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REVIEW PAPER

ZINC IN LLAMAS AND ALPACAS

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Abstract

Trace elements, including zinc, are crucial for the proper course of various biochemical processes occurring in the organisms of South American camelids. The increasing population of these animals in Europe necessitates the knowledge of their anatomy, physiology and nutrient requirements by breeders, scientists, and veterinary practitioners. Unfortunately, nutrition, mineral supplementation and treatment of trace elements deficiencies of llamas and alpacas cannot be fully adopted from cattle and small ruminants because South American camelids have different digestive tract anatomy, nutrient requirements and dietary habits than those species. Zinc plays a key role as a catalytic, structural or regulatory cofactor for a great number of enzymes and proteins in all mammals. It participates in carbohydrate, fatty acids and protein metabolism, collagen fibril degeneration, destruction of free radicals, erythrocyte membrane stabilisation, carbon dioxide transport, and it also influences transcription and cell replication. This element is also required for skin health and epithelial growth. Plasma zinc concentration differs from its concentration in whole blood due to zinc presence in erythrocytes. Age does not affect Zn serum and plasma levels but female llamas and alpacas have significantly higher whole blood zinc concentration than males. Zinc deficiency occurs relatively rarely but because zinc is necessary for the maintenance of healthy skin and coat appearance, this condition typically manifests in various skin lesions. Its contribution to changes in healthy appearance of coat and skin is a matter of great importance in llamas and alpacas because to a great extent those animals are bred for their fleece.

Keywords: New World camelids, llama, alpaca, zinc, trace mineral homeostasis.

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INTRODUCTION

South American camelids, also referred to as New World camelids, that is llamas (*Lama glama*) and alpacas (*Vicugna pacos*), have been recently gaining popularity in many European countries not only as farm animals bred for their fleece, which is considered to be one of luxury fibres, but also as pets and therapy animals (D'Alterio et al. 2006). The increasing population of these animals in Europe necessitates knowledge of their anatomy, physiology and nutrient requirements, including trace elements, by breeders, owners and veterinary practitioners worldwide. However, the research on trace elements, i.e. their requirements, status, clinical and subclinical deficiencies and toxicities in these species, is scarce because nutritional diseases of llamas and alpacas are often underreported. There are very few scientific publications on trace mineral requirements, and reference ranges for llamas and alpacas. Unfortunately, we cannot fully adopt their nutrition, mineral supplementation, and treatment of trace elements deficiencies and poisonings from cattle and small ruminants because the New World camelids have different dietary habits, digestive tract anatomy and nutrient requirements than those species. Van Saun (2009) believes that despite those differences llamas and alpacas are not less susceptible to nutritional diseases, and they display similar diseases resulting from nutrient toxicities and deficiencies as other farm animals.

Zinc, assigned the symbol Zn in the periodic table of elements, with the atomic number of 30 and atomic weight of 65.38 u, is an essential micronutrient functioning as a catalytic, structural or regulatory cofactor for a number of enzymes and proteins. In 1930s and 1940s this element was discovered as necessary for proper functioning of farm animals (Hill, Shannon 2019). However, the first indication that this element might be required by animals was reported a few decades earlier by Mendel and Bradley (1905). Zinc is needed for various biochemical processes, including the synthesis of DNA, RNA and many other proteins. It is also necessary for proper epithelial growth and for maintaining healthy skin appearance. Zinc deficiency and its contribution to the occurrence of skin lesions are of great importance in South American camelids because llamas and alpacas are very often bred for their fibre, also called fleece.

The aim of this article is to review current knowledge on the zinc status in llamas and alpacas as well as consequences of its deficiency in these species, and to identify gaps in the knowledge regarding those issues.

