


MINI-REVIEW

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Nano selenium in broiler feeding: physiological roles and nutritional effects

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Abstract

Using nanotechnology, while improving the health of broiler chickens, it is possible to control and reduce the conflict of minerals in the intestines, and toxicity of and pollution by these elements. It could be shown that the antioxidant and immune modulation effects of nano selenium are significantly superior compared to other sources of selenium. In addition, improving the quality of meat products with the use of nano selenium has promising results in the future perspective of quality improvement and food safety. Nutrition of permitted and optimal levels is very important in the consumption of nano selenium form and as it can have significant beneficial functional and health effects, in case of errors in the selected levels and doses, irreparable side effects and adverse results can occur. In this review report, an attempt has been made to introduce the position and importance of selenium and the approach of smart consumption of its nano form in the nutrition of broiler chickens. The novelty of using nanotechnology in feeding broiler chickens can be a unique opportunity to improve the bioavailability of important and rare elements such as selenium.

Key points

- There are beneficial and strong effects of nano selenium compared to other types.
- Despite promising results, nano technology and the cost of producing is a challenge.
- Considering the high bioavailability of nano selenium, it should always be used with utmost care and control to prevent side effects from overdose.

Keywords Antioxidant, Bioavailability, Broilers chickens, Immune modulation, Nano selenium, Smart consumption

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Introduction

The increase in world population, the warming of the earth and the subsequent spread of climate and environmental crises have created a situation where the pressure on the consumption of food resources has doubled, and human food security will face even more aggravated challenges in future (Hosseintabar-Ghasemabad et al. 2024). The crises mentioned in Fig. 1 have led to the call for sustainable food production around the world and to focus on the use of nutritional solutions as well as new technologies in order to increase human food security in the future (Dumlu and Bölükbaşı 2023; Dumlu 2024).

There are novel reports on positive effects of food and feed additives in humans (Liu et al. 2023; Chuai et al. 2023; Zhen et al. 2024; Liang et al. 2024) and animals (Movahhedkhah et al. 2019; Chand et al. 2021; Osita et al. 2022; Das et al. 2023; Hosseintabar-Ghasemabad et al. 2024; Belali et al. 2024). The poultry industry, in turn, as one of the main pillars of food security in terms of quality and quantity, can play a great role in solving the challenges and crises mentioned in the future perspective of food security (Seidavi

et al. 2023b). The 38% share of poultry meat from the 360 million tons of meat produced in 2022 and the first rank in meat production confirms the role of this industry in the field of food security, and this trend is still strong (Fig. 2) (Teyssier et al. 2022). The feed conversion ratio (FCR) of poultry is significantly better than that of cattle, and white meat is also healthier than red one.

The increase in people’s awareness and nutrition culture has led to an increase in the demand for high-quality food products (Baghban-Kanani et al. 2023; Akbarimehr et al. 2023). However, there is a growing consensus to develop agriculture more productively and diversely, and these demands are increasing not only due to the growth of the world population but also due to climate change and reduced access to natural resources (Seidavi et al. 2023b; Dumlu 2024; Hosseintabar-Ghasemabad et al. 2024). On the other hand, the focus of production is not always on increasing the amount of food produced, but sometimes the goals are set in such a way that the needs are met by using fewer resources. Thereby, possible environmental effects are reduced without affecting the livelihood and

