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Review

The Effects of Selenium Sources on Bioavailability of Selenium, Meat Quality and Reproduction in Lambs: A Review Article

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Abstract

In many parts of the world, soil is depleted of selenium (Se), resulting in selenium-poor plants, animals and, therefore, humans. It was recognized that a study to examine the functionality of new products on the market to address this problem was required. Selenium is recognized as an essential trace element and its deficiency in ruminants can result in numerous deficiency symptoms. According to Edens (2002) there are two sources of Se with which to supplement animal diets, an inorganic source and an organically bound source. Inorganic Se is available mostly in the form of Sodium selenite (Na Se), while organically bound Se is most common as selenides yeast in the form of selenomethionine. According to Mahan (1999) Na Se has a lower bioavailability in the rumen and some of the consumed Se is utilized by microorganisms for their metabolism. Organically bound Se instead can by-pass the rumen as it is in the form of selenoamino acids. The main advances in Se status assessment and Se requirements were established based on the activity of glutathione peroxidase (GSH-PX), an enzyme which for many years was considered to be the main selenoprotein. Recently it was discovered that it is only one of at least 25 various selenoproteins. Se research and practical applications are developing quickly and they are very exciting and promising in this papers, an attempt has been made to review effects the different Se sources on growth, Se bioavailability and the quality and lipid oxidation of muscle in the Lambs.

Keywords: Dietary Trace Mineral, Se bioavailability, milk yield, Performance, Reproductive and Immunity

INTRODUCTION

Selenium is an important trace mineral in livestock. Selenium is required for the function of many enzymes and proteins, specifically glutathione peroxidase, deiodinases, and thioredoxin reductases (Allan *et al*., 1999). These enzymes play an important role in cell integrity because of their involvement in the catabolism of peroxides that are synthesized during lipid oxidation (Burk., 1991). Because of selenium's role in the function of these enzymes it is hypothesized that Se plays an important role in immunity and reproduction. A clinical deficiency in Se can lead to many reproductive disorders such as retained placentas, infertility, cystic ovaries, metritis, delayed conception, and erratic, weak or silent heat periods leading to poor fertilization (Corah and Ives., 1991).

Selenium acts through the activity of glutathione peroxidases in the cytosol to reduce hydrogen peroxide and other organic peroxides into less damaging products (Corah and Ives., 1991). This is similar to the role of Vit E as it works in the cellular membrane to reduce peroxides into less harmful products (Underwood., 1981). As both Se and Vit E function as antioxidants, it would lead to the conclusion that Se adequate herds may not have improved reproductive performance, but Se deficient herd's supplementation with Se, Vit E or both may improve reproduction.

An Australian study investigated the effects of supplementation of Se to ewes grazing Se deficient (0.05±0.005 mg Se/kg DM) pasture (Godwin *et al*., 1970). Four to eight weeks before the breeding season Se was supplemented via an oral dose of sodium selenite, or from an intraruminal selenium pellet containing elemental selenium and iron (Godwin *et al*., 1970). Ewes that received Se supplementation had improved conception rates (76%) compared to those that did not receive Se supplementation (49%) (Godwin et al., 1970). However, in other studies there was no effect of supplementing Se to ewes grazing Se deficient pastures on conception rates (Maxwell., 1972).

