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Review

The vital roles of boron in animal health and production: A comprehensive review

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ABSTRACT

Boron (B) has many beneficial functions in biological, metabolic and physiological processes for plants and animals. It plays a vital role in maintaining animal health and preventing nutritional disorders. Boron deficiency has been correlated with low immune function and high incidence of osteoporosis which increases mortality risk. Extraordinary boron level causes cell damage and toxicity in human and different animal species. In the past few years, attention has been paid to clear the pleiotropic effects of boron including activating of immune response, antioxidant detoxification activities, affecting bone metabolism, enhancing animal performance and modulating various body systems. Furthermore, the role of boron as anti-heat stress agent has been identified in plants and suggested in animals. Liver metabolism also shows significant alterations in dairy cows in response to the dietary supplementation of boron. Likewise, adding boron to animal feed enhances bone density, wound healing and embryonic development. Additionally, boron has a potential impact on the metabolism of numerous minerals and enzymes. In view of the information about boron benefits, high or low level boron merits the concern. As well, researches are required to do more in-depth investigations on boron influences, and to adjust its requirements in different animal species.

1. Introduction

In tropical conditions, trace minerals play a vital role in health and production of livestock [1] and hence it is essential to understand the role of new elements. Boron is a trace element, has an important function for plants and may be essential to human and animal. Deficiency of B is a common trouble for area of crop production anywhere huge losses of revenue occur once a year both qualitatively and quantitatively [2]. In agricultural approaches, several reports have reported that sufficient B source is imperative for gaining good quality and high yields of crops, and increasing evidence proposes a metabolic role or at least valuable impacts of B in animal nutrition [3]. Superficially, the association between the B administration and animal biological responses has been widely documented. However, substantial parts of this inconsistency may be due to a lake of assessment. So, the importance of B as essential element for biological systems is not clearly understood in animals [4]. Many researches investigated the biological impacts of B including: transportation methods [5], cellular membrane roles [6], functions in cell-wall creation [7], and its antioxidant activity [8] and its effect on anti-oxidant status, and tissue damage in diabetic rats [9]. Supplementation of B- in diets of Wistar rats showed positive influence on digestibility of dry matter, crude protein, crude fat and growth performance [10]. A constructive or even critical function of B in animal nutrition is reinforced by the outcomes that B deficiency induces the mitogen-activated protein kinase (MAPK) pathway in cultured animal cells and that cell lines with a knockout of the B transporter NaBC1, the mammalian homolog of AtBor1, end to progress and procreative [11]. The vital biological impacts of boron may be returned to its impacts on the actions of at least 26 various enzymes [3], and many of these enzymes are necessary in energy status or/and metabolism [12]. Apparently, boron indirectly influences calcium, phosphorus and magnesium metabolism, by manipulating hormone or enzyme systems of animals. The aim of this review was to summarize the different biological function of B in animal nutrition.

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2. General properties of boron and sources

Boron is a metalloid established on the thirteen groups in the periodic table with atomic number 5, atomic mass 10.811 g/mol and chemical icon B. Even if boron complexes have been identified for many centuries, it had various types of isotopes; ^{10}B and ^{11}B are the utmost constant ones. Naturally, B is not found in a lone form, so it is accompanying with sodium or oxygen consisting organoboron complexes forms, which are the physiologically essential sort of B in organisms [3]. It is found in soil, rocks and water, and the main world B producers are sited in Turkey and USA [13]. The nutritional origins of organoboron are of plant founded (fruits, vegetables, and nuts). An important quantity of boron is located in all focal categories of feed, which is comparable to the quantity of other necessary trace elements such as copper and zinc. In most instances, fruits are a rich source of boron including berries, pineapple, and citrus. Besides, foliage plants, dry fruits, and nuts have an extraordinary level of B [14].

Organoboron complexes, which contain B—N or B—O bonds such orthoborates, are essential in biological process. These organoboron complexes are formed in animal, human and plant tissues. Mostly, 96% of boron is found as boric acid B $(OH)_3$ form; while, a small percentage of boron is found as borate anion $B(OH)_4$ [14]. The primary sources of borates are sighted as Tibetan lakes and imparted from Himalaya's area to India [15]. Turkey started to manufacture the borate as calcium borate mining in 1865, and discovered in Nevada and California at the same period time. Besides, Turkey has distributed borates for European boric acid manufacturers for many years [16]. As a consequence, now, Turkey is well identified for being the major B produces in the world [14].

Both of boric acid and the sodium salts of B (disodium and tetraborate borax) are generally used as bactericide, cleaning and antiseptic agents such as detergents and soaps, fire retardants, preservatives, fertilizers, herbicides and insecticides. B is also used in many industrial purposes including fiberglass insulation, glass production, ceramic glazes, porcelain enamel, and metal alloys [17].

