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To cite this article: R Markovi *et al* 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **85** 012032

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New scientific challenges – the possibilities of using selenium in poultry nutrition and impact on meat quality

R Marković, M Glišić, M Bošković and M Ž. Baltić

University of Belgrade, Faculty of Veterinary Medicine, Bulevar oslobođenja 18,
Belgrade, Republic of Serbia

E-mail: glisic.mica@gmail.com

Abstract. Physiological stress is one of many concerns facing modern broiler production. In conditions when birds are exposed to stress, supplementation of selenium, which is a crucial glutathione peroxidase enzymatic cofactor, increases the antioxidant capacity of the animals and decreases the harmful effects of free radicals. Dietary selenium improves production performance and health of animals, and positively affects the immune system, the quality, selenium content and fatty acid composition of meat and eggs. There are several different forms of selenium, the most common dietary supplements being an inorganic form (sodium selenite) and an organic form (selenomethionine). However, in recent years, new forms of selenium, such as a 2-hydroxy-4-methylselenobutanoic acid (HMSeBA) and nanoselenium, which have more bioavailability, bioefficacy, and low toxicity have been designed. In this short comparative overview discusses the effects of inorganic, organic and nanofoms of selenium on production results, glutathione peroxidase activity, meat quality and level of toxicity in poultry.

1. Introduction

It is estimated that the world population in 2025 will number 8 billion inhabitants, and in 2050, up to 9 billion inhabitants [1]. The Food and Agriculture Organisation of the United Nations predicts that annual meat production of 200 million tons will be required by 2050 to respond to this increase in human population [2]. Consequently, there is a forecast that global broiler meat production is going to rise by 1% to a record 89.5 million tons in 2017 and that this trend will continue in the coming years [3]. The constant need for more foods of animal origin, especially chicken meat, has led to the development of much research directions to improve production results and health of animals. In recent years, feed formulations were manipulated using different additives (various sources, forms, formulations, etc.) with the aim of improving poultry growth and conversion ratios, and obtaining better quality and value-added products, and therefore, achieving cost-effectiveness of production [1]. Also, given the increasing world population, it will be increasingly necessary to use modern technologies such as nanotechnology and nanobiotechnology in agricultural and food sciences [4].

The efficiency of contemporary poultry production is based on well-balanced nutrition and highly productive lines of birds. This production involves a number of different stress factors to which broilers and hens are exposed. Particularly, in such conditions, the positive effect of selenium on the animals must not be neglected [5,6].

2. Selenium and antioxidant properties



Selenium was discovered by Jacob Berzelius in 1817 and initially considered toxic to humans and animals [7]. The word “*selenium*” originates from the Greek word Selene, which means moon goddess. Later on, selenium was recognized as a nutritionally essential trace element that is important in many biological processes in mammals and birds [8]. Selenium is an integral part of a large number of seleno proteins (more than 30), which participate in the regulation of various functions of the body, including redox balance maintenance and antioxidant defenses, of which glutathione peroxidase (GSH-Px) was the first identified in 1973 [9]. Vitamin E is considered to be the most important antioxidant in biological systems, but selenium-dependent GSH-Px is considered as the second most important factor in antioxidant defense. Hence, dietary selenium, as GSH-Px and as thioredoxin reductase enzymatic cofactor, participates in two levels of antioxidant cell defense (first: detoxification of H₂O₂ resulting from SOD activity; second: detoxification of hydroperoxide) [5].

In poultry, a delicate antioxidant/prooxidant balance in the body is an important determinant of chicken health, embryonic and postnatal development, immunity, muscle function, sperm quality and probably productive and reproductive characteristics of poultry [8]. Poultry diets deficient in selenium result in poor growth and development, increased mortality, reduced egg production, decreased hatchability, nutritional encephalomalacia, nutritional pancreatic atrophy, exudative diathesis, and muscle myopathies [10].

2.1. Selenium in soil and plants

Metallic selenium, selenite (Se⁴⁺), selenate (Se⁶⁺), and selenide (Se²⁻) are the inorganic forms of selenium found in soils. Plants absorb inorganic forms of selenium from soil to create organic forms, the seleno-aminoacids, in which selenium is bonded to different amino acids: selenomethionine, Se-methyl-selenomethionine, selenocysteine (the 21st amino acid), and Se-methyl-selenocysteine. Among these, selenomethionine is the most prevalent (it comprises up to 50% of the selenium in cereal grains) [5]. The selenium concentration in soil varies significantly and its availability to plants depends on many factors [11]. In acidic soils with low levels of aeration (low oxidation reduction potential), selenium can form insoluble complexes with iron hydroxide, and in this form, it cannot be absorbed by plants, so therefore, the content of selenium in animal feed also varies. Feed rich in selenium (mainly selenomethionine) includes grasslands, legumes hay, silage, and grain feeds (soybeans), as well as feed of animal origin [5].

