CAPÍTULO 2

SELENIUM ABSORPTION, METABOLISM, DEFICIENCIES, AND INTOXICATION IN RUMINANT AND NON-RUMINANT ANIMALS

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ABSTRACT: Selenium is an essential mineral in animal nutrition, playing a key role in promoting health and productivity. This trace element is involved in bone formation, maintenance of the immune system, and regulation of enzymes and hormones. Adequate selenium supplementation can significantly improve reproductive performance, meat quality, and disease resistance. In ruminants, selenium is absorbed predominantly in the small intestine, with lower efficiency compared to non-ruminants due to the chemical environment of the rumen. In non-ruminants, such as pigs and poultry, absorption occurs directly in the small intestine, with selenomethionine being more efficiently absorbed. Selenium is transported and distributed throughout the body linked to proteins such as selenoprotein P and glutathione peroxidase, which are essential for cell protection against oxidative stress. Selenium deficiency can cause myopathy, reproductive problems, and reduced immunity in ruminants and non-ruminants. Selenium intoxication, on the other hand, can lead to liver and kidney damage, reproductive problems, and death. In conclusion, balanced management of selenium supplementation is fundamental to guaranteeing the health and productivity of animals, preventing both deficiencies and intoxications.
KEYWORDS: Selenium, Microminerals, Antioxidant, Farm animals.

ABSORÇÃO, METABOLISMO, DEFICIÊNCIAS E INTOXICAÇÃO POR SELÊNIO EM ANIMAIS RUMINANTES E NÃO RUMINANTES

RESUMO: O selênio é um mineral essencial na nutrição animal, desempenhando um papel fundamental na promoção da saúde e produtividade. Esse micronutriente está envolvido na formação óssea, na manutenção do sistema imunológico e na regulação de enzimas e hormônios. A suplementação adequada de selênio pode melhorar significativamente o desempenho reprodutivo, a qualidade da carne e a resistência a doenças. Em ruminantes, o selênio é predominantemente absorvido no intestino delgado, com eficiência inferior em comparação aos não ruminantes, devido ao ambiente químico do rúmen. Nos não ruminantes, como suínos e aves, a absorção ocorre diretamente no intestino delgado, sendo a selenometionina mais eficientemente absorvida. O selênio é transportado e distribuído pelo organismo ligado a proteínas como a selenoproteína P e a glutationa peroxidase, essenciais para a proteção celular contra o estresse oxidativo. A deficiência de selênio pode causar miopatias, problemas reprodutivos e imunidade reduzida em ruminantes e não ruminantes. Por outro lado, a intoxicação por selênio pode levar a lesões no fígado e nos rins, problemas reprodutivos e até a morte. Em conclusão, o manejo equilibrado da suplementação de selênio

é crucial para garantir a saúde e a produtividade animal, prevenindo tanto deficiências quanto intoxicações.
PALAVRAS-CHAVE: Selênio, Microminerais, Antioxidante, Animais de produção.

1 I INTRODUCTION

The study of minerals in farm animal nutrition has gained widespread recognition due to their crucial role in promoting health and production efficiency. Minerals such as calcium, phosphorus, zinc, copper, and selenium are fundamental to various biological functions, including bone formation, maintenance of the immune system, and regulation of enzymes and hormones (Kim et. al.,2013). Recent studies indicate that adequate supplementation of these minerals can significantly improve reproductive performance, meat quality, and disease resistance in farm animals (Ammerman and Goodrich 1983). In addition, the bioavailability and form of administration of minerals are critical aspects that influence their nutritional efficacy (Zheng et al., 2022). Ongoing research has highlighted the need for more precise and personalized mineral supplementation strategies to meet the specific requirements of different species and production phases.

Selenium is an essential trace element for animal health, playing a critical role in antioxidant function and the immune system. Belonging to the chalcogen family, selenium has chemical and physical characteristics. Its versatile capacity for oxi reduction is fundamental to its role in the active center of the enzyme glutathione peroxidase, which is responsible for eliminating peroxides, or free radicals, from the body (Behne and Kyriakopoulos, 2001; Zoidis et al., 2018). Recent studies show that selenocysteine, a key component of selenoproteins, significantly improves enzymatic efficiency, playing a vital role in cell signaling and immune function (Zoidis et al., 2018; Zheng et al., 2022). In addition, selenium deficiency can lead to a decrease in T-cell counts, antibody responses, and neutrophil efficacy, increasing susceptibility to diseases and disorders such as white muscle disease in calves and encephalomalacia in chicks (Huang et al., 2001; Gromadzińska et al., 2008; Zoidis et al., 2018).

