70, 80, 90, and 100% as a replacement for dicalcium phosphate).The findings demonstrated that, in comparison to the control group, birds fed with 50 and 60% NCP had noticeably greater FCR and weight increases. In a different study, the co-precipitation approach used to NCP that would increase the availability of P in broiler chicks (Gutiérrez-Arenas, *et al.,* 2021).

2-Economic efficiency:

Table (3) presents the economic efficiency and relative efficiency of broiler chicks fed diets with varying levels of NHA as a replacement for DCP. Economic efficiency is calculated as the ratio of total returns to total costs (e/a), and relative efficiency compares the performance of each treatment group to the control group (T1), which is set at 100%.

The control group (T1) had the highest economic efficiency. Replacing DCP with 80%, NHA (T3) provided the closest results (97.47) to the control group (100) in terms of economic efficiency. As the percentage of NHA increased or decreased away from 80%, the economic efficiency generally declined, with the lowest values observed in the 100% NHA (86.84) and 20% NHA (84.21) groups. In contrast, Sohair *et al.* (2017) found that using hydroxyapatite nanoparticles at concentrations of 2, 4, 6, 8, and 10% have cost-effective compared to control diets.

3- Carcass traits:

Table (4) presents the results for mean carcass weight, giblet weight, abdominal fat weight, meat weight, and dressing percentage of body weight, as influenced by different concentrations of NHA. Notably, there were significant ($P\leq0.01$) differences in carcass weights among birds fed varying amounts of NHA compared to the control (100% DCP).

The carcass weight for the 100% DCP group was considerably higher (1464.72g) than that of the other treatments. The control group (T1) and T3 (80% NHA) had the best percentages, indicating that replacing 80% of DCP with NHA maintained similar performance to using 100% DCP. Carcass weight and percentage generally declined as the NHA level moved away from 80%, with the 100% NHA and 20% NHA groups showing the lowest results. When compared to other treatments, birds fed 60, and 40% NHA substituted DCP in the basal diet had higher percentages (P≤0.01) of giblet weight. However, birds fed 100% DCP had the highest giblet weight (P≤0.05).

Meat weight as percentage of LBW varied significantly (P≤0.01) between the control and other treatments, with T3 (39.81%), T1 (39.67%), and T2 (39.09%) showing the highest meat percentages. Birds fed T5 had lower abdominal fat weights and percentage (P≤0.01) (T5 and T6 the same significance), while T2 (100% NHA) had higher abdominal fat weights and percentage (P≤0.05).

As shown in Table (4), birds fed with T3 exhibited higher dressing percentages (P≤0.01), with values of 79.19 (T3 and T5 the same significance), compared to the other treatments. The significant differences in dressing percentages among treatments suggest that the feed interventions had a negative impact on metabolism.

Vijayakumar and Balakrishnan (2014b) found that supplementing with Ca-P NPs did not significantly alter dressing percentage, heart weight, or liver weight. Similarly, Samanta *et al.* (2019) reported that biochemical parameters and carcass features were unaffected by the use of Ca phosphate nanoparticles, whether used alone or in conjunction with conventional Ca P. In line with these findings, Sobhi *et al.* (2020) demonstrated no differences in carcass parameters among various feeding regimens, including 1% DCP plus 0.1% NHA (50% DCP), 2% DCP (100% DCP), 0.5% DCP plus 0.1% NHA (25% DCP), and 0.1% NHA only (0% DCP).

Similar to the present findings, Makola *et al.* (2021a) verified that meat yield enhanced in broilers by replacing 40% of DCP with calcium phosphate nanoparticles (NCP). Furthermore, Sohair *et al.* (2017) demonstrated that the treatment fed 6% NCP recorded the best carcass weight, followed by that fed 8% NHA. The possible causes of this discrepancy between researches attributed to variations in the food treatments and the length of the investigations.

4- Digestive tract parameters and immune organs:

The immune system parameters of the chicks, except for spleen weight, and digestive tract parameters, except for gut percentage, significantly affected by the dietary quantities of NHA as shown in (Table 5). The data indicated that the relative gut weight was significantly higher (P≤0.05) in the 100% DCP diet group, at 64.13g, compared to the other treatment groups. However, gut percentages did not show significant changes. Additionally, there were highly significant differences (P≤0.01) in intestine length between the control group and the other treatments, with the control group having the longest gut length at 185.44 cm. Spleen weight showed only slight variation between treatments. In contrast, spleen percentage differed significantly (P≤0.05), with T2 (100% NHA) recording higher value at 0.13%.

