

The Importance of Sulfur in Ruminant Nutrition

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Abstract

Sulfur (S) is one of the basic building elements; after calcium and phosphorus, it is the third most abundant mineral in the human body. Sulfur is also essential in animal nutrition. It has long been recognized that S represents an essential element for rumen microbes and is closely related to nitrogen metabolism. Sulfur is an important constituent of amino acids, enzymes, and vitamins in humans and animals. Sulfur is a component of various organic nutrients required by ruminants. It is crucial for producing certain enzymes, vitamins, hormones, and amino acids in the rumen, including cystine, methionine, and cysteine. Sulfur amino acids, for instance, are found in collagen, the primary structural protein in mammalian tissues. Also, sulfur is not stored in the body. Therefore, it needs to be presented in animal diets in order to maintain the synthesis of these nutrients in the rumen. In ruminants, sulfur supplementation is essential for overall health, growth and production, amino acid balance, and wool quality. Despite this, excessive sulfur digestion may cause a toxic effect on animals and adversely affect animals' performance and health, even causing serious diseases such as polioencephalomalacia (PEM). High sulfur levels in diets can significantly reduce animal performance, decrease milk production and sometimes even result in death. This article will focus on current knowledge about the metabolism and role of sulfur in the ruminant, factors affecting the production of hydrogen sulfide in the rumen, and the potential mechanisms behind sulfur toxicity in cattle. Additionally, possible strategies for minimizing sulfur toxicity in cattle diets will be discussed.

Keywords: *animal nutrition; microorganisms, ruminants, ruminant digestion, sulphur*

1. Introduction

Sulfur (S) is one of the basic macroelements which play a significant role in animals and humans participating in various physiological, digestive, and biosynthetic processes. This element is a critical part of some B vitamins (thiamine and biotin), amino acids (i.e., methionine, cystine, and cysteine), and other cellular components. Also, sulfur is present in keratin (which affects the health of the coat and hooves) and is part of glutathione, which plays a crucial role in the oxidation system. S is also essential for the acid-base balance in the organism

and, as a component of coenzyme-A, is a part of energy metabolism [1]. Sulfur is important to wool and hair production in small ruminants due to the high amounts of both cystine and methionine found in hair [2]. In addition, S-containing amino acids and B-vitamins are noted for their importance to milk and tissue protein production, collagen and connective tissue development, blood clotting, enzyme synthesis, and endocrine function in animals [3].

In the rumen, dietary components ingested by the animal are digested and fermented by a myriad of microorganisms. S has long been thought to be a crucial component for rumen microbes because the metabolism of S is closely linked to nitrogen metabolism. The intake of S can affect the digestion of cellulose and the efficiency of protein synthesis [4]. In the rumen, bacteria reduce S to sulfide or hydrogen sulfide (H₂S), which can

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subsequently be absorbed and converted to sulfate in the liver via microbial protein synthesis. Sulfur is necessary for regular performance and productivity in the right proportion, but excessive S intake can be hazardous. High dietary S intake, especially in the form of sulfate (SO_4), leads to the active utilization of S and increased sulfide production by rumen microbes [5]. The balance between produced sulfide and H_2S in the rumen depends on pH; a high pH level leads to increased H_2S . High concentrations of H_2S cause exceed dietary S and can negatively affect cattle growth and health, causing diarrhea, muscle twitching, and other neurological symptoms in ruminants [6]. A higher level of H_2S in the rumen is also related to metabolic activity and S utilization by sulfate-reducing bacteria (SRB). Despite representing only 1% of the microbial population in the rumen, SRB can cause a significant threat to animal health [7]. Exceeding hydrogen sulfide production by SRB can cause S-related polioencephalomalacia (S-PEM, brain cortex necrosis) and, in some cases, lead to animal death. Generally, excessive S in cattle diet can have implications on trace mineral absorption and dry matter intake, decrease overall cattle growth and performance, and create potential toxicity. Also, S deficiency may lead to anorexia, excessive salivation, weight loss, and poor growth performance [2]. Thus, it's important to provide an

adequate level of S in cattle's diet to keep optimal microbial activity in the rumen and maintain overall performance.

2. Sulfur dietary sources and requirements in ruminants

Sulfur is a part of practically all feeds and concentrates. Forages such as turnips, canola, and oilseeds are also rich in sulfur. The sulfur-containing amino acids presented in protein-rich forages (e.g., sorghum) or in protein-rich meals (e.g., soybean or corn) can contribute significant amounts of S to the diet.

Grasses typically contain low levels of S; however, it depends on the S concentration in the soil. Forages with higher dry matter (e.g., corn silage, hay, root crops) usually have a low S content and, therefore, are less used by animals. Kudrna [8] reported a significant effect of S supplementation on milk yield depending on the breeding conditions. The by-products of corn, molasses, and sugar beet can also have a high S content after their distillation because acidifying agents containing sulfur are commonly used in their processing. Including ethanol co-products in beef cattle can increase the S level in the diet and thus increase S toxicity [9]. The amount of S in plants depends on the fertilization and nutrition technologies used for crops.