The antioxidant action of selenium is related to these selenoproteins, which reduce the production of reactive oxygen species, protecting macromolecules and cell membranes against oxidation. Selenium deficiency is a global concern and has been identified in several regions of the world, including Brazil, making it essential to supplement the diet of farm animals (Zheng et al., 2022; Banuelos et al., 2023).

Selenium plays a crucial role in various biological functions in farm animals, including ruminants and non-ruminants. In ruminants, it is vital for preventing conditions such as white muscle disease and for maintaining efficient immune function. Selenium deficiency can lead to myopathies, reduced fertility, and increased susceptibility to infections (Hosnedlova et al., 2017). The presence of selenium at adequate levels is crucial for the development of calves and lambs, preventing neonatal mortality and promoting healthy growth (Arshad et al., 2021).

For non-ruminants such as pigs and poultry, selenium is also essential for preventing myopathies and promoting general health. Deficiency of this micronutrient can result in muscular dystrophies, liver necrosis, and impairment of the immune system (Arshad et al., 2021; Hosnedlova et al., 2017). In poultry, for example, selenium deficiency can lead to bone deformities and reduced egg production (Sun et al., 2017).

Selenium supplementation in farm animal diets is effective in preventing these deficiencies and improving productive and reproductive performance. However, it is essential to monitor selenium levels in the diet, as both selenium deficiency and excess can have significant adverse effects on animal health (Gong et al., 2014). Therefore, proper management of selenium supplementation is crucial to ensure the health and productivity of farm animals.

This article aims to provide a brief review of how this mineral is absorbed, how it is metabolized and the causes of its deficiencies and intoxication in ruminant and non-ruminant animals in production.

2 I SELENIUM ABSORPTION IN RUMINANT ANIMALS

Ruminants absorb selenium less efficiently (approximately 54%) than non-ruminants (80%) because the chemical environment of the rumen favors the reduction of selenium (Ortolani, 2002). In these animals, selenium absorption occurs predominantly in the small intestine. The form of selenium, whether inorganic (selenate and selenite) or organic (selenomethionine and selenocysteine), affects the efficiency of its absorption. Studies indicate that selenite is rapidly reduced to selenide by the rumen microbiota before being absorbed (Surai, 2006).

According to McDowell (2003), inorganic selenium, such as selenite, is transformed into selenide in the rumen, where it can be incorporated into microbial proteins or absorbed directly. The absorption of organic selenium, such as selenomethionine, is more efficient because this form is incorporated directly into body proteins, without the need for microbial transformation.

The absorption capacity of selenium in ruminants is also influenced by the diet and the presence of other minerals that can compete for absorption. For example, high levels of sulfur and molybdenum in the diet can reduce selenium absorption by forming insoluble complexes in the rumen (Sunde, 2001).

3 I SELENIUM ABSORPTION IN NON-RUMINANT ANIMALS

In non-ruminants such as pigs and poultry, selenium is absorbed directly in the small intestine. The absence of a rumen means that both inorganic and organic selenium are absorbed directly by the intestinal enterocytes. According to Mahan and Parrett (1996), selenomethionine is absorbed more efficiently than selenite due to its direct incorporation into proteins. Surai (2006) points out that, in non-ruminants, selenomethionine is incorporated directly into body proteins during protein synthesis, thus increasing absorption efficiency.

The inorganic form of selenium, such as selenite, is absorbed through specific transporters in the enterocyte membrane, but less efficiently than selenomethionine. In addition, the bioavailability of selenium can be affected by the composition of the diet and the presence of other nutrients. For example, diets rich in protein and sulfur amino acids can improve selenium absorption, while diets rich in phytates can reduce their bioavailability (McDowell, 2003).

Figure 1 shows the forms of absorption between organic and inorganic selenium.

