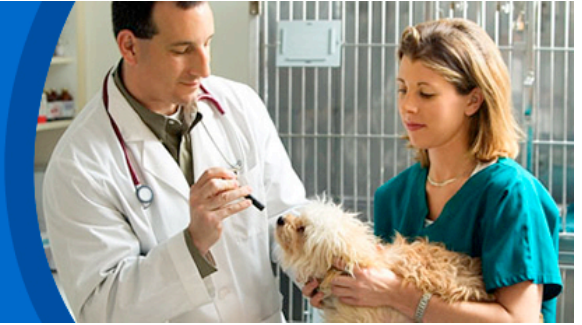




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Chromium as a functional micromineral in poultry: A comprehensive review of growth, immunity and stress mitigation

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ABSTRACT

Chromium (Cr) is a trace mineral that has attracted considerable interest in animal nutrition because of its potential role in glucose metabolism, insulin action, lipid metabolism, cell preservation, stress regulation, immunity, and productive performance. In poultry, dietary chromium supplementation has been investigated in inorganic, organic, chelated, yeast-based, and nanoparticle forms. Available evidence indicates that chromium may enhance insulin sensitivity and glucose utilization and may improve metabolic responses, antioxