 DOI: 10.19601/j.cnki.issn1943 – 9903.2024.12.010

Research Progress of Organic Selenium in Animal Nutrition

Yina LU

College of Life Sciences, Zhaoqing University, Zhaoqing 526061, China

Abstract Selenium, an essential trace element that is critical for animal health, primarily exists in nature in both inorganic and organic forms. Inorganic selenium exhibits high toxicity, whereas organic selenium is noteworthy due to its reduced toxicity and enhanced bioavailability. In the field of animal feeding, the incorporation of organic selenium has been shown to markedly enhance various aspects of animal performance, including immunity, fertility, antioxidant capacity, and meat quality. Furthermore, it can contribute to a reduction in farming costs while simultaneously improving the overall quality of animal products. Selenium deficiencies can lead to the onset of various diseases in animals, in addition to causing stunted growth and diminished reproductive performance. This paper presents a thorough review of the existing research on the application of organic selenium in animal nutrition. Additionally, it investigates the potential for integrating modern technology with selenium, with a specific emphasis on the prospective use of nano-selenium as a novel source of selenium. The objective of this study is to establish a foundational reference for the role of selenium in the field of animal nutrition research and its practical applications.

Key words Selenium, Animal nutrition, Application research

1 Introduction

Selenium, a vital trace element, is typically present in animal tissues at concentrations ranging from 0.05 to 0.2 mg/kg. Research has demonstrated that the highest levels of selenium are located in animal muscle. Furthermore, selenium plays a pivotal role in modulating various physiological functions in animals, including the enhancement of immune responses and the prevention of disease. Although initial studies indicated that selenium might be toxic to animals, potentially leading to mortality and malformations, extensive subsequent research has established selenium as an essential nutrient for animals, highlighting its critical role in various enzymatic and protein metabolic processes. Selenium has been shown to improve sow fertility, increase milk production, enhance boar sperm viability, and elevate meat quality, thereby promoting animal health both directly and indirectly[1]. Selenium is present in both organic and inorganic forms in nature. However, inorganic selenium is increasingly being supplanted by organic selenium, which exhibits a bioavailability of up to 95%. This shift is attributed to the high toxicity, low uptake, and poor conversion efficiency associated with inorganic selenium[2]. Organic selenium has been shown to enhance various aspects of animal performance, including immunity, fertility, antioxidant capacity, and meat quality. These improvements are crucial for reducing farming costs and enhancing product quality[3]. The addition of organic selenium into animal feed can significantly elevate the rate of selenium deposition in animals[4]. Furthermore, selenium plays a crucial role in the nutritional and biological functions of aquatic animals. The appropriate supplementation of selenium can substantially enhance the growth of these animals, as well as bolster their antioxidant capacity and immune response, thereby improving the overall quality of aquatic products[5]. This paper presents a thorough review of the existing research on the application of organic selenium in animal nutrition. Additionally, it investigates the potential for integrating modern technology with selenium, with a specific emphasis on the prospective use of nano-selenium as a novel source of selenium. The objective of this study is to establish a foundational reference for the role of selenium in the field of animal nutrition research and its practical applications.

2 Sources of organic selenium

2.1 Plant sources In cereal foods, selenium is predominantly present in the form of organic compounds. Research indicates that in maize, wheat, and soybeans, approximately 81% of selenium exists as L-selenomethionine, while other forms of selenium-containing compounds are primarily identified in selenium-rich plant species[6]. In addition, plants that contain this selenium compound can be cultivated in selenium-enriched media. Selenomethionine is predominantly found in its L form in natural plants, which enhances its absorption and utilization by the human body.

2.2 Animal sources In the animal body, selenomethionine is present in a significantly more diverse manner, with organic selenium typically being mediated by enzymes or proteins. To date, researchers have identified over 30 selenoproteins, which include six enzymic proteins, such as glutathione peroxidases (GPXs)[7]. Additionally, selenoproteins serve transport functions within the bloodstream. Consequently, selenium is crucial for various cellular biochemical processes.

2.3 Microbial sources Preliminary findings indicate that media supplemented with selenium enable yeast and *Escherichia coli* to demonstrate antioxidant properties, engage in redox processes, and affect the metabolism of thyroid hormones. The addition of inorganic selenium compounds, such as sodium selenite, during the growth of yeast can yield a microbial fermentation product known as selenium-enriched yeast. In this yeast, the organic sele-

Received: August 15, 2024 Accepted: November 5, 2024
Yina LU, master, teaching assistant, research field: fish immunology.

nium content can constitute up to 90% of the total selenium content, with selenomethionine representing 70% and selenocystine accounting for 20% of the total[8]. Furthermore, microorganisms present in the rumen, along with specific algal species, are capable of synthesizing organic selenium[9].