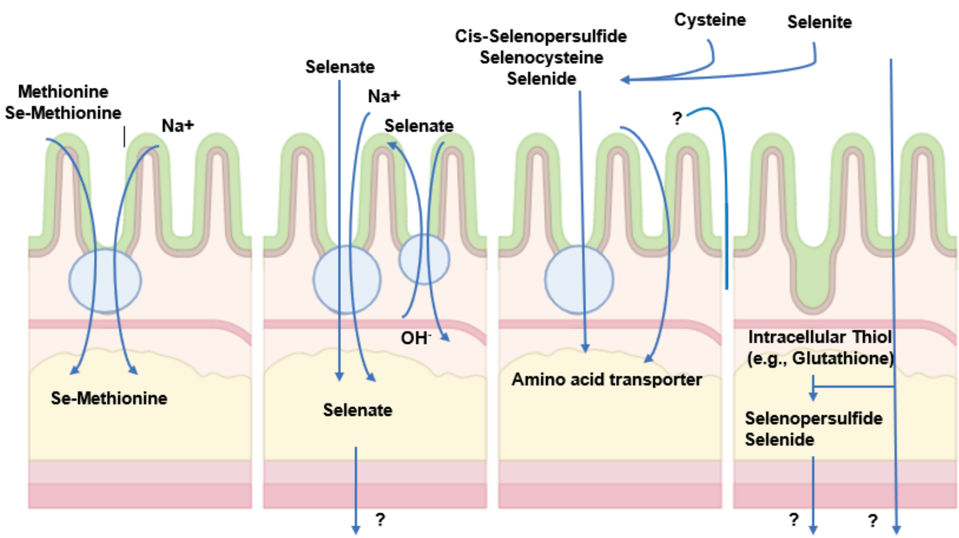

Figure 1. Intestinal absorption of different forms of selenium. (Source: Melo, 2011).

4 I SELENIUM METABOLISM

4.1 Transportation and distribution in ruminant animals

After absorption, selenium is transported in the plasma bound to proteins such as albumin and selenoprotein P. These proteins play a crucial role in the distribution of selenium to various tissues, including the liver, skeletal muscles, and kidneys. Selenoprotein P not only transports selenium but also serves as a selenium reserve for peripheral tissues (McDowell, 2003).

4.2 Transportation and distribution in non-ruminant animals

In non-ruminants, the transport and distribution of selenium follow a similar pattern to that of ruminants. Selenoprotein P plays a central role in the transport and distribution of selenium (Surai, 2006). In poultry, for example: Glutathione peroxidase (GSH-Px) is crucial to protect against oxidative damage, especially during embryonic development (Sunde, 2001).

4.3 Functions of selenium in ruminant animals

As already mentioned, selenium is an essential component of selenoproteins, including GSH-Px and selenoprotein P. GSH-Px protects cells against oxidative stress by reducing hydrogen peroxides and peroxidized lipids (McDowell, 2003).

Zanetti et al. (1998) concluded that oral supplementation with 5mg of Se in the last month of pregnancy significantly increased the serum level of the mineral in dairy cows, reducing the incidence of subclinical mastitis diagnosed by CMT.

4.4 Functions of selenium in non-ruminant animals

In non-ruminants, selenium is also crucial for the function of selenoproteins. In pigs, GSH-Px plays an essential role in neutralizing reactive oxygen species (Mahan and Parrett, 1996). In poultry, selenoprotein W is involved in regulating calcium metabolism and protecting against oxidative stress during embryonic development (Surai, 2006). Figure 2 shows a schematic of how selenium is distributed and its functions in the body.

