CAPÍTULO 10

MAGNESIUM ABSORPTION, METABOLISM, DEFICIENCY, AND TOXICITY IN RUMINANTS AND NON-RUMINANTS

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SUMMARY: This literature review sought to explain the importance of minerals, specifically magnesium, in production animals, i.e., ruminants and non-ruminants, highlighting their metabolism, absorption, possible cases of deficiency within the animal production chain, and toxicity in cases of excess. The review also highlighted the similarities, differences, and specificities

of the relationship between this mineral and animal species. Magnesium is essential as it participates in various functions in the body, is present in practically all metabolic pathways, and acts as an activator of enzymes related to glycolysis. It is extremely important that magnesium, as well as other essential minerals for farm animals, are in perfect balance in the diet provided, as cases of excess or deficiency can cause serious problems. Cases of magnesium deficiency and excess are not common, but it is important to be aware of possible cases, as these situations cause damage and problems for the animal›s health and consequently its performance and productivity.
KEY WORDS: Animal production, macrominerals, toxicity, hypomagnesemia.

MAGNESIUM ABSORPTION, METABOLISM, DEFICIENCY, AND TOXICITY IN RUMINANTS AND NON-RUMINANTS

ABSTRACT: This literature review sought to explain the importance of minerals, more specifically magnesium, in production animals, that is, ruminants and non-ruminants, highlighting their metabolism, absorption, possible cases of deficiency within the animal production chain, and toxicity, in excess cases. The review also highlighted the similarities, differences, and specificities of the relationship between this mineral and animal species. Magnesium is essential as it participates in several functions of the body, is present in practically all metabolic pathways, and acts as an activator of enzymes related to glycolysis. It is extremely important that magnesium, as well as other essential minerals for farm animals, are in perfect balance in the diet provided, as cases of excess or deficiency can cause serious problems. Cases of magnesium deficiency and excess are not common, however, it is important to be aware of possible cases, as these situations bring harm and problems to the animal›s health and consequently its performance and productivity.
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INTRODUCTION

Food is any substance or mixture that, when ingested, provides elements for the formation, development, and maintenance of organisms and must be non-toxic (Vicenzi, 2015). The feed provided to animals is considered to be concentrated when it has a fibre content below 18%, or bulky when it has a fibre content above 18%. Some forms of feed supplied to animals are silage, hay, flour, bran, rations, pies, or even fresh forage (Goes et al., 2013).

According to Goes et al. (2013), concentrated feeds can be divided into protein and energy feeds. Protein feeds have more than 20 per cent crude protein, and energy feeds have less than 20 per cent crude protein. The same author comments and argues about minerals and vitamins in animal feed, citing bicalcium phosphate, limestone, copper sulphate, magnesium oxide, etc., as categories of minerals used.

Therefore, to define the importance of an element for a given animal, it is of the utmost importance to understand its requirement, which is defined as the nutritional requirement. This requirement is determined as the daily amount of a nutrient that the animal must consume to achieve a certain level of production. Every animal has a specific requirement for water, proteins, energy, minerals, carbohydrates, and other compounds, varying according to species, sex, weight, age, and production (Albertini et al., 2015).

With this in mind, this literature review aims to explain and exemplify the process of absorption, metabolism, deficiency, and toxicity, as well as the importance of magnesium in various functions in the organisms of ruminant and non-ruminant animals.

MINERALS IN ANIMAL FEED

According to Pappas (2006), minerals are inorganic elements with a well-defined chemical composition. Normally, minerals are not combined with other molecules in the body, but they can be combined with other organic molecules such as proteins, hormones, and enzymes. Previously, Georgievskii (1982) and Dayrell (1993) had already commented on the importance of minerals for animals. According to them, these elements make up around 2 to 5.5 per cent of the body of vertebrate animals and, due to the various functions they perform in the body, are extremely important in the whole field of traditional biochemistry.

