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Essential metal nanoparticles in Poultry Nutrition and Production

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Abstract

One can add nanoparticles to food to provide a great platform for incorporating different chemicals, like dietary supplements and vaccinations, because of their high body absorption rate and wide surface area to volume ratio. Nanotechnology is the study of atom, molecular and supramolecular-sized particles. In addition to offering other health advantages, nanoparticles can facilitate the direct delivery of substances to specific organs or systems while avoiding the rapid degradation that antibiotics are known for. this article reviews the application of nanoparticles in the poultry industry with zinc and magnesium being the most widely employed materials. The impact of nanoparticles on the immune system, oxidative status, blood parameters, gastrointestinal tract and bacterial account in chickens. Nanoparticles as a supplement to poultry feed are reviewed here, along with the benefits and drawbacks of nano-feed as documented by international researchers.

Keywords: Element minerals, nanoparticles, Zn, Mn, boiler chickens.

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1. Introduction

Generally, materials with a length of 1–1000 nm and a diameter of 1–100 nm are considered nanomaterials. According to the EU Commission, nanoparticles (NPs) are materials that contain at least 50% of components that have diameters between one and one hundred nanometers and can exist naturally or artificially [1]. This scale may modify the physical, chemical, and biological characteristics of materials, significantly improving the usefulness and effectiveness of feed additives. These additions can have a greater impact on animals' digestive systems and optimize nutritional absorption because of the tiny size, large surface area, and enhanced reactivity of NPs [2].

Nanoscale (<100 nm) materials are being extensively researched for usage in a wide range of applications in numerous industries. To improve absorption and maximize the use of feed that would otherwise be poorly digested and/or secreted without retaining all of the available vitamins and minerals, nanoparticles (NP) have been added to poultry feed. Within the agricultural sector, poultry is one of the fastest-growing sectors due to the enormous interest in animal nutrition and the pursuit of research and development aimed at enhancing productivity, disease resistance, and overall health [3].

The material's nanoscale can enhance feed molecule functionality in addition to raising animal output. Through improved digestion and absorption, feed can be absorbed by animals more efficiently thanks to nano feed additives. Nevertheless, this strategy comes with several drawbacks. These include health risks, ethical issues, environmental concerns, the potential for endotoxin production, reduced nutrient absorption from interactions with natural nutrients, the potential for nanoparticle accumulation in the animal body, and some unfavorable effects like interference with natural nutrients that can be avoided by encapsulation [1].

Despite receiving a lot of interest in the field of broiler nutrition, nano-trace elements may have unintended consequences because to their increased activity and efficiency. Like micro-trace elements, nano-trace elements can be harmful when present in amounts higher than those needed for biological function [4].

To maintain health and productivity, the body's antioxidant defense system also requires trace minerals including zinc, copper, selenium, and magnesium. These elements are crucial for preventing damage to tissues caused by free radicals [5]. NPs are utilized to provide an animal's elemental needs, boost productivity, enhance immunological function and microbial profile, and lower disease risk. Antibacterial, antifungal, antiviral, antiprotozoal, and antioxidant effects are well-known for nanoparticles. Nanoparticles of silver, copper, selenium, and zinc can be used as substitutes for antibiotics to promote growth and alternative health [6]. Zinc (Zn) is an extremely significant trace mineral that plays a wide range of roles in the immune system, hormone production, wound healing, carbohydrate, protein, and lipid metabolism, appetite control, and nucleic acid and protein synthesis [7,8]. Zinc deficiency leads to a failure in GH secretion from the pituitary and a decline in circulating [9]. Manganese is one of the trace elements that is frequently utilized in poultry, and broilers are especially interested in it due to its vital functions in metabolism, skeletal growth, enzyme activities, and immunological responses. The antibacterial action of immune cells depends on the continuous activity of superoxide dismutase, which is facilitated by manganese. Thus, to improve the immunological response in broilers, larger doses of manganese are added to their diets [10].

1.1. Nanoparticles in feed

NP integration as potential feed supplements for poultry is becoming more and more popular as a means of enhancing general health and feed conversion ratio. While some NP types have been demonstrated to promote the growth of good bacteria and may therefore be used to enhance growth and performance, other NP types have been utilized in poultry feed to reduce the amount of harmful bacteria in the chicken the gut microbiome [11].