Dietary levels of NHA had a highly significant impact (P≤0.01) on thymus weight and percentage, with T4, showing the greater values. The highest thymus weight and percentages observed in T3, T4, T5, and T6, all with the same significance. The relative weight and percentage of the Fabricius bursa were significantly improved ($P \leq 0.01$) in birds fed with 40% NHA compared to other treatments. In contrast, Mohamed *et al.* (2016) reported no significant changes in the mineral composition of the liver, heart, or gizzard. They suggested that diets providing 100% of the required non-phytate phosphorus from CDCP replaced with diets containing only 25% of this element from NCP. Sohair *et al.* (2017) also found no statistically significant differences in liver, heart, or gizzard weights across all treatments by replacing 2% to 10% of DCP with calcium phosphate nanoparticles (NCP). These findings are consistent with those of Hassan *et al.* (2016) and Vijayakumar and Balakrishnan (2014b). Furthermore, Makola *et al.* (2021b) observed that birds fed 40% NCP had the longest villi, suggesting better mineral absorption. The study concluded that replacing 40 or 60% of DCP with NCP could enhance functional intestinal morphology and immune response in broiler chickens without adversely affecting hematological parameters.

Calcium phosphate nanoparticles found to enhance the nutritional value of broiler chicken by increasing their bioavailability and efficiency of utilization of essential minerals like calcium and phosphorus (Matuszewski, *et al.,* 2020). These nanoparticles also improve the availability of phosphorus, an essential mineral involved in poultry metabolism and development.

In contrast, the use of NCP in broiler chicken feed raises environmental concerns. The production process may involve energy-intensive processes and toxic chemicals, potentially leading to environmental pollution. Nano-sized particles, such as NCP, may have adverse effects on aquatic organisms and the environment due to their small size and high surface area to volume ratios. Traceability and safety concerns arise as these nanoparticles can accumulate in the environment and potentially affect wildlife and ecosystems. While some studies have shown positive results in growth performance and nutritional value, long-term effects of NCP in broiler chicken nutrition are also under investigation.

CONCLUSION

Overall, while NHA substituted of DCP in the basal diet shows promise in improving certain performance and health metrics in broiler chicks, 100% DCP remains superior in key growth and carcass parameters. The study suggests that further research needed to optimize NHA levels for balanced performance improvements and cost efficiency, while considering the potential benefits and drawbacks of using nanoparticles in poultry nutrition.

Table (1): Formulation and chemical analysis (determined and calculated) of the experimental basal diets.

Ingredient (%)	**Starter (0-8day)**	**Grower (9-18day)**	**Finisher (19-35day)**
Yellow corn	51.26	56.00	61.38
Soybean meal (46%CP)	41.30	36.00	30.50
Soybean oil	3.00	3.50	3.70
Di-calcium phosphate	2.15	2.10	2.06
Limestone	0.80	0.92	0.91
Sodium chloride	0.40	0.38	0.38
Mineral premix[1]	0.30	0.30	0.20
Vitamin premix[2]	0.10	0.10	0.10
DL- Methionine	0.33	0.33	0.30
L-Lysine	0.18	0.22	0.20
Threonine	0.10	0.15	0.12
Feed fix	0.05	-	0.05
Diclazril	0.02	-	-
Lincomix	0.01	-	0.05
Salinomycin	-	-	0.05
Total	100.00	100.00	100.00
Chemical analysis			
a-Calculated analysis (according to NRC, 1994)			
Metabolizable energy (Kcal/kg)	2924	3012	3088
Crude protein (CP, %)	23.7	21.72	19.61
Lysine (%)	1.406	1.286	1.137
Methionine (%)	0.665	0.647	0.594
Methionine + Cystine (%)	1.030	0.979	0.899
Calcium (%)	0.907	0.927	0.900
Available Phosphorous (%)	0.554	0.534	0.516
b-Determined analysis			
Moisture (%)	8.65	8.92	8.68
Crude protein (%)	22.85	20.74	18.86
Crude fiber (%)	3.44	3.59	3.71
Ether extract (%)	4.56	5.46	6.58
Crude ash (%)	5.25	5.43	5.69
Nitrogen free extract (%)	55.25	55.86	56.48

