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REVIEW ARTICLE
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Role of trace elements in animals: a review

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Abstract

Trace elements, though required in minute quantities (less than 100 mg/kg dry matter), are essential for maintaining health and immunity. They are involved in growth, production and reproduction. Trace elements act as cofactors of enzymes which are important to the immunity of animal. Superoxide dismutase , glutathione reductase, glutathione peroxidase, thioredoxin reductase, ceruloplasmin and catalase are important enzymes that have trace elements as cofactors. These enzymes act as antioxidants and prevent oxidative stress by neutralizing oxidants produced under different stresses. Besides, trace elements contribute to general health of animal thereby enhancing disease resistance. Trace elements are important for proper functioning of a number of enzymes and proteins which are involved in many physiological, biochemical and metabolic processes that contribute to growth and production. Overall, trace elements improve immune competence and productive performance.

Key words: animals, health, immunity, production, reproduction, trace minerals

Introduction

Trace elements are required in small amounts, usually less than 100 mg/kg dry matter [1,2] and are present in very minute quantities in animal serum [3], usually less than 2 ppm. The seven main trace elements include copper, iron, zinc, cobalt, iodine, manganese and selenium [4]. Among these, iron (1.0-2.0 ppm) is most abundant in serum followed by zinc (0.8-1.2 ppm) [4,5] and copper (0.57-1.0). On the other hand, cobalt (1-3 µg/dl), iodine (2.4-14 µg/100ml), manganese (18-19 µg/dl) and selenium (50-220 ng/L) are present in least amounts [4,5]. These are usually supplied via dietary intake of feeds and fodders [1]. Though required in minute amounts, they are highly essential for health and immunity [5,6]. They contribute to growth [7,8], production [7,9,10] and reproduction [5,11]. In particular, aspects relating to host immunity have received importance in the recent past. Trace elements act as cofactors of enzymes like superoxide dismutase (SOD) [12,13], glutathione reductase, glutathione peroxidase, thioredoxin reductase [14,15], ceruloplasmin [16] and catalase [17]. These enzymes are important to maintain the immunity of animals [7,18]. They act as antioxidants [5,19] and prevent oxidative stress by neutralizing oxidants produced under different stresses like environmental or production stress or stress related to infections or diseases [7]. Trace elements also contribute to health and well being of animal through maintaining proper homeostatic mechanisms and playing a vital role in many physio-biochemical processes like protein, enzyme and hormone synthesis [20,21] or involving in oxidation-reduction reactions and immune functions [22]. Trace elements are important for functioning of a number of enzymes and proteins which are essential for a large number of digestive, physiological and biosynthetic processes within the body [23]. Thus, they play a vital role in growth, production and reproduction [7,11].

Health and immunity

Trace elements are essential for health and immunity [24]. They are important for functioning of various components of the immune system [5]. Their deficiency reduces disease resistance and increases the susceptibility to diseases [18]. As they are involved in oxidation and reduction reactions through metallo-enzymes and metalloproteins, their deficiency predisposes the cells to oxidative stress because oxidants are not neutralized. Oxidative stress affects animal health by damaging cells and tissues by free radicals or oxidants [7]. Uncontrolled oxidation reactions may impair the animal's immune status [25] thus lowering immunity of animals. Different immune cells and their mechanisms of phagocytic activities are affected by trace element deficiencies and hence trace element supplementation can boost immunity. For example, selenium supplementation improves neutrophil's phagocytic capacity [26] and low copper status results in reduced neutrophil phagocytic capacity [27]. Selenium supplementation decreased somatic cell count (SCC). Sordillo et al. [28] have discussed how selenium, copper and zinc can enhance the function of several immune cells, including

leucocytes, lymphocytes and neutrophils. Role of iron in immunity is reported by Eisa and Elgebaly [29].

Being components of the anti-oxidant system [18], trace elements prevent oxidative stress. Copper is the essential element in two enzymes that are important for immune competence; copper/zinc-superoxide dismutase and ceruloplasmin [16]. Iron is an essential component of catalase, peroxidase and cytochrome oxidase [19,30]. These play important roles in oxidative stress [12,19]. Selenium is an essential part of a family of enzymes called glutathione peroxidases (GSH-Px) and thioredoxin reductases [15] which are important for neutralizing free radicals or oxidants. Zinc and manganese, in addition to copper, are also integral parts of SOD [13,17]. All these neutralize free radicals like peroxides, super oxides or hydroxyl ions.

It is important to note that the concentration of trace elements change under different infections or inflammations. These ion changes reflect changes in cation binding of plasma proteins, and more importantly, alterations in cellular uptake mechanisms [5]. These ionic changes help in preventing infection or disease. In dairy cattle, plasma iron and zinc concentrations are decreased during the acute phase response to immunological challenges [31], whereas plasma copper concentration may increase [32]. During mastitis, increased secretion of lactoferrin in milk, a binding protein, occurs which decreases the amount of available iron for Gram-negative bacterial growth [33]. Trace elements contribute to general health by building body defense mechanisms and improving metabolism and hence their deficiency can predispose to diseases. Zinc is an essential trace element involved in the catalytic, structural and regulatory processes of keratinisation and in general protein metabolism [34]. Consequently, teat canal keratin production is dependent on zinc status [34]. Zinc is important for immune function [21]. There are increased risks of metritis, mastitis, locomotion problems or diarrhoea in calves when zinc or copper levels are either marginal or deficient [35].

