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Review article

Environmental responsibilities of livestock feeding using trace mineral supplements

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A R T I C L E I N F O

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A B S T R A C T

Trace elements are essential dietary components for livestock species. However, they also exhibit a strong toxic potential. Therefore, their fluxes through the animal organism are tightly regulated by a complex molecular machinery that controls the rate of absorption from the gut lumen as well as the amount of excretion via faeces, urine and products (e.g., milk) in order to maintain an internal equilibrium. When supplemented in doses above the gross requirement trace elements accumulate in urine and faeces and, hence, manure. Thereby, trace element emissions represent a potential threat to the environment. This fact is of particular importance in regard to the widely distributed feeding practice of pharmacological zinc and copper doses for the purpose of performance enhancement. Adverse environmental effects have been described, like impairment of plant production, accumulation in edible animal products and the water supply chain as well as the correlation between increased trace element loads and antimicrobial resistance. In the light of discussions about reducing the allowed upper limits for trace element loads in feed and manure from livestock production in the European Union excessive dosing needs to be critically reconsidered. Moreover, the precision in trace element feeding has to be increased in order to avoid unnecessary supplementation and, thereby, heavy metal emissions from livestock production.

1. Introduction

The increase in its sustainability is the key challenge for animal production in the 21st century. In this context animal nutrition is of considerable importance. The effectiveness by which the organism is able to transform feed biomass into edible animal products determines the total amount of feed which is necessary as well as the majority of emissions from animal production (Niemann et al., 2011; Gerber et al., 2013; Windisch et al., 2013). Trace elements play a special role in this context as they are not only highly essential dietary components but also heavy metals with strong toxic potential (Goldhaber, 2003). Their fluxes through the animal organism are tightly regulated and oversupplied amounts are excreted via faeces and urine (Windisch, 2002). Thereby, they have the potential to accumulate in manure and the environment, which demands great responsibility when using trace element supplements. This review focusses on trace elements in livestock feeding and environmental concerns arising thereof. The ambivalent nature of trace elements will be discussed as well as the mechanisms which regulate their fluxes within the animal organism, in order to highlight the connection between livestock feeding and element emissions. Furthermore, the consequences of an environmental accumulation of trace elements as a result of certain supplementation strategies are highlighted. Finally, potential approaches to reduce heavy metal emissions from animal production are discussed.

2. Between deficiency and toxicity – the ambivalent nature of essential trace elements

Most of the essential trace elements belong to the group of transition metals. Therefore, in nature they exist either in an ionic

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state or bound to certain molecular ligands (Weller et al., 2014). This physicochemical property is the base of their essentiality for the animal. Within the organism, trace elements interact with certain biomolecules, thereby maintaining their function (Fraga, 2005). Prominent examples include hemoglobin and alkaline phosphatase, which need to bind iron and zinc ions, respectively (Muginova et al., 2005; Camaschella, 2015). Therefore, under the terms of physiological deficiency of one or more trace elements metabolic imbalances arise, which foster the development of pathological deficiency diseases. These phenotypes are associated with unspecific symptoms like impaired growth development, feed refusal, impaired fertility etc., highlighting the ubiquitous importance of essential trace elements in maintaining metabolic function. Although, the more common phenotype in men and animals, especially livestock, is a latent deficiency which is characterized by a reduced trace element status as well as subsequent metabolic imbalance and, at the same time, the absence of visible symptoms of deficiency disease (Holt et al., 2012). It has been shown that even short periods of insufficient alimentary supply are able to promote significant physiological changes (e.g., Brugger et al., 2014). Such data clearly highlights the necessity to use trace element supplements in practical livestock husbandry in order to ensure animal wellbeing and productivity.

On the other hand, like various other transition metals (e.g., cadmium and mercury) essential trace elements also have a strong toxic potential as heavy metals. The mode of action of trace element toxicity equals that of trace element essentiality. In fact, in both cases it is due to their interaction with biomolecules (Goldhaber, 2003). Although under the impact of toxic overload, this interaction is no longer specific and not controlled by homeostatic counter regulation. Furthermore, increased trace element accumulation in animal tissues has been proven to promote oxidative stress which is another important aspect of their toxicity (Valko et al., 2005). The ambivalent nature of trace elements as essential nutrient compounds and toxic heavy metals becomes obvious by taking a closer look on the example of iron. On the one hand, iron is the most important cofactor for oxygen transport and transfer within the organism (Finch and Lenfant, 1972). Additionally, it is part of several other bio-factors like cytochromes and catalase, thereby, representing a key factor in essential pro- and antioxidative reactions within animal cells (Dlouhy and Outten, 2013). On the other hand, as a strong pro-oxidative agent, iron is involved in the production of reactive oxygen species through Fenton reactions. Iron overload is associated with a nonphysiological increase in cellular stress (Puntarulo, 2005). Apart from this, iron is an important proliferative factor of pathological microorganisms like *Escherichia coli* (Schaible and Kaufmann, 2004). Therefore, iron fluxes have to be tightly regulated in health and disease in order to maintain a steady state of iron contents behind the gut barrier (Andrews and Schmidt, 2007).