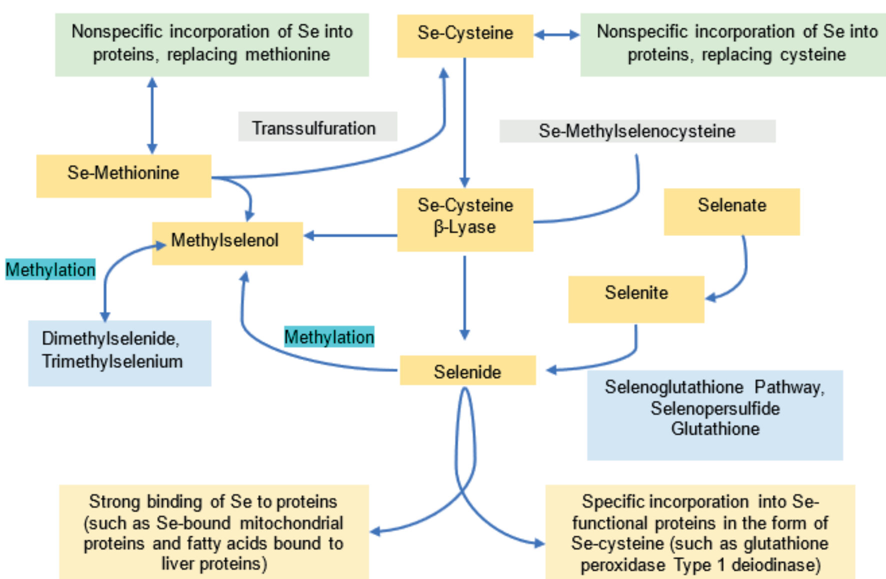

Figure 2. Metabolism of the organic and inorganic forms of selenium. (Source: Melo, 2011).

4.5 Selenium excretion in ruminant animals

Selenium excretion in ruminants occurs mainly via feces, with less excretion via urine and milk. The greater fecal excretion is due to the incorporation of selenium into rumen microorganisms and the non-absorption of inorganic forms (McDowell, 2003).

4.6 Selenium excretion in non-ruminant animals

In non-ruminants, the main route of selenium excretion is urine, with smaller amounts excreted in the feces. In poultry, a significant amount of selenium can also be excreted through eggs (Sunde, 2001). Studies show that urinary excretion is a direct reflection of dietary selenium intake (Mahan and Parrett, 1996). Table 1 compares the similarities and differences we can observe in selenium metabolism between ruminant and non-ruminant animals.

Similarities	Forms of Selenium Absorbed	Both absorb selenium in inorganic forms, with selenomethionine being more efficiently absorbed.
	Main Organs of Storage	Liver, muscle, and kidneys are common to both.
	Biological Functions	The role of selenium in selenoproteins, such as GSH-Px, is essential for antioxidant protection.
Differences	Absorption Efficiency	Selenium absorption efficiency is lower in ruminants due to microbial transformation in the rumen, while selenomethionine is well absorbed in both.
	Excretion	Ruminants excrete more selenium through feces, while non-ruminants primarily excrete it through urine.
	Gut Microbiota	The presence of the rumen in ruminants alters selenium metabolism, with the conversion of selenite to selenide and its incorporation into microbial proteins.

Table 1. Similarities and differences in selenium metabolism in ruminant and non-ruminant animals.

(Source: Author).

5 I SELENIUM DEFICIENCY IN RUMINANT ANIMALS

5.1 White muscle disease

White muscle disease, or nutritional myopathy, is caused by selenium and/or vitamin E deficiency in ruminants and is often observed in calves, lambs, and young goats. This condition can be triggered by inadequate dietary intake or low availability of these nutrients in soil and forage plants (Zheng et al., 2022; Givens et al., 2024). Selenium deficiency leads to a decrease in the activity of glutathione peroxidase, a crucial enzyme for cell protection against oxidative damage. Without adequate levels of this enzyme, muscle cells are more susceptible to oxidative stress, resulting in muscle damage and degeneration.

Clinical signs of the disease include muscle weakness, difficulty getting up, muscle tremors, and, in severe cases, sudden death. Affected animals may have a staggering gait, muscle stiffness, and pain on palpation of the muscles. In calves and lambs, the condition is often noticed shortly after birth or during periods of rapid growth (Brown et al., 2001). Diagnosis is based on clinical history, clinical signs, and laboratory findings. Reduced levels of glutathione peroxidase in the blood and low levels of selenium in the serum or liver confirm the deficiency. Histopathological examinations of the muscles show muscle degeneration, necrosis, and inflammatory cell infiltration (Zheng et al., 2022; Banuelos et al., 2023). Treatment consists of immediate supplementation of selenium and vitamin E, so proper management of selenium supplementation is crucial to ensure the health and productivity of farm animals.

5.2 Reduced immunity

Selenium deficiency in ruminants is associated with compromised immune function. Selenium is crucial for the activity of glutathione peroxidase (GSH-Px), an antioxidant enzyme that protects cells from oxidative stress. Selenium deficiency reduces GSH-Px activity, resulting in increased susceptibility to infections and reduced immune response (Arthur et al., 2003). In addition, deficiency can affect the response to vaccination and resistance to pathogens (Weiss, 2003).