The following section is a summary of different types of NPs and couplings, including various metals, natural products and bacteria, injected and/or fed to poultry to either exercise a positive or negative effect. Focus is divided between various aspects such as overall health and immunity, growth and performance and antibacterial prospects of NPs in poultry. The addition of nano-sized feed additives has emerged as a game-changing development in the effort to increase the efficiency of animal nutrition. With the ability to deliver essential nutrients in precise doses, these additives play a critical role in improving animal health and performance. Each nanoparticle has a different mechanism of action.

For both humans and animals, zinc (Zn) is a crucial trace element that is involved in a variety of metabolic processes [12]. Since zinc cannot be stored in an animal's body, regular dietary supplements of zinc are required [13]. The required amount of zinc in chicken diets is 40–75 mg/kg, according to [14]. Reduced feed intake (FI) and feed utilization are signs of zinc deficiency in animals, which results in slowed growth [15]. During heat stress, poultry diets must include zinc supplements [16]. Nevertheless, there has been contradictory research on the impact of dietary zinc supplementation on the performance of heat-stressed birds in the past.

Zinc (Zn) is a special kind of micromineral because it plays a key role in the regulation of sex hormones, protein and fat metabolism, and the function of numerous enzymes, including carbonic anhydrase, alkaline phosphatase, and superoxide dismutase. Three types of this mineral are used in chicken production: inorganic, organic, and nanoparticle. Because of its superior absorption, bioavailability, and effectiveness over other traditional forms of zinc, the nanoform is preferred in application [17].

Numerous scientific fields have witnessed a sharp increase in the development of nanotechnology and its associated products; in fact, this field of study has had a profound impact on the lives of people, animals, the environment, and industry. Zinc Oxide (ZnO) nanoparticles have garnered significant interest due to their unique characteristics. These include huge surface area, strong adsorbing capacity, size, shape, high surface activity, and high catalytic efficiency [18].

Zn in nano-form has been considered an emerging alternative dietary supplement for poultry owing to its enhancing effects on metabolic activity and the health status of the birds, as well as their antibacterial and immuno-stimulant properties [19]. A mineral salt called nano-Zn has particles that range in size from 1 to 100 nm [20], which exhibit superior absorption and bioavailability over other inorganic or organic zinc [21]. Incorporating nano-forms of zinc into broiler diets in place of inorganic zinc may enhance performance metrics during the first periods of production and lower mortality rates [22]. Furthermore, nano-Zn sources are thought to be less expensive than inorganic and organic Zn sources [23].

Zinc in nanoparticle form (ZONPs) gained significant interest as a substitute for organic and inorganic Zn sources in feed supplements due to its absorption, bioavailability, stability, affordability, and effectiveness at the same or lower dosages. It also appears to be less hazardous [24]. Furthermore, it has been shown that ZONPs' unique characteristics—such as their smaller size, greater surface area, high number of surface active centers, stronger adsorbing quality, catalytic efficiency, increased bioavailability, absorbability, and superior efficacy—allow them to exert more beneficial effects and yield better results [25].

In addition to strengthening the immune system and the GIT microbial population, earlier research suggested that adding ZONPs to diet could increase performance (body weight gain, feed conversion ratio, meat quality, and egg production) [26, 27]. Using ZnONPs at modest dosages (10 and 20 ppm) may have good impacts on the body weight gain and feed conversion, biochemical indicators, carcass features, humeral immunity, and the cecal microbial population of broilers. On the other hand, ZONPs at high doses (40 ppm) might be detrimental to certain measurements [28].