Global warming

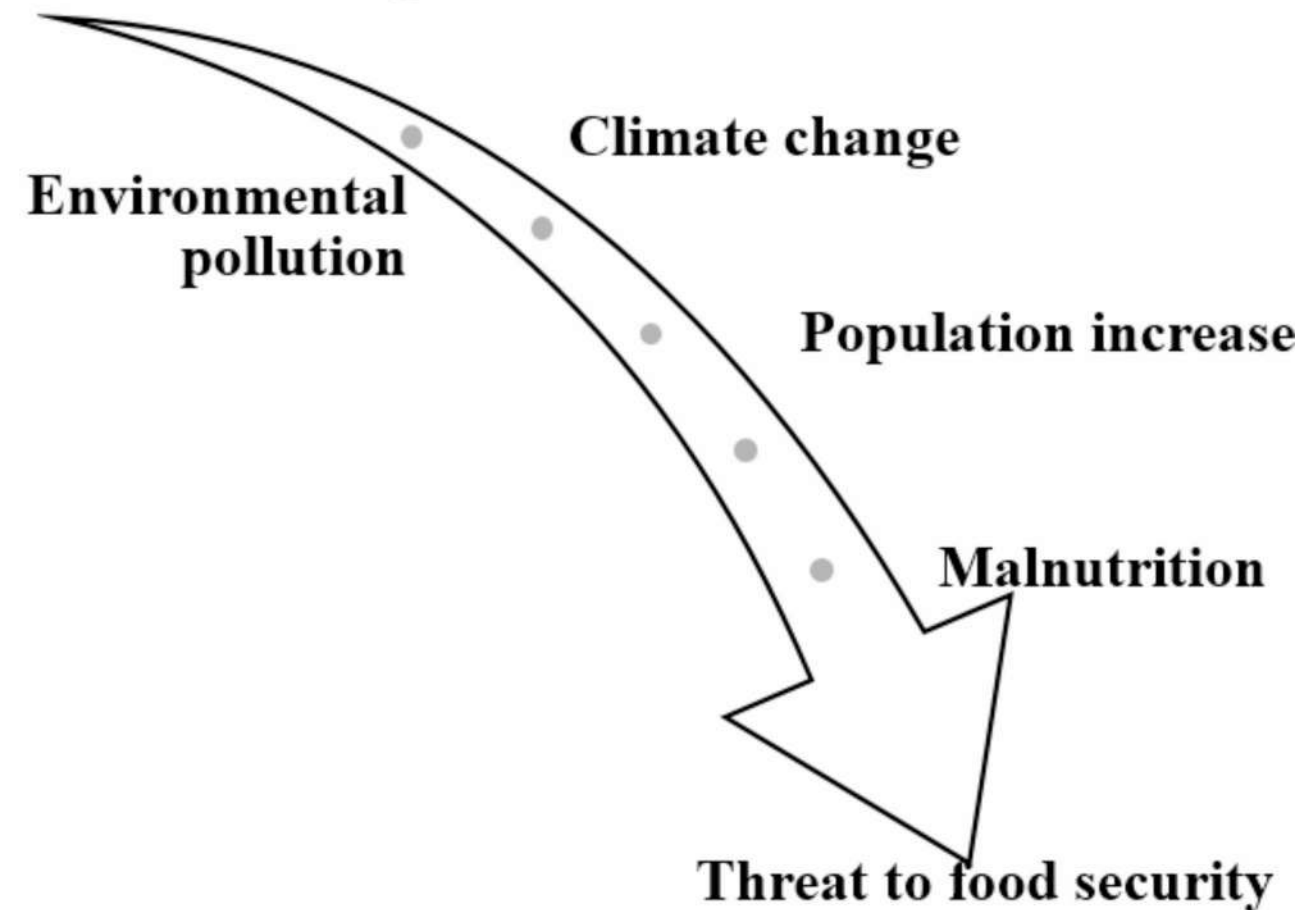


Fig. 1 Items threatening food security

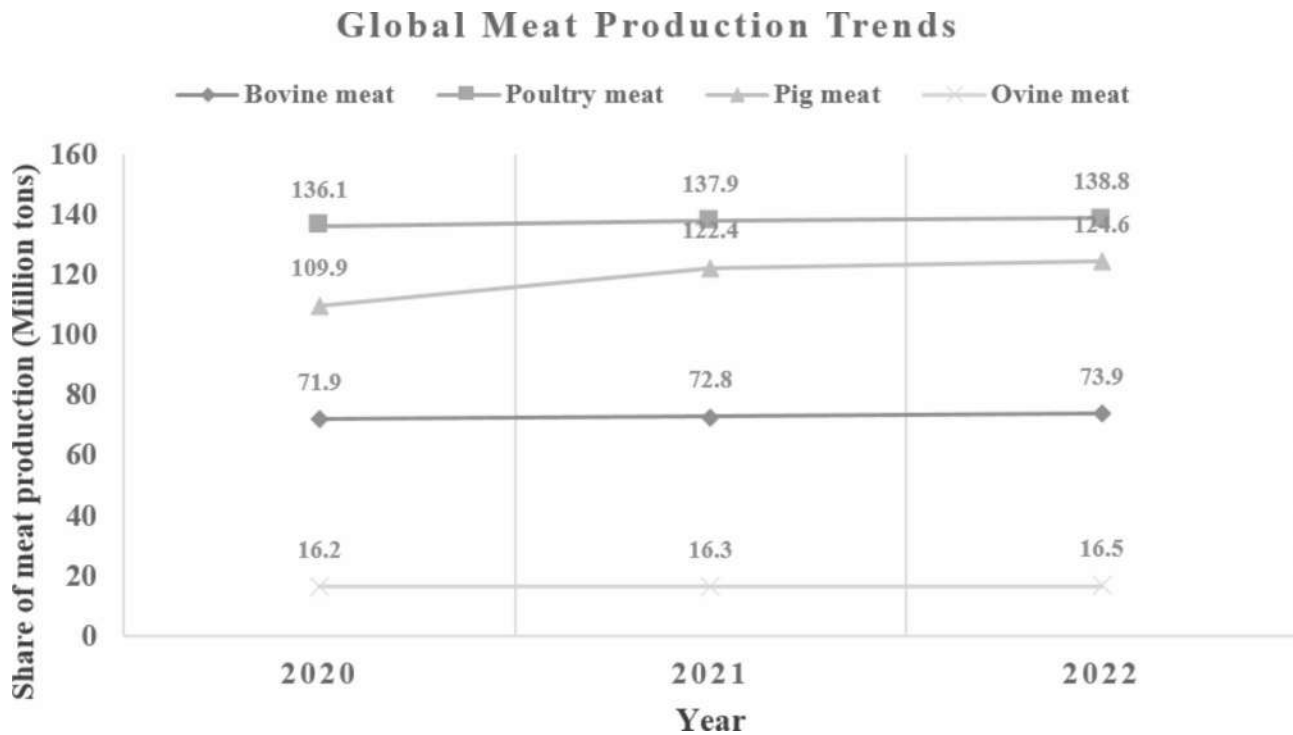


Fig. 2 Comparison of global meat production trends

economy negatively (Amirdahri et al. 2023; Hosseintabar-Ghasemabad et al. 2024). Therefore, a set of balancing measures to overcome crises and respond to needs has always been a global challenge that requires a thoughtful strategic approach to food production and consumption (Dumlu and Bölükbaşı 2023). Any effort and use of new technologies in order to improve the livelihood and optimize the use of nutrients and micronutrients in poultry feeding can contribute to the development of this industry and help to improve the quality and quantity of the meat. One of the innovative and promising technologies is nanotechnology, which with a wide range of applications and socio-economic potential in the poultry industry can guarantee successful strategies and prospects (Seidavi et al. 2023b; Sadr et al. 2023). Considering the importance and place of the element selenium in broiler chickens and its biological status, its toxicity and its complex biochemical mechanism in the body have led to the fact that with proper understanding of the use of this substance in the formulation of practical chicken diets, there can be improved health of the flock. Despite its consumption in low doses, its effectiveness on important parameters and traits of broiler chickens can be important. Therefore, this mini review was compiled while introducing the chemical element selenium (Se) with the aim of providing up-to-date information about the effect of nano selenium on nutrition, physiology and health of broiler chickens. This work emphasizes the use of nanotechnology in feeding broilers, which can create a unique opportunity to improve the bioavailability of important and rare elements such as selenium.

Methodological approach

In their review report, the authors examined the status of the poultry industry and evaluated different strategies for using nanotechnology with a case study on the element selenium. To collect information from searches in, ScienceDirect, Scopus, Web of Science and PubMed databases as well as Google and Google Scholar, using keywords selenium, nano selenium, broilers, nanotechnology and poultry nutrition, most of the important articles and the criteria for the last five years were reviewed systematically.