5.3 Reproductive problems

Selenium deficiency can also affect reproduction in ruminants. Selenium-deficient cows have higher rates of retained placenta and lower fertility. In addition, selenium deficiency in sheep is associated with higher rates of embryonic and neonatal mortality (McDowell, 2003). In dairy cows, deficiency can lead to problems such as metritis and mastitis, affecting milk production and quality (Harrison et al., 1984).

6 I SELENIUM DEFICIENCY IN NON-RUMINANT ANIMALS

6.1 Pigs

In pigs, selenium deficiency can lead to myopathy and liver necrosis, also known as dietary hepatosis. Reduced GSH-Px activity due to selenium deficiency increases oxidative stress, resulting in damage to muscle and liver tissues. Selenium supplementation in the diet of pigs has been shown to prevent these conditions and improve the general health of the animals (Mahan and Parrett, 1996).

6.2 Birds

In poultry, selenium deficiency causes myopathy and muscular dystrophy. Reduced GSH-Px activity due to selenium deficiency results in increased oxidative damage to muscles. In addition, selenium deficiency can compromise immune function in poultry, resulting in increased susceptibility to infectious diseases (Surai, 2006). Studies indicate that selenium supplementation improves the viability of embryos and the general health of birds (Leeson and Summers, 2001).

6.3 Fish

In fish, selenium deficiency can result in muscle and liver necrosis, as well as growth problems. Selenium supplementation in fish diets has been shown to improve growth, health, and resistance to disease (Bell and Cowey, 1989). Selenium deficiency in fish is also associated with skeletal deformities and increased mortality (Hilton et al., 1980).

7 I SELENIUM INTOXICATION IN RUMINANT ANIMALS

7.1 Clinical symptoms

Acute selenium intoxication in ruminants can result in symptoms such as depression, weakness, difficulty walking, dyspnea, and, eventually, death. Chronic intoxication, also known as "alkaline blindness" in cattle, can cause alopecia, hoof lesions, anemia, and reduced weight gain (NRC, 2001; McDowell, 2003).

7.2 Effects on organs

Ruminants that ingest too much selenium can suffer liver and kidney damage. These lesions are the result of oxidative processes caused by excess selenium that exceeds the body's antioxidant capacity. Histologically, liver necrosis, renal tubular degeneration, and inflammatory cell infiltration can be observed (Pehrson et al., 1999).

7.3 Reproductive changes

Studies indicate that selenium intoxication can lead to reproductive problems in ruminants, including reduced fertility, increased embryonic mortality, and fetal malformations. These effects are particularly severe in sheep and goats exposed to high levels of selenium (Hefnawy and Tórtora-Pérez, 2010).

8 I SELENIUM INTOXICATION IN NON-RUMINANT ANIMALS

8.1 Pigs

In pigs, selenium intoxication can cause loss of appetite, lethargy, and signs of abdominal pain. The chronic form of intoxication can result in alopecia, hoof lesions, and sterility. In acute cases, pigs can present pulmonary edema, emphysema, and liver necrosis, leading to death (Mahan and Parrett, 1996).

8.2 Birds

In poultry, selenium intoxication can manifest itself through neurological symptoms such as paralysis and incoordination, as well as beak and feather damage. Chronic intoxication can cause bone deformities and reduced egg production. In severe cases, selenosis can lead to the death of the birds (Surai, 2018).

8.3 Fish

In fish, chronic exposure to high levels of selenium can cause skeletal deformities, developmental problems, and mortality. Fish exposed to selenium also show changes in behavior, such as erratic swimming and lethargy (Hamilton, 2004).

9 I CONCLUSIONS

Selenium is an essential element for the health and productivity of production animals, both ruminants and non-ruminants. Its antioxidant capacity, associated with selenoproteins, is crucial for cell protection against oxidative stress, maintaining immune function, and promoting healthy growth. However, selenium deficiency can lead to several health problems, including myopathies, reduced fertility, and increased susceptibility to infections. On the other hand, selenium intoxication can also result in serious consequences, such as liver and kidney damage, reproductive problems, and even death. The absorption and metabolism of selenium varies between ruminants and non-ruminants. In ruminants, absorption is less efficient due to the chemical environment of the rumen, while in non-ruminants, absorption occurs directly in the small intestine. The form of selenium (organic or inorganic) and the diet significantly influence its absorption and bioavailability. Adequate selenium supplementation in diets is essential to prevent deficiencies and improve the productive and reproductive performance of animals. However, it is crucial to carefully monitor selenium levels to avoid toxicity. Thus, balanced management of selenium supplementation is fundamental to guaranteeing the health and productivity of farm animals, ensuring that they receive the necessary benefits without the risks associated with an excess of this trace element.