Minerals are fundamental to the animal organism and are classified according to their need into macro and micro elements. Macroelements are required in greater quantities by the animal organism, while microelements are required in smaller quantities. Macro elements are Calcium (Ca), Phosphorus (P), Potassium (K), Magnesium (Mg), Sodium (Na), Chlorine (Cl), and Sulphur (S). The microelements are Iron (Fe), Copper (Cu), Cobalt (Co), Iodine (I), Manganese (Mn), Zinc (Zn), Selenium (Se), Molybdenum (Mo), and Fluorine (F) (Bertóli, 2010).

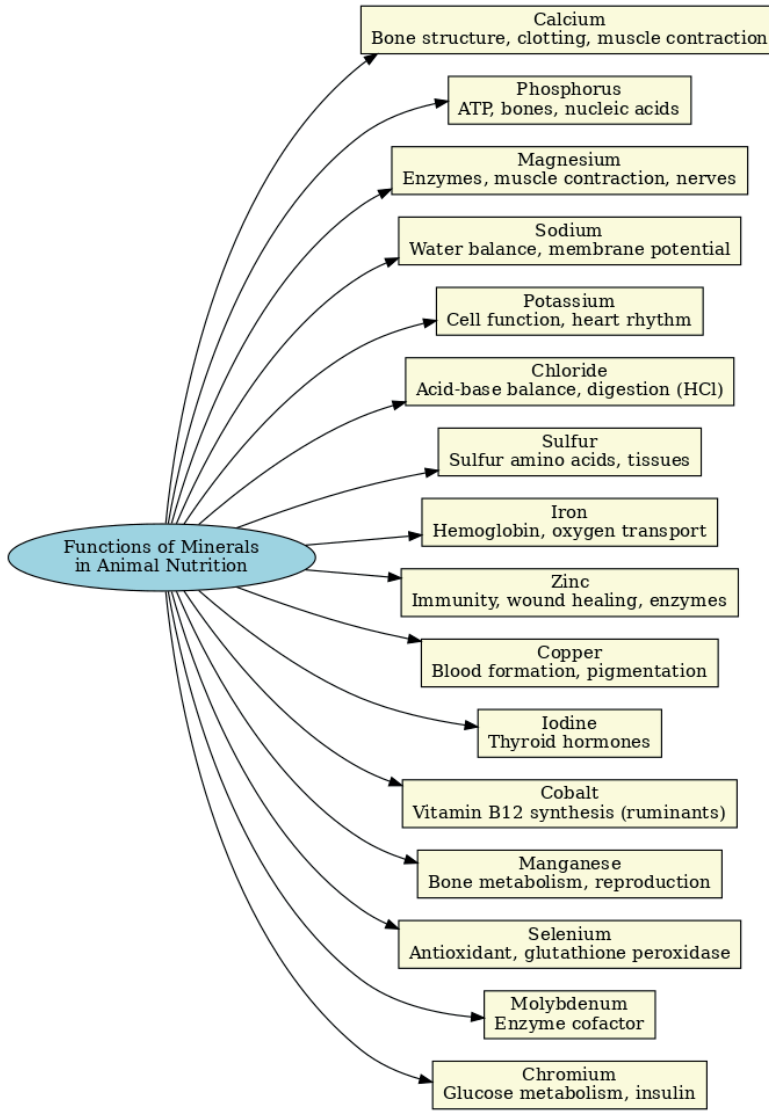

Figure 01: Functions of Minerals in Animal Nutrition. Source: adapted of González & Silva, 2019.

These elements are involved in almost every metabolic pathway in the animal organism, performing numerous vital functions in the body. Minerals are also essential constituents of the body›s soft tissues and fluids, as well as being related to reproductive performance, growth maintenance, energy metabolism, and other physiological functions (Morrison, 1966). Mendonça Júnior et al. (2011) comment that, in addition to influencing physiological functions, these elements are also present in some animal products, such as milk proteins like casein.

According to Bertóli (2010), the action of minerals can be divided as follows:

1) Energetic: Energy transfer linked to cellular metabolism;

2) Plastic: Fundamental constituents of protoplasm and the structures, growth, and maintenance of tissues (bones, muscles, and fat);

3) Physico-chemical: They help maintain and establish osmotic pressure, acid-base balance (K and Na), cell permeability (Ca and Mg), regulation of body processes, and neuromuscular excitability;

4) Functional: They participate in the constitution of enzymes, vitamins, secretion, and hormones, and play a role as transporters (protein synthesis and oxygen transporters).