3 Effect of selenium on animal performance

3.1 Effect of selenium on growth performance of animal

The findings from numerous studies indicate that selenium plays a crucial role in improving animal growth performance and feed utilization. Zou Xiaoting *et al.* conducted an experiment in which they supplemented the daily feed of Lingnan yellow chickens with selenomethionine and selenium-enriched yeast. The results demonstrated that, in comparison to the control group, the daily gain of the yellow chicken group receiving selenomethionine increased significantly by 16.08% ($P<0.01$), while the group supplemented with selenium-enriched yeast exhibited an even greater increase of 17.86% ($P<0.01$). Additionally, the feed conversion efficiencies for these groups improved significantly by 15.26% ($P<0.01$) and 16.19% ($P<0.01$), respectively. These findings suggest that organic selenium can substantially enhance both the daily gain and feed conversion efficiency in chicks[10]. Furthermore, researches have demonstrated that selenomethionine effectively promotes daily gain and reduces the feed consumption ratio in meat pigs[11-12].

Selenium plays a crucial role in bolstering the immune system of animals, thereby improving their growth performance. A deficiency in selenium can result in diminished antibody levels in the serum of animals and a weakened function of immune cells, which ultimately reduces the animals' capacity to resist diseases and infections. Research has demonstrated that selenium-enriched yeast facilitates the proliferation of lymphocytes in dairy cows, indicating that selenium may enhance the animal's capacity to resist disease by enhancing the proliferative activity of immune lymphocytes[12]. These findings underscore the significance of selenium in bolstering organism-specific immunity and combating diseases. Moreover, selenium facilitates the growth and development of the animal by enhancing the synthesis and accumulation of proteins within its body.

3.2 Effect of selenium on laying performance and egg protein of laying hens Selenium has been shown to improve both the laying rate and quality in laying hens. Additionally, it significantly increases the laying rate in broiler breeders, enhances the hatchability of breeding eggs, and improves the shelling rate of chicks. Wei Tao *et al.* added 0.089 g of sodium selenite and 2 000 mg/kg of yeast selenium into the basal diet of 27-week-old Romain White Shell laying hens and conducted feeding experiments over a duration of 8 weeks. The experimental findings indicated that the average daily egg production and the average weight of eggs from hens supplemented with yeast selenium were significantly improved. Additionally, the incidence of broken eggs was reduced, and the selenium content in the eggs was markedly increased[13]. Selenium enhances the production performance and feed conversion efficiency of laying hens primarily by modulating the microecological balance of intestinal flora and facilitating the synthesis of various enzymes and nutrients[14]. Eggs that are enriched with selenium have emerged as a highly desirable health food, offering benefits such as improved immune function. Research has shown that the efficiency of selenium deposition and the overall selenium content in eggs can be significantly enhanced through the administration of selenium-enriched feeds[15-17].

3.3 Effect of selenium on reproductive performance of animals Selenium is essential in animal reproduction, particularly in the processes of spermatogenesis and the enhancement of sperm motility. Research indicates that organic selenium markedly improves sperm motility to a greater extent than inorganic selenium. This enhanced effect is correlated with increased activity of glutathione peroxidase (GSH-Px), decreased activity of nitric oxide synthase (NOS), a reduction in free radicals, inhibition of cellular damage, including membrane lipid peroxidation, and the preservation of the structural integrity of the sperm tail[5].

Organic selenium positively influences reproductive efficiency in sows. Research indicates that the addition of organic selenium into the daily diet of sows significantly enhances the birth weight of piglets, reduces mortality rates, and improves the absorption of selenium from breast milk, thereby enhancing the immune response of the piglets. Both organic and inorganic selenium, when added into the feed at a concentration of 0.15 mg/kg, have been shown to enhance the reproductive performance of sows. Notably, organic selenium is particularly effective in further decreasing the stillbirth rate. The inclusion of organic selenium in the diet of sows resulted in a 63% reduction in the stillbirth rate compared to the control group that did not receive selenium[18]. The addition of organic selenium into poultry feed has been shown to improve both the laying rate and hatchability of eggs. A study investigating the effects of organic selenium on poultry and laying hens revealed that increasing the selenium supplementation to 0.5 mg/kg resulted in a 30% higher selenium concentration in the eggs of the organic selenium group compared to the inorganic selenium group. Furthermore, this enhancement contributed positively to embryonic development and chick hatching[19]. Research has demonstrated that selenium deficiency results in alterations in spermatoblasts and spermatogenesis in rats, potentially culminating in the total loss of germ cells. This deficiency may subsequently induce growth arrest and reproductive dysfunction. Selenium is crucial for the maintenance of normal reproductive function in animals. A deficiency in selenium can lead to irregular estrous cycles or a complete absence of estrus in females, as well as decreased fertility. In males, selenium deficiency may result in impaired development of testicular seminiferous tubule germ cells, reduced sperm viability, and an increased rate of malformations[6,19]. Adequate selenium supplementation is beneficial for enhancing reproductive function; however, excessive selenium intake can adversely impact the reproductive capabilities of animals. Consequently, it is crucial to maintain appropriate selenium levels within the body to ensure normal reproductive function of animals.