Selenium and its physiological role in the body

Selenium (Se) is considered a quasi-metal element belonging to the group (six) VI A of the periodic table, which has an atomic number of 34, an atomic weight of 78.96 g/mol, a melting point of 217 °C and a boiling point of 684.9 °C. Two types of acids are obtained from selenium with the formulas H_2SeO_3 and H_2SeO_4 , respectively, and the resulting salts are called selenites and selenates, respectively. Selenium (Se) and sulfur (S) are in the same group in the periodic table and their chemical properties are largely similar, so that they have the same covalent and ionic bond length and comparable electronegativity. H_2Se is a stronger acid than H_2S (Payne 2004). Selenium exists in two chemical forms, inorganic (mineral) and organic (Fig. 3).

The amount of selenium in the earth's crust is estimated to be about 0.09 parts per million on average. This element enters the soil through the decomposition of rocks,

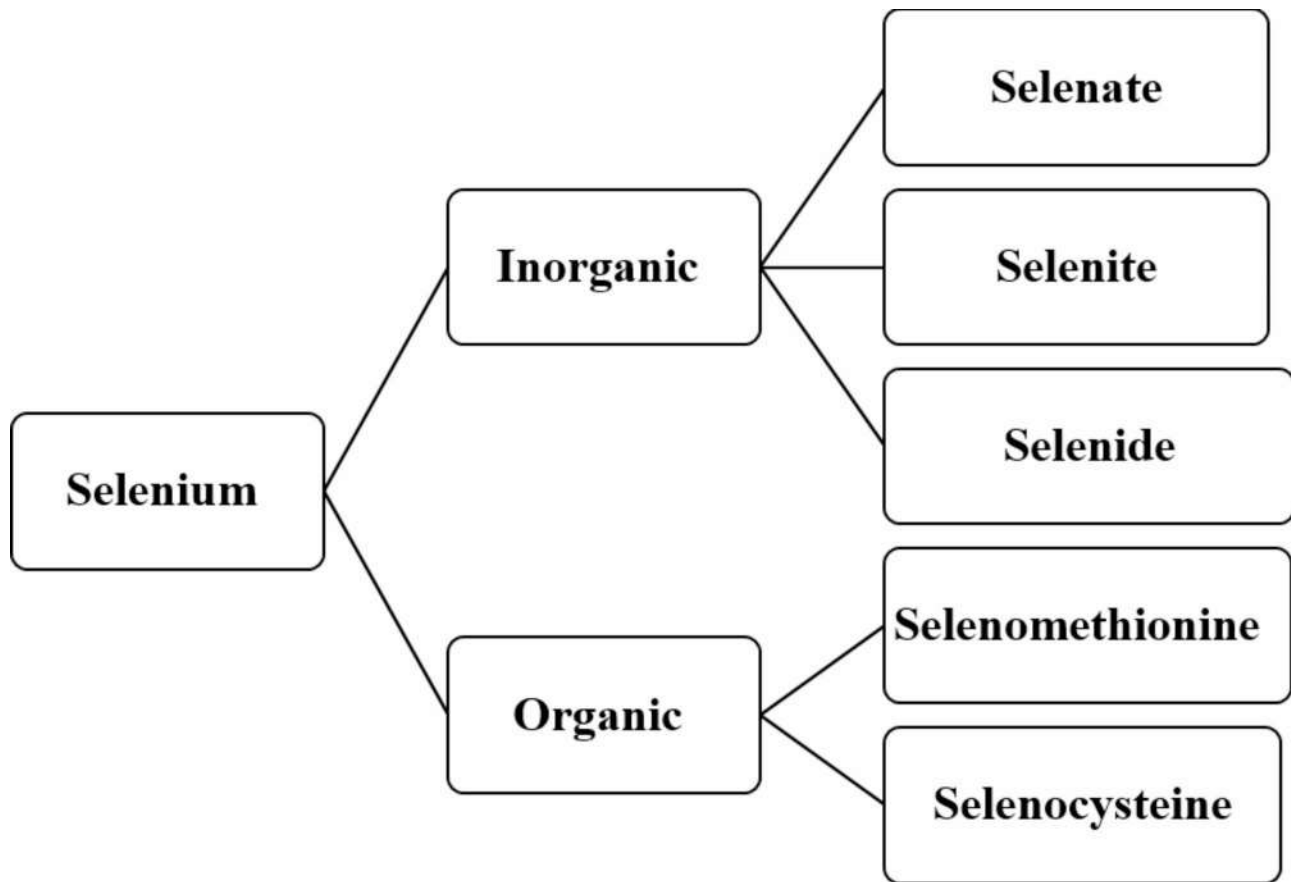


Fig. 3 Different forms of selenium

some phosphate fertilizers and some water sources. Most water sources contain very low levels of selenium (from 0.1 to 100 $\mu\text{g/L}$). Most soils have about 0.1 to 0.2 parts per million of selenium. Only a part of soil selenium is available for plants. Soils containing a large amount of available selenium are called ferrous selenium soils. Soil selenium is available to plants in the form of selenite and selenate, but reduced selenium is not usable by plants. Selenium is converted into selenate in alkaline soils that are well aerated, therefore, soil acidity affects the availability of selenium to plants. In food sources such as wheat, alfalfa, and yeast, selenium has a favorable bioavailability (Surai and Fisinin 2014; Habibian et al. 2015; Surai and Kochish 2019).

Selenium (Se) can be supplemented in different forms of inorganic, organic and nanoparticles in poultry diets. In general, the chemical form (speciation) and concentration of selenium play an important role in the rate of absorption, retention and metabolism of this element. For example, the inorganic form of selenium is mostly excreted through urine and the nano form of selenium is excreted through feces (Saleh and Ebeid 2019; Bień et al. 2023). In addition, the inorganic and mineral form of selenium has less bioavailability compared to other forms

and affects oxidation processes and has toxic effects in high doses, selenium has bioavailability, absorption power, high efficiency and stronger catalytic efficiency in chickens (Pedro et al. 2021; Bień et al. 2023).