Selenium

In 1817 selenium (Se) was discovered in the flue dust of iron pyrite burners by the Swedish chemist, Jons Jacob Berzelius (Levander., 1986). In 1943, Nelson et al. classified Se as a carcinogen. It was considered a dangerous element until 1957 when Schwarz and Foltz identified Se to be one of three compounds that prevented liver necrosis in rats, thus establishing Se as a nutritionally essential trace mineral. Nutritionists and scientists then started numerous studies to discover the metabolic function of the element and record the consequences of its deficiency in human and animal diets. It was not until 1974 that Se was added as a supplement to animal diets. The discovery of severe Se deficiency in certain parts of China in the 1970s has proven that this trace element is also an essential nutrient for human health (Keshan Disease Research Group., 1979; Levander., 1991; Ge and Yang., 1993), and its role has been reviewed recently (Rayman., 2000, 2004). It was reported (Phipps et al., 2008) that between 1975 and 1995, Se intake in the United Kingdom decreased from around 60 to 34 µg/d per person, which means that the current (2011) intake is about half of the UK Reference Nutrient Intake. The Se content of foods obtained from plants and animals are, to a great extent, influenced by the availability of soil Se for uptake by plants (Shrift., 1969). Evidence suggests that the Se intake in large parts of Europe is too low when compared to the recommended intake (Rayman., 2000). The decreasing Se intake in the last decades has been mainly credited to a change in the source of wheat for bread and cereal products, from primarily North American to European origin (from a high to low selenium content). These are reflected in decreasing levels of Se in human plasma and serum (Biesalski., 2005). This decline has caused concern because suboptimal intake is associated with a number of serious health issues.

In nature Se occurs inorganically as selenite, selenate, elemental Se or selenide, and organically bounded forms include selenomethionine (Se Met) and selenocysteine (Se Cys) (Ike et al., 2000). A number of positive effects were observed in feeding trials, when researchers increased the Se dosage for the animals. In 1987 the regulation was modified in the US and the allowed supplemental Se level was increased from (0.1 ppm) to 0.3 ppm in ruminant diets, but the approved sources (sodium selenite and selenate) did not change. With constant research and new data, the FDA (2003) had to update the regulation in September 2003 to permit the use of organically bound Se in the form of Se yeast in the diets of beef and dairy livestock. The maximum supplementation rate allowed in the US was maintained at 0.3 ppm of Se, though it was higher at 0.5ppm in Europe.

Absorption and metabolism

Selenium absorption in the intestine is affected by the form of dietary Se (Sunde., 1997). A number of studies done on various animal species including sheep, pigs (Wright & Bell., 1966) and rats (Whanger *et al*., 1976) confirmed that the duodenum is the site where the greater part of dietary Se is absorbed, regardless of source. Selenium that occurs naturally in feeds is largely found as selenoamino acids, with selenomethionine (Se Met) compromising more than 50 % of total Se in many feed ingredients, it fulfils the criteria of an essential aminoacid (Schrauzer., 2003). Inorganic selenium is generally supplemented in animal diets as sodium selenite. Sodium selenite is absorbed through the small intestine by simple diffusion, while SeMet is actively absorbed by the same amino-acid transport system as methionine (Sunde., 1997). Both forms of Se are well absorbed in monogastric animals. Overall, however, the absorption of Se is poorer in ruminants and this may be connected to the reduction of dietary Se to insoluble forms in the rumen environment (Spears., 2003). The absorption of Se is not regulated by dietary Se concentration or Se status, and Se homeostasis is primarily regulated by the urinary excretion of Se (Schlegel *et al*., 2008).

The chemical form and the amount of Se ingested will regulate the metabolism thereof. Following absorption, sodium selenite and Se Met are metabolised differently (Sunde., 1997). Sodium selenite is reduced to selenide which can be used for synthesis of selenocysteine (Se Cys), or methylated and excreted in urine. Selenocysteine is the form of Se present in selenoenzymes such as Glutathione peroxidase (GSH-PX). Se Met can be incorporated into proteins in place of methionine, or be reformed to Se Cys. Dietary methionine levels will affect the extent to which Se Met is incorporated into general proteins (Butler et al., 1989). The pathway of the metabolism of Na Se was summarised by Sunde (1997). First, the selenate is converted to selenite (Axley and Stadtman., 1989); this is then nonenzymically reduced by glutathione to elemental Se, forming seleno-diglutathione (Ganther., 1966). With the lack of oxygen, selenide is formed by glutathione reductase from seleno-diglutathione (Hsieh and Ganther., 1975); from where it can take various routes. The selenide can be methylated to various forms (Hsieh and Ganther., 1977), but the relevant path is where selenide binds to selenium-binding proteins. It can also form part of the synthesis of selenoproteins (Sunde., 1997) by tRNA, which will convert the inorganic Se to its organically bound form, which is found in mammalian tissues.