3.4 Effect of selenium on immune performance of animals Selenium plays a crucial role in the optimal functioning of the immune system in both animals and humans, contributing to the defense against pathogens and cancer. In the field of animal husbandry, an animal's capacity to resist disease significantly influences its morbidity and survival rates. Contemporary vaccines are instrumental in the prevention of infectious diseases, as they work in conjunction with the animal's innate immune response to enhance their efficacy and mitigate the risk of widespread mortality. Organic selenium has been shown to enhance the cellular immune response and improve lymphocyte transformation. Research indicates that the addition of 0.15 mg of organic selenium per mg of feed significantly elevates lymphocyte activity in chicks, suggesting that organic selenium effectively activates the immune system and enhances immune function[20]. Organic selenium has been shown to enhance humoral immunity and promote the production of immunoglobulins. In a study conducted by Li Guanghui *et al.*, the addition of 0.1 and 0.3 mg/kg of organic selenium to the feed of weaned piglets resulted in an increase in the number and activity of B-lymphocytes. This finding suggests that selenium may stimulate the organism's ability to produce antibodies and improve the bactericidal capacity of serum[21-22].

In conclusion, the appropriate supplementation of selenium in animal organisms has the potential to enhance immune function by promoting the proliferation of T- and B-lymphocytes, increasing antibody levels, and enhancing the bactericidal activity of immune cells.

4 Effect of selenium on animal products

The primary mechanism through which organic selenium enhances meat quality is attributed to its antioxidant properties. Selenium serves as an essential component of GSH-Px. By influencing the synthesis of GSH-Px in various tissues, selenium contributes to the improvement of the organism's antioxidant status, thereby safeguarding living cells against oxidative damage. Furthermore, selenium plays a crucial role in maintaining the integrity of cell membranes, preventing the loss of intracellular fluids, and minimizing the leakage of juices from muscle tissue for a period following the slaughter of the animal. This contributes to an enhancement in the quality of livestock meat[23]. In recent years, there has been a growing demand among consumers for high-quality meat products. The assessment of meat quality characteristics typically considers water retention capacity, color, and flavor as essential indicators. Selenium, recognized as a significant antioxidant, plays a vital role in inhibiting the oxidation of polyunsaturated fatty acids in animals, thereby improving the quality of meat products[24].

5 Application of nano-selenium in animal nutrition

Nano-selenium represents a novel form of selenium additive characterized by its small size, high reactivity, low toxicity, and effective absorption. This compound has been employed in the treatment of various diseases due to its diverse bioactivities, including the enhancement of the immune system[25]. A substantial body of experimental research has demonstrated that nano-selenium enhances the activity of selenoenzyme, exhibiting effects comparable to those of organic selenium while presenting lower toxicity. Furthermore, it has been reported that selenium deficiency diminishes the cytotoxic capacity of neutrophils and adversely impacts T-cell proliferation and differentiation, NK cell activity, and antibody responses[26]. Nano-selenium enhances reproductive and immune functions in animals and plays a significant role in combating both diseases and tumors[27].

Ruminants exhibit a low absorption rate of elemental selenium, primarily due to the presence of gastric microbes. However, the application of nano-selenium has the potential to significantly enhance the bioavailability of selenium[28]. Nano-selenium significantly enhanced the selenium content in porcine tissues, and the total antioxidant capacity, along with the activities of related enzymes in serum, exhibited a linear increase corresponding to the escalating levels of nano-selenium incorporated into the diet[29]. This enhancement contributes to the improvement of both antioxidant capacity and immune function in pigs. Furthermore, nano-selenium exerts significant effects on poultry, as evidenced by research indicating that its inclusion in chicken feed enhances intestinal integrity, mitigates inflammation, and diminishes oxidative damage by maintaining the functionality of the intestinal mucosa. These effects contribute positively to the overall intestinal health of poultry[30-33]. The addition of nano-selenium into aquaculture feeds has been shown to enhance the growth performance of aquatic animals, as well as to improve their antioxidant properties and immune responses[34].