MAGNESIUM ABSORPTION

The absorption of mineral elements, along with their transport, storage, and excretion, are stages in a dynamic system that maintains normal feed intake, resulting in homeostasis. This variation is partly a function of the animals› needs, age, and physiological state (Mendonça Júnior et al., 2011). Animals› digestive systems are different because they have different degrees of specialisation according to the environment in which they live, i.e., adaptations to the type of food (Rocha, 2015).

Absorption is the passage of substances from the external environment into the animal. Digestive absorption occurs due to the passage of food through the intestinal mucosa into the blood and lymph. Most digestion and absorption take place in the small intestine (duodenum, jejunum, and ileum). In ruminant digestion, absorption also takes place in the rumen, reticulum, and omasum, but it is still in the small intestine that favourable conditions for absorption are found (Andriguetto et al., 1982; Oliveira, 2015).

In the case of horses, for example, the stomach is small about the size of the animal, which means that certain groups of animals, depending on their nutritional requirements, do not consume enough forage to meet their needs. This makes it essential to use concentrated feed and/or supplementation (Oliveira, 2015).

In general, most nutrients are absorbed in the small intestine, while water is absorbed in the large intestine. The digestion and absorption of nutrients in food take place as the food passes through the gastrointestinal system. The absorption of water, minerals, and water-soluble vitamins does not require a breakdown, but proteins, lipids, and sugars need to transform until they reach their simplest (lightest) forms for absorption (Rocha, 2015).

Foods can be categorised into three groups according to how quickly they are absorbed:

1) Rapidly absorbable: chlorides, bromides, iodides, acetates, etc.

2) Absorbed slowly: nitrates, lactates, silicates, sulphates, phosphates, citrates, and carbonates;

3) Not absorbed: oxalates, phytates, etc.

MAGNESIUM METABOLISM

Bone metabolism is not very involved in Mg homeostasis. The magnesium present in the skeleton can be utilised by the animal during times of deficiency, but this skeletal reserve is much smaller than that of calcium. The mobilisation of magnesium in the bones is slow, so the animal depends on Mg from the diet to replenish the necessary Mg concentrations. In ruminants, Mg is absorbed in the rumen by active transport. In monogastrics, absorption takes place in the intestine. The intestinal absorption of Mg is because PTH promotes the synthesis of 1.25 dihydroxycholecalciferol at a renal level, which increases the absorption of Ca from the intestine, interfering with the absorption of Mg (Caneppele, 2014).

Excess Mg is excreted in the urine, so urinary and blood levels of Mg are good indicators of the animal›s intake/outtake balance. The normal plasma Mg concentration is around 1.8 to 3.0 mg/dL (Caneppele, 2014). Several factors influence Mg absorption:

1) Sodium and potassium: High potassium supplementation inhibits Mg absorption in the rumen. However, when Na is supplemented, maintaining a ratio of Na:K (5:1), there is an increase in the linear absorption of Mg.

2) Ammonia: High rumen ammonia concentrations have been shown to impair Mg absorption. Young pastures with high protein contents are converted into ammonia in the rumen, and this acute increase in rumen ammonia is what most interferes, resulting in a reduction in blood flow to the rumen wall, reducing Mg absorption.

3) Energy deficit: When there is an energy deficit, less microbial protein and volatile fatty acids are formed. An energy reduction will lead to less Mg absorption.

4) Calcium: calcium interferes with the absorption of Mg, as it has the same sites of action and by altering intestinal permeability.

