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Impacts of Mineral Deficiencies on Reproductive Performance in Bovines

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Reproductive efficiency is a key determinant of productivity and profitability in the dairy industry and is closely linked to the mineral status of bovines. Both macro- and micro-minerals play essential roles in metabolic processes, hormone synthesis, antioxidant defense and reproductive physiology. Deficiencies, imbalances, or excesses of minerals adversely affect reproductive functions, leading to conditions such as delayed puberty, anestrus, repeat breeding, retained placenta and reduced conception rates. In developing countries like India, mineral deficiencies are largely area-specific due to variations in soil, fodder and feeding practices, making blanket supplementation strategies ineffective. This review highlights the roles of major and trace minerals in bovine reproduction, outlines the reproductive disorders associated with their deficiencies and emphasizes the importance of region-specific, evidence-based mineral supplementation programs. Understanding mineral interactions, bioavailability and physiological requirements is crucial for improving reproductive performance, ensuring animal health and enhancing the sustainability of dairy production systems.

Introduction

The dairy industry stands as one of the most rapidly developing sectors of livestock enterprise globally, with its success fundamentally dependent on the reproductive wellbeing of animals. Reproductive efficiency represents a major factor affecting profitability in ruminants, as improving fertility and lifetime efficiency of dairy animals is essential for profitable dairy operations S. Upadhyay *et al.,* 2006. The production efficiency of farm animals is largely dependent on their reproductive performance, with clear interactions existing between reproductive performance and mineral status that directly influence farm profitability and sustainability. For maintaining a successful livestock enterprise with steady income, it is essential to have animals with optimal reproductive status, as infertility and reproductive disorders have emerged as important problems in livestock populations worldwide A. Ahuja *et al.,* 2017.

Among the four key factors determining livestock performance and reproduction—genetic legacy, environment, nutrition, and management—nutrition emerges as the most critical factor, capable of influencing the effects of all other factors. Twenty-two mineral elements are believed to be essential for the physical and mental wellbeing of animals, playing vital roles in maintaining optimum production and reproductive performance. These minerals function as inorganic nutrients required in small amounts but with profound impacts on metabolic processes, serving as structural components of organs and tissues, cofactors or activators in enzyme and hormone systems, constituents of body fluids and tissues, and regulators of cell replication and differentiation M. Sharma *et al.,* 2007. Micro-nutrients have

critical roles in key interrelated systems of immune function, oxidative metabolism, and energy metabolism in ruminants, with trace minerals such as zinc, copper, manganese, and selenium being essential components of key antioxidant enzymes and proteins B. Y. Amin *et al.*, 2016. Studies have demonstrated that minerals are involved in intracellular detoxification of free radicals, biosynthesis of steroids, and cellular metabolism of carbohydrates, proteins, and nucleic acids.

Mineral deficiencies, imbalances, and toxicity severely inhibit livestock production in developing countries and are often of more significance compared to infectious diseases. The consequences of inadequate or excessive dietary mineral intake include delayed puberty, impaired spermatogenesis, prolonged postpartum anestrus, and various other reproductive disorders that significantly impact animal productivity Ogbuewu Ifeanyi Princewill *et al.*, 2015. In India specifically, the main factor affecting reproduction is nutritional status, particularly mineral deficiency, which represents an area-specific problem requiring region-specific supplementation strategies. Most roughages, greens, concentrates, and even commercial feeds available in the Indian market are deficient in trace mineral elements, necessitating adequate micro-mineral supplementation B. Y. Amin *et al.*, 2016 (b). Due to the diversity of terrain and agro-climatic regions of India, therapeutic treatments suitable for one region may not be appropriate for others, highlighting the need for mapping various nutrient statuses in soil, fodder, and animals to develop area-specific mineral supplementation programs. Requirements of minerals for reproduction and immunity are generally higher than maintenance requirements, and supplementation requires correct knowledge of bioavailability, sources, animal requirements, and mineral interactions with other nutrients Vinod Kumar *et al.*, 2015.

This comprehensive review aims to examine the intricate interactions between dietary minerals and reproduction in bovine species, addressing the mechanisms by which minerals influence reproductive performance, though these mechanisms are not completely clear but evidence suggests their effects are mainly exerted at higher neural centers or the hypothalamus. The scope encompasses both beneficial and detrimental effects of minerals on animal physiological wellbeing depending on their balance, reviewing negative effects when minerals are over-fed, and serving as a ready source of literature for researchers in animal nutrition and nutritional reproductive physiology.

Overview of Mineral Requirements in Bovines

Mineral requirements in bovines represent a complex nutritional framework involving two distinct categories: macrominerals and trace minerals, each serving critical physiological functions that directly impact animal health, productivity, and reproductive success. Macrominerals, including calcium, phosphorus, magnesium, potassium, sodium, and sulfur, are required in substantial quantities ranging from grams to tens of grams daily for dairy cows, while trace minerals such as copper, iron, manganese, selenium, zinc, cobalt, and chromium are needed in much smaller amounts measured in milligrams to micrograms J. Goff *et al.*, 2018. These minerals function as essential cofactors in enzymatic processes, hormone synthesis, antioxidant systems, and reproductive mechanisms, with deficiencies or excesses causing detrimental effects on growth, production, and fertility Rajesh Kumar *et al.*, 2025. Research on Nellore cattle has established specific dietary requirements including 5.12 g/kg dry matter intake for calcium, 2.38 g/kg for phosphorus, and varying retention coefficients ranging from 0.80% for zinc to 86% for cobalt L. F. Costa e Silva *et al.*, 2015. However, mineral bioavailability is significantly influenced by multiple factors including soil mineral content, forage quality, presence of antagonistic elements like iron, molybdenum, and sulfur, dietary interactions within the rumen environment, and the animal's physiological state including age, lactation status, and pregnancy stage J. Arthington et al., 2021. Maternal mineral status particularly impacts offspring health through placental nutrient transfer, colostrum quality, and milk composition, making precise mineral supplementation strategies essential for optimizing both dam and calf performance while avoiding environmental contamination from excessive mineral excretion M. V. Van Emon *et al.*, 2020.