REFERENCES

AMMERMAN, C. B.; GOODRICH, R. D. **Advances in mineral nutrition in ruminants.** Journal of animal science, v. 57, n. suppl_2, p. 519-533, 1983.

ARTHUR, J. R.; McKENZIE, R. C.; BECKETT, G. J. **Selenium in the immune system.** Journal of Nutrition, v. 133, n. 5, p. 1457S-1459S, 2003. https://doi.org/10.1093/jn/133.5.1457S

ARSHAD, MUHAMMAD ADEEL; EBEID, HOSSAM MAHROUS; HASSAN, FAIZ-UL. **Revisiting the effects of different dietary sources of selenium on the health and performance of dairy animals: a review**. Biological trace element research, v. 199, n. 9, p. 3319-3337, 2021.

BANUELOS, G. S.; Lin, Z. Q.; Broadley, M. **Selenium biofortification of agricultural crops**. Plant Soil, v. 374, n. 1-2, p. 1-19, 2023. https://doi.org/10.1007/978-3-319-56249-0_14

BEHNE, D.; KYRIAKOPOULOS, A. **Mammalian selenium-containing proteins**. Annual Review of Nutrition, v. 21, p. 453-473, 2001. https://doi.org/10.1146/annurev.nutr.21.1.453

BELL, J. G.; COWEY, C. B. **Digestibility and bioavailability of dietary selenium from fish meal and selenite for Atlantic salmon (Salmo salar)**. Aquaculture, v. 81, n. 1-4, p. 61-68, 1989. https://doi.org/10.1016/0044-8486(89)90230-5

BROWN, K.M.; ARTHUR, J. R. **Selenium, selenoproteins and human health: a review**. Public Health Nutrition, v. 4, n. 2b, p. 593-599, 2001. https://doi.org/10.1079/PHN2001143

GONG, J.; Ni, L.; Wang, D.; Shi, B.; Yan, S. **Effect of dietary organic selenium on milk selenium concentration and antioxidant and immune status in mid-lactation dairy cows**. Livestock Science, v. 170, p.84-90, 2014. https://doi.org/10.1016/j.livsci.2014.10.003

GROMADZIŃSKA, J.; RESZKA, E.; BRUZELIUS, K.; WASOWICZ, W.; ÅKESSON, B. **Selenium and cancer: biomarkers of selenium status and molecular action of selenium supplements**. European Journal of Nutrition, v. 47, n. 1, p. 29-50, 2008. https://doi.org/10.1007/s00394-008-2005-z

HAMILTON, S. J. **Review of selenium toxicity in the aquatic food chain**. Science of the Total Environment, v. 326, n. 1-3, p. 1-31, 2004. https://doi.org/10.1016/j.scitotenv.2004.01.019

HARRISON, J. H.; HANCOCK, D. D.; CONRAD, H. R. **Vitamin E and selenium for reproduction of the dairy cow**. Journal of Dairy Science, v. 67, n. 6, p. 123-132, 1984. https://doi.org/10.3168/jds.S0022-0302(84)81275-8

HEFNAWY, A. E.; TÓRTORA-PÉREZ, J. L. **The importance of selenium and the effects of its deficiency in animal health**. Small Ruminant Research, v. 89, n. 2-3, p. 185-192, 2010. https://doi.org/10.1016/j.smallrumres.2009.12.042

HILTON, J. W.; HODSON, P. V.; SLINGER, S. J. **The requirement and toxicity of selenium in rainbow trout (Salmo gairdneri)**. Journal of Nutrition, v. 110, n. 12, p. 2527-2535, 1980. https://doi.org/10.1093/jn/110.12.2527

HOSNEDLOVA, Bozena et al. **A summary of new findings on the biological effects of selenium in selected animal species—a critical review**. International journal of molecular sciences, v. 18, n. 10, p. 2209, 2017.

HUANG, Z.; XIANG, J.; GUO, B. **Research progress in physiological functions of selenoenzyme and other selenocompounds**. Progress in Physiological Sciences, v. 32, p. 293-297, 2001.

