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Copper Supplementation in Broiler Diets: Mechanisms of Action and Performance Improvement: Subject Review

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Annotation: Broiler diet supplementation with copper is an important strategy that improves growth performance, feed utilization, immune response, and health of poultry. As a critical cofactor of vital metalloenzymes responsible for energy metabolism, bone development, and antioxidant defense of broilers growing fast, copper meets the high metabolic requirement of rapidly growing broilers. In this review, several types of copper sources (traditional inorganic forms, nanoparticles, chelated complexes, etc.) are compared, with respect to bioavailability and environmental safety. It also discusses the need to optimize copper dosage for maximizing benefits and minimizing risks of toxicity in relation with currently permitted doses. Moreover, copper's role in enhancing gut health and protection against pathogens further supports the positive effects of copper on productivity of poultry. This article summarizes the latest scientific evidence and provides practical recommendations for the nutritionist and the producer seeking to maximize the impact of sustainable copper supplementation in today's commercial poultry.

Keywords: Copper, Broilers, Immunity, Antioxidants, Improvement.

Introduction

Mineral nutrition is a vital factor in the modern poultry industry for the optimum growth production, health, and immunity in broilers. Among the essential minerals, especially, trace elements although present in trace amounts exert significant physiological and biochemical status. One of these is Cu, which has been investigated to a greater extent as it has a multifaceted function including some enzymes, iron metabolism, bone growth, and immune function in poultry (Kim et al., 2022; Lu, 2018;Al-Obaidy et al.,2022). Copper is a cofactor of several metalloenzymes, such as cytochrome c oxidase, lysyl oxidase, superoxide dismutase, which involving in essential metabolic customers (Yatoo et al., 2013). Its dietary supplement has been verified to be efficient for poultry, parents not only for metabolism, but it also for gut health, its antioxidant defense systems, and its resistant to pathogens (da Cruz Ferreira Júnior et al., 2022). Moreover, recent advances in copper source technologies, such as copper nanoparticles or chelated copper, have underlined the potential effectiveness of this cation on the regulation of bioavailability and its environmental excretion (Al- Ruwad et al., 2024). It was reported that of Se and Zn supplements improve the bio-chemical and reproductive status of the ruminant (Palani et al., 2024a, Palani et al., 2024b) and the impact of the heavy metal viz., lead and molybdenum on the oxidative stress (Palani et al., 2025), representing the important of providing the correct sustainable food as the health as the environmental security issue of the animal (Palani et al., 2022).

Copper in Poultry Physiology

Copper: As a trace element it is vital for poultry with multifunctions. Its requirement is very minor although biologically it is of much significance particularly in case of broilers that have fast growth rate, not only this but high metabolic rate of broiler and broiler chicks cause very high mineral requirement. Copper is predominantly involved in several important physiological processes, such as haematopoiesis, bone metabolism, immune modulation, and cellular oxidative equilibrium. In broilers, dietary copper had a dose dependent effect on growth performance, feed conversion ratio and response to pathogenic bacterial challenge, indicating its importance to broiler health and productivity (Kim et al., 2022; da Cruz Ferreira Júnior et al., 2022). Copper is the auspicious catalytic cofactor of a number of key metalloenzymes. For example cytochrome c oxidase is a key enzyme of mitochondrial respiration and ATP formation, and therefore involved in the energy metabolism of fast growing birds. Another important copper-dependent enzyme is lysyl oxidase, which is responsible for the cross-linking of collagen and elastic fibres, and it is thus essential for the integrity of the structural skeleton of tissue. It is also extremely important for activity of superoxide dismutase (SOD) which provides antioxidant protection from the production of superoxide radical to less harmful products. All of these enzymes provide a very strong evidence for the effect of copper on cellular defense systems and tissue development (Yatoo et al., 2013, Al-Ruwad et al., 2024). The absorption and utilization of copper in chicks is physiologically regulated in many ways. Copper is absorbed mainly in the small intestine, particularly in the duodenum, by transporters CTR1 and DMT1. By absorption it is bound to proteins, predominantly to albumin and to a lesser extent to transcuprein, then it is transported via the liver to be metabolized. Within the cell, certain chaperone proteins act to deliver the copper to organelles and other enzymes while maintaining the ions at concentrations that are low enough to avoid creating pools of free ions that can act as catalysts for ROS formation. And the liver produces ceruloplasmin, which is the main copper-carrying protein in the blood, and which is involved in iron metabolism and is a potent antioxidant. In these cases, the regulation of the copper homeostasis is important to prevent copper deficiency or toxicity in chicken growth. The liver controls the systemic copper homoeostasis by accumulation or excretion into the bile of the excess copper. Proteins like ATP7A and ATP7B export and redistribute copper as part of the regulation of cellular copper levels. The bioavailability of copper from the diet is highly dependent on chemical form and source of copper. Copper sulphate as inorganic source of copper are in wide use that can react with other dietary constituents. Organic sources and copper as nano-particles have been advocated as an alternative as they have these advantages compared to inorganic metallic copper sources (higher bioavailability, ecological benefit) (Lu, 2018; Al-Ruwad et al., 2024). In general, the dietary Cu requirements for broilers are introduced according to the enzyme reactions, metabolic regulations, and thereby the dietary Cu inclusion and the staff controlled dietary level applied is critical for the overall highest health and development of the poultry production.