3. Basic principles of trace element homeostasis in mammals

As a result of the ambivalent nature of trace elements, mammal evolution has evolved a complex network of regulative mechanisms to control trace element fluxes through the mammal organism (Lichten and Cousins, 2009; Colvin et al., 2010). This is particularly important as the homeostatic regulation machinery extends the range between satisfied trace element requirements and toxicity, thereby stabilizing trace element load behind the gut barrier under the terms of fluctuations in alimentary supply and physiological status. Furthermore, this has a great benefit for practical livestock feeding as it enables the usage of safety margins to compensate for such fluctuations.

Homeostatic control of trace elements depends on two basic mechanisms – the control of absorption from the gastrointestinal lumen as well as the elimination of overload behind the gut barrier by endogenous excretion mainly via the kidney. Essential trace elements can be grouped by being either regulated via absorption (e.g., Zn, Cu, Mn, Fe) or excretion (e.g., Se, I) (Windisch, 2002) (Fig. 1). The behavior of homeostatic response to varying dietary supply (deficient, sufficient and oversupply) is very consistent. Under the impact of deficient alimentary supply, the response of homeostatic measures (bio-factors which are affected by either absorption or excretion) exhibit a direct dose–response to varying alimentary supply. In contrast, from the point of sufficient trace element supply on, these parameters exhibit a plateau in response with further rising alimentary supply (Kirchgessner et al., 1997; Brugger et al., 2014; Fig. 2). This becomes evident by monitoring trace element accumulation in animal products (e.g., egg, milk) which also exhibit a plateau in behavior above the level of satisfied requirements (Schwarz and Kirchgessner, 1975; Paulicks and Kirchgessner, 1994). Earlier published data on the response of zinc homeostasis dependent measures in weaned piglets clearly highlight this basic principle of trace element homeostasis. Below the gross zinc requirement threshold, the apparently digested amount of feed zinc linearly declined with further decreasing alimentary supply levels (Brugger et al., 2014). At the same time expression of the ZIP 4 (SLC39A4) gene, which represents the major transport pathway for luminal zinc into the enterocyte (Lichten and Cousins, 2009), showed an inverse relationship by increasing from the gross zinc requirement threshold with further declining alimentary Zn supply (Brugger et al., 2015). However, above the gross zinc requirement threshold (~60 mg Zn/kg feed; NRC, 2012) both factors exhibited a plateau in response with increasing alimentary supply. This nicely illustrates how the organism adapts to varying supply levels by increasing absorption efficiency in times of deficient supply and, on the contrary, by refusing active uptake of trace element amounts supplemented above the gross requirement threshold. Hence, every milligram (mg) trace element supply which exceeds the bodies' net demand accumulates in faeces or urine and subsequently in manure (Windisch and Kirchgessner, 1994; Kirchgessner et al., 1997; Fig. 3). Therefore, it can be concluded that excessive trace element supply for the purpose of demand coverage is useless from a physiological point of view.

4. The more, the better? – usefulness of excessive dietary trace element supplementation

The main feed sources for livestock nutrition are plant based. In case of monogastric species, this means that the bioavailable amount of trace elements is rather low. In an earlier study, we

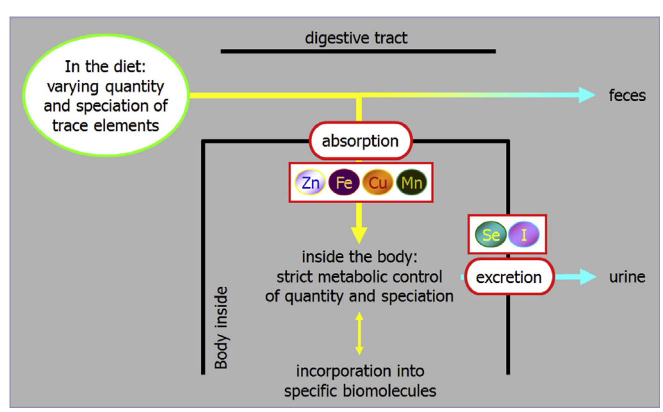

Fig. 1. Basic principles of trace element homeostasis in mammal organisms. The organism provides a steady state of trace element contents behind the gut barrier by regulation of absorption and excretion (Windisch, 2002).