Feeding organic zinc may have enhanced resistance to mastitis causing pathogens because of improved skin integrity and keratin lining of the teat canal. Zinc plays role in maintaining structural integrity and health of the hoof and udder [13,36]. Like zinc, both copper and manganese are important for keratin formation [13]. This provides udder immunity.

Production

Trace elements improve growth [7,8] and production [7,9,10]. They improve feed intake, digestibility and feed conversion thereby improving production [19,23]. Kinal et al. [37] have reported significantly increased milk production following trace mineral supplementation. Zinc has a catalytic, coactive, or structural role in a wide variety of enzymes that regulate many physiological processes including metabolism and growth [21]. Metalloenzymes of which trace elements are essential part are involved in multiple physiological processes including respiration, carbohydrate and lipid metabolism, antioxidant activities, and collagen formation [5,13,19], thereby favoring body growth and production. Trace elements are also important for hormone synthesis which plays an important role in growth and production [3]. Zinc is involved in hormone secretion and function (somatomedin-c, osteocalcin, testosterone, thyroid hormones, insulin, and growth hormone). Effect of trace elements on growth and milk production has been widely studied [9,34,38-46]. Role of copper in growth is reported by Hesari et al. [8], that of iron by Mohri et al. [47], manganese by Hansen et al. [48], cobalt by Nagabhushana et al. [49] and zinc by Fagari-Nobijari et al [50].

Reproduction

Trace elements are essential for reproduction [51]. Earlier Manspeaker et al. [52] reported the importance of trace minerals in reproduction in cattle. Rabiee et al. [38] reported higher conception rates with organic trace elements in cattle. Trace minerals are important for reproductive performance in livestock [53] because their supplementation improves reproduction [54]. Studies show that the ovarian activity of ruminants is influenced by mineral deficiency [11]. They are also involved in synthesis of hormones that are important for reproduction. Their deficiency affects both steroid [11] and thyroid [55] hormone production.

Copper and zinc play an important role in regulating progesterone production by luteal cells via involvement of superoxide dismutase [56]. Copper is also involved in steroidogenic enzymes cytochrome P_{450}, 17α-hydroxylase and cytochrome P_{450} side-chain cleavage and lysyl oxidase [57]. Zinc is involved in the reorganization of ovarian follicles which are the source of progesterone. This occurs through the involvement of metalloproteinase-2 (MMP-2) enzyme, which is a member of zinc endopeptidase family [58]. Zinc is also involved in the secretion and function of male hormone testosterone through the enzymes that control the arachidonic acid cascade [59,60]. Zinc is essential for thyroid hormone secretion and function. Thus, zinc plays an essential role in sexual development and spermatogenesis. Involvement of manganese in the synthesis and production of oestrogen and progesterone may be due to the fact that it acts as a cofactor in the synthesis of cholesterol, a precursor for steroids, including estrogen and progesterone [39]. Iron also plays an important role in ovarian activity [61]. Positive correlation was reported between serum progesterone level and copper-zinc in cows by Yildiz and Akar [62]. Trace elements are important for reproduction [38,60] also via contributing to the normal health of reproductive organs and reproductive cycles. Selenium is important in normal cattle production systems as its apparent direct link to postpartum uterine involution [6]. Inadequate zinc levels have been associated with

decreased fertility, abnormal oestrus, and abortions [63,64]. Slight decrease in serum levels of zinc and copper may induce or predispose animals to repeat breeding and anoestrus. Organic minerals have a beneficial role to play in the resumption of follicular growth and fertility in dairy cows. Importance of trace elements in reproduction has been widely reported [11,38, 60, 64-66].

Copper, iron and zinc are all important for thyroid hormones due to their role in synthesis or conversion of thyroid hormones [55]. Copper deficiency impairs secretion of tyrosine hydroxylase and dopamine beta-enzyme systems which are both copper containing, in the hypothalamic neurons. This causes inhibition of synthesis of thyroid hormone releasing factor. The copper containing peroxidase enzyme of the thyroid gland impairs thyroid hormone secretion [67]. Iron deficiency lowers thyroid peroxidase (TPO) activity and thereby interferes with iodine metabolism in the thyroid [68]. The T_3 receptor is thought to require zinc to adopt its biologically active conformation. Some of the effects of zinc deficiency, therefore, may be due to loss of zinc from the T_3 receptor and the subsequent impairment of T_3 action [69]. The role of seleno-proteins in thyroid hormone synthesis is well known [70].

Requirements of trace minerals

Trace mineral requirements in animals are variable and depend on age [71], sex [72], stage of growth or production [2,19] breed and genotype [73,74,75]. They are recommended by different agencies like National Research Council, India [2,19,74], Agricultural Research Council, India [76] or researchers [3,75,77] in both livestock and poultry.

Conclusion

Trace elements are essential for health, growth, production and reproduction. They are essential for functioning of a number of components of the immune system. Thus, they contribute to maintaining proper health and immunity. They are important for functioning of a number of enzymes and proteins which are involved in many physiological and biochemical processes. These physio-biochemical processes are related to growth, production and reproduction. Hence trace elements affect both the health and production performance of animals.

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