CHAPTER 6

Effect of selenium nanoparticles on poultry farming

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Abstract: The physiological processes of selenium (Se), an essential trace element, include cellular homeostasis, body metabolism, and antioxidant defense. Se is a crucial component of at least 25 selenoproteins in the body, which govern free radicals and reactive oxygen species in the cells through regulating cellular redox and antioxidant defense systems. Dietary Chickens need the right amount of se in their meals to maintain good reproductive and productive performance, and se plays a critical role in immunity, development, and fertility. Dietary supplementation with selenium nanoparticles (SeNPs) has improved microbiota, increased the quality of meat and eggs, and improved growth performance, feed conversion ratio, reproductive performance, egg production, immunological response, and antioxidant status in the past ten years. It has been demonstrated that se increases the relative weights of the thymus and bursa, two organs involved in immunity. Feeding Se-NPs to broilers and layers can increase glutathione peroxidase activity and antioxidant status. Utilizing Se-NPs at 0.9 mg/kg feed in broilers increased the number of helpful bacteria and produced short-chain fatty acids, which enhanced intestinal health. This review focuses on the value of SeNPs to the poultry industry and discusses their advantages over traditional sources of selenium in chicken diets.

Keywords: Selenium nanoparticles; health benefits; antioxidant defense; performance; poultry.

6.1 Introduction

To fulfill the growing needs of the human population, the poultry industry makes a significant contribution to the supply of meat and eggs that are high in protein. It has recently had difficulties as a result of rising input prices (such as feed, medications, vaccines, and labor) as well as the advent of many pressures and diseases. These factors include microbial infections that cause disease and abiotic factors including pollution and environmental changes that might negatively impact livestock's ability to produce [1, 2, 3]. To overcome these obstacles, several strategies have been used to improve the poultry's immune system and productivity [4, 5, 6, 7, 8]. These strategies include the addition of growth promoters, nutraceuticals, pharmaceuticals, microminerals, and antioxidants to feed. Following, dietary supplementation of trace elements is reviewed in light of their crucial functions in bird growth, metabolism, and immunity [9, 10]. Due to its structural makeup and several physiological functions, particularly in avian species' antioxidation, selenium (Se) is one of the necessary trace minerals [11]. In the last ten years, the fields of diagnosis, medicine, and nutrition have given great attention to nanotechnology. The potential use of nanomaterials in poultry feeding has recently attracted more attention. The primary use of nanotechnology in poultry is the use of nanomineral elements, which can lessen any antagonistic behavior that is typically observed in the gastrointestinal tract with traditional inorganic minerals, improve bioavailability, and reduce effective doses [12]. Additionally, improved mineral absorption and bioavailability can improve metabolism while lowering mineral excretion into the environment [13]. In poultry feeding, nanoparticles have been utilized to lower harmful bacterial burdens while favoring probiotic bacteria, improving performance[14]. Broiler growth performance has been demonstrated to be improved by dietary supplementation of zinc nanoparticles [15]. According to Ahmadi and Kurdestany [16] and Aparna and Karunakaran [17], including silver and selenium nanoparticles in broiler feeds improved antioxidant status and decreased oxidative stress. In addition, copper nanoparticles and nano-Fe have been demonstrated to promote hatchability and performance in poultry [18, 19] and immunological responses and growth [20]. According to Pelyhe and Mézes [21, 22], selenium nanoparticles (SeNPs) can boost immunological responses, growth, reproduction, and feed consumption.