Sources and Forms of Dietary Copper

Copper is provided in the poultry diet by several sources and chemical forms that differ in bioavailability, effectiveness, cost and impact on bird performance and the environment. One of the most important factors, which influence the physiological forms of copper was the selection of copper form, especially in broilers because of high turnover and fast growth rate the efficient uptake of minerals is a prerequisite. Commercial sources of cooper available for poultry are mainly copper inorganic salts (red pepper) and industries that produce inorganic copper, like copper sulphate ($CuSO_4$) and copper chloride. These compounds however are cheap and widely available; however, their bioavailability may be limited through antagonistic interaction with other dietary factors such as phytates, zinc and calcium. Second, high copper level in the diet may lead to the over excretion in manure which is concern to the environmental issues (Lu, 2018; da Cruz Ferreira Júnior et al., 2022). Organic copper complexes have been recently reported to overcome the deficiencies of inorganic copper. These are copper proteinate and copper chelates and it is a chelated form of minerals where it is bound to amino acids or peptides so they stay together during the trip through the gut and they are better absorbed than inorganic minerals. Bioavailability of Cu from organic sources is in general higher compared with that from inorganic salts because they interact less with other dietary constituents and are more efficiently absorbed from the intestinal epithelium. Improved growth performance, immunity, and oxidant status of broilers fed organic sources of copper have been recorded in some studies compared to conventional inorganic sources (Al-Ruwad et al., 2024; Kim et al.,2022). Nowadays, with the special physicochemical properties of nano materials, nano copper is regarded as a new replacement, with bright future in application. Nanoparticulate copper has a high surface area, which could enhance its adherance to the gut cells and favour absorption. It is assumed that nano-copper may have higher bioavail- ability compared to inorganic and organic sources of the mineral, and lower dietary levels of inclusion may be required to obtain similar or superior biological performance. This nano-copper also displayed strong antimicrobial activities and enhancing poultry antioxidant status but remains concern about safety, tissue retention in addition to long-term environmental impact (Al-Ruwad et al., 2024). Comparative determinations on copper sources indicated evident differences with regard to bioavailability. It should be noted that the inorganic copper many use is often not well absorbed. Organic sources in general, and chelated forms in particular, are better used than inorganic sources due to greater solubility and stability. Nano-copper Although this is indeed an area for further research, one type of copper that might be most effective for its uptake and biological impact could be nano-copper. However, cost-effectiveness and compatibility with other dietary components and the environment may be taken into account when selecting a source of copper. An optimal feeding strategy might be to use different forms and to possibly lower doses of very effective sources, but lower doses are not expected to satisfy physiological needs without increasing mineral overload in the environment (Lu, 2018; Yatoo et al., 2013).