1.2. Trace mineral nanoparticles impact on broiler production performance

When broiler diets were supplemented with zinc oxide nanoparticles at a rate of 100 mg/kg, the feed conversion ratio was noticeably higher than in the control group [29]. The feeding 10, 20 and 40 mg/kg of zinc oxide nanoparticle supplementation significantly ($P<0.01$) decreased feed intake in comparison to the control group [30]. The broilers given feed enriched with 20 and 60 mg/kg of nano-ZnO had significantly higher body weights ($P < 0.05$) [27]. Feeding broilers with zinc supplements at a dose of 60 mg/kg significantly enhanced their body weight gain, feed intake, and feed conversion ratio when compared to the control group [31]. Similar results were observed by [32] who supplemented 50 mg/kg of zinc methionine and Nano-ZnO and found that the broiler group's body weight gain, feed intake and feed conversion ratio were significantly higher than those of the control group. Similarly, the average daily body weight gain, feed conversion ratio, and feed intake were significantly higher in the broiler group fed a diet supplemented with zinc methionine at 50 and 100 mg/kg than the control group [33]. Furthermore, adding Zn oxide nanoparticles at 40 and 80 mg/kg to the diet of broilers greatly increased their body weight gain and feed conversion ratio [34]. Nevertheless, Feed conversion ratio was unaffected by the addition of various zinc sources, including zinc-methionine, zinc-sulfate, nano-Zn sulphate, nano-Zn methionine, and zinc-nano max at 80 mg/kg [35]. The application of NanoMn$_2$O$_3$ to broiler chickens decreased their excretion of Mn but had no adverse effects on their growth or development [36]. Zinc supplementation showed a favorable influence on the growth performance of heat-stressed broiler chicks [37]. On the other hand, broiler performance under heat stress was unaffected by dietary Zn supplementation [38]. The effects of varying doses of manganese (10, 50, and 100 mg/kg diet), in the form of manganese oxide (MnO) or manganese nanoparticles (NPs-Mn$_2$O$_3$), on growth performance, absorption, and accumulation of Mn, Zn, and Cu, as well as antioxidant and immunological status in growing organisms, were investigated [39]. It has recently been shown that substituting Mn$_2$O$_3$ nanoparticles (NanoMn$_2$O$_3$) for MnO had no detrimental impacts on turkey growth performance, but instead increased Mn ileal digestibility [40]. In comparison to the control group, ZnONP supplementation led to increased body weight, enhanced feed intake, and an improved performance index [41].

1.3. Trace mineral nanoparticles impact on gastrointestinal tract for broiler chickens

A major defense against the transport of nanoparticles is provided by digestive enzymes. It is possible to prevent enzymatic and hydrolytic breakdown by applying a polymeric coating on the NPs' surface [42]. Cell-specific carbohydrates are displayed on the surface of enterocytes and mononuclear (M-cell) cells. This barrier can be removed by adding the right ligands and target strategies to colloidal drug carriers, which will enhance the interaction between the NPs and M-cells and adsorptive enterocytes defense, allowing the NPs to pass through the cellular layer [43].

The creation of micelles for absorption that have a lower residence in the intestinal tract, less excretion via the excreta, and easier membrane mobility are the biological benefits of nano nutraceuticals [44]. Remarkably, NPs-Mn2O3 substituted for MnO increased ileal Mn digestibility and decreased Cu accumulation in the liver and breast muscle [45]. In addition to improving overall nutritional value and digestibility, zinc oxide NPs also boost the synthesis of volatile fatty acids. Specifically, zinc oxide helps reduce environmental impact by lowering mineral loss from feces. Additionally, helpful to the gut, it may raise villus height, deepen crypts, and increase villus surface area [46].

1.4. Effect of Nanoparticles of trace minerals on carcass criteria and internal organs of broilers

Broilers fed 30 to 90 nanoparticles of zinc oxide had a considerably larger relative weight of liver than the control group; however, the weight of the gizzard, pancreas, proventriculus, and heart was unaffected [47]. The broilers fed supplements with zinc methionine at 50 and 100 mg/kg saw a significant decrease in the relative weight of belly fat; however, liver weight remained unchanged when compared to the control group [33]. Supplementing with various zinc sources (zinc-methionine, zinc-sulphate, nano-zinc sulphate, nanoparticles of zinc methionine, and zinc-nano max at 80 mg/kg) had no effect on the relative weight of the gastrointestinal tract, heart, or liver; however, the relative weight of abdominal fat in broilers was significantly lower than in the control group [35].