Bioavailability

Bioavailability may be defined as that part of Se absorbed from the gastrointestinal tract which is metabolically available for the maintenance of the normal structures and physiological processes of an organism under defined conditions (Wolffram., 1999). The bioavailability of organically bound trace minerals in ruminants is proven to be superior to that of inorganic sources (Spears, 2003). Criteria that have been used to assess Se bioavailability include GSH-PX activity (Gabrielsen and Opstvedt., 1980), and prevention of Se deficiency symptoms (Cantor *et al*., 1975). Bioavailability estimates for Se sources (especially Se Met relative to selenite) varies greatly depending on the criterion used. Feeding Se Met or selenised yeast increases Se concentrations in blood (Ortman and Pehrson., 1999) and muscle compared with selenite (Mahan *et al*., 1999). Clearly Se incorporation into non-specific proteins does not represent utilisation of Se for a specific biochemical function. When chicks were fed selenium-deficient diets after receiving supplemental Se from either selenite or Se Met, whole blood (Moksnes and Norheim., 1986) and plasma GSH-PX (Payne and Southern., 2005) declined more rapidly in birds which had originally received selenite. This confirms that Se Met from non-specific proteins is released during normal protein catabolism and used as a source of Se for GSH-PX synthesis.

Selenium deficiency

Deficiencies of Se have been observed in cattle and sheep under grazing conditions worldwide. These deficiency symptoms include white muscle disease (Muth et al., 1958), particularly in young animals or lambs born to selenium-deficient ewes, loss of Glutathione peroxidase activity and selenoprotein (Yeh *et al*., 1997), suppression of immunity (Yamini and Mullaney., 1985) and infertility in ewes grazing in selenium-poor pastures. The economic losses of poor performance and wool growth due to marginal Se deficiency may be underestimated because of the absence of clinical signs (Hill *et al*., 1969). Likely responses to supplementation can be expected in growth, wool growth and fertility in sheep with selenium-poor grazing or diets (<0.1 mg Se/kg DM). Van Ryssen., *et al*. (1989) observed that the greatest effects of inorganic Se versus high-selenium wheat on Se concentration in tissues were to be found in the liver, muscle and wool. Clinical deficiency symptoms are however not readily observed; Van Ryssen and co-workers (1999) recognised lambs with Se concentrations of between 9 and 26ng Se/ml whole blood as selenium-deficient, although clinical deficiency symptoms had not been observed. Puls (1994) regarded levels of < 50ug/L as indicative of Se deficiency in sheep. However, Se levels regarded as deficient, marginally deficient and adequate differ slightly between sources.

Inorganic Se supplementation is still the norm to prevent Se deficiency in ruminant animals, but evidence is now emerging that the organic form has additional benefits over inorganic Se supplementation of livestock feeds. According to Mahan, (1999) inorganic Se has a lower bioavailability in the rumen and some of the consumed Se is utilised by microorganisms for their metabolism and only small amounts is incorporated into body proteins (Wolfram., 1999).

Organicly bound Se on the other hand can by-pass the rumen, as it is in the form of selenoamino acids. Selenomethionine is found naturally in edible plant protein and is actively transported through intestinal membranes during absorption and actively accumulated in the liver and muscle (Lyons *et al*., 2007). Those different characteristics make commercially available organically bound Se supplements a suitable form of Se for animal nutritional supplementation.

Selenium concentrations in tissue

The concentration of Se that can be found in the body tissues is dependent on a number of factors. The chemical form, the length of time over which it was consumed, the amount of Se provided by the diet and the species of animal, will all have an influence. Although Se is present in all tissues, an especially high concentration is found in the liver, kidney, and spleen, and to a lesser extent, skeletal muscle, cardiac muscle, intestine, and lung. Tissue concentration of Se is influenced by amount and chemical form of Se in the diet (Pond et al., 1995). About 45% of total body Se is associated with the muscle, 4.6% with the liver and 6.9% with the kidneys (Grace., 1985).