Effects of Copper Supplementation on Growth Performance in Broilers

Copper (Cu) is a trace element essential for a variety of metabolic and enzymatic processes in poultry. The effect of dietary copper supplementation on growth performance species in broiler diets has been widely researched, especially BWG, FI and FCR. Often the effects of copper are dose-dependent, and both a deficiency and excessive levels can be detrimental. A number of studies have clearly proved that appropriate doses of Cu supplementation (usually 8–250 mg/kg feed based on the form of supplemented Cu and feed grade- inorganic or organic, respectively) greatly improve BWG and FCR of broilers (Samanta et al., 2011; Liu et al., 2022). Increased BWG has been associated with better nutrient utilization, increased activity of digestive enzymes, and antimicrobial properties that promote good gut health. On the other hand, copper toxicity may decrease in feed consumption, hepatic function, and oxidative stress (Gou et al., 2021; Yang et al., 2020). The effects of copper on other minerals, especially Zn and Fe, are of particular relevance. Zinc absorption may be inhibited by elevated copper levels, which compete for similar transport pathways in the intestinal mucosa (Zhang et al., 2021). Hyper-dietary copper may also hinder the metabolism of iron, resulting in impaired production of hemoglobin and oxygen transport (Khan et al., 2020). Thus, optimal mineral composition in diets is vital to prevent competitive inhibition and allow corresponding beneficial effect. Also, the response to copper addition differs among growth phases, the starter (0–10 days), the grower (11–24 days) and the finisher (25–42 days). It has been reported by the research that broilers were more sensitive to copper supplementation in the starter and grower period, and the metabolic activity and growth rate of broilers is the highest in starter and grower periods (Samanta et al., 2011). Conversely, copper excess 15 in the finisher phase might not result in proportional benefits and instead lead to extra tissue depositions and environmental issues. In summary, regarding broiler diet, copper supplements should be used in a controlled manner to optimize performance without causing damage. It has been suggested that future strategies should focus on precision feeding, and would involve the use of chelated forms of copper to prevent any un-absorbed free copper, and the development of integrated trace mineral programs to both enhance efficiency, and minimize environmental impact.

Copper and Immune Function in Broilers

Copper is the primary modulator of immune function in chicken, affecting both humoral and cellular immunity. It is a principal co-factor of many antioxidant enzymes such as superoxide dismutase (SOD) that play a role in the redox balance and immune homeostasis (Samanta et al., 2011). Sufficient concentration of copper can stimulate the antibodies production and lymphocytes proliferation, regulate the function of macrophage in the body of bird to improve the resistance of broiler breeder against the pathogens (Liu et al., 2022). Furthermore, copper supplementation influences the expression of cytokines and inflammation mediators, and in turn the immune response. Studies have demonstrated that organic sources of copper, for example, copper proteinate or copper amino acid chelates, could upregulate anti-inflammatory cytokine (IL-10) and could down-regulate pro-inflammatory mediators, including TNF-α and IL-6, particularly manganese under immunological or environmental stress (Berg et al., 2005). This exacerbated immune activation is beneficial as it facilitates reduced inflammation induced damage to the tissue and aids in recovery. Under stress, including heat stress, mycotoxins or infectious challenges, copper plays a protective role through antioxidant capacity improvement, and stabilization of the immune response (Zhao et al., 2021). Birds with higher copper levels also show decreased oxidative stress indicators (such as malondialdehyde MDA) and higher level of activity of glutathione peroxidase (GPx), that attenuate the immunosupressing effects of stress (Ognik et al., 2018).

Copper Toxicity and Environmental Concerns

Although it is essential in poultry, the surplus addition of copper leads to toxicity which is also considered to be one of the environmental hazards. Dietary Copper: Dietary stores of copper in tissues, in particular of liver, kidney, and muscle contents, become elevated at higher levels of dietary copper, particularly from inorganic sources. This bioaccumulation has been found to not only inhibit the normal functioning of organs, but also create concerns regarding human food safety upon consumption (Yang et al., 2020; Khan et al., 2020).

Clinical signs of copper poisoning in poultry are reduced feed intake, depressed weight gain, anemia, green feces, swollen liver and death in severe cases. Therefore toxic thresholds vary with the species concerned, however copper intake levels in the diet higher than 300 mg/kg are generally related to subclinical or clinical toxicity, especially when the balance with zinc and iron is altered (Samanta et al., 2011). Environmentally, the remaining copper in manure is lost by the animal and is excreted once it is applied to soil, it builds up in soil, causing soil microbiota, plant growth and water quality to all be affected detrimentally. The temporal accumulation could also lead to the copper-resistant bacterial community in long term, which may serve as an environmental reservoir of AMR (Chen et al., 2021). Approaches to attenuation are the supplementation of chelated copper sources, which enhance bioavailability at low inclusions and are followed by reduction in excretion. In addition, precision feeding, the rotation of Cu sources and thet use plant based additives, are the strategies that could help to reduce environmental impact of Cu (Ognik et al., 2018).