A review of the scientific literature has proven that selenium is an integral part of the glutathione peroxidase enzyme, which as an antioxidant enzyme helps to reduce the level of hydrogen peroxide and fat peroxide (which are produced during normal metabolic activities). Selenium in the diet is necessary for the activity of almost all functions of the immune system (Surai and Kochish 2019). The presence of four types of glutathione peroxidase enzymes containing selenium (GPX1, GPX2, GPX3, GPX4) in different tissues of the body always controls the oxidation reactions. Of course, other enzymes such as superoxide dismutase, catalase, glutathione sulfur transferase, and also a non-enzymatic compound called vitamin E play a role in preventing peroxidation reactions. The World Health Organization (WHO) recommended the consumption of selenium for adults between 50 and 200 micrograms per day, which indicates the importance of this element in daily diets, and the effects of its severe deficiency have been confirmed in more than 40 human diseases. The reduction in activity or imbalance of the

body's immune system and the increase of diseases such as cancer, cataracts, diabetes and thyroid dysfunction can be noticeable effects of the lack of this element (WHO 2011; Cai et al. 2022; Cardoso et al. 2022).

Nabi et al. (2020) stated in their review report that selenium is present in the main structure of at least 25 selenoproteins, and selenocysteine (SeCys) is its active catalytic site. A review of the scientific literature shows that selenoproteins strengthen the catalytic and antioxidant potential in the body and play a vital role in the regulation and balance of enzymatic redox reactions on the cell surface. Processes such as DNA synthesis, redox signaling, reduction of oxidized proteins and membranes, removal of toxic and signaling peroxides, transportation and storage of selenium in tissue reserves, and metabolism of thyroid hormones are among the key physiological roles of the element selenium in the form of selenoproteins in the body (Fig. 4).

In poultry, three major groups of selenoproteins are effective on physiological function, including thioredoxin reductases (TrxR), iodothyronine diiodinases, and glutathione peroxidases (GSH-Px). TrxR includes thioredoxin (Trx) and NADPH, which affects the redox system of the cell, and in parallel, and it can play a key role in vital activities such as DNA synthesis, strengthening the body's defense system against oxidative stress, endoplasmic reticulum integrity, thyroid hormone synthesis, gene expression of transcription factors including nuclear factor kappa light chain enhancer of activated B lymphocytes (NF- κ B), apurinic/aprimidinic endonuclease/redox factor-1 (Ref-1), activator Protein-1 (AP-1), apoptosis-regulating kinase (ASK1) and glucocorticoid receptor (Nabi et al. 2020). The set of these effects affects health, immune responses, and the overall growth of the body (Nabi et al. 2020). Selenoprotein GSH-Px is engaged in reducing and regulating the concentration of free radicals in the cell and can inhibit the formation of reactive

oxygen species (ROS) (Sarkar et al. 2015; Nabi et al. 2020).

Hyperthermia can increase the production of ROS, which in turn increases lipid peroxidation in tissues and doubles the accumulation of free radicals and oxidative stress in broiler chickens (Eid et al. 2023). At temperatures over 22 degrees Celsius, for each degree of temperature increase, feed consumption decreases by 3.6% and growth by 1.5%, respectively, which is due to the negative effects of heat stress in broilers (Eid et al. 2023). Therefore, the inclusion of compounds that reduce heat stress such as selenium, whose biochemical role has been proven in bird physiology, can be very helpful and important (Eid et al. 2023). In addition, selenium deficiency can be associated with an increase in muscular dystrophy and myopathy in chickens, and the subsequent decrease in performance and immunity will be certain (Ali 2017; Habibian et al. 2015; Bień et al. 2023). It has been proven that selenium deficiency has a negative effect on the ratio of unsaturated fatty acids in the body of broiler chickens, and with the more severe oxidation of different forms of omega-3 fatty acids (alpha-linolenic acid, eicosapentaenoic acid and docosahexaenoic acid), it can increase the content and ratio of omega-6/omega-3. Considering that the oxidation of omega-3 is more intense, increasing the ratio of omega-6 to omega-3 can stimulate the herd's immune system and make it susceptible to all kinds of sensitivities against external factors, and the herd does not have a balanced performance against pollution and pathogens (Schäfer et al. 2004; Zanini et al. 2004; Pereira et al. 2012; Bień et al. 2023). In addition, recent studies show that the modulation of intestinal health through increasing the abundance of beneficial microbes (*Lactobacillus* and *Facalibacterium*) and the production of short-chain fatty acids after consumption of Se-containing nanoparticles can be considered a potential of using nano-additives (Hassan et al. 2020). One of the goals of