1.5. Effect of Nanoparticles of trace minerals on blood parameters of broilers

Supplementation of Nanoparticles of Zn Oxide at 50 mg/kg to broilers diet did not affected serum concentration of aspartate aminotransferase (AST) and Alanine aminotransferase (ALT) compared to control group [32]. Similarly, Broilers given feed supplemented with nanoparticles of zinc oxide at 10, 20, and 40 mg/kg showed no significant change in blood activities of ALT, AST, and creatine kinase [30]. When compared to the control group, the serum levels of total cholesterol were significantly lower in broilers fed a meal supplemented with 50 mg/kg of zinc methionine or zinc oxide nanoparticles [32]. Thus, adding 40 mg/kg of zinc oxide nanoparticles to a diet of broilers did not affect the total cholesterol levels in their serum when compared to the control group [48]. In addition, the amounts of the hormones thyroxine (T4) and estrogen were unaffected in the layer-fed diet enriched with 30 mg/kg Zn, but that the concentration of triiodothyronine (T3) was considerably lower in comparison to the control group [49]. The effects of zinc oxide NPs (ZnONPs) synthesized by *Alternaria tenuissima* on concentrations were serum cholesterol, triglyceride, low-density lipoprotein, and uric acid decreased, while high-density lipoprotein and liver enzyme concentrations were increased. Zinc accumulation in serum, liver and muscle showed a linear increase with the increase in zinc supplementation [41]. In conclusion, it has been reported that supplementation with low levels of ZnONPs 40 or 60 mg/kg gives positive results for criteria blood.

1.6. Effects of nano-trace minerals on oxidative stress

Enhancing serum oxidant status and decreasing oxidative stress are further benefits of supplementing with nano-minerals. It is usual for ZnNPs to exhibit a decrease in malondialdehyde (MDA) and an increase in the activity of antioxidant enzymes such as glutathione peroxidase (GSH-Px), superoxidase dismutase (SOD), catalase (CAT), and total antioxidant activity (AOA) [50, 32, 51,52]. Adding Mn in the form of nanoparticles demonstrated the correct operation of the antioxidant system, as demonstrated by the rise in Mn-SOD, GPx, and CAT activity [53]. The superoxide anion radical dismutation reaction is catalysed by superoxide dismutase (SOD) and results in H2O2. Glutathione peroxidase (GPx) then breaks down H2O2 into water. Catalase (CAT) further breaks it down to water and molecular oxygen at high H2O2 concentrations. They concluded that there is more oxidative stress because of the changes in redox status measures. The superoxide dismutase enzyme is a crucial antioxidant defense against oxidative stress that can be activated by nano-copper and nano-zinc [54].

1.7. Effects of nano-trace minerals on the humeral immunity system

A significant decrease in antibody titer against Sheep red blood cells was revealed in the nano-manganese supplementation of 100 and 150 mg/kg compared to the control group. In addition, the antibody titers against infectious bronchitis and Newcastle disease were significantly lower in all nano-manganese groups compared to the control group. No significant difference was observed for the antibody titer against avian influenza among the trial groups [55]. Supplementing with nano-Zn (0.06 mg/kg diet) increased humoral immunity and raised the weight of lymphoid organs in broiler chickens, like that of an organic Zn diet (15 mg/kg) [56]. The poultry researchers found that supplementing broiler chickens with ZnONPs rather than ZnO improved the synthesis of IgY and cellular immunity (total lymphocyte count, macrophages, phagocytic activity, and index) [57]. The growth performance, immunological response, and antioxidant status of broiler chickens raised in high temperatures might be positively impacted by the addition of zinc in the forms of Zn-Met and ZnONPs at a dose of 40 mg/kg of diets [58]. In contrast to the broiler chicken group fed the basal diet supplemented by inorganic zinc, the scientists found that broiler hens fed 100 or 50 mg ZnONPs/kg food instead of 100 mg ZnO/kg diet showed increased lysosomal activity and phagocytic activity [59]. Therefore, through increasing thymulin activity, maturing T lymphocytes, and activating B-lymphocytes, the high bioavailability of ZnONPs may stimulate immunological responses in broiler chickens [60]. Poultry feeding researcher discovered that supplementing broiler chickens with Zn and Mn at concentrations of 80 and 60 ppm, respectively, considerably enhanced their humoral immune response. Poultry nutritionists demonstrated that reducing the amount of Mn supplementation in the form of MnO and NP-Mn_2O_3 increased the levels of IgM in plasma, particularly when Mn was lowered to 10 mg/kg of diet. Most frequently, the major immunological reaction to exposure to an immunogen or pathogen is linked to an elevated IgM level [53].

