Role of Metallic Nanoparticles as Additives in Poultry

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Abstract

The poultry industry is fulfilling the major requirements of protein for humans. The poultry industry is booming around the globe to compete with chicken meat production. The growth of the poultry sector needs advancements in every field significantly the feed advancements. There is a significant increase in the efficiency of the feed for growing and laying birds with the help of nanoparticles. There are multiple types of nanoparticles that are under study. However, the metallic nanoparticles are the best that enhance the effectiveness of the feed. Metal nanoparticles include zinc, selenium, copper, and silver. Nanoparticles have the ability to offer less toxicity, improved bioavailability, and improved absorption of the feed. Metallic nanoparticles have shown potential results in the improvement of egg production, efficiency of feed, meat texture, growth promotion, and productivity. However, the safety index of the nanoparticles must be evaluated through extensive research. This chapter demonstrates the benefits and limitations of the metallic nanoparticles in the poultry industry and its future implementations.

Keywords: Nanoparticles, Metallic nanoparticles, Poultry, Additives, Alternative

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Introduction

Poultry is a core component of global food systems, providing a scalable and adaptable source of protein for populations worldwide (Ferdous et al., 2023). It fulfills the nutritional requirements of expanding populations, especially in regions with limited access to other protein sources (Kleyn & Ciacciariello, 2021). Poultry sector empowering millions of people worldwide, mainly developing countries (Ahmed et al., 2021). To optimize the performance and quality of products, experts have applied nano-biotechnology, and it proves to be an advancement in the poultry field if followed by farmers properly with precaution and care (Sadr et al., 2023). Nanoparticles (NPs) are characterized by their nanoscale dimensions and tiny particle size and possess a broad spectrum of attributes (Khan et al., 2022). NPs are acquiring widespread acceptance in poultry farming owing to their favorable attributes, such as low toxicity, high bioavailability and significant surface area relative to macro-scale particles, and extended action (Saeed et al., 2025). Implementation of different nano-sized trace element supplements in the poultry industry has been proven to be efficient in the world practice (Nechitailo et al., 2025). It enhances the economic benefits of poultry farming by boosting meat and egg productivity (Naumenko et al., 2023). It enhances digestibility in the gut and their action on specific body tissues (Pramanik et al., 2023). These NPs play a beneficial role in the treatment, diagnosis, and prophylaxis of diseases in poultry (Heshmati et al., 2023).

Nevertheless, metallic NPs like calcium, copper, selenium, iron, gold, silver, zinc, and chromium etc. appear to be effective as mineral supplements compared to inorganic mineral supplements because of their improved absorption (Michalak et al., 2022). These mineral NPs avoid antagonistic effects with other minerals, developmental efficiency, and physiological activities (Alharby et al., 2021; Wohlmuth et al., 2022). They work commendably at notably reduced doses compared to the levels recommended for larger particles (Tripathi et al., 2024). These nanoparticles can be synthesized by different methods, including physical, chemical, green, and biosynthetic methods (Alsaiari et al., 2023). Supplementing diets with mineral NP might be a promising strategy in the future (Bhagat & Singh, 2022). Even with their toxicological limitations to metallic NPs, multiple studies have explored the effects regarding metabolism, productivity, health, and notably antioxidant properties (Wang et al., 2024). The incorporation of metal nanoparticles into poultry production represents a promising area of research (Ahmad et al., 2022). It is targeting the development of nutritional additives, antimicrobial agents, and growth promoters because of their antioxidant, antibacterial, and immune-modulating properties (Ashraf et al., 2024). More detailed research is also necessary on the harmful effects and the strategies to combat it (Solano et al., 2021).

Synthesis and Properties of Nanoparticles

A nanoparticle is a microscopic entity measuring 1 to 100 nanometers (Ahmad et al., 2024; Qurashi et al., 2024). Nanoparticles have

distinct physical and chemical properties because of their miniature size and extensive surface area (Joudeh & Linke, 2022). Nanoparticles can be synthesized in various ways like physical, chemical and biosynthesis (Hachem et al., 2022). These processes are further classified into multiple steps or methods (Table 1).