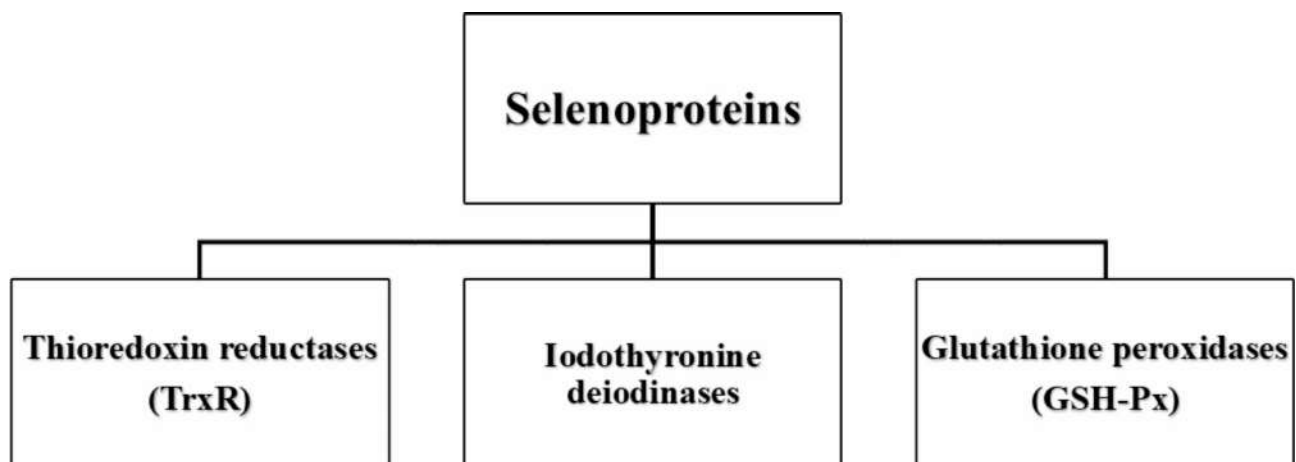


Fig. 4 Types of Selenomethionine

using nanoparticles in poultry nutrition is to reduce harmful bacteria and subsequently improve growth performance by developing beneficial bacteria and adjusting the ecosystem and providing nutrients for the beneficial microbiota of the digestive system. Many nano additives can improve feed efficiency by reducing the production of bacterial toxins, improving the absorption of nutrients through the thinning of the intestinal epithelium and reducing the circulation and mobility of the epithelial cells of the intestinal mucosa, increasing the birds' more effective use of nutrients (Marappan Gopi et al. 2017; Gopi et al. 2022; Gelaye 2024). In fact, nano-additives can increase growth and production with less consumption and simultaneously strengthen the gut health and immune system of the herd (Gelaye 2024). In addition to improving feed efficiency, improving the bioavailability of nutrients and micronutrients, helping to improve the performance, safety and health of chickens, it has been determined that by using nanomaterials in the form of feed additives, it is possible to reduce the harmful effects of some substances such as selenium in the environment (Wang and White 2022; Dumlu 2024).

After the general introduction of the vital role of the element selenium in the physiology of the body in different forms, meeting the requirements of this element as a feed additive in poultry nutrition is very important, and the attention and focus of research is often on improving the bioavailability of this element and, in parallel, reducing harmful environmental effects in broiler chickens.

Nanotechnology and introduction of nano selenium

Nanotechnology is an emerging technology that has promising potential to revolutionize food production worldwide (Srivastav and Dhuria 2023). Nano is derived from the Latin word *nanus* and means very small. $1\text{ nm}=10^{-9}\text{m}$, and the definition of nanotechnology, by the National Nanotechnology Initiative (NNI) in America, is the understanding and control of matter at the nano scale, in the dimensions of 1 to 100 nanometers. According to other researchers, particles $<1\text{ }\mu\text{m}$ in either x-, y- or z-dimension, are considered nano-scale. Due to the potential impact of nanomaterials, research in the conditions in vitro and in vivo is of interest in many sciences (Bhagyaraj and Oluwafemi 2018; Seidavi et al. 2023b).

Prescribing and using minerals in the form of nanotechnology is a type of bio-fortification, which is considered as a new, sustainable, long-term and cost-effective method in nutrition, which improves absorption and bioavailability, and also nutrient availability (Younas et al. 2023). However, due to the lack of sufficient knowledge about the potential of nanotechnology in the poultry industry, the position of this technology is still

challenged. Yet, it has been proven that minerals, especially rare minerals that have little bioavailability in the birds' body, in the form of nanotechnology can be effective in improving the absorption power and bioavailability of elements. Nanoparticles of rare elements can reduce the elimination and antagonism of minerals in the intestine, and as a result of this event, an increase in absorption is seen and as a result, a decrease in their excretion in the external environment. In this context, nanotechnology has the potential of improving bird immune responses and digestive efficiency in chickens (Hassan et al. 2020).

In poultry nutrition, nano additives in different forms can guarantee the improvement of performance and health of the flock. A series of studies showed very promising results, including the improvement of livelihoods and the reduction of pollutants (Hassan et al. 2020; Seidavi et al. 2023b). In general, nanotechnology is considered as a smart solution to overcome several poultry feeding challenges, especially for nutritional and non-nutritive additives (El Sabry et al. 2018; Seidavi et al. 2023b). Once can observe an increase in the demand by consumers for natural products. Therefore, the use of nanotechnology to meet nutritional needs in the field of poultry nutrition can be used as an opportunity to improve the quality and quantity of food products (El Sabry et al. 2018). Nanotechnology has the potential to improve nutrient delivery and bioavailability and influence metabolic and physiological effects (Singh 2016). Research in the field of nano for the poultry industry is often aimed at stimulating and modulating the immune system, improving the biological status of nutrients and micronutrients, strengthening antimicrobial and disinfectant effects, accurate and rapid diagnosis of some poultry diseases, and use in the field of it is a medicine for effective and quick treatment (Srivastav and Dhuria 2023; Sadr et al. 2023; Gelaye 2024). Spent poultry and its effects on improving the digestibility and absorption of nutrients, promoting growth and development and modulating the immune system will be noticeable (Dumlu 2024). Many feed additives and many nutritious and bio-active compounds that are used in poultry nutrition have better bioavailability in the nanoscale compared to the macro form and in other words, it can be acknowledged that with lower doses, increased growth, elimination of pathogen residues and reduction of environmental pollutants can be seen, and the subsequent improvement of performance and safety, as well as reduction of antibiotic consumption and reduction of herd disease, is noticeable and promising (Dei 2021; Gelaye 2024). The hypothesis is that nanoparticles can affect the biological activities, viability and productivity of animals, and most scientific findings emphasize and confirm the positive and productive effects (Salem and Fouda 2021; Sadr et al. 2023). In

the poultry industry, the restriction and ban on the use of additives containing antibiotics and the resistance to their use has alarming consequences, including the potential emergence of resistant pathogenic microorganisms and the negative effect on the quality of the products. Poultry industry activists are interested in and tend to use natural additives (Phillips *et al.* 2023). A series of evaluations and forecasts show that the demand for food will double until 2050, and on the other hand, with the increase in public awareness and expectations for healthy, safe, and diverse feed, it can be expected that poultry industry will need to respond to these needs in the future (Baghban-Kanani *et al.* 2019; Bölükbaşı *et al.* 2023; Seidavi *et al.* 2023a; Dumlu 2024).

In recent years, research has shown that a series of minerals in nanofoms can be used as low-dose antibiotic alternatives and have similar properties with fewer side effects in poultry nutrition so that the growth of poultry and reduction of pollutants and qualitative and quantitative improvements of animal products can be preserved and even improved (Gelaye 2024). The use of high doses of mineral salts in poultry nutrition is common, as it is believed to enhance the growth and health of the flock. However, due to their low bioavailability and potential environmental hazards, alternative solutions like nanotechnology are being considered for the future (Dumlu 2024).