KIM, Mi-Hyun; CHOI, Mi-Kyeong. **Seven dietary minerals (Ca, P, Mg, Fe, Zn, Cu, and Mn) and their relationship with blood pressure and blood lipids in healthy adults with self-selected diet**. Biological trace element research, v. 153, p. 69-75, 2013.

KINCAID, R. L. **Assessment of trace mineral status of ruminants: a review**. Journal of Animal Science, v. 78, n. 3, p. 455-457, 2000. https://doi.org/10.2527/jas2000.77E-Suppl1x

LEESON, S.; SUMMERS, J. D. **Nutrition of the Chicken**. University Books, 2001.

MAHAN, D. C.; PARRETT, N. A. **Evaluating the efficacy of selenium-enriched yeast and sodium selenite on tissue selenium retention and serum glutathione peroxidase activity in grower and finisher swine**. Journal of Animal Science, v. 74, n. 12, p. 2967-2974, 1996. https://doi.org/10.2527/1996.74122967x

McDOWELL, L. R. **Minerals in Animal and Human Nutrition**. Elsevier Health Sciences, 2003. https://doi.org/10.1016/B978-0-444-51367-0.50003-9

MELO, L. Q. **Incorporation into milk and selenium balance in cows supplemented with selenized yeast. 2011**. Thesis (PhD) - Federal University of Lavras, Lavras, 2011. http://repositorio.ufla.br/jspui/handle/1/4192

NATIONAL RESEARCH COUNCIL (NRC). **Nutrient Requirements of Dairy Cattle**. 7. ed. Washington, DC: National Academies Press, 2001.

ORTOLANI, E. L. **Mineral deficiencies in ruminants**. In: GONZÁLEZ, F. H. D.; BARCELOS, J. O.; OCAMPO, C. B. E. (Eds.). Metabolic and nutritional disorders in ruminants. Porto Alegre: UFRGS, 2002. p. 137-159.

PEHRSON, B.; ORTMAN, K.; MADJID, N.; TRAFIKOWSKA, U. **The influence of dietary selenium as selenium yeast on the concentration of selenium in the blood and milk of dairy cows and the selenium status of their calves**. Journal of Animal Science, v. 77, n. 12, p. 3371-3376, 1999. https://doi.org/10.2527/1999.77123371x

SUN, P.; WANG, J.; LIU, W.; BU, D.P.; LIU, S.J.; ZHANG, K.Z. **Hydroxy-selenomethionine: a novel organic selenium source that improves antioxidant status and selenium concentrations in milk and plasma of mid-lactation dairy cows**. Journal of Dairy Science, v. 100, n. 12, p. 9602-9610, 2017. https://doi.org/10.3168/jds.2017-12610

SUNDE, R. A. **Selenium**. In: RUCKER, R. B.; SUTTIE, J. W.; McCORMICK, D. B.; MACHLIN, L. J. (Eds.), Handbook of Vitamins. 3. ed. New York: Marcel Dekker, Inc., 2001.

SURAI, P. F. **Selenium in Nutrition and Health**. Nottingham: Nottingham University Press, 2006.

SURAI, P. F. **Selenium in poultry nutrition and health**. Poultry Science, v. 81, n. 4, p. 199-211, 2018.

WEISS, W. P. **Selenium nutrition of dairy cows: comparing responses to organic and inorganic selenium forms**. Proceedings of the 18th Western Nutrition Conference, Winnipeg, Manitoba, p. 7-15, 2003. https://en.engormix.com/dairy-cattle/vitamins-minerals-dairy-cattle-nutrition/selenium-nutrition-dairy-cows_a33391/

ZANETTI, M. A., Neunhaus, L. E. D., Schalch, E., & Martins, J. H. **Effect of selenium and vitamin E supplementation in dairy cows**. Revista Brasileira de Zootecnia, 1998, Vol. 27, No. 2, 405-408.

ZHENG, Yuhui et al. **Effects of selenium as a dietary source on performance, inflammation, cell damage, and reproduction of livestock induced by heat stress: A review**. Frontiers in Immunology, v. 12, p. 820853, 2022.

ZOIDIS, E.; SERELIS, I.; KONTOPOULOS, N.; DANEZIS, G. P. **Selenium-dependent antioxidant enzymes: actions and properties of selenoproteins**. Antioxidants, v. 7, n. 5, p. 66, 2018. https://doi.org/10.3390/antiox7050066