6.2 Mechanisms of action and role of nano-Se in poultry nutrition

Selenium was first found in 1817 and is derived from the Greek term selene [23]. Se was formerly thought to be toxic by researchers and scientists, but in the 1950s it was shown to be a vital trace element for living things [24]. Se naturally occurs in either organic or inorganic chemical forms. Organic forms of selenium, or those found in natural plant and animal tissues, are typically selenomethionine (SeMet) or selenocysteine (SeCys). Inorganic forms of selenium include selenate (Se6+), selenite (Se4+), and selenide (Se2). SeCys is the active catalytic site in at least 25 selenoproteins, and Se is their primary structural component [25]. Through selenoproteins, which offer their catalytic or antioxidant capacities, the bulk of selenoproteins play a crucial part in enzymatic redox processes at the cellular level. Selenoproteins are essential for several physiological processes, including DNA synthesis (biosynthesis of dNTPs), scavenging of harmful or signaling peroxides, reducing oxidized proteins and membranes, redox signaling, thyroid hormone metabolism, and transport and storage of Se in tissue reserves [26]. Regarding crucial physiological processes in mammals and birds, there are three main categories of selenoproteins: thioredoxin reductases (TrxR), iodothyronine deiodinases, and glutathione peroxidases (GSH-Px). The main redox system that efficiently controls numerous crucial cellular processes, such as DNA synthesis [27, 28] body defenses against oxidative stress [29] and the integrity of the endoplasmic reticulum is the thioredoxin system, which is composed of TrxR, thioredoxin (Trx), and NADPH. Additionally, this system controls the production of thyroid hormones and facilitates the transformation of T4 (the inactive form of thyroxin) into T3 (the active form), which affects the growth and metabolism of the entire body. An apoptosis-regulating kinase (ASK1), NF-B, Ref-1, AP-1, P53, and the glucocorticoid receptor are a few of the transcription factors that the thioredoxin system uses to mediate the regulation of gene expression. As a result, it has an indirect impact on several important physiological processes, such as the cell cycle, apoptosis, and the activation of immunological responses [30].

The GSH-Px family of selenoproteins, which controls the concentration of free radicals at the cellular level [31, 32], is the second-most significant group of selenoproteins. To ensure normal immunological function, growth performance, and fertility in livestock—which play a variety of roles—the correct amount of selenoprotein (Se) must be fed to the animals. A therapeutic amount of serum may lower the risk of several diseases, including oxidative stress, muscular dystrophy, cardiovascular disease, cystic fibrosis, and arthritis, according to previous research [33]. Due to its direct relationship with immunity and carcinogenesis, se is widely employed as a feed supplement [34]. Since Nano-Se offers more health advantages than other sources, it has gained interest as a supplement in poultry diets. Due to the production of nanoemulsions, nanoparticles' comparative advantage and effectiveness arise from their tiny size and huge surface area, which increases mucosal permeability and increases intestinal absorption. Even though selenoproteins, particularly TrxR and GSH-Px, mediate most of the large indirect effects (on performance) that Se has on feed intake and growth, which, according to [35], are universally needed in redox systems to mediate thyroid metabolism and serve the first lines of defense against reactive oxygen species (ROS). This helps to reduce oxidative stress and ensure correct cellular physiology. SeNPs can also improve intestinal epithelial health, which improves nutrient digestion and absorption. Se shortage impairs body redox and cellular homeostasis, which has detrimental impacts on the health of birds and lowers their ability to reproduce.

6.3 Effect of SeNPs on chicken health

Oxidative stressors, which thwart cellular homeostasis, are sensitive to physiological systems and their macromolecules. ROS produced by oxidative stress, including hydroxides, superoxides, and hydrogen peroxide radicals, drive the death process in cells [36]. Several enzymes, including glutathione-s-transferase, superoxide dismutase, catalase, and peroxidase, are used by antioxidant defenses to neutralize ROS. According to Reeves and Hoffmann [37], SeCys is a structural part of the antioxidant defense mechanism in GSH-Px and TRxR. In addition, SeNPs, as opposed to other forms of Se, can enhance the antioxidant status of heat-stressed birds by modulating GSH-Px and malondialdehyde (MDA) levels and enhancing immunoglobulins (IgM and IgG) levels [38]. Additionally, Se-NPs have been demonstrated to lessen the effects of chromium toxicity on antioxidant enzyme levels, including catalase, superoxide dismutase, glutathione, and MDA, as well as to prevent cell damage [39]. Se can up-regulate the expression of GSH-Px through the formation of selenophosphate, which is an essential part of tRNA selenocysteine, while the main antioxidant activity of Se has been attributed to selenoproteins (GSH-Px and TRxR), which play crucial roles in scavenging ROS and the cellular redox system [40]. The production of cellular ROS is reduced by Se-dependent GSH-Px. According to [41], birds fed diets containing SeNPs at levels of 0.15–1.2 ppm had higher antioxidant status and immunity. In addition, Se-NPs increased IgM and IgG in comparison to birds fed diets enriched with other forms of Se[38], upregulating the antioxidant status of birds subjected to heat stress through modulating GPx and MDA. Similar to this, [42] found that feeding laying hens 0.25 ppm SeNP increased GSH-Px activity. Similar effects of SeNPs on immunological status, antioxidant status, and growth performance were seen in broilers exposed to high ambient temperature [43, 44] **(Figure 6.1).**

