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Physiological roles and importance of micronutrients in animal health and production

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Abstract

Micronutrients, including vitamins and trace minerals, are indispensable components of animal nutrition, required in minute quantities yet essential for sustaining health, productivity, and physiological efficiency. They play critical roles as coenzymes, antioxidants, and regulators of metabolic and biochemical processes, contributing to oxygen transport, enzymatic reactions, immune function, skeletal integrity, and reproductive performance. Adequate micronutrient nutrition supports normal growth, efficient feed utilization, metabolic homeostasis, and resistance to disease. Imbalances or deficiencies of key trace minerals such as iron, copper, zinc, selenium, manganese, cobalt, and iodine, as well as vitamins A, D, E, K, B-complex, and C, can result in anemia, impaired immunity, skeletal abnormalities, reproductive disorders, reduced growth, and lowered productivity. Consequently, precise formulation and balanced supplementation of micronutrients are essential to optimize animal performance, maintain health, and enhance the economic and sustainability outcomes of livestock production systems.

Keywords: Micronutrients, animal health, livestock production, trace minerals, vitamins

Introduction

Micronutrients play a fundamental role in sustaining animal health, productivity, and overall physiological efficiency. Although required in relatively small amounts, micronutrients including trace minerals and vitamins are indispensable for normal growth, reproduction, immune competence, and metabolic regulation in livestock and poultry. In modern animal production systems, the importance of micronutrients has gained increased attention due to intensified farming practices, higher genetic potential of animals, and greater demand for animal-derived food products.

Trace minerals such as iron, copper, zinc, selenium, iodine, manganese, and cobalt function as essential components of enzymes, hormones, and antioxidant defense systems. Similarly, vitamins act as regulators of metabolic pathways, cellular differentiation, and immune responses. Deficiencies or imbalances of these micronutrients can result in subclinical or clinical disorders, reduced feed efficiency, compromised immunity, poor reproductive performance, and significant economic losses.

The availability of micronutrients to animals is influenced by factors such as soil composition, feed ingredients, antagonistic interactions among minerals, and bioavailability of nutrient sources. In many regions, reliance on conventional feedstuffs without strategic supplementation often fails to meet the micronutrient requirements of high-producing animals. Therefore, understanding the role of micronutrients and implementing appropriate supplementation strategies are critical for optimizing animal health and production efficiency This article reviews the role of major micronutrients in animal health and production, highlighting their physiological functions, effects on growth and productivity, deficiency-related disorders, and practical approaches for effective micronutrient management in livestock production systems.

Classification of micronutrients

Micronutrients can be broadly classified into two main categories: trace minerals and vitamins.

Trace minerals

Trace minerals are inorganic elements required in minute quantities for essential physiological functions. They serve as cofactors for enzymes, participate in hormone synthesis, and contribute to antioxidant defense mechanisms. Important trace minerals include: - Iron (Fe) - Copper (Cu) - Zinc (Zn) - Selenium (Se) - Iodine (I) - Manganese (Mn) - Cobalt (Co).

Vitamins

Vitamins are organic compounds required in small amounts to regulate metabolic processes and maintain cellular health. They are classified based on solubility: - Fat-soluble vitamins**:** A, D, E, and K - Water-soluble vitamins: B-complex vitamins and vitamin C.

Each micronutrient has specific roles in growth, reproduction, immunity, and overall health, making balanced supplementation essential for optimal animal performance.

Role of trace minerals in animal health and production

Trace minerals, though required in small amounts, are indispensable for numerous physiological processes and overall animal productivity. Their roles can be summarized as follows:

Iron (Fe)

Iron (Fe) is an essential trace mineral in animal nutrition, primarily required for the formation of hemoglobin and myoglobin, thereby facilitating oxygen transport and cellular respiration; it also functions as a component of cytochromes and several enzymes involved in energy metabolism and immune defense. Iron is naturally present in green forages, legume hays, oilseed cakes, animal protein sources, and soil contamination, with ferrous forms being more readily absorbed in the duodenum. Deficiency of iron leads to nutritional anemia, characterized by pale mucous membranes, poor growth, lethargy, and increased susceptibility to infections, and is most commonly observed in piglets due to the low iron content of sow's milk and indoor rearing systems. Although iron toxicity is rare, excessive intake may interfere with copper and zinc absorption and cause digestive disturbances; therefore, balanced supplementation, including injectable iron in piglets, is essential for maintaining animal health and optimal production.

Copper (Cu)

Copper functions as a vital cofactor for enzymes involved in iron metabolism (ceruloplasmin), connective tissue formation, melanin synthesis, and antioxidant defense through enzymes such as superoxide dismutase. Deficiency of copper results in anemia, bone and skeletal abnormalities, depigmentation of hair or wool, impaired growth, and reduced immune competence, leading to increased susceptibility to diseases and lowered animal productivity.

Zinc (Zn)

Zinc is a vital trace mineral required for enzyme activation, protein and nucleic acid synthesis, maintenance of skin, hoof, and epithelial integrity, immune competence, and normal reproductive performance. Deficiency of zinc leads to retarded growth, skin lesions such as parakeratosis, poor wound healing, reduced fertility, and increased susceptibility to infections, ultimately impairing overall animal health and productivity.