6 Conclusions and prospects

The preceding analysis indicates that selenium is integral to the domain of animal nutrition. It not only enhances the productivity and quality of animal products significantly but also contributes to the provision of safe and high-quality selenium-enriched food for humans. Consequently, this opens up extensive opportunities for the application of selenium in animal production. The practical application of selenium in animal husbandry continues to encounter several challenges. Firstly, the production of organic selenium involves a complex and costly process, which is typically confined to controlled indoor experiments, thereby limiting its practical use in animal husbandry[23]. Secondly, the optimal dosage of organic selenium that should be administered requires further investigation, as both excessive and insufficient amounts can adversely affect animal growth. Thirdly, there are variations in the absorption efficiency of selenium compounds depending on their forms and sources, necessitating comprehensive studies to elucidate their specific impacts on animal growth. Additionally, selenium may exhibit synergistic or antagonistic interactions with other substances within the body. Consequently, it is imperative to conduct in-depth research on the interactions between selenium and other substances and their effects on animal growth.

Nano-selenium exhibits significant potential in the domain of animal nutrition research; however, its mechanism of action remains inadequately understood. There is an urgent necessity to elucidate its mechanism of action through functional experiments conducted both *in vitro* and *in vivo*, utilizing contemporary biotechnological methods.

References

[1] WANG Y, JIANG ZY, GAO YY. Research progress of organic selenium in animal nutrition[J]. Feed Industry, 2009, 30(4). (in Chinese).

[2] ZHONG GQ, ZHANG ZP. Synthesis of organic selenium and its application in culture[J]. Feed Industry, 2009, 16: 29 – 31. (in Chinese).

[3] LI SH, JIN EH, ZHOU JX, *et al.* The research progress of applications of organic selenium in humans and animals[J]. Journal of Anhui Science and Technology University, 2013, 27(1): 1 – 5. (in Chinese).

[4] LI ZY. Characteristics of selenium in yeast and its application in animal nutrition[J]. Guangdong Feed, 2016, 25(6): 35 – 37. (in Chinese).

[5] YAN XX, WANG YB. Research progress of elemental selenium in aquatic animal nutrition[J]. Feed Industry, 2013, 34(24): 45 – 47. (in Chinese).

[6] XIA DH, LI M, MA L, *et al.* Effect of active dry yeast supplemental level on rumen fermentation *in vitro*[J]. Feed Research, 2011(4): 42 – 44. (in Chinese).

[7] QIAN LP, HUANG SH. Function and addition method of selenium in pig body[J]. China Animal Husbandry & Veterinary Medicine Digest, 2011, 27(3): 178 – 179. (in Chinese).

[8] CHEN XY, DONG AH, XU CH. Research and application of yeast source biological feed[J]. Guangdong Feed, 2012, 21(S1): 90 – 93. (in Chinese).

[9] MENG FC. Study on the effects of different selenium sources on production performance of broilers[D]. Zhengzhou: Henan Agricultural University, 2009. (in Chinese).

[10] DENG GW. Optimization of synthesis process of selenomethionine and its elimination of free radical[D]. Guangzhou: South China Agricultural University, 2020. (in Chinese).

[11] LU ZY, NIE CL, JIANG JY, *et al.* Application of selenium yeast in pig production[J]. China Feed, 2013(6): 29 – 31. (in Chinese).

[12] TAO LL, KOU Q, LIANG MJ. Research progress of selenium in livestock production[J]. Jiangxi Feed, 2011, 5. (in Chinese).

[13] WANG L, SHAN AS. Recent advances of nano-selenium in animal nutrition[J]. China Animal Husbandry & Veterinary Medicine, 2011, 8(4): 38 – 42. (in Chinese).

[14] LIU LJ. Study on mutagenesis selection and cultivation condition of selenium-riched yeast with ultraviolet[D]. Hefei: Anhui Agricultural University, 2007. (in Chinese).

[15] ZHANG FP, HUA SS, FU ZY. Effect of dietary supplementation with organic selenium on reproductive performance and egg quality in the breeder hens[J]. Guizhou Journal of Animal Husbandry & Veterinary Medicine, 2007(5): 4 – 5. (in Chinese).