ROLES OF ZINC IN MAMMALS

Zinc plays a variety of roles in organisms of mammals and is involved in many metabolic processes. It is essential for the synthesis of collagen, hormones such as glucagon and insulin, nucleic acids, and proteins. This mineral is an activator of nearly 200 enzymes, e.g. aminopeptidase, alkaline carboxypeptidase, alkaline phosphatase, carbonic anhydrase, phospholipase C, superoxide dismutase (McClung 2019). Zinc inhibits lipid peroxidation, stabilizes biological membranes, and stimulates bone formation and mineralization in young mammals. It also plays an important role in the DNA synthesis, cell division, and gene expression; it activates DNA and RNA polymerases and participates in the development of the inflammatory reaction. Several trace elements, i.e. copper, selenium, and zinc, support the immune function of the dam and neonate in many animal species and their deficiencies may play a role in pregnancy loss and perinatal mortality in farm animals (Van Saun 2008, Wessels et al. 2017, Lodde et al. 2020).

ZINC SOURCES AND REQUIREMENTS

The primary source of zinc for new born crias is milk or a milk replacer. Morin et al. (1995) determined that Zn is the most abundant trace element in llama's milk, similarly to cow's and mare's milk, and its concentration in collected samples ranged from 2.55 to 7.10 ppm. Llamas and alpacas are not animals kept for dairy purposes, and therefore detailed data on their milk composition and milk yield are rather scarce. The main objective of the studies focused on this matter was to determine whether other farm animals' milk is suitable as a milk replacer for young crias.

The basic and the most important source of all minerals for young and adult South American camelids is forage. There are many soils all around the world that are deficient in zinc and result in forages and pastures that contain low amounts of this micronutrient. The amount of this element in unfertilized and uncontaminated soil is related to the chemical composition of the parent rock and weathering processes. In agricultural soils, the zinc content can range between 10-300 mg kg^{-1} (Malle 1992). Zinc enters the environment from several sources, mainly from the erosion of soil particles containing Zn, but also from mine drainage or industrial and municipal waste. The lowest amounts of zinc can be found in sandy soils, and the highest in calcareous and organic soils. Most plants contain 30-100 mg of Zn per kg of dry matter (Noulas et al. 2018).

Zinc can also be found in water, which can be considered as a secondary natural source of minerals for living organisms. According to the Food and Agricultural Organization (FAO) and World Health Organization (WHO),

water with more than 3 mg l^{-1} of zinc has an astringent and undesirable taste (FAO/WHO 1982). Research on water palatability for animals is very limited, so any current recommendations for Zn or any mineral concentration in drinking water for farm animals would be based on guidelines for human palatability (WHO, 2006), and we can extrapolate the conclusion that water with high amounts of zinc will decrease water intake by South American camelids.

Mineral nutrition is one of the controllable management factors that can influence animal reproduction (National Research Council 1981, 1985, 1996). Sufficient zinc content in a diet is also necessary for the proper course of many biochemical processes in the body, for maintaining health and proper growth. It is also worth mentioning that wool/ fleece production urges a high demand for macro- and micronutrient intake (White et al. 1994)

Initial zinc requirements for llamas and alpacas were extrapolated from the nutrient requirements for beef cattle, goats and sheep by Van Saun (2006), who suggested the following minimum zinc requirements: 0.53 mg kg^{-1} of body weight for maintenance and growth, and 0.67 mg kg^{-1} of body weight during pregnancy and lactation. On the basis of this assumption, the recommended dietary concentration of zinc should oscillate around 35-54 mg kg^{-1} of dry matter.

Currently, we have references for most blood haematological and biochemical parameters and nutritional requirements for South American camelids, although some of those have been obtained from a small study population (Husakova et al. 2014). Foster et al. (2009) summarise their work on haematology and biochemistry in South American camelids with the statement that reference intervals for copper and zinc in these animals are generally lower than those reported for sheep and cattle.

The knowledge of zinc intake and requirements is important for prophylactic measures against its deficiency and for maintaining proper growth and health of animals. It should also be paired with the evaluation of the copper status because those two minerals are not only important for the growth, reproduction and wool production, but they also interact with each other. Taking into consideration the available data on zinc requirements for llamas and alpacas, it is important to point out that research on this matter conducted on large study populations and on populations on different continents would be beneficial to everyday dietary and veterinary care of those animals, especially in problematic herds. Research on water palatability and changes in water intake in llamas and alpacas due to different mineral concentrations would also be interesting and would fill an obvious knowledge gap.