Regulatory Standards and Guidelines

Use of copper in poultry industry The inclusion of copper in the broiler nutrition programs has to face the strict legal and legislative environment to grant animal health, product safety and environment protection. Transparent directions for inclusion of copper in the diet are developed by regulatory authorities like NRC (National Research Council), EFSA (European Food Safety Authority) and FDA (Food and Drug Administration of the United States). The lowest dietary copper level for broilers, to fulfill physiological requirements, has been suggested to be around 8 mg/kg feed (NRC, 1994). Nevertheless, higher levels of copper are usually supplemented for its growth promoting effects and antimicrobial properties, particularly in areas where pharmacological doses are permitted (Samanta et al., 2011). The EFSA (2020) proposes more conservative maximum levels for no environmental contamination and no accumulation in tissues, with a maximum of 25 mg/kg for poultry feeds. Copper sulfate, together with other approved forms, is allowed by the FDA in poultry diets; however, permissible levels/limits by law depends on the compound and if it is a feed additive or medication (Yang et al., 2020).

Knowledge Gaps and Future Perspectives

There are several areas of deficiency in knowledge about the use of copper in poultry nutrition, despite a considerable amount of research. One of the most promising areas is research into novel technologies (nano-copper, encapsulated copper), which provide higher bioavailability and reduce its environmental excretion (Ognik et al., 2018). These forms enable lower incorporation dietary rates while obtaining the same or better physiological effects. Another less studied frontier is the chronic effects of copper supplementation on the gut microbiome. Although, the antimicrobial action of the copper is very well known, the long-term use of copper could change the diversity of the microorganism, develop resistance bacteria or have influence on the development of gut-immune axis (Liu et al., 2022). Further longitudinal studies are required to evaluate these effects in controlled and commercial settings. The growing importance of precision mineral nutrition offers an opportunity for the optimization of copper utilization. For participants in the breeding value estimation, age, breeds, breeding country, clinical diagnosis of the suspected copper deficiency or toxicity and management of the flocks were considered as explanatory variables and identification of the flocks as random factors.値 estimation 24)512 Tailoring copper supplementation according to the age and breed of the animals, their health status, the soil and vegetation in the pasture reduce the risk of failure of supplementation as well as the risk of excessive copper supplementation (Berg et al., 2005). This will necessitate the incorporation of digital monitoring devices, copper-status biomarkers and environmentally friendly diets. Current economic and sociopolitical trends analysis are emphasizing both challenges and potentials in Iraq such as housing crises and the effect of foreign loans on credit improvement (Palani, 2025a; Palani, 2025b) and industrial efficiency rankings as a mirroring indicators for the national economic performance (Palani & Hussen, 2022). These data offer essential context for consideration of the social and economic drivers of regional development and resource use. While the Awassi ewes have been reported to achieve a superior reproductive performance by the supplementation of hormonal treatment, and to influence a number of blood biochemical parameters (Alwan et al., 2018a; Alwan et al., 2018b), the supplementation of selenium- or zinc-yeast in local Iraqi goats improved antioxidant indices and functions on liver and kidney treated, indicating that targeted mineral and hormonal intervention in ruminant species can have physiological advantage (Shareef ,2025).

Conclusion

The use of copper is still common practice in modern broiler production for promoting growth, enhancing immune performance and increasing feed utilization. However, its biological effect is directly dependent on its dose, on the interactions with the other dietary minerals, and on the possibility of toxicity, which makes its nutritional management very hard. The present review emphasizes the importance of detecting the optimal dietary copper level, particularly copper dosage for inclusion, at the early life stage in poultry to maximise beneficial effects and to minimise undesired effects. Opportunities exist to enhance copper bioavailability and reduce environmental waste of copper by increasing the effectiveness of delivery systems such as chelated forms and nano-copper technologies. It is essential to meet international regulatory guidelines for the safe and sustainable utilization of feed and food. The utilization of precision nutrition, and responsible supplementation becomes essential in the future to establish a balance between production efficiency, animal health, and ecological sustainability through poultry production.

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