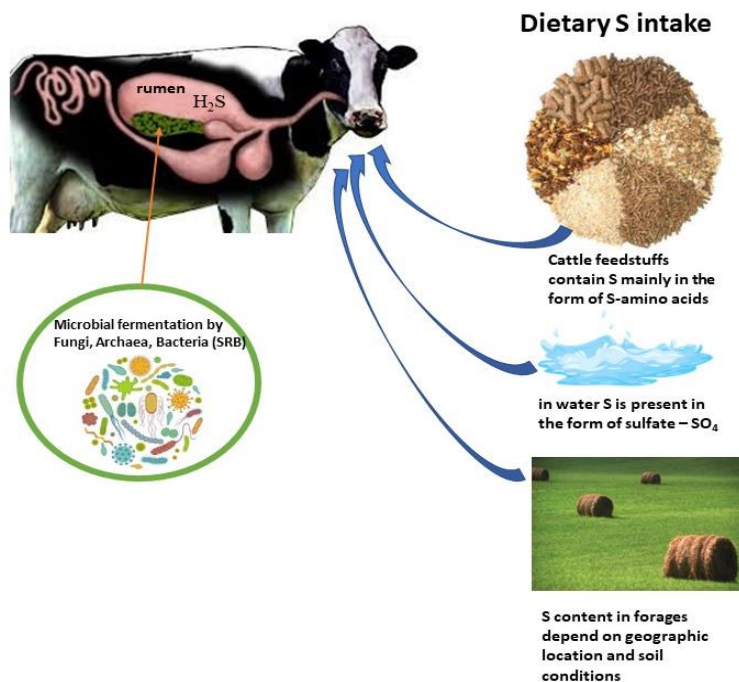


Figure 1. Dietary Sulfur sources

Sulfur is thus often indirectly added to the mineral mixture through the sulfate forms of minerals. This must be taken into account when balancing the feed ratio. Supplemental S sources differ in their ability to increase ruminant microbial activity. Sodium sulfate and methionine have been shown to stimulate riboflavin and vitamin B12 synthesis by rumen microorganisms to a greater extent than cysteine or elemental sulfur. Several authors [10, 11] recommended inorganic S sources (ammonium sulfate, elemental sulfur) as an available dietary S source for animals, which is reported effectively support microbial synthesis proteins and some volatile fatty acids in the rumen. The main forms of S absorbed in the animals' digestive system include synthetic amino acids, sodium sulfate, ammonium sulfate, calcium sulfate, and elemental sulfur. Nevertheless, only a small amount of S can be absorbed from H₂S or after S-containing amino acid oxidation [12]. C. S. McSweeney [4] reported that supplementing beef cattle with organic S sources (3-mercaptopropionic acid and 3-mercapto-1-propane sulfonic acid) had a stimulatory effect on microbial population in the rumen, increasing microbial protein synthesis.

Sulfur is essential for the growth and metabolism of many ruminal microorganisms (especially cellulolytic bacteria) to provide sufficient S-compounds to the cattle's diet [9]. NRC [2] recommended minimum limit of S in the beef cattle diet is 0.15%, and the maximum permissible level of S in cattle diet ranges from 0.30 to 0.40 % of DM; whereas in diets containing greater than 85% concentrate, the maximum has been suggested to be 0.3% and in diets containing greater than 40% forage 0.5% [13]. In feedlot cattle, S intake shouldn't exceed 0.30% DM [2]. In cattle feedstuffs, sulfur is presented mainly in the form of S-amino acids and in drinking water in the form of sulfate [9]. Depending on geographic location, the amount of sulfur in forages and water can vary and contain a high S amount as well [14, 15]. For instance, problems with high S water contention have been recorded in the western United States [14, 16]. Water sulfate concentration should not exceed 600 mg/l for cattle, as recommended by NRC [13]. Since the sulfur contributions from both water and feed sources are additive, the total S intake by cattle should be determined using both.

Table 1. Sulfur requirements and maximum tolerable S level in ruminant diets

Animals	Dietary S (% of DM)	The toxic level of S in the diet
Dairy cattle	0.20	0.5
Beef cattle	0.15	0.3–0.5
Small ruminants (goats, sheep)	0.18–0.26	0.4–0.5

Cereal grains (e.g., corn, oats) generally contain from 0.14% to 0.23% of S, while protein sources (e.g., soybean) up to 0.5% [17]. Forages often contain up to 0.3 % S or greater and tend to be variable in S contention [18]. Alfalfa hay, for example, typically contains between 0.25 and 0.5 % of S, while contrarily, grass hays (e.g., brome, prairie) contain little or no sulfur. Cattle in pasture require at least 0.15% of S [15].