[1] Each 1 kg of vitamin mixture contained: 12.000.000 IU vit. A, 3.000.000 IU vit. D3, 40.000 mg vit. E, 3.000 mg vit. K3, 2.000 mg vit. B1, 6.000 mg vit. B2, 5.000 mg vit. B6, 20 mg vit. B12, 12.000 mg pantothenic acid, 45.000 mg Nicotinic acid, 2.000 mg Folic acid and 70 mg Biotin.

[2] Each 2 kg of minerals mixture contained: 360.000 mg choline chloride, 10.000 mg Cu, 1.000 mg I; 30.000 mg Fe, 100.000 mg Mn, 100 mg Co and 200 mg Se.

Table (2): Growth performance (x̄±SE) of broiler chickens as affected by different levels of dietary nano-hydroxyapatite (NHA).

Treatment groups (T)	**Levels of NHA**	**LBW at 5 wk**	**BWG 0-5 wk**	**FI 0-5 wk**	**Average FCR**	**MR (%)**
T1	0% (100%DCP)	1971.36^{a}±17.29	1930.70±17.30	2984.87±54.29	1.546^{b}±0.026	0.6
T2	100% NHA	1723.32^{c}±20.94	1682.42^{c}±20.93	2865.72±37.26	1.718^{ab}±0.107	3.3
T3	80% NHA	1834.75^{b}±17.84	1794.25^{b}±17.84	2858.98±116.58	1.590^{ab}±0.039	2.8
T4	60% NHA	1703.93^{c}±18.05	1663.65^{c}±18.05	2859.48±64.89	1.717^{ab}±0.022	2.2
T5	40% NHA	1694.21^{c}±20.09	1653.52^{c}±20.10	2837.45±64.70	1.720^{ab}±0.069	5.6
T6	20% NHA	1674.57^{d}±17.24	1633.81^{c}±17.26	2900.64±96.92	1.772^{a}±0.035	1.1
Sig.		**	**	NS	*	

$^{a-d}$ means within each column followed by different letters differ significantly, * = P≤0.05, ** = P≤0.01 and NS =Non-significant. DCP =Di-calcium phosphate. LBW: Live body weight, BWG: Body weight gain, FI: Feed intake, FCR: Feed conversion ratio, MR: Mortality rate, wk: Week.

Table (3): Economic efficiency of broiler chicks as affected by different levels of dietary nano-hydroxyapatite (NHA).

Treatment groups (T)	**Levels of NHA**	**[1]Total feed cost (L.E.) /kg=a**	**Average final LBW (kg)=b**	**[2]Price /kg LBW (L.E.) = c**	**Total revenue (L.E.) =b × c = d**	**[3]Net revenue (L.E.)=d-a=e**	**Economic efficiency = (e/a)**	**[4]Relative efficiency**
T1	0% (100%DCP)	23.75	1.971	35.00	68.99	45.24	1.90	100
T2	100% NHA	22.74	1.723	35.00	60.31	37.57	1.65	86.84
T3	80% NHA	22.57	1.835	35.00	64.23	41.66	1.85	97.47
T4	60% NHA	22.44	1.704	35.00	59.64	37.20	1.66	87.37
T5	40% NHA	22.14	1.694	35.00	59.29	37.15	1.68	88.42
T6	20% NHA	22.51	1.675	35.00	58.63	36.12	1.60	84.21

[1] Based on average price of starter, grower, and finisher diets, respectively during the experimental time.

[2] According to the local market price at the experimental time.

[3] Net revenue per unit feed cost. [4] Assuming that the economic efficiency of control diet equal 100.

Table (4): Carcass characteristics ($\bar{x}$±SE) of broiler chicks as affected by different levels of dietary nano-hydroxyapatite (NHA).