1.8. Content of Zinc oxide and Manganese in faeces

As Mn dosages increased, so did the concentration of Mn in excreta. In line with the lowest Mn concentration in feed, the control group had the lowest Mn content in excreta. The Mn content in the excreta of the nano groups was substantially lower than that of the stand groups ($P < 0.01$). Additionally, a significant interaction ($P < 0.01$) was seen between the dosages and the source of excreted Mn. Compared to stand groups, the nano had a considerably greater Mn retention rate [62]. In another study broilers were fed with zinc oxide NPs (ZnO NPs) added to the diets at specific ratios. At the end of the experiment, broilers fed diets containing ZnO NPs exhibited significantly higher zinc retention compared to those in the control group, which was statistically significant ($p < 0.05$). This increased zinc uptake subsequently led to decreased zinc excretion in their feces. This increased Zn absorption and bioavailability, decreased zinc excretion, and demonstrated potential antibacterial activity against the tested pathogens [63].

1.9. Effects of nano-trace minerals on microbial account

The most significant hazard to the poultry industry is infectious microorganisms since they can significantly reduce growth rate and efficiency and result in substantial economic losses. ZnO NPs are used as a feed addition in animal diets, but they also contain antibacterial qualities and have been demonstrated to have considerable potential as an in vitro and in vivo antibiotic substitute [64]. Additionally, zinc oxide nanoparticles showed an anticoccidial effect in broiler chickens experimentally infected with a mixture of *Eimeria maxima*, *E. acervulina*, *E. mivati*, and *E. tenella* and appeared as effective as diclazuril, a chemical anticoccidial drug, through evaluation of growth performance, parasitological and hematological parameters, as well as antioxidant activity [65]. Zinc nanoparticles are characterized by antimicrobial activity, especially against foodborne pathogenic bacteria, such as *Escherichia coli*, *Listeria monocytogenes*, *Salmonella*, and *Staphylococcus aureus* [66]. Replacement of ZnO by 100 or 50mg of ZnONPs increased cecal total bacterial counts and Lactobacillus bacterial count while reducing total coliform count [59]. Furthermore, the addition of 120 mg/kg Zn to the diet prevented *Salmonella* colonization in the intestinal tract to a certain extent, which was conducive to maintain the steady state of intestinal microflora and improve the production performance of broilers [67]. On the other hand, they reported that Zn supplementation reduced the amount of *Lactobacillus* in the ileal digesta of broilers [68]. Likewise, tested several doses of ZnNPs (45, 90, 135 and 180 mg/kg) on broilers [54]. The addition of zinc nanoparticles up to 90 mg/kg had a positive effect on reduction in population of pathogenic intestinal bacteria (E. coli and Salmonella sp.). In addition, they exerted antifungal activity against toxigenic moulds in feed systems (Aspergillus flavus, A. *ochraceus* and *A. niger*) [69]. Magnesium oxide nanoparticles (NPs) have potent antibacterial activity against gram-positive and gram-negative bacteria, providing efficient microbial control. Furthermore, by inhibiting microbial communities' ability to build biofilms, these NPs support microbial control. By enhancing bacteria development in the digestive tract, iron oxide and copper nanoparticles promote intestinal health [46, 70]. This effect was reported by feeding researchers which was characterized by a significant reduction in the number of *Enterococcus species*, while the population of beneficial partner bacteria such as *E. coli* and lactic acid bacteria remained unaffected when fed with zinc oxide NPs (ZnO NPs) [64].

2. Conclusions

In general, it can be suggested that zinc and Mn nanoparticles have the potential to be taken into consideration as an alternative to other supplies and to enhance the health and productivity of grill chickens. However, more studies conducted in controlled environments are still required to assess the precise mode of action and establish the ideal level of dietary inclusion to maximize meat output, nutritional digestibility, and bird health.

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