Wang [45] discovered that although neither inorganic Se nor SeNPs had any positive impact on oxidative stress, Se did increase broiler survival rates. Along with GSH-Px, superoxide dismutase, and erythrocyte catalase, SeNPs increased the humoral and cellular immunological responses in commercial layers and broilers [46, 47]. Through the upregulation of GPx4 and GPx1 levels, SeNPs recently considerably improved the antioxidant status in egg-laying birds [48]. According to these findings, SeNPs are less toxic than inorganic Se and more effective and efficient at increasing the expression of selenoenzymes [49, 50].

6.4 Effect of SeNPs on growth performance in chicken

SeNPs have been assessed for their effects on the performance of poultry **(Table 6.1)**. Numerous studies have shown that adding inorganic Se sources, such as sodium selenite, to broiler diets does not improve growth or meat quality [38]. SeNPs in diets at levels of 0.2, 0.3, 0.4, and 0.5 mg/kg significantly improved carcass features and growth in broilers without having any negative effects on their internal organs [52]. Additionally, SeNPs and a probiotic (based on Aspergillus spp.) together demonstrated synergistic benefits that markedly improved muscle fatty acid profile, growth, and serum tocopherol level [53]. In comparison to other forms of Se in poultry, Se-NPs have been shown in numerous studies to have more favorable effects [54]. When compared to inorganic selenium, SeNPs have demonstrated a similar ability to increase the expression of selenoenzymes, but with significantly less harmful effects on mice (seven times less toxic than sodium selenite) [55, 56]. SeNPs also have higher tolerated limits than traditional sources of Se since there is a wider range between their optimum and hazardous levels [57]. SeNPs also reduced any harmful effects of inorganic Se, inhibited infections, and prevented fatty liver in broilers, according to Wang et al.'s [58] findings. When compared to broilers that received 0.30 ppm inorganic selenium, broilers fed diets containing SeNP at doses of 0.15-1.20

ppm demonstrated a significant improvement in body weight gain. These results suggested that, in comparison to sodium selenite, SeNPs can have beneficial effects at low concentrations with minimal harmful effects. Broilers' FCR, growth performance, meat quality, and antioxidant status were all considerably improved by dietary supplementation with 0.3 ppm SeNPs[57] and Guanxi yellow chicken [58]. According to a different study [45], feeding both inorganic Se and SeNPs boosted FCR and daily weight growth. According to [59], adding SeNPs to broiler diets at doses of 0.2, 0.3, 0.4, and 0.5 mg/kg had a good impact on growth, immunity, and carcass without having any negative impacts on internal organs. In comparison to either inorganic or organic sources, SeNPs have recently demonstrated more strong effects in enhancing the quality of frozen broiler meat [60].