[16] GUO F. Effects of Se sources and interaction of organic Se with methionine on performance, meat quality and physiological and biochemical indices of broilers[D]. Tai'an: Shandong Agricultural University, 2004. (in Chinese).

[17] WU D, XIA LZ, CHEN LY, *et al.* Effects of insect protein selenium on selenium deposit and anti-oxidation function in tissues of spotted-brown chickens[J]. Cereal & Feed Industry, 2008(7): 42 – 44. (in Chinese).

[18] LI F, CHEN M, LIANG XL. Effect of yeast selenium on the GSH-Px activity in the immune organs and tissue of broilers[J]. Journal of Anhui Agricultural Sciences, 2010, 38(4): 846 – 1848. (in Chinese).

[19] YAN XH, ZHAI MR, LI GH, *et al.* Research progress on the regulation mechanism of nutrition factors on porcine reproduction[J]. Livestock and Poultry Industry, 2000(5): 28 – 30. (in Chinese).

[20] WANG PY, WANG HY, DUAN WJ, *et al.* Research and application of feed additives derived from *Saccharomyces cerevisiae*[J]. Feed Industry, 2011, 32(2): 30 – 35. (in Chinese).

[21] LI WB. Effects of selenium-rich yeast on LPS-induced immune-stressed early weaned piglets[D]. Ya'an: Sichuan Agricultural University, 2009. (in Chinese).

[22] LI BC, ZHU L. Effects of different selenium sources on the growth performance of laying chicks and the development of their immunity organs[J]. Animal Husbandry and Feed Science, 2009, 30(2): 15 – 17. (in Chinese).

[23] LI SH, JIN EH, ZHOU JX, *et al.* The research progress of applications of organic selenium in humans and animals[J]. Journal of Anhui Science and Technology University, 2013, 27(1): 1 – 5. (in Chinese).

[24] WANG ZG, ZHOU AG, WANG ZS. Advances in organic selenium in swine nutrition[J]. Chinese Journal of Animal Science, 2007, 43(7): 37 – 40. (in Chinese).

[25] WANG BY, WANG LL. Research progress on physiological function of selenium and application of nano-selenium in animal nutrition[J/OL]. Chinese Journal of Animal Science, 1-9. https://doi.org/10.19556/j.0258-7033.20230905-04.

[26] GILL H, WALKER G. Selenium, immune function and resistance to viral infections[J]. Nutrition & Dietetics, 2008, 65: S41 – S47.

[27] WANG R, LIANG YY, LI FQ, *et al.* Research progress of nano-selenium in ruminant production[J]. Neijiang Technology, 2016, 37(11): 43 – 44. (in Chinese).

[28] HOSNEDLOVA B, KEPINSKA M, SKALICKOVA S, *et al.* Nano-selenium and its nanomedicine applications: A critical review[J]. International Journal of Nanomedicine, 2018, 10(13): 2107 – 2128.

[29] ZHENG Y, DAI W, HU X, *et al.* Effects of dietary glycine selenium nanoparticles on loin quality, tissue selenium retention, and serum antioxidation in finishing pigs[J]. Animal Feed Science and Technology, 2020, 260: 114345.

[30] MAHMOUD HED, IJIRI D, EBEID TA, *et al.* Effects of dietary nano-selenium supplementation on growth performance, antioxidative status, and immunity in broiler chickens under hermoneutral and high ambient temperature conditions[J]. Journal of Poultry Science, 2016, 53(4): 274 – 283.

[31] HU CH, LI YL, XIONG L, *et al.* Comparative effects of nano elemental selenium and sodium selenite on selenium retention in broiler chickens[J]. Animal Feed Science and Technology, 2012, 177(3 – 4): 204 – 210.

[32] CAI SJ, WU CX, GONG LM, *et al.* Effects of nano-selenium on performance, meat quality, immune function, oxidation resistance, and tissue selenium content in broilers[J]. Poultry Science, 2012, 91(10): 2532 – 2539.

[33] GANGADOO S, DINEV I, CHAPMAN J, *et al.* Selenium nanoparticles in poultry feed modify gut microbiota and increase abundance of *Faecalibacterium prausnitzii*[J]. Applied Microbiology and Biotechnology, 2018, 102: 1455 – 1466.

[34] CHEN CX, SHANG XD, DAI YY, *et al.* Research progress of nano-selenium in aquatic animal nutrition[J]. Scientific Fish Farming, 2017(11): 27 – 29. (in Chines).