The soil in many regions of the world has low levels of selenium, and its low availability for plants has created a problem with selenium levels in humans [12]. It is considered that the selenium deficiency areas contain less than 0.5 mg/kg of selenium in the soil. In the Balkans, areas that are highly deficient in selenium are: Vojvodina (0.024-0.450 mg/kg), Sjenica-Pester plateau (0.046 mg/kg), some parts of Macedonia, the Pozega Valley in Croatia (0.038 mg/kg) and Zeta (Montenegro) (0.280 mg/kg). In Serbia, soil, wheat, and forages are more or less poor in selenium (from 20 to 70 mg Se/kg) [13].

3. Selenium sources and dietary needs

In poultry as well as in other animal species, selenium can be added to diets in different forms, on which depends its metabolic fate [14]. Daily selenium requirement during intensive broiler growth is 0.15 mg/kg [15]. Regardless of selenium source, the maximum amount of supplemental selenium that can be added to animal diets is limited to 0.3 mg/kg of diet in the United States [16], while in the European Union, the maximum amount of selenium allowed in animal diets is 0.5 mg/kg of diet [17], and in Serbia, the minimum amount of selenium allowed in animal diets is 0.15 mg/kg of diet [18].

Selenomethionine is highly bioavailable and currently the most suitable form of selenium for nutritional supplementation [19]. In addition to organic selenium compounds, some selenium-enriched feedstuffs have been created: selenium-enriched yeast – an organic form of selenium produced by *Saccharomyces cerevisiae*, selenium-enriched algae *Scenedesmus quadricauda*, selenium-enriched unicellular alga *Chlorella* and selenium chelate [20]. Beside these organic forms of selenium, a new form of organic selenium has been developed based on 2-hydroxy-4-methylselenobutanoic acid

(HMSeBA), which is a hydroxyl-analog of selenomethionine; HMSeBA has already demonstrated high dietary efficacy in poultry nutrition. Namely, HMSeBA, a probable precursor of selenomethionine, enabled more efficient selenium incorporation into proteins in egg and muscle than selenium-enriched yeast [21].

In recent years, the possibility of using nanoparticles as supplements in poultry feed has developed. The particle size of minerals as feed additives in nanoparticle form is typically between 1-100 nm (or more appropriately, 0.2-100.0 nm) and this property distinguishes them with respect to their physical, chemical, and biological properties (great specific surface area, high surface activity, many surface active centers, high catalytic efficiency and strong adsorbing ability) from non-nano, larger particle sizes [20,22]. Nano additives can also be incorporated in micelles or capsules of protein or another natural food/feed ingredient [23]. Nanoparticles have been used in poultry feed to decrease numbers of harmful bacteria in broilers' digestive systems (silver, gold, zinc, copper, metal oxides – Al₂O₃, Fe₃O₄, CeO₂, ZrO₂, MgO), while other nanoparticles, such as nanoselenium, can be used to improve growth and performance [1]. Numerous studies have shown that a new source of elemental selenium, nano selenium, possessed a higher efficiency than selenite, selenomethionine, and methylselenocysteine in upregulating selenoenzymes, higher bioavailability, and exhibited a lower toxicity [7].

3.1. Different forms of selenium – bioavailability and application in poultry nutrition

The absorption mode of various selenium forms is different, leading to different digestibility and bioavailability. Organic selenium is absorbed in the small intestine via the transport mechanism for amino acids, inorganic selenium is absorbed by passive transport, while the nanoparticles have a high specific surface area, small particles, and form nano emulsion droplets that are well absorbed in the intestines [24].

Inorganic forms of selenium can lead to a production of selenocysteine, which is incorporated specifically into selenoproteins, and not to *de novo* synthesis of selenomethionine, whereas organic selenium sources can lead to the production of selenomethionine as well as selenocysteine [8,21]. The cell can nonspecifically incorporate selenomethionine into the structural proteins and, thus, increase the selenium deposit in all tissues [5,8].