The phenomenon of hidden hunger is a significant concern in both human and animal nutrition. The lack of nutrients and micronutrients, in terms of their physical and biological availability, has created a need for innovative solutions to address this crisis. Research aimed at solving this problem is always welcome. (Baghban-Kanani *et al.* 2020; Janmohammadi *et al.* 2023). The qualitative and quantitative content of food in the body can be a strategic choice and decision by stakeholders in the poultry industry (Azimi-Youvalari *et al.* 2017; Mantovani *et al.* 2022; Kianfar *et al.* 2023). Despite the reduction in the use of antibiotics and the parallel increase in synthetic and natural additives in poultry nutrition, the concern of low absorption or high excretion, in other words, non-ideal nutrition utilization, is of high interest to researchers in this field (Phillips *et al.* 2023). A clear example is mentioned in the report of Eskandani *et al.* (2022) in which these researchers stated that the bioavailability of L-carnitine in many studies was less than 20% when its nano form was used. The values increased significantly, which can lead to the effectiveness of this additive in improving blood lipid profile and bird health (Hosseintabar *et al.* 2015). However, with the nanotechnological and biotechnological approach, the effectiveness and the market of feed additives in the poultry industry can be put on the right path and successful prospects, and the challenges of food supply and food security

problems can hopefully be solved (Pirgozliev *et al.* 2019; Younas *et al.* 2023; Dumlu 2024). Clinical studies indicate that particles smaller than 100 nm in tissues and particles smaller than 300 nm in blood can spread in the body and can show increased effectiveness (Prabhu and Poulouse 2012; Dumlu 2024). In addition, with nanotechnology and nano additives, the lifespan and effectiveness of key body enzymes such as trypsin and peroxidase enzymes can be increased, and in parallel, the stability of protein enzymes and important biological processes in digestion, metabolism and absorption enhanced nutrients (Sharma *et al.* 2007; Singh 2016). In fact, nanoparticles can pass through the capillary walls much more easily in the intestine by passive diffusion in the mucous cells and also by active transport in the intercellular space and manifest their biochemical and physiological effects (Wang *et al.* 2022). The set of these events reduces the risk of environmental pollution or chemical accumulation and promotes biological interaction and effective absorption and delivery of nutritious and non-nutritive compounds (Tian *et al.* 2022; Gelaye 2024). To better understand these effects with nanotechnology, it can be acknowledged that nanoparticles are similar to gas molecules in the air or like large molecules in solutions that are easily diffused. Nanoparticles have better biodegradability and less deposition, and they have fast and effective absorption in the digestive system and intestinal lining cells, and due to the increase in surface area and persistence in the intestine, they strengthen the intestinal cleansing mechanisms and show significant tissue penetration. With high absorption capability and greater penetration depth, they can reach the liver and spleen through the lymphatic system and finally reach the tissue and target cells (Singh 2016; Sadr *et al.* 2023). It should be noted that the absorption, distribution, decomposition and excretion of nanoparticles in the poultry body depends on the physical and chemical characteristics in terms of solubility, charge and size (Gelaye 2024).

Research on the use of nanotechnology in poultry nutrition often has promising and less risky results for nano minerals, and in the form of nano emulsions, micelles, and protein capsules, these additives are useful stimulants for growth, immune modulators and reducing antagonistic behavior high bioavailability is the main reason in research (El-Sayed and Kamel 2020; Hassan *et al.* 2020).

Nutritional effects of nano selenium on broiler chickens

In general, in the body of poultry, nanoparticles in the form of nutritional and non-nutritive additives exhibit multiple physiological roles, the most prominent of which include providing and creating opportunities for vital biological reactions through increasing the level of

compounds, a wider provision for enzymatic reactions by increasing the shelf life in the digestive system, optimizing the process of digestion and absorption and reducing excretion in the digestive system, facilitating the passage of substances through the capillaries and reaching the depth tissues and their effective absorption in body cells can be mentioned (Pelyhe and Mézes 2013; Bunglavan *et al.* 2014; Hameed 2021).

As mentioned, the relative advantage and efficiency of nanoparticles is due to their small size and large surface area, which leads to increased mucosal permeability and more intestinal absorption. Studies have shown that selenium does not have a significant direct effect on feed consumption and growth of poultry, but in complex physiological and biochemical processes with indirect effects, mainly through selenoproteins, especially TrxR and GSH-Px, they can affect redox systems and cell homeostasis and thyroid mediators have an effect and influence the parameters related to the performance and health of the herd (Hosnedlova *et al.* 2018). In addition, it has been determined that in the conditions of oxidative stress, the negative effects of ROS should be minimized, and selenium is one of the well-known elements in the body's defense lines for the mentioned conditions (Gangadoo *et al.* 2016).

Oxidative stress in poultry is always a potential concern and affects the performance of the flock and their health, research has proven that physiological systems are highly sensitive to stress conditions, and disturbance in cell homeostasis can have irreparable consequences in the short and long-term for the bird to follow. For example, ROS can produce a series of harmful hydroxides, superoxides and hydrogen peroxide radicals, which subsequently stimulate the process of apoptosis on the cell surface and the body's defense line by known enzymes such as glutathione-s-transferase, catalase, peroxidase and to activate superoxide dismutase (Sarkar *et al.* 2015). In addition, selenocysteine, as an important part of the structure of the antioxidant defense system in GSH-Px and TRxR, can improve the antioxidant status in poultry, especially in heat stress conditions, by mediating and improving the levels of GSH-Px and malon dialdehyde (MDA) and increase important immunoglobulins such as IgM and IgG. In general, the main antioxidant activity in inhibiting ROS and reducing cellular oxidation in selenium is attributed to GSH-Px and TRxR selenoproteins. In addition, the presence of selenophosphate in the structure of tRNA can strengthen the antioxidant effects (Mizutani *et al.* 2000). In Fuxiang *et al.* (2008) research, nano selenium feeding at levels of 0.15 to 1.2 ppm aimed to improve the immunity and antioxidant status of chickens, and in the continuation of the research, nano selenium was able to mediate GPx and MDA content in the bird's stress conditions increase and the IgM and IgG