Treatment groups (T)	**Levels of NHA**	**Carcass**		**Giblet**		**Dressing**	**Abdominal fat**		**Meat yield**		
		(g)	**(%)**	**(g)**	**(%)**	**(%)**	**(g)**	**(%)**	**(g)**	**(as % of BW)**	**(as % of Carcass)**
T1	**0% (100%DCP)**	1464.72^{a} ±38.97	74.41^{a} ±1.70	81.33^{a} ±2.15	4.14^{b} ±0.11	78.52^{ab} ±1.76	13.88^{ab} ±1.06	0.71^{b} ±0.05	780.67^{a} ±20.00	39.67^{a} ±1.01	53.27^{a} ±2.29
T2	**100% NHA**	1238.06^{cd} ±23.71	72.85^{bc} ±0.98	72.48^{c} ±1.60	4.27^{b} ±0.09	77.20^{bc} ±0.92	15.63^{a} ±1.71	0.92^{a} ±0.10	664.22^{c} ±6.94	39.09^{a} ±0.39	53.64^{a} ±1.96
T3	**80% NHA**	1388.33^{b} ±36.98	74.82^{a} ±1.80	78.83^{ab} ±1.78	4.24^{b} ±0.09	79.19^{a} ±1.72	13.59^{ab} ±1.33	0.73^{ab} ±0.07	738.89^{b} ±6.65	39.81^{a} ±0.33	53.23^{a} ±1.67
T4	**60% NHA**	1216.67^{d} ±30.68	74.01^{ab} ±1.21	75.18^{bc} ±1.79	4.58^{a} ±0.12	78.57^{ab} ±1.21	10.30^{bc} ±1.25	0.63^{b} ±0.07	612.89^{d} ±8.65	37.27^{b} ±0.46	50.35^{b} ±2.29
T5	**40% NHA**	1253.89^{c} ±44.01	74.47^{a} ±1.21	77.28^{abc} ±1.63	4.58^{a} ±0.09	79.07^{a} ±1.46	9.79^{c} ±0.80	0.58^{b} ±0.05	603.33^{d} ±10.08	35.84^{b} ±0.58	48.11^{c} ±2.86
T6	**20% NHA**	1180.56^{e} ±46.36	71.76^{c} ±3.28	76.61^{abc} ±1.72	4.67^{a} ±0.11	76.40^{c} ±3.48	9.82^{c} ±1.14	0.60^{b} ±0.07	549.33^{e} ±9.02	33.39^{c} ±0.60	46.55^{c} ±3.05
Sig.		**	**	*	**	**	**	*	**	**	**

$^{a-e}$ means within each column followed by different letters differ significantly, * = P≤0.05 and ** = P≤0.01.

Table (5): Digestive tract measurements and immune organs of broiler chicks as affected by different levels of dietary nano-hydroxyapatite (NHA).

Treatment groups (T)	**Levels of nano-hydroxyapatite (NHA)**	**Digestive tract measurements**			**Immune organs**					
		Intestine			**Spleen**		**Thymus**		**Bursa**	
		(g)	**(%)**	**length (cm)**	**(g)**	**(%)**	**(g)**	**(%)**	**(g)**	**(%)**
T1	0% (100%DCP)	64.13^{a} ±1.92	3.26 ±0.10	185.44^{a} ±4.04	1.83 ±0.08	0.10^{c} ±0.01	4.07^{c} ±0.51	0.21^{c} ±0.03	2.72^{bc} ±0.19	0.14^{b} ±0.01
T2	100% NHA	58.59^{ab} ±2.29	5.53 ±0.12	172.35^{b} ±5.39	2.14 ±0.20	0.13^{a} ±0.01	4.26^{bc} ±0.50	0.25^{bc} ±0.03	2.85^{bc} ±0.13	0.17^{b} ±0.01
T3	80% NHA	59.77^{ab} ±1.26	3.22 ±0.07	161.17^{bc} ±4.07	1.80 ±0.14	0.10^{bc} ±0.01	6.23^{a} ±0.46	0.34^{ab} ±0.03	3.54^{ab} ±0.40	0.19^{ab} ±0.02
T4	60% NHA	55.92^{b} ±1.59	3.40 ±0.10	155.35^{c} ±2.16	0.96 ±0.13	0.12^{ab} ±0.01	6.53^{a} ±0.83	0.40^{a} ±0.05	2.24^{c} ±0.19	0.14^{b} ±0.01
T5	40% NHA	55.45^{b} ±1.82	3.27 ±0.11	161.11^{bc} ±2.60	1.80 ±0.15	0.11^{abc} ±0.01	6.13^{a} ±0.59	0.37^{a} ±0.04	4.07^{a} ±0.52	0.24^{a} ±0.03
T6	20% NHA	59.89^{ab} ±2.51	3.64 ±0.16	159.75^{c} ±1.97	1.88 ±0.12	0.12^{abc} ±0.01	5.84^{ab} ±0.55	0.36^{a} ±0.03	2.91^{bc} ±0.27	0.08^{b} ±0.02
Sig.		*	NS	**	NS	*	**	**	**	**