In young animals, Se concentration can also depend on the level of dietary Se consumed by the dam. When Na Se is fed to a young subject, the tissue concentration approaches a plateau as the Se level in the diet rises. The effect is not the same when Se Met is the Se source; the Se concentration keeps on rising to some threshold beyond that of selenite.

Selenium toxicity

Originally the importance of Se in animal health was related to its toxic properties when it was proven that it causes malformation in animals and in extreme situation can lead to death (Meyer and Buran., 1995), and certain plants such as the Astragalus species in the USA were found to accumulate selenium. Livestock grazing on these plants was poisoned, a condition called alkali disease (Thacker., 1961). The signs of acute Se toxicity in ruminants include elevated temperature and pulse rate, watery diarrhoea, extensive tissue haemorrhage and oedema. Death is due to circulatory failure and myocardial damage (Howell., 1983). Chronic Se toxicity occurs when sheep consume plants for a period of time which contain >3ppm Se and it is associated with loss of appetite, lameness, poor growth and wool production, delayed conception and blindness (Howell., 1983). In 2006, Tiwary concluded that the organically bound Se source, Se Met is slightly less toxic than the inorganic Se source, Na Se.

Immunology

Selenium deficiency has been reported to decrease both cellular and humoral immune function in man and laboratory animals (Combs and Combs., 1986). The knowledge of specific mechanisms in livestock is less detailed than in laboratory animals although the increase in susceptibility to disease in deficient livestock is well documented (Maas., 1998). Sordillo *et al*. (1997) reported that Se deficiency is an established risk factor in mastitis incidence and has been correlated with decreased bactericidal activity of neutrophils and the severity of mastitis infection. Injections of barium selenite decreased the incidence of mastitis in dairy goats (Sanchez *et al*., 2007), and Se yeast in the diet has decreased episodes of diarrhoea in calves (Guyot *et al*., 2007).

Oxidation

Most animals, plants, and microorganisms depend on oxygen for the efficient production of energy. However, free radicals derived from oxygen can damage many types of biological molecules and are potentially toxic for living organisms. The formation of free radicals is a pathobiochemical mechanism involved in the initiation or progression of various diseases (Hogg., 1998). The presence of natural antioxidants in living organisms enables their survival in an oxygen-rich environment (Halliwell., 1994). In livestock production, free radical generation and lipid peroxidation are responsible for the development of various diseases, reduction in animal productivity, and product quality (McDowell., 2000).

There are several methods that exist to measure total antioxidant capacity, but the majority of literature refers to three methods;

1. FRAP (ferric reducing ability of plasma – Benzie.,1996)
2. TEAC (trolox equivalent antioxidant capacity – Rice-Evans.,1994)
3. ORAC (oxygen radical absorbance capacity – Cao.,1999)

Accordind to Cao (1998) is the ORAC method of measuring antioxidant status the most accepted, because its measurements are based on fluorescence rather than absorbance. The ORAC test is a hydrogen atom transfer assay that determines antioxidant capacity by measuring competitive kinetics. It consists of three basic components: a fluorescent probe, a radical donor and a fixed amount of antioxidant against which to compare the sample antioxidant capacity. As the radical donor increases, the fixed amount of fluorescent agent present in the reaction mixture will progressively become quenched. Any antioxidant present in the system would scavenge the radicals, effectively out-competing the fluorescent probe as substrate (Cao *et al*., 1993). It is the only methodology that links the inhibition time with the degree of inhibition (Ou *et al*., 2001), thus increasing the sensitivity and so permits a lower molar ratio of antioxidant sample to reagents, thus minimising the possibility of cross-reactions between the two.

Selenium in meat

Selenium plays an important role in muscle (meat), not only to increase Se availability for human consumption through food, but also to improve meat quality. Meat colour, fat content, in pack purge and price determine how consumers perceive quality, which in turn influences purchasing behaviour (Grunert.,2006). Meat colour is the foremost selection criterion used by consumers in the purchase of meat and is commonly used as an indicator of freshness. Cooked meat colour, juiciness and tenderness are also important product quality cues during consumption. Consumers regard meat tenderness as the most important palatability trait (Pietisik & Shand., 2004) and juicy meat is generally preferred over dry meat (Risvik., 1994).