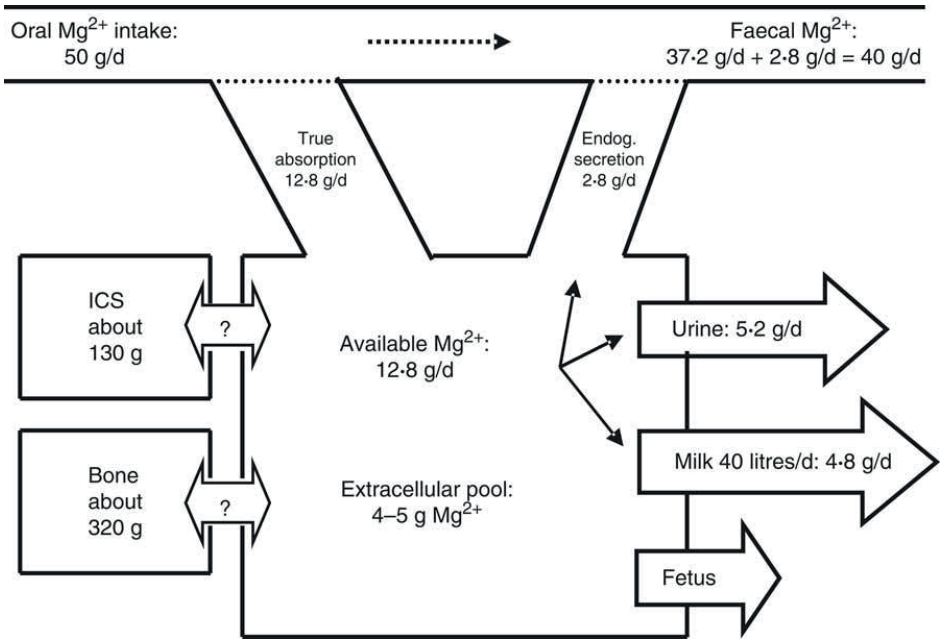

Figure 02: Scheme of Mg^{2+} metabolism in a non-pregnant dairy cow of 700 kg body weight (BW). Source: Martens et al. (2018).

DISABILITY

Hypomagnesemia is a metabolic disease characterised by insufficient magnesium in the body. The causes of hypomagnesemia can be grouped into five classes: nutritional causes, intestinal causes, endocrine/metabolic causes, renal causes and conditions associated with the neonatal period. Its signs and symptoms are often associated with or masked by manifestations of the underlying disease or associated disorders (Silva, 2002).

One of the causes is an increase in cellular free calcium levels caused by Mg deficiency. Another cause of Mg deficiency is linked to the consumption of pastures with an excess of potassium (K) and nitrogen (N) and/or fodder with a high concentration of K and crude protein, since K has an antagonistic effect and its excess ends up inhibiting the absorption of Mg. Magnesium deficiency in animals is manifested by a series of clinical signs, such as stunted growth, hyperirritability and tetany, anorexia, muscle incoordination, and convulsions. The most characteristic clinical picture of magnesium deficiency is pasture tetany, when serum levels of the element can be up to ten times lower than normal (Berchielli, 2011).

Hypomagnesemia can be treated orally or intravenously. The use of oral solutions of Mg salts, such as Mg chloride or Mg sulphate is not very effective, even in animals in the early stages of the disease. The use of intravenous solutions guarantees a longer persistence of Mg blood levels and prevents the clinical case from recurring (Berchielli, 2011).

Deficiency in Chickens

All macrominerals and microminerals must be balanced in the diet fed to the animals, as an excess of one mineral can impair the absorption of another. In the case of chickens, excess calcium can affect the availability of other minerals such as phosphorus, magnesium, manganese, and zinc, leading to secondary deficiencies. Birds can regulate their feed intake according to their diet.with the level of calcium in the diet and a deficiency of this mineral increases consumption (Souza et al., 2020).

Deficiency in Pigs

Magnesium deficiency rarely occurs in pigs due to its presence in various foods. Clinical signs of deficiency include anorexia, poor growth, hyperirritability, muscle spasms, loss of balance, tetany, and death. Information on intoxication by this mineral is scarce. It is accepted in the literature that a level up to 0.3% magnesium in the total dry matter of the diet does not cause harm to pigs (Patience & Zijlstra, 2001; Yagüe, 2009).

Deficiency in Cattle

Reports of magnesium deficiency in animals kept on pasture in Brazil are rare. Normally, cattle are more susceptible to magnesium deficiency as they get older, due to a progressive difficulty in mobilising the mineral from the skeleton and a reduction in the element›s intestinal absorption capacity (Underwood, 1981). Normal levels found in plasma correspond to 1.8-3.0 mg%. Magnesium deficiency can also occur when green fodder is available in winter. They provide large amounts of potassium and highly degradable proteins, causing a decrease in Mg absorption. In turn, Mg is excreted in faeces, urine, and milk production. The magnesium requirement for dairy cows is between 13 and 14 ppm of Mg in the feed (Calderón 2017).