Table 1: Different Methods of Synthesis of Nanoparticles

Physical Method	Chemical Method	Biological method
• Condensation and Evaporation method • Chemical vapor deposition method • Electric arc discharge method • Laser ablation method • Gas phase synthesis method • Ball milling–annealing method • Physical vapor precipitation method (Jagdeo, 2023)	• Reduction method, this method is further divided into 2 reduction methods: chemical and indirect reduction methods. • Inert gas condensation. • Sedimentation method. (alkaline, sol gel, coprecipitation hydrothermal) (Khan et al., 2022)	• Green synthesis, that is, by extraction of plants or microorganisms (algae, virus, fungi, and bacteria) (Pandit et al., 2022)

Use of nanoparticles in poultry farming show evident results by promoting growth rates of birds (Sharif et al., 2021). Best results are because of the effective absorption of these NPs from the gastrointestinal tract, exerting a stronger biological effect on the body (Waheed et al., 2022). NPs improve the nutritional value of products while minimizing the toxicity of the agents used and support high bioavailability of minerals (Arshad et al., 2021; Thangavelu et al., 2024). The integration of nanoparticles to enhance feed efficiency and poultry well-being can effectively reduce the antibiotic resistance and incidence of diseases (Abreu et al., 2023). Nanoparticles can achieve desired effects at lower doses compared to traditional supplements (Abdelnour et al., 2021).

These NPs are useful because of cost-effectiveness, more efficiency, minimum dosage requirements, lower antagonism and enhanced bioavailability of essential nutrients (Raza et al., 2024). Nanoparticles can help maintain a balanced nutrient profile in poultry diets. Nanoparticles can enhance immunity and disease resistance, reduce oxidative stress and heat stress, give antimicrobial effects, promote overall health and well-being. It enhances eggs and meat production and quality and improves meat texture. NPs promote healthy gut microbiomes of birds and results in optimal digestion and nutrient absorption (Qu et al., 2023). Nanoparticles exhibit antimicrobial, antiviral, antiprotozoal, antifungal, and antioxidant properties, demonstrating their potential as therapeutic agents.

Table 2: Benefits of Metallic Nanoparticles

Sr. no.	Metallic Nanoparticles	Benefits or Results
1.	Zinc oxide NPs	Pronounced antioxidant properties, positive effect on productivity, weight gain, feed digestibility, and carcass characteristics and homeostasis of poultry, egg quality, immune status and improve serum enzymes activity during the starter period (Czyżowska & Barbasz, 2022).
2.	Zinc NPs	Improvement of performance, carcass characteristics, humoral immunity, meat quality, antioxidant activity. No deleterious effect on the developing embryo and percentage of hatchability in case of in-Ovo administration (Grasso et al., 2022).
3.	Silver & Gold NPs	potential alternatives to antibiotics and could solve the resistance problem of microorganisms to antibiotics (Toczek et al., 2022).
4.	Copper NPs	Improved percentage of breast and leg muscles, chicken growth
5.	Copper oxide NPs	Antioxidant, improve production, egg quality, and immune status but limited in usage because of their toxicokinetic (Tortella et al., 2024).
6.	Chromium NPs	positively affect sperm survival in turkeys, increase the resistance of the broiler chickens' body to heat stress and normalizing the metabolism of sex hormones (Majewski et al., 2022).
7.	Silver, copper, Zinc NPs	Alternative to antibiotics against the main pathogens of poultry infectious diseases, such as *Salmonella* and *Campylobacter* (Raja et al., 2023).
8.	Iron oxide NPs	Produce safe and high-quality meat, enhance detoxify biological fluids, antimicrobial therapy, and tissue regeneration, solve oxidative stress (Kumar et al., 2024).
9.	Calcium carbonate NPs	Better average feed conversion rate and increased relative eggshell mass and eggshell mass/surface area (Fadia et al., 2021).
10.	Manganese NPs	Added to sperm diluent increased the mitochondrial membrane potential and activity of the plasma membrane. As a result, all spermatozoa showed good motility during the storage period (Haque et al., 2021).
11.	Selenium NPs	Improvement of growth performance, increased water holding capacity of meat, mainly improved the oxidation resistance or control oxidative stress (Bano et al., 2021).
12.	Chromium NPs	Improved the weight gain and feed conversion ratio of heat-stressed chicks, enhanced antibody titers of heat-stressed broilers as well as antibody titters against avian influenza and infectious bronchitis (Manzoor et al., 2022).