levels increase in parallel (Senthil Kumaran *et al.* 2015). In broiler chickens, the improvement of immunity and antioxidant status and the subsequent growth of flock performance after the consumption of nano selenium are promising, and this effect has been significant and greater in stress conditions (Mahmoud *et al.* 2016). On the other hand, Wang (2009) stated that the use of nano selenium did not have a beneficial effect on reducing oxidative stress and could only improve the survival rate in broiler chickens. In the reports of Gulyás *et al.* (2017) and Ahmadi *et al.* (2018) strengthening humoral and cellular immune responses by investigating the improvement of GSH-Px, superoxide dismutase and red blood cell catalase levels in broiler chickens and laying hens after feeding nano selenium was promising. In the report of Pathan *et al.* (2024), it is also stated that the selenium requirement of poultry is low in physiological conditions, and amounts between 0.15 and 0.2 mg/kg is recommended, while in commercial diets up to the level of 0.3 mg/kg is used and it is recommended, and this level is approved in America. However, the recommended amount of selenium in modern commercial poultry rations is recommended in such a way that even up to three times the consumption, it does not threaten the herd. Considering the difference in suggestions and recommendations for selenium consumption and possible concerns about overdose and possible toxicity, by choosing and consuming nano selenium, you can intelligently reduce the worries and parallelly the positive effects of selenium consumption are effectively used. Because nanoparticles can improve the absorption of nutrients by reducing the opposite effects of divalent cations in other microelements and put bioavailability in a favorable state and help reduce its physiological side effects by less excretion of this element (Marappan Gopi *et al.* 2017; Gelaye 2024). In general, organic selenium supplements that contain selenomethionine are an active compound compared to sodium selenite/selenate forms, which can be beneficial in maintaining the expression of selenoproteins under stress conditions (Pathan *et al.* 2024). Researchers believe that the use of nanoparticles as an additive in poultry feed can be effective in order to reduce harmful bacteria and grow beneficial bacteria in the microbiome of the digestive system (Gelaye 2024) and in parallel increase short-chain fatty acids (SCFAs), especially butyric acid, and following these increases, SCFAs, as a favorable source of energy in the intestine, help to regulate the microbiota and increase immune and health responses and intestinal integrity even compared to probiotics, these effects were greater (Gangadoo *et al.* 2016).

Basically, nanoparticles can provide higher bioavailability with a lower dose rate, and following this event, improved absorption efficiency and more stable interaction will be created (Zha *et al.* 2008; Gelaye 2024). Hu *et*

al. (2012) reported that the use of nano selenium sources compared to sodium selenite in the feeding of broiler chickens could more effectively provide selenium needs in the body and improve growth performance. Lee et al. (2020) evaluated the effects of different concentrations and sources of selenium in the diet and concluded that the antioxidant activity in birds fed with nano selenium at levels (0.15, 0.30 and 0.45 ppm) compared to sodium selenite. It was more and the reason for it was better absorption.

In the report of Ahmadi et al. (2020), supplementation with optimal levels of 0.3 and 0.4 mg/kg in the diet of broiler chickens with nano selenium could improve body weight gain and FCR. Bień et al. (2023) in their research by examining the effects of organic and inorganic levels, selenized yeast, and nano selenium in the feeding of broiler chickens announced that the source of nano selenium in a dose of 0.5 mg/kg of feed was able to provide bioavailability. It provides a higher biological value with less toxicity without any negative effect on growth performance parameters, and in parallel, breast muscle quality parameters (improvement of sarcomere length and strengthening of muscle elasticity) and health condition of chickens (in the form of protection against injuries mitochondria in liver cells and increase the antioxidant potential. In general, inorganic sources are passively absorbed in the intestine through the simple diffusion process and compete with many inorganic elements for absorption pathways. The organic source was also actively absorbed through the amino acid transport mechanism and had better bioavailability compared to the inorganic form. In the form of nano selenium at a concentration of 0.5 mg/kg of feed, increasing the content of polyunsaturated fatty acid (PUFA) and protecting lipids against reactive oxygen species is promising and impressive, and in total, at doses higher than 0.3 mg/kg, performance is maintained or improved. It was associated with improving the quality of manufactured products and guaranteeing the health of the herd. Previous research shows that nano selenium has a higher absorption rate and better antioxidant capacity in a wide range between dietary and toxic doses compared to sodium selenite, and following this situation, the toxicity of nano selenium is even lower than that of selenomethionine, and the amount of selenium and Possible pollution is also much less. In the study of Yoon et al. (2007), chickens fed with a lower dose of 0.2 mg/kg of nano selenium had similar growth performance to groups fed with sodium selenite. However, poultry growth performance is related to the expression of selenoprotein P and type I selenoenzymes, all of which play key roles in thyroid hormone synthesis and selenium transport (Zhan et al. 2014). A series of studies have tried to investigate the pH of the tissue after killing the bird by evaluating the accumulation of lactic acid, using sources

of delay in pH reduction to help reduce protein denaturation and subsequently strengthen the ability of skeletal muscle to retain water. However, the increase in glutathione peroxidase activity after selenium consumption affected the concentration of myoglobin and nitrite oxide, and the resistance to the oxidation of myoglobin or oxy-myoglobin increased, and the color of meat and the condition of myofibrils, sarcomeres, and mitochondria were positively affected (Berri et al. 2007; Bień et al. 2023). The effect of changes in the volume of the matrix within the physiological range of stimulation of the electron transport chain and oxidative phosphorylation in order to meet the metabolic needs of the cell is considered a vital and necessary process that by opening the mitochondrial permeability transition pores of other independent mechanisms, the function and integrity of the mitochondria will become more efficient (Javadov et al. 2018; Bień et al. 2023). However, mitochondrial dysfunction is a prominent phenomenon in the pathogenesis of various diseases, and taking the optimal dose of selenium is effective on mitochondrial function, and the changes in the structure and function of this organelle are quite noticeable (Bai et al. 2017; Zahedi et al. 2018; Liu et al. 2020). The increase in antioxidant indices of muscle and liver of chickens after feeding with nano selenium sources indicates oxidative stability in mitochondria, which can affect the health of chickens (Bień et al. 2023). Nano selenium sources are able to improve free radicals by improving the activity of selenoenzymes and with less toxicity, improve the antioxidant status of serum and the antioxidant effect of nano selenium in the family of glutathione peroxidase, thioredoxin reductase can also be spectrum reduce a wide range of harmful effects of peroxides such as H_2O_2 , phospholipid hydroperoxide, fatty acid hydroperoxides and thymine hydroperoxyl groups (Sarkar et al. 2011). Pathan et al. (2024) by examining different forms of selenium (0.2 mg/kg) along with vitamin E (100 mg/kg) on the performance of broiler chickens, announced that supplementing diets with nano selenium and Vitamin E could economically and effectively improve growth performance, carcass traits, meat quality, immunity, and antioxidant status.