The prevention of hypomagnesemia focuses on two factors: supplying amounts of Mg that meet the animal›s dietary needs and increasing the rumen›s bioavailability of Mg. For the animal to remain healthy, the diet of ruminants must contain a minimum of 0.18% Mg to meet the daily needs of the mineral, while for lactating cows, the diet must be richer in Mg and contain between 0.22 and 0.35% Mg. It is also important to emphasise that K is an antagonist to Mg, and unbalanced K intake above what is necessary tends to require a higher intake of Mg to compensate (Berchielli, 2011).

Figure 03: Animal diagnosed with hypomagnesemia. Source: Perulactea, 2006.

Deficiency in Sheep

To avoid this deficiency, especially in lactating females, supplements containing the mineral, such as magnesium oxide, sulphate, carbonate, or chloride, are recommended. Magnesium requirements for adult sheep are 0.3 to 1.4g per day. Lactating sheep become more demanding and require 2.0 to 2.5g of Mg per day (Riet-Correa et al., 2001). As with cattle, animals raised on pasture may be more prone to this deficiency, as some pastures can have high levels of potassium, hurting Mg absorption (Schonewille et al., 1999).

Sheep with magnesium deficiency show some clinical signs, such as tremors, involuntary contractions (spasms), difficulty walking, and sensitivity to touch. If treatment is not carried out quickly and efficiently, the animal may die. The most practical way to avoid a possible deficiency in grazing animals is to ensure that the potassium content of the pasture does not exceed 2.5% (Eblex, 2008). Treatment in cases of hypomagnesemia involves the subcutaneous administration of magnesium hypophosphite or the administration of a combined calcium and magnesium solution.

TOXICITY

The opposite of deficiency is hypermagnesemia, caused by an excess of magnesium, which, in certain circumstances, can cause intoxication due to the excess. This phenomenon occurs less frequently than hypomagnesemia. Contrary to what happens in situations of Mg deficiency, normal serum values cannot be found in cases of increased Mg reserves (Martin, 2009). Mg levels above 4 mEq/L are associated with adverse clinical signs (Schaer, 1999).

Hypermagnesemia has been observed in situations of renal failure, endocrinopathies, and excessive Mg administration, especially in animals with impaired renal function (Swaminathan, 2003; Martin, 2009). Renal failure is the most common cause of hypermagnesemia (Schaer, 1999; Boag, 2012). Mg excretion declines as the glomerular filtration rate decreases, so it is normal for most patients with hypermagnesemia to suffer from some degree of renal failure. Thus, the degree of hypermagnesemia can generally be related to the degree of renal insufficiency (Martin, 2009).

It is difficult to get magnesium poisoning from natural foods, but it is possible to get toxicosis from excessive Mg supplementation. Clinical signs of Mg toxicosis include lethargy, locomotion problems, anorexia, low yield/performance, drowsiness, and in some cases, death. Ruminant animals can tolerate 0.5% Mg in feed (Gonzaléz, 2019).

Treatment for hypermagnesemia consists of suppressing the administration of exogenous Mg or specific treatment of the primary disease (Schaer, 1999; Martin, 2009; Bateman, 2012). Further treatment is based on the degree of mineral excess, clinical signs, and renal function (Martin, 2009). Fluid therapy with saline solutions or Ringer›s lactate (RL) combined with loop diuretics should be the first line of treatment in patients with functional kidneys and hypermagnesemia that is not immediately life-threatening. In patients with severely compromised kidney function, peritoneal dialysis may be necessary (Martin, 2009).

CONCLUSION

Magnesium, like other macrominerals and microminerals, is extremely important for farm animals, as it plays a role in various functions in the animal body. Knowledge about minerals and how they affect animal performance is essential to avoid problems within the production chain, whether they are related to deficiency, lack of supplementation, or in rarer cases, excess in the diet, since problems related to minerals can have a negative influence on animal health and productivity.

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