Use of Metallic Nanoparticles as Poultry Feed Additives

Metal/metal oxide Nanoparticles such as zinc, copper, silver, and selenium, nanoparticles can serve as alternative growth and health enhancing supplements to antibiotics, providing a potential alternative for promoting animal health (Krishnani et al., 2022). These can be given directly to the drinking water or feed, by parenteral injection or by in-Ovo route and can provide the embryos with extra nutrients. It is proposed

that in-Ovo administration of metal-containing nanoparticles enables more efficient use of microelements during embryo development compared to feed supplementation, which could enhance embryo development (Michalak et al., 2022).

Silver, selenium, and zinc nanoparticles are primarily evaluated as antimicrobial agents (Ifijen et al., 2022). The most studied are silver nanoparticles, which display a wide range of antimicrobial properties (Bamal et al., 2021). It proves effective against multiple bacteria like *Salmonella typhimurium, Salmonella pullorum, Pseudomonas, Escherichia coli, Staphylococcus aureus* and *Klebsiella* (Abou Elez et al., 2021).

Current research suggests that metal NPs in poultry feed additives require immediate scientific attention and more comprehensive investigation related to their safe doses and toxicity issues (Wang et al., 2024). The main elements of the positive effects of metal NPs on poultry health include a synergistic combination of antioxidant, antimicrobial, and immune-modulating effects (Abd El-Hack et al., 2023). Here are the results of the research on the use of metal nanoparticles in poultry and their possible potential listed in Table 2.

Limitations to the use of Nanoparticles

Besides the advantages of the use of NPs, it is essential to consider their potential negative outcomes (Adams et al., 2022). There is a possibility of potential deposition of nanomaterials in the ecosystem through excretion and development of new forms of environmental contamination (Malakar et al., 2021). They may contaminate air, soil and water sources, affecting plant and aquatic life (Bhardwaj et al., 2023). If these NPs accumulate in birds, it leads to bio-magnification in the food chain and directly harms consumers (Uddin et al., 2021). NPs mainly cause harm if not used in the right quantity or dose. So, always take great care of the dose given to the birds (Bhardwaj et al., 2023). This can also be solved by conducting further detailed research to ensure the exact quantity of NPs necessary for beneficial outcome. It is mandatory to assess the potential risks associated with nanomaterials used to ensure safety (Committee et al., 2021). Addition of nanoparticles to the animal diet can cause pathological alterations in animal tissues, including pancreas, kidney, liver, adrenal glands, small intestine and brain. There is a continuous need for research and development to understand the potential impacts of nanomaterials (Gottardo et al., 2021). Proper precautionary measures can help prevent potential harm to humans and the environment (Dhama et al., 2021).

Conclusion

Poultry provides a fundamental and flexible nutritional supply that continues to grow in global demand for protein. Progressive alternatives based on metallic nanoparticles, which include zinc and silver and copper and selenium, and chromium, can enhance both efficiency and productivity and quality of the product while boosting immunity. These nanoparticles benefit from their dimensions at the nanometer level because they increase nutrient absorption while minimizing interactions between different nutrients and produce better overall biological function at lower concentration levels. NPs demonstrate antioxidants along with antimicrobial and anti-viral and antifungal and immune-modulatory characteristics which produce significant benefits for improving egg and meat quality along with gut health and disease resistance and stress tolerance. The poultry sector benefits from nanoparticles synthesized using physical, chemical and green methods which demonstrate the agents' versatility. The in-Ovo administration of NPs represents a novel technique for embryonic development improvement as well as enhanced nutrient utilization. The multitude of advantages derived from nanoparticles should be acknowledged, but environmental plus toxicological risks surrounding their use demand continued investigation. The application of improper dosage levels might cause tissue accumulation issues in birds as well as chain-based bio-magnification effects which thereby risk both human consumers and ecosystem health. Researchers have yet to unravel all possible effects which nanoparticle exposure has on poultry organs and general health outcomes. The application of metallic nanoparticles should be handled with care even though they stand as groundbreaking technological developments with considerable promise. The successful implementation of nanoparticles in poultry farming depends on maintaining proper drug concentrations and ongoing testing and complete toxicological study for risk reduction. Future developments in nanotechnology sustainability together with strict scientific examination will lead to safe nanoparticle applications in poultry farming which boost animal well-being and secures food supplies and protect the environment.

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