For poultry producers, laying hen health and commercial egg production, both in terms of number and quality, are top priorities. The diet must contain the proper amounts of minerals to maintain excellent performance in layers. Se supplementation is a frequent method to improve health status and egg production due to Se's critical function in folliculogenesis and reproductive physiology [61, 62]. When alternative sources of Se (SeNPs, Se yeast, or SeMet) were evaluated, however, dietary supplementation of SeNPs in laying hens did not influence egg quality or production, and egg bulk, weight, and selenium retention were higher regardless of Se sources Se is essential for reproduction, yet in ovo delivery of SeNPs at inclusion rates of 0.075, 0.15, 0.225, and 0.3 g/egg did not affect hatchability [63]. However, [64] found that adding 0.25 ppm of SeNPs to layer diets may have increased egg production and Se content, while [65] found that adding 0.3 mg/kg of SeNPs to diets had a similar effect. The ability of SeNPs to increase egg production and create Se-enriched eggs was demonstrated by these findings. To compare the biological effects of SeNPs on hatchability and immunological responses, more research in egg-laying birds is necessary. Effect of SeNPs on Chicken Gut Health Limited research has been done on the possible effects of SeNPs on Chicken Gut Development, Intestinal Morphology, Intestinal Permeability, and Chicken Gut Integrity. But adding SeNPs (0.9 mg/kg) to the diet has been found to improve the health of birds' guts by boosting the numbers of good bacteria (Lactobacillus and Faecalibacterium spp.) and short-chain fatty acids (SCFAs), particularly butyric acid. This demonstrated SeNPs capacity to alter gut flora, which can greatly improve immune response, gut health, and intestinal integrity. Additionally, the gut should produce more SCFAs since these are used by the intestinal cells as an energy source **(Figure 6.1).**

Future research can now study the application of SeNPs to strengthen the gut microbiota to the helpful microorganisms Lactobacillus and *Faecalibacterium* spp., significantly enhancing chicken gut health. SeNPs drawbacks and restrictions In general, using nanoparticles as dietary supplements within allowed levels is harmless. Broiler meals should not contain more than 1.0 ppm of SeNP supplements because 0.3 to 0.5 ppm is the range recommended by and [66, 67] for appropriate supplementation. Increased concentrations may cause toxicity and alter the shape of the liver. Studies have examined the bioavailability and toxicity of SeNPs in broilers fed higher doses (4.25 ppm), which caused stress at a cellular level and altered the metabolism of carbohydrates and fatty acids as shown by the roles of differently produced proteins [68]. Due to their small size and improved absorption, nanoparticles were mostly to blame for this. According to studies using mouse models, 8 F. Nabil et al. Se consumption at 5 mg/kg body weight (BW) retarded growth, while higher levels produced liver abnormalities (6.4 mg/kg BW) and anemia and increased mortality at 8 mg/kg BW. To understand the toxicity of SeNPs and their potential negative consequences in hens, more research is necessary.