According to various trials, the majority of the physical properties of meat described above (i.e., colour, texture, and firmness of raw meat; juiciness and tenderness of cooked meat) will be to some extent be dependent on the meat’s water-holding capacity (WHC) (Avanzo *et al.,*

Table 1. Roles of some minerals on physiological functions reproductive failures and toxicity in Lambs

Mineral element	Physiological functions	Deficiency	Toxicity
Calcium and Phosphorus	Intracellular messenger for transmission of nerve impulses. Release ATP/ADP and nucleic acids	Lowered milk production, milk fever by hypocalcemia in lactating ewes and does, estrus suppression and poor conception rates	Hypercalcemia and soft tissue calcification, Urinary calculi formation and skeletal softening
Magnesium	Synthesis of nucleic acids and glutathione	Tetany	Urolithiasis, lethargy, disturbance in locomotion, diarrhea, and lower feed intake
Copper and Molybdenum	Enzyme component and catalyst involved in steroidogenesis and prostaglandin synthesis	Delayed and depressed estrus, abortion, death fetuses, infertility, congenital ataxia	Haemolytic crises, haemoglobinuria, haemoglobinaemia, and jaundice; Severe diarrhea, weight loss, anorexia, and reproductive failure
Selenium	Component of selenoproteins, antioxidant function	Lamb mortality, reduced sperm motility and uterine contraction, cystic ovaries, low fertility rate, retained fetal membranes	Poor growth, abnormal gait, vomiting, dispnea, titanic spasms, labored respiration, and death
Zinc	Component of numerous metalloenzymes, influences transcription and cell replication	Impaired spermatogenesis and development of secondary sex organs in males, reduced fertility	Reduced weight gain and feed efficiency, depressed feed intake, and eventually pica

Adapted from Minatel and Carfagnini (2000), Smith and Akinbamijo (2000), Underwood and Suttle (2003), McDowell (2003), NRC (2005), NRC (2007), Blache et al. (2008), Hefnawy and Tórtora-Pérez (2010).

2001). Although some of these trials are confounded by the inclusion of other components such as Vitamin C and E (Munoz *et al.,* 1996). Mahan *et al*. (1999) reported no difference for drip loss in pig meat with NaSe addition, and a linear increase in Hunter L value (paleness) of muscle also with added selenite. There are a number of trials looking at drip loss in broiler meat, and some suggest a positive effect of Se-yeast over Na Se, but overall the evidence is inconclusive (Naylor *et al*., 2000). Clyburn *et al*. (2000) suggested a trend for beef flavour and flavour intensity to be improved by organically bounded Se, although the data reported were somewhat inconclusive.

Selenium in Reproduction

Diets and feedstuffs deficient in trace minerals requirements, can have deleterious effects on reproduction functions, in both males and females of both species (Table 1), thus, for feeding purposes, the mineral status of the animal should be considered in preparation of the final diets (Smith and Akinbamijo., 2000). Moreover, cattle and goats are less susceptible to Cu toxicity than sheep, and young ruminants are more susceptible than adults because of higher absorption (NRC., 2005). Although Cu poisoning has been recorded in sheep grazing pastures fertilized with chicken litter, the inclusion of poultry litter in sheep rations is recommended by some researchers as an alternative source of protein and energy, but attention should be taken to avoid copper toxicity (Christodoulopoulos and Roubies., 2007).

In areas from southeast of the State of Tlaxcala and the mountain area of the State of Puebla, the mortality of the lambs from birth to 60 d of age was 62 percent; the lambs had symptoms of nutritional myopathy and the main finding at necropsy was nutritional muscular dystrophy, due to Se deficiency (Ramírez-Bribiesca *et al*., 2004). It is worth mentioning that Se is the most toxic essential trace element; so its supplementation should be cautious, especially in non-selenium deficient areas (Underwood and Suttle., 2003).