Selenium (Se)

Selenium is an essential trace mineral that forms a key component of antioxidant enzymes, particularly glutathione peroxidase, which protect cells from oxidative damage; it also plays an important role in reproductive performance and immune function. Selenium deficiency results in white muscle disease, impaired fertility, embryonic losses, and increased susceptibility to infections, leading to reduced growth, productivity, and overall animal health.

Iodine (I)

Iodine (I) is an essential trace mineral required for the synthesis of thyroid hormones (thyroxine and triiodothyronine), which regulate basal metabolic rate, growth, development, and thermoregulation in animals. Adequate iodine is crucial for normal reproductive performance and fetal development, while deficiency leads to goiter, reduced growth rate, infertility, weak or hairless newborns, and lowered productivity due to impaired metabolic activity.

Manganese (Mn)

Manganese (Mn) is an essential trace mineral involved in enzyme activation, carbohydrate and lipid metabolism, bone and cartilage formation, and reproductive function, and it also plays a role in antioxidant defense as a component of manganese superoxide dismutase. Deficiency of manganese results in skeletal abnormalities, poor growth, impaired fertility, and in poultry causes perosis (slipped tendon) and reduced hatchability, leading to compromised animal health and production performance.

Cobalt (Co)

Cobalt (Co) is an essential trace mineral primarily required by ruminants as a component of vitamin B_{12}, which is synthesized by rumen microorganisms and is vital for propionate metabolism, red blood cell formation, and energy utilization. Cobalt deficiency leads to vitamin B_{12} deficiency, resulting in anemia, loss of appetite, poor growth, weight loss, unthriftiness, and reduced productivity, particularly in grazing ruminants raised on cobalt-deficient soils.

Balanced supplementation of trace minerals ensures optimal growth, immunity, reproduction, and productivity in livestock and poultry. Understanding species-specific requirements and bioavailability is critical to avoid deficiency or toxicity and to maximize production efficiency.

Role of vitamins in animal health and production

Vitamins are essential organic micronutrients that regulate metabolic functions, growth, reproduction, immunity, and overall health in animals. Their roles can be summarized as follows:

Vitamin A

Vitamin A is a fat-soluble vitamin essential for **vision (especially night vision),** maintenance of **epithelial tissues, immune function,** normal **growth**, and **reproductive performance** in animals. It also supports embryonic development and resistance to infections. Deficiency of vitamin A results in **night blindness,** dryness and keratinization of epithelial tissues, **reduced fertility**, weak offspring, poor growth, and increased susceptibility to diseases, ultimately impairing animal health and productivity.

Vitamin D

Vitamin D is a fat-soluble vitamin essential for the regulation of calcium and phosphorus metabolism, thereby supporting bone and teeth formation, normal muscle function, and growth in animals. It enhances intestinal absorption of calcium and phosphorus and maintains their proper balance in blood. Deficiency of vitamin D leads to rickets in young animals, osteomalacia in adults, bone deformities, lameness, and reduced productivity due to impaired skeletal development.

Vitamin E

Vitamin E is a fat-soluble vitamin that functions primarily as a biological antioxidant, protecting cell membranes from oxidative damage and working synergistically with selenium. It plays an important role in immune function, muscle integrity, and reproductive performance. Deficiency of vitamin E results in nutritional muscular dystrophy (white muscle disease), impaired immunity, reduced fertility, and increased susceptibility to stress and infections in animals.

Vitamin K

Vitamin K is a fat-soluble vitamin essential for the synthesis of blood clotting factors such as prothrombin, thereby playing a critical role in normal blood coagulation. It is also involved in bone metabolism. Deficiency of vitamin K leads to prolonged clotting time, internal or external hemorrhages, anemia, and increased mortality, particularly in young animals and poultry..

B-complex vitamins

B-complex vitamins are a group of water-soluble vitamins that function mainly as coenzymes in energy, protein, and fat metabolism, supporting normal nervous system function, red blood cell formation, growth, and overall health in animals. They include thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folic acid, and vitamin B_{12}; deficiencies may result in poor growth, neurological disorders, anemia, skin lesions, reduced feed efficiency, and lowered productivity, although ruminants usually synthesize adequate amounts through rumen microbial activity.

Vitamin C

Vitamin C (ascorbic acid) is a water-soluble vitamin that acts as a powerful antioxidant, supporting immune function, collagen synthesis, wound healing, and resistance to stress in animals. Most farm animals can synthesize vitamin C endogenously; however, during stress conditions such as heat stress, disease, or high production, requirements may increase. Deficiency, though rare, can lead to reduced immunity, poor wound healing, and lowered stress tolerance, adversely affecting animal health and performance.

Conclusion

Micronutrients, though required in minute amounts, are indispensable for optimal animal health, growth, reproduction, lactation, and maintenance. They act as cofactors for enzymes, antioxidants, and regulators of metabolism, influencing oxygen transport, bone development, immune function, and reproductive efficiency. Requirements vary with physiological stages higher during growth,

reproduction, and lactation, and moderate during maintenance. Deficiencies or imbalances can lead to anemia, skeletal deformities, reduced fertility, impaired immunity, poor growth, and lower productivity, causing significant economic losses. Therefore, stage-specific, balanced micronutrient supplementation is essential to ensure healthy animals, efficient production, and sustainable livestock management.

Conflict of Interest: Authors should declare no competing or conflict of interest.