ZINC STATUS AND CONCENTRATION IN SELECTED ORGANS AND BODY FLUIDS

The most common specimen for mineral status determination is venous blood because it is obtained during an easy and less invasive procedure. However, due to the complex metabolism of many minerals, it is not an ideal source of information, and samples of liver tissue are considered to be much more accurate for mineral status evaluation. Liver tissue of llama or alpaca can be obtained during a percutaneous biopsy or post-mortem examination (Anderson, Silveira 1999). Trace mineral storage in the liver can be nonuniform due to variations of the portal blood flow to specific liver lobes. Differences in trace minerals concentrations between the lobes were found in cattle, sheep, horses and South American camelids (Pearce et al. 1997). However, Anderson (2004) described the mean zinc concentration in the liver of 5 llamas and 5 alpacas as equal around 35-37 ppm, and concluded that in the case of llamas and alpacas differences in trace mineral concentration between the liver lobes were considered insignificant during the interpretation of result of copper, iron, selenium and zinc concentrations.

The zinc plasma concentration differs from the zinc concentration in whole blood due to zinc presence in erythrocytes. It is believed that in most animal species approximately 10 times higher amounts of Zn are transported within erythrocytes than in plasma (Smith et al. 1998). However, a study by Pechová et al. (2017) reveals a 3.5-fold higher whole blood zinc concentration in comparison to plasma in alpaca. They also reported females to have significantly higher whole blood zinc levels than males. The plasma zinc concentration varied in individual animals from that study and ranged from 1.56 up to 8.01 μmol L^{-1}, which shows large variation in the Zn status of individual animals. Some researchers say that age does not affect the Zn serum and plasma levels in South American camelids (Pechová et al. 2017, Smith et al. 1998).

Judson et al. (1996) demonstrated that alpacas had lower plasma zinc concentrations (approximately 3-6 mmol L^{-1}) than those usually described in healthy ruminants. Espinoza et al. (1982) observed similar results in relation to llamas and sheep grazing on the same pastures. Johnson (1989) proposed a normal serum zinc reference range for llamas at the level: 4.6-7.7 μmol L^{-1}. Bechert and Smith (1996) reported serum zinc level at 2.45-5.66 μmol L^{-1}. However, Cebra et al. (2014) in their book *Llama and alpaca care: medicine, surgery, reproduction, nutrition and herd health* reported expected zinc serum concentration in alpacas to range between 2.90-31.35 μmol L^{-1} (Pechova et al. 2017). According to Clauss et al. 2004 plasma zinc concentrations lower than 3 mmol L^{-1} could be associated with zinc-responsive lesions in alpacas, which will be further described in the next chapter of this paper.

Domesticated South American camelids as well as their wild cousins (guanaco – *Lama guanicoe* and vicuña – *Vicugna vicugna*) are an important

source of protein for people from the Andean highlands (Neely et al. 2001, Pérez et al. 2000). The mineral content of meat from llamas and alpacas is comparable to other meats, commonly used in human diet. Polidori et al. (2007) evaluated the mineral composition of llama's and alpaca's meat sampled from *musculus longissimus thoracis*. The mean zinc content in that study oscillated around 4 mg per 100 g of muscle, without any statistical differences between both species (4.44±0.81 mg per 100 g in llama and 3.87±0.93 mg per 100 g in alpaca).

The knowledge of the zinc concentration in tissues and body fluids is important for evaluation of the zinc status in individual animals and herds, and it supports veterinary practitioners in efforts to assure that llamas and alpacas enjoy good health. It also provides practical information on the dietary value of products from llamas and alpacas (carcass and milk). However, there is a need to conduct studies on the mineral status of South American camelids that cover large populations, and to observe possible differences between animals bred on different continents.