The maximum tolerable level of S is still under debate, as there are reported cases when supplementation of 0.5% S in dry-tolerant cows didn't negatively affect the animal's performance. Furthermore, the addition of sulfate ions in the dosage above 0.5% in diets of dry cows can decrease the ratio cation-anion difference and, thus, help to prevent milk fever [19]. The optimum level of S in the diet for dairy cows was suggested as 0.40% S [20]. J. Hawley et al. (2014) didn't find a beneficial effect of including 0.40% S

in the beef cattle diet. Sulfur supplementation at this level did not have a significant impact on steer performance and beef carcass characteristics as well.

Finishing steers fed diets with increased dietary S (0.31 - 0.46% S of DM), tolerated up to 0.31% S in the feed without adverse effects on their performance. However, 0.46% S in animals' diets significantly decreased average daily gain (ADG) and dry matter intake (DMI) (Spears et al., 2011). Sulfur is a major trace mineral antagonist in ruminants, because it can form insoluble complexes with other minerals (iron, zinc, selenium, copper) that reduce their absorption into the intestine. Supplementation of more than 4 g S/kg dry matter reduced the absorption of other minerals, such as Cu and Se [9].

Sulfur requirements vary among ruminant species depending on their production. For example, sheep raised for wool have a different need for

sulfur in feed, as sulfur as part of keratin affects its quality. Among other factors that can influence S requirements are age, physiological state, and sources of supplemented nitrogen and sulfur [10]. It is possible to get an overview of S supply by the animal by estimating the total sulfur concentration (TSC) in the dry matter of all feed ration components, including water (expressed as a percentage). Based on this information, the correct amount of S in the animals' feed ratio can be chosen. When creating feed regimens and formulation feed ratios, this issue has to be researched in greater detail. Currently, there is little information in the available literary sources; therefore, more research is required in order to expand knowledge in the given area.

3. Sulfur toxicity in ruminants

An excess of sulfur in animal feed can have harmful effects on animal performance and health, manifested by symptoms such as limiting microbial activity, reducing fiber digestion, diarrhea, breathlessness, blindness, muscular twitching, and causing death in some cases [2]. These symptoms are commonly referred to as sulfur-related polioencephalomalacia (S-PEM), which can induce blindness, coordination problems, lethargy, and seizures in cattle. Gould [21] found an association between ruminal H₂S concentration and S-PEM cases in cattle fed high-S diets. In his study [22], 2 of the three steers fed consumed the diet with a high amount of sulfate showed clinical signs of PEM (episodic ataxia and blunted or absent menace reaction). Similar results were obtained by Niles et al. [23] when all heifers supplemented with high doses of S (0.55 and 0.70%) showed clinical symptoms of PEM while ruminal concentrations of H₂S for these treatments were 14,500 and 18,642 mg/L, respectively. Loneragan et al. [24] have also reported the correlation between a high concentration of H₂S in the rumen and the development of PEM in animals fed a high-S diet. The relation between growing causes of S-related PEM and ingestion of sulfates from the water was observed in regions with warm climates (Colorado, South Dakota) as

animals had higher water intake to combat the heat [16]. To minimize the risk of PEM development in cattle is important to fully understand the availability of S in ruminant diet, S

metabolism by rumen microbes, and dietary factors affecting the synthesis of H₂S. Future research in this area is strongly required to propose an effective mitigation strategy and improve cattle feed management.

Moreover, a higher level of S in the organism may also negatively affect dry matter intake, preventing the absorption of other minerals in the rumen [9]. In such circumstances, rumen microbes create an excessive amount of H₂S, which is easily absorbed into the bloodstream via the rumen wall and binds to hemoglobin forming sulfhemoglobin (SHb). Due to this, the blood's capacity to deliver oxygen to the tissues is reduced, hindering cellular energy creation [11, 25].

Several studies showed that increasing the amount of S in the feed ration (if the quality of forage and fiber is lower) leads to an increase in weight, wool, and milk yield. A combination of the following indicators further accompanies this phenomenon: increased digestibility of dry matter, fiber, and cellulose, increased feed intake, and improved nitrogen balance [9]. Supplementation of S in beef cattle in the form of mineral salt containing 4.5% urea and 1.2% of S resulted in increased average daily weight gain (0.63 kg/day), improved carcass quality of heifers, and additionally, reduced cost of feeding [26].

The concentration at which sulfur in a ruminant diet becomes toxic is still unclear, as various studies show great differences in response to dietary S concentration. Thus, further research is required to develop correct and efficient nutritional strategies to improve animal productivity and minimize S toxicity and health problems.

4. Conclusions

In summary, to prevent and minimize S toxicity and keep an adequate level of S in the diet, it is necessary to evaluate sulfur levels in water and soil, investigate the potential mechanisms behind sulfur toxicity in cattle, and establish preventative management strategies that will enhance animal health and welfare.

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