3.1.1. Growth performances and glutathione peroxidase activity. Effects of various sources and levels of selenium in poultry diet on production performances have been a subject of a number of studies and results are not uniform, with both negative and positive responses being reported [25,26,27]. Boostani et al. [9] demonstrated that supplementation with selenium (0.3 mg/kg of diet), of different sources increased the antioxidative capacity of broiler chicken under oxidative stress, where the nanoselenium effect was higher than an organic or inorganic source. Other authors determined that organic selenium-enriched yeast (0.2 mg/kg of diet), was more beneficial than inorganic selenium in increasing GSH and GSH-Px activity in blood and liver [28,29].

3.1.2. Selenium and meat quality. The supplementation of selenium, through GSH-Px activity and overall antioxidant defense of muscle against lipid peroxidation that causes excessive cellular damage and drip loss, improves the meat quality (water holding capacity, fatty acid composition, better color stability of heme pigments) and shelf life of poultry meat and also improves selenium retention in muscle [30]. In addition, differences in the antioxidant defense system between animals and muscles would affect calpain activity, proteolysis, and thus quality characteristics influenced by proteolysis such as tenderness and water holding capacity [31]. Visha et al. [32] demonstrated that nanoselenium supplementation (0.3-0.6 mg /kg) caused a significant reduction in breast muscle drip loss and lipid peroxidation as compared with the control and other selenium forms (sodium selenite and selenomethionine). De Medeiros et al. [27] showed that selenium also positively affects organoleptic properties of broiler chicken meat and that selenium-rich meat is juicier, crisper, and better looking.

With the use of special diet enriched with selenium, foods of animal origin with higher nutritive value can be produced, so-called functional foods. Thus, for example, selenium-enriched eggs have

32.6 µg Se, which is about three times the content of selenium in standard eggs [20], while with supplementation of broiler diets with 0.3, 0.6 and 0.9 ppm of selenium-enriched yeast, selenium enriched breast and drumstick meats, containing 0.29 to 0.86 mg/kg Se, were obtained, which was up to 8 times more than in standard meat [33,34]. Haug et al. [35] reported that dietary treatment with rapeseed oil, linseed oil and two levels of selenium-enriched yeast (50 mg/kg and 84 mg/kg) resulted in increased concentration of selenium and very long chain fatty acids (eicosapentaenoic, docosapentaenoic and docosahexaenoic acids) in broiler thigh muscle. Also, Jlali et al. [8] showed that HMSeBA has greater ability to increase the selenium concentration in egg and breast muscle of laying hens than selenium-enriched yeast and sodium selenite given at the equivalent doses.

3.1.3. Selenium forms and toxicity. Selenium doses lower than 3-5 mg/kg feed are usually not associated with toxicity, but selenium is toxic to poultry when used in high doses (when dose exceeds the physiological requirement by at least 10 fold), especially inorganic compounds, which are more toxic than organic ones. The molecular mechanisms of selenium toxicity can be explained by substitution of selenium for sulfur, which could result in weakened protein structure, and by reaction between selenite and glutathione with the production of free radicals (i.e. a prooxidant effect)[36]. In birds with selenosis, hepatic degeneration, diffuse tubulo-nephrosis, myocardial and skeletal myodegeneration, damage to the bursa Fabricius and cerebellar edema can be observed [5]. The most toxic forms of selenium are selenite and selenate, then selenocysteine, while methylated selenium compounds and nanoselenium show the lowest levels of toxicity [37]. Supplementing 0.3 to 0.5 mg/kg of nanoselenium seemed to be effective and advantageous in improving oxidation resistance, and the maximum supplementation of nanoselenium should not be more than 1.0 mg/kg [31].

4. Conclusion

In conclusion, selenium has a very important role in poultry nutrition due to its antioxidant effects, and its supplementation in animal feed is necessary especially in areas with soils that are deficient in selenium. Also, because of the possible toxic effects and poorer properties of inorganic forms of selenium (sodium selenite), there is a constant need to design new formulations of organic and especially nanoselenium. However, a precautionary approach should be adopted, so further research is needed to determine the safety of their application. In spite of this, in the future, nanotechnology will likely have potential to play a major role in animal nutrition.

Acknowledgment

This paper was supported by Ministry of Education, Science and Technological development, Republic of Serbia, through the funding of Project No 31034.

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