Mineral concentrations in the liver are the best indicator of the endogenous mineral status of the animal (Humann-Ziehank *et a*l., 2008). Nonetheless, blood analysis is more frequently used, because blood samples are easily taken and are also considered a non-invasive procedure (Kincaid., 2000). Trace elements deficiencies are expressed in the animal by diverse forms, since these elements form molecule complexes of the metabolism of proteins, lipids and carbohydrates, where they play key roles as components and enzyme cofactors (Cu) or transcription factors (Zn) (McDowell., 2003; Underwood and Suttle., 2003). Based on the aforementioned information, the mineral status of the animal has effects on every phase of the reproductive cycle (Smith and Akinbamijo., 2000; Robinson *et al*., 2006). For instance, during gestation, both, the mother and fetus are very susceptible imbalances in micronutrients in the diet, during the time of rapid growth and cell differentiation (Gürdoğan *et al*., 2006; Ghany-Hefnawy *et a*l., 2007). Additionally, kilograms of offspring weaned per female exposed may be affected by both trace mineral supplementation and source (Ahola *et al.,* 2004).

However, the mechanisms of action by which these micronutrients affect reproduction in sheep and goats are not completely understood, mainly due to the complexity in the mode of action of the metallobiomolecules and the neuro-hormonal relationship (Smith and Akinbamijo, 2000; Wilkins and Wilkins., 2002; Zatta and Frank., 2007).

Organically bound v. inorganic Se

For many years it has been recognised that the selenoamino acids Se Met and Se Cys are the sources of naturally occurring Se (Burk., 1976; Levander, 1986; Cai *et al.*, 1995) and constitute 50-80% of the total Se in plants and grains (Butler and Peterson., 1967). Selenomethionine cannot be directly synthesised from selenite or selenate by animals (Cummins and Martin., 1967; Sunde., 1990).

The tissue retention of organically bound or inorganic Se differs (Ku *et al.*, 1973). Inorganic Se has a reduced bioavailability in the ruminant because of the anaerobic conditions in the rumen. Although part of the oxidised form of Se (Sodium selenite) is reduced in the rumen to the unabsorbable elemental or inorganic selenide forms, which is not absorbed through the rumen or the intestinal tract, some of the consumed Na Se is used by rumen microbes for their metabolism. The microbial protein thus formed with Se can pass into the small intestine and serve as a source of dietary Se for the ruminant. The selenium-enriched yeast protein is hydrolysed in the rumen and small intestine to the respective amino acids. The selenoamino acid, Se Met can be non-specifically incorporated into body protein (Kincaid, 1995) and most probably serve as Se storage capacity. Subsequent research has demonstrated that blood GSH-PX activity in ruminants is lower when the inorganic form of the element is fed to dairy animals, but that Se levels in milk can be increased up to four or five times by feeding the lactating cows organically bound Se (Pehrson *et al.*, 1999).

CONCLUSIONS

In this review paper, we concluded the following:

1) The Organically bound Se has a higher bioavailability for small ruminants than Na Se. Organically bound Se will therefore have a positive impact on small ruminant health and production, which will result in an indirect advantage for human health.

2) The organically bound Se, which has been proven to be more bioavailable than it's inorganic or conventional counterpart, should have a positive influence on lipid oxidation and meat quality.

3) The main advances in Se status assessment and Se requirements were established based on the activity of GSH-PX, an enzyme which for many years was considered to be the main selenoproteins. Recently, it was discovered that it is only one of at least 25 various selenoproteins. Se research and practical applications are developing quickly and they are very exciting and promising. RE The main advances in Se status assessment and Se requirements were established based on the activity of GSH-PX, an enzyme which for many years was considered to be the main selenoproteins. Recently, it was discovered that it is only one of at least 25 various selenoproteins. Se research and practical applications are developing quickly and they are very exciting and promising.

4) There is also lack of proper acts and regulations for monitoring their quality for commercial marketing.

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