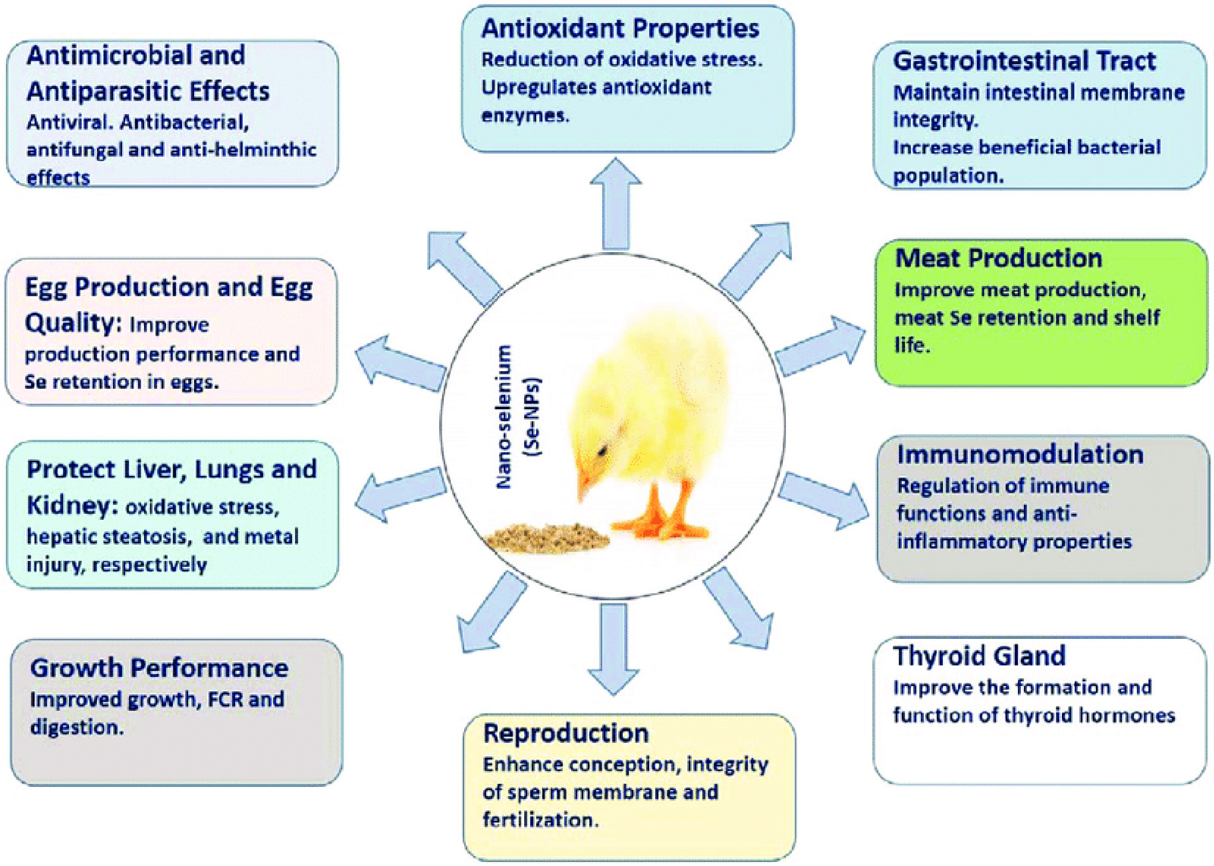

Figure 6.1. Schematic representation of effect of SeNPs on chicken health, growth, reproduction and nutrition (Adopted from Nabi et al. 2020)

Table 6.1 Selenium nanoparticles impact on poultry birds farming

Parameter	Character	Reference
Humoral immune response (ND Titre test)	The birds that received 1.50 mg/kg of diet nano-Se showed higher ($P < 0.05$) total immunoglobulin and IgG titers in primary and secondary immune responses against sheep erythrocytes respectively.	[69]
Egg production	The productivity of Se-supplemented laying hens was significantly higher than that of the basal diet, and the hens fed a diet with 0.5 mg/kg SY (SY-H) were highest	[70]
Effect on vital organs	Histological studies of the liver and kidney in the highest nano-Se-treated groups (T4 and T5) did not show any abnormal changes	[71]
Se in breast	broiler chickens fed nano-Se had higher Se and vitamin E concentrations in breast muscle than broiler chickens fed the control diet. dietary supplementation with nano-Se at 0.3 mg/kg diet might enhance growth performance by improving antioxidative or immune properties in broilers reared under high ambient temperature.	[44]
Bio availability	Se supplementation significantly increased the Se concentration of breast muscle ($P < 0.0001$).	[69]
	The Se levels in the liver, breast muscle, kidney, brain, and gizzard were significantly ($P < 0.05$) increased with increased dietary nano-Se	[72]
Toxicity	Nano-Se is more efficient than SeMet in increasing GST activity irrespective of supranutritional or toxic level	[50]

6.5 Conclusions

Selenium is a crucial component that is frequently employed in poultry diets because of its many health advantages. Due to their increased bioavailability and lower toxicity, SeNPs have proven to be superior to traditional selenium sources. SeNPs have the potential to enhance poultry performance and health, according to published research. SeNP use can also improve absorption by lowering mineral antagonism in the colon (common with inorganic forms), which lowers Se excretion in the environment. SeNPs can efficiently boost the Se content in meat and eggs, allowing them to be sold as high-quality functional foods for people. Before its commercial adoption, more research is needed to understand the mechanism of action of SeNPs in chickens and to determine the optimal quantities of these compounds in poultry feeds for birds at various physiological stages.

6.6 References

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