In their research, Eid et al. (2023) investigated the recovery effect of sodium selenite and nano-selenium on broilers exposed to heat stress, and the results indicated that the consumption of 0.15 mg/kg of nanoparticles of selenium and sodium selenite increased and decreased in total body weight and FCR was observed in chickens under heat stress. In addition, the groups consuming nano selenium and sodium selenite supplements faced a decrease in serum aspartate aminotransferase (AST), alanine aminotransferase (ALT), urea, creatinine, and malondialdehyde (MDA). In parallel, total serum protein, superoxide desmutase (SOD),

Table 1 Selected research on the use of nano selenium in feeding broiler chickens

Reference	Nano selenium levels (mg/kg)	Effects of consumption
Wang (2009)	0.2 and 0.5	Increase in bird weight, bird survival, tissue selenium content and GSH-Px concentration, respectively
Hu et al. (2012)	0.15, 0.3, 0.6 and 1.2	Increase in growth performance, GSH-Px concentration, bioavailability of selenium in serum, liver and other organs, respectively.
Cai et al. (2012)	0.3, 0.5, 1 and 2	Increase in meat quality, immune system and oxidation resistance respectively
Shirsat et al. (2016)	0.3 and 0.6	Decrease in humoral immunity and liver enzymes respectively
Ahmadi et al. (2018)	0.1, 0.2, 0.3, 0.4 and 0.5	Increase in carcass performance and safety respectively
Ibrahim et al. (2019)	0.3, 0.45 and 0.6	Reducing meat oxidation and increasing growth performance
Kazem and Al-Khafaji (2023)	1 and 1.5	The number of red blood cells and the vpacked cell volume cells increased and better and significant results were obtained
Debata et al. (2023)	0.0375, 0.075, 0.15 and 0.3	Average weight gain and feed conversion ratio (FCR) were best observed at 0.15 and 0.3. Antibody titer was significantly increased in all groups consuming nano selenium. At the end of the period, erythrocyte glutathione peroxidase, catalase and superoxide dismutase activities increased significantly, and lipid peroxidation values decreased significantly. Selenium levels increased in the liver, breast muscle, kidney, brain, and bone marrow, but no abnormal changes in tissue appearance and function occurred.
Lochi et al. (2023)	0.3	In the conditions of heat stress, the use of selenium nanoparticles to improve body weight, FCR and intestinal parameters had improving effects.
Abd El-Hack et al. (2024)	1.5 and 2	The final weight, weight gain and functional and productivity indicators increased compared to the control group

lysosome (LZM), IgG, IgM, and complement 3 (C3) increased. The noteworthy point in the current research was the superior effect of nano selenium on the improvement of hematological and histopathological parameters, which was able to improve the antioxidant status and strengthen the immune response during heat stress. Nabi et al. (2020) in their review report presented better responses of nano selenium form on growth performance and meat quality compared to other forms of selenium. Saleh (2014) using nano selenium and a type of probiotic (based on *Aspergillus* species) in the feeding of broiler chickens, observed a significant increase in serum alpha-tocopherol level, growth, and muscle fatty acid profile, and the effects of the improvement

in these parameters was promising. Compared to inorganic selenium, nano selenium have better efficiency for the expression of selenoenzymes and are seven times less toxic than sodium selenite (Zhang et al. 2008). In Table 1, some research related to the effects of nano selenium consumption in broilers is mentioned.

However, nanotechnology in poultry nutrition, in addition to respecting the birds' welfare and guaranteeing the safety of consumers, it is also necessary to pay attention to its economic nature. In many studies on the beneficial and effective deployment of nano selenium compared to other sources, the results were quite promising, but the discussion of technology and the cost of producing these sources is a challenge that should be considered in future applied research. Adhering to the permissible range of nano selenium consumption between 0.3 and 0.5 mg/kg resulted in promising results in terms of performance and health in broiler chickens, but levels exceeding the permissible limit can cause toxicity and cellular stress, and disturbance. It affects the metabolism in the system for chickens and subsequently affects the health and performance of the flock negatively. Considering the high bioavailability of nano selenium and its unusual absorption in the cell, it should always be used with utmost care and control to prevent its side effects and in parallel with its beneficial and impressive effects in terms of antioxidants and reducing the conflict of minerals in the intestine and improving the condition of the intestinal microflora. Therefore, by solving technical challenges and reducing production costs, it is possible to contribute to more practical research on the use of nano selenium in the nutrition of broiler chickens to increase the interest and tendency to use this resource in order to improve bioavailability increase and in parallel the use of the benefits and potential effects of this vital element in metabolism and physiology in poultry nutrition has a promising perspective.

Abbreviations

ALT	Alanine aminotransferase
AP-1	Activator Protein-1
ASK	Apoptosis-regulating kinase
AST	Aspartate aminotransferase
FCR	Feed conversion ratio
GSH-Px	Glutathione peroxidases
LZM	Lysosome
MDA	Malon dialdehyde
NF- κ B	Nuclear factor kappa light chain enhancer of activated B lymphocytes
NNI	National Nanotechnology Initiative
PUFA	Polyunsaturated fatty acid
Ref-1	Apurinic/apurimidinic endonuclease/redox factor-1
ROS	Reactive oxygen species
SCFAs	Short-chain fatty acids
Se	Selenium
SeCys	Selenocysteine
SOD	Superoxide desmutase
WHO	World Health Organization

Author contributions

B.H-G. and A.Z.M.S. coordinated the project. B.H-G., A.S. and A.Z.M.S. wrote the main part of the principal draft, to which K.O.V., S.E.V., B.A.V., and F.Z., had contributed. A.Z.M.S. M.M.M.YE, MS and ML have revised the manuscript. All authors approved the final draft. All authors have read and agreed to the published version of the manuscript.

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