3. Mode of action of boron in animal nutrition

Superficially, the B mode of action is depending on the boron chemistry; boric acid joined with OH of organic components and forming ester complexes (Fig. 1). This process generally produces complex formations with several biologically necessary sugars [18], and these sugars encompass ribose in the cells, which is a part of adenosine [14].

Based on recent scientific investigations, the multitalented beneficial influences of B occur via disturbing the biomolecules which want to comprise with adenosine. Adenosine phosphates (ADP) and Sadenosylmethionine (SAM-e) in animal cells are the principles biomolecules that have more boron alliances. ADP is followed in most animal tissues or cells and attends as indicative nucleotides in neuronal response. SAM-e is one of the main frequently use enzyme substrate in the body tissues [19]. SAM-e is related to methylation responses in the cells, which mark the DNA, RNA, proteins and phospholipids and hormonal activities [14].

Experiment in rats showed that boron deficiency excessed plasma homocysteine and decreased SAM-e which clearly boosts the hypothesis that boron biological capability is by means of an effect on SAM-e formation [20]. Moreover, the depress in SAM-e has been established in syndromes such as arthritis, osteoporosis, urolithiasis, and diabetes which are affected by nutritional utilization of B [21].

Subsequently, it can be hypothesized that bioactivity of B expressed via fastening cyclic NAD+ and ADP ribose and suppression calcium ion liberation, which is important in several processes counting brain activity, bone formation, immune response, embryonic development, liver function, and prohibiting the influences of heavy metal (Fig. 1). Furthermore, B has the ability to protect cell proliferation, alleviate DNA damage and contribute in maintaining the cell membrane stability during high temperature conditions. All of these biological functions of boron are set out in (Fig. 1).

4. Embryonic development

Earlier reports from several years has been identified consistently that B is beneficial or crucial for many biological and physiological process in animals/humans [3]. Fort et al. [22] indicated that B is important for supporting embryonic proliferation and development, at any rate for vertebrates, anywhere B deficiency leads to elevated proportion of anomalous development of the gut and necrotic eggs in Xenopus laevis. Additionally, the initial stages of growth of mated zebrafish (*Danio rerio*), is particularly critical to B incompetence [23]. Boron has been presented to be indispensable for the close of the life cycle (i.e., shortage B cause impaired development, growth, or maturation such that proliferation is banned) for microorganisms in all phylogenetic kingdoms [24]. Though the target molecules are probable to be diverse, there is a consistency in plant and animal metabolism for B to be especially necessary at early stages of differentiation, and the study has been revealed by Behrendt and Zoglauer [25] showed that suspensor progress procreation in somatic embryos is blocked as a consequence of B deprivation supply for Larix decidua. Further, Boron is considered to have important function in several metabolic events pathways, through it is ability to represent as a metabolic regulator in various enzymatic systems [25]. Earlier data of in *vitro* and *in vivo* studies, showed that boron impacts on mammalians. 2-cell embryos from low (0.04 µg boron/g) and adequate (2.00 µg boron/g) boron administered rats were established for 72 h. Blastocyst stage progression and degenerations in embryos has been reduced as result to low dose fed rats. In this line, based on previous reports, it has been hypothesized that boron deficiency in the animals showed that damaged the early embryonic development.

Ince et al. [68] studied that the *in vivo* influences of boron on mRNA expression of NANOG, HEX, and OCT-3/4 genes in fetal development. In this study, it was noticed that in the boron-administered groups, NANOG, HEX, and OCT-3/4 gene expressions and protein levels were superior shaped attributed to increasing dose, and in a deficiency group on boron, these levels were repressed or not sufficiently active. This condition can be instigated from metabolism regulating and pharmacological impacts of boron. Therefore, these findings revealed that boron has a remarkable function for regulating early embryonic genes involved in the onset of pregnancy. So, low dose of boron in animal had adverse effects on the early stages of embryonic development as well down regulation of some genes which are related to the regulating the onset of pregnancy and embryonic creation.

5. Bone metabolism

Results of many scientific reports support the beneficial influences of B in bone metabolism of animals. Dietary deficiency of B reduces the bone development, and may cause bone anomalies in the vitamin D–scarce chick [26]. Boron plays a significant function in the development [27], mineralization and proliferation of bones [28]. The biological importance of boron on metabolism and absorption of some other minerals is proposed that boron have impassive impact a multiplicity of metabolic actions in bones. Boron acts together with vitamin D, calcium and magnesium; all of which fulfill an essential function in the bone metabolism [29]. Vitamin D deficiency and B supplement to rats feed improve retention and absorption of phosphorus (P) and calcium (Ca) and promote femur magnesium (Mg) level [30]. This synergistic link between Ca and Mg homeostasis promotes bone strength; as a consequence, it is hasten the osteoblastic cell activity through calcium flux [31]. Dietary supplementation with 5 and 15 mg B/kg in male pig diet, reduced bone lipid compared with control groups [32]. In view of that, the physiological levels of B on bone metabolism and