CONDITIONS ASSOCIATED WITH AN ABNORMAL ZINC STATUS IN LLAMAS AND ALPACAS AND ZINC SUPPLEMENTATION

Zinc deficiency occurs relatively rarely, but it has been reported in various animal species, including llamas and alpacas (Hensel 2010, Scott et al. 2010). Because zinc is necessary for the maintenance of healthy skin and coat appearance, this condition typically manifests in various skin lesions. So far, skin lesions associated with low trace element status, especially zinc and copper, have been reported in South American camelids by many researchers. They usually develop in rather hairless areas of the body, such as the abdomen, axilla, inguinal region, etc. Lesions begin as papules and progress to plaques. Skin in those areas is also thickened. Such condition is referred to as zinc-responsive dermatosis (Rosychuk 1989). It is considered to be a condition of great importance in llamas and alpacas probably because many are kept for their fleece.

Clauss et al. (2004) studied the susceptibility of llamas and alpacas with different fleece colours in order to find out whether the fleece colour is a factor that makes animals more or less susceptible to mineral deficiencies and skin lesions. Animals with coloured fleece are believed to be more susceptible to skin lesions because coloured fleece is higher in mineral content and has higher demands concerning mineral metabolism. They also described 25% incidence of skin lesions in the studied herd with serum zinc levels 3.36±0.76 μmol L^{-1} for llamas, and 2.6±0.46 μmol^{-1} for alpacas. According to a survey about the population of South American camelids in the United

Kingdom (D'Alterio et al. 2006), zinc deficiency along with infestation by ectoparasites constituted the majority of presumptive causes of skin conditions in those species during the studied period. A retrospective study by Scott et al. (2010) diagnosed 8% of the cases of zinc-responsive dermatitis in alpacas with skin conditions. However, that research was conducted on a rather small population (n=68).

Hyperextension of the metacarpophalangeal and metatarsophalangeal joints affects all age groups of camelids. This condition ultimately leads to degenerative joint disease and soft tissue calcification. Study on llamas (Reed et al. 2007) showed low copper levels in the liver and high serum zinc concentrations in animals with this condition. Such results may suggest secondary copper deficiency. However, the study was conducted on a small population and those differences were nonsignificant, when only adult animals were compared. Semevolos et al. (2013) hypothesised that serum trace mineral imbalances and high zinc concentrations would be found in affected animals, and stated that increased zinc concentrations may be more important in adult camelids than in young ones suffering from this condition.

The diagnostic procedure of zinc deficiencies involves a clinical interview and clinical examination, but the final diagnosis is made on the basis of laboratory tests – serum zinc concentration, zinc content in hair or liver biopsy specimen. Serum alkaline phosphatase and carbonic anhydrase and zinc content in soil and feed are also helpful diagnostic tools in course of such conditions.

Zinc is traditionally added to almost all commercial mineral supplements dedicated to camelids in order to prevent zinc-responsive dermatitis. It is usually used in the form of zinc sulphate or zinc methionine. These supplements are administered daily *per os* with feed or are available *ad libitum* for animals in form of mineral licks. However, one should remember that zinc supplements are not very palatable, and this element is usually paired with others to make the supplement more attractive to the animals. Judson et al. (2018) investigated whether plasma Zn concentrations in alpacas are responsive to increased intake and Zn supplementation with an intraruminal controlled-release device (CRD). The results of their experiment showed that CRD formulated to deliver zinc in the form of zinc oxide provided an additional amount of this element over a 60-day period. Intraruminal controlled-release devices or intraruminal boluses can be a useful form of mineral supplementation in many species, including llamas and alpacas. However, more studies on this issue are required.

CONCLUSIONS

Owing to the crucial functions that zinc plays in the organisms of South American camelids, its deficiency may entail the risk of health deterioration in these animals. Despite the fact that zinc was described as necessary for farm animals in the 1930s and 1940s and its role is relatively well known in mammals, reference values of its concentrations in various body fluids of llamas and alpacas have been determined in rather small study populations. There are still many gaps in the knowledge regarding the roles of zinc in South American camelids, reference values of this micronutrient in body fluids, forms of its supplementation, etc. Thus, it is justified to say that zinc in llamas and alpacas can be an interesting research topic that will not only fill current knowledge gaps, but also contribute to a higher level of welfare and health of llamas and alpacas, and therefore will make breeding of llamas and alpacas more profitable.

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