$^{a-c}$ means within each column followed by different letters differ significantly, * = P≤0.05, ** = P≤0.01 and NS =Non-significant.
DCP =Di-calcium phosphate.

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Broiler, nano-hydroxyapatite, growth performance, carcass traits, immunity.

الملخص العربي

تأثير إستبدال النانو هيدروكسي أباتيت محل ثنائي فوسفات الكالسيوم على الأداء الإنتاجي ومقاييس الذبيحة والأعضاء المناعية لبدراي اللحم

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تهدف هذه الدراسة الى استبدال ثنائي فوسفات الكالسيوم التقليدي (DCP) بالهيدروكسي أباتيت النانوي (NHA) كدراسة محتملة لتعزيز القيمة الحيوية للعناصر المعدنية وتقليل تكاليف الأعلاف في مزارع الدواجن. تم قياس تأثير مستويات مختلفة من NHA في النظام الغذائي على الأداء الإنتاجي لبداري اللحم، خصائص الذبيحة، قياسات القناة الهضمية، والاستجابة المناعية. تم توزيع عدد 1080 كتكوت عمر يوم غير مجنس من نوع "Cobb 500" على ستة معاملات تجريبية بثلاثة مكررات لكل معاملة (60 كتكوت لكل مكرر) بتصميم عشوائي كامل. احتوي الكنترول (T1) على 100% DCP في النظام الغذائي. أما المعاملات من T2 إلى T6 فاحتوت على نسب 100و80و60و 40 و20% من NHA استبدالا لـ DCPعلى التوالي.

أشارت النتائج إلى أن الكتاكيت التي تغذت على 100% DCP أظهرت أفضل أداء انتاجي ووزن ذبيحة ($P\leq0.05$) مقارنة بتلك التي تغذت على مستويات أقل من NHA. وتحديداً، حققت مجموعة 100% DCP أعلى وزن للذبيحة ($P\leq0.05$)، بينما أظهرت المعاملات الغذائية التي تحتوي على 80 % من NHA أعلى نسبة للذبيحة. بالمقابل، أظهرت الطيور التي تناولت نسب أقل (60،40 ، 20%) من NHA أعلى نسبة للأجزاء المأكولة ($P\leq0.05$)، ولوحظ ان أقل وزن لدهون البطن كان عند مستوى 40% من NHA. كان وزن الأمعاء النسبي أعلى بشكل ملحوظ ($P\leq0.05$) في مجموعة الكنترول (100% DCP) مقارنة بالمعاملات الأخرى. كما ان نسبة الطحال الأعلى وبشكل واضح وجدت في المجموعة التى تغذت على100% NHA، وأدى استبدال NHA في النظام الغذائي إلى زيادة كبيرة في وزن ونسبة الغدة التيموسية، خاصة في المجموعة T4، ومزامنة مع تحسن مماثل في المجموعات الأخرى. كما أظهرت الطيور التي تغذت على 40% من NHA وزيادة ملحوظة في الوزن والنسبة لغدة البرسا بمجموعة 60% NHA مقارنة بالمجموعات الأخرى.

الخلاصة انه على الرغم من الفوائد المحتملة لإستبدال NHA في تغذية بداري دجاج اللحم، إلا انه هناك حاجة إلى المزيد من الأبحاث لتحديد المستوي الأمثل، والعائد الإقتصادى، والظروف الملائمة، وتأثير استخدامها على البيئة لإدراج هذه الجسيمات النانوية في أعلاف الدواجن.