Impact of Specific Macro-Mineral Deficiencies

Macro-mineral deficiencies significantly impair livestock reproductive performance through both direct and indirect mechanisms, with calcium and phosphorus exerting direct influences while magnesium, sodium, chlorine and sulfur acting indirectly on reproductive function.

Calcium (Ca):- Calcium deficiency disrupts ovarian function and uterine contractions, leading to silent heat, delayed uterine involution, prolonged estrus and ovulation timing, retained placenta, and increased dystocia due to weakened muscle contractility Y. Yanuartono *et al.*, 2016 (a).

Phosphorus (P):- Phosphorus deficiency, critical for energy metabolism through ATP formation, causes anestrus, decreased conception rates, repeat breeding, delayed sexual maturity, and embryonic death, with animals receiving only 70-80% of phosphorus requirements showing severely impaired fertility D. Talukdar *et al.*, 2016.

Magnesium (Mg):- Magnesium deficiency affects neuromuscular function and hormone release, resulting in poor libido, irregular estrus, impaired uterine tone, and increased retained placenta incidence through its antagonistic relationship with calcium metabolism Y. Yanuartono *et al.*, 2016 (b).

Sodium & Chlorine (Na, Cl):- Sodium and chlorine deficiencies disrupt osmotic balance and overall reproductive health, causing weak estrus expression, endometritis, follicular cysts, and reduced milk yield that indirectly affects fertility Y. Yanuartono *et al.*, 2016 (c).

Sulfur (S):- Sulfur deficiency compromises rumen microbial protein synthesis, reducing amino acid availability essential for embryo viability and development, while the overall impact of these mineral imbalances causes various reproductive problems leading to lowered reproductive efficiency in livestock D. Talukdar *et al.*, 2016.

Impact of Specific Micro-Mineral Deficiencies

Micro-mineral deficiencies in bovines systematically impair reproductive performance through distinct but interconnected pathways.

Copper (Cu):- Copper deficiency disrupts essential enzyme systems and ovarian activity, resulting in delayed puberty, irregular estrus cycles and early embryonic death M. Hidiroglou *et al.*, 1979 (a).

Zinc (Zn):- Zinc deficiency impairs cell division, growth and reproductive hormone metabolism, leading to poor follicular development and reduced conception rates B. Y. Amin *et al.*, 2016.

Selenium (Se):- Selenium deficiency compromises antioxidant defense mechanisms, causing retained placenta, metritis and overall reduced fertility M. Hidiroglou *et al.*, 1979 (b).

Manganese (Mn):- Manganese deficiency disrupts steroidogenesis, manifesting as poor libido, anestrus and decreased conception rates.

Iron (Fe):- Iron deficiency, while primarily affecting oxygen transport, indirectly impacts fertility through compromised overall health and immunity

Iodine (I):- Iodine deficiency impairs thyroid hormone synthesis, resulting in weak estrus expression, increased abortions and stillbirths M. Hidiroglou *et al.*, 1979 (c).

Impacts of Mineral Supplementation on Reproductive Performance

A systematic approach to mineral supplementation for improving bovine reproductive performance involves: Assessing baseline mineral status through soil, feed, and serum analysis to identify deficiencies S. Tiwari *et al.*, 2012, Formulating area-specific mineral mixtures tailored to local biogeochemical conditions and identified deficiencies K. Górski *et al.*, 2021, Implementing strategic supplementation timing during critical reproductive periods such as pre-breeding, pre-calving, and early lactation when metabolic demands are highest Roberto Palomares *et al.*, 2024, Providing appropriate dosages (typically 40-50g/day for cattle and buffalo) of key trace minerals including zinc, copper, manganese and selenium S. Kantwa *et al.*, 2022, Monitoring reproductive parameters including conception rates, services per conception, calving intervals and estrus expression K. Górski *et al.*, 2021, and evaluating economic returns through benefit-cost analysis to ensure sustainable

implementation. This systematic methodology ensures targeted, evidence-based mineral supplementation that addresses specific regional deficiencies while optimizing reproductive outcomes in bovines.

Conclusion

Minerals play a fundamental role in bovine nutrition and are critical determinants of reproductive efficiency, animal health and overall productivity. Adequate supply of both macro- and micro-minerals is essential for maintaining normal reproductive physiology, as deficiencies or imbalances adversely affect hormonal regulation, energy metabolism, immune competence and antioxidant defense mechanisms. In India and many other developing countries, reproductive inefficiency in bovines is largely attributed to region-specific deficiencies arising from variations in soil mineral composition and fodder quality. Therefore, adoption of strategic and area-specific mineral supplementation programs, based on systematic assessment of soil, feed and animal mineral status, is imperative. Such targeted supplementation has been shown to improve estrus expression, conception rate and calving interval, thereby enhancing productivity and economic viability of dairy enterprises. Future research efforts should prioritize precise estimation of mineral requirements under different physiological states, deeper understanding of mineral interactions at cellular and molecular levels, and development of cost-effective, regionally tailored supplementation strategies to sustainably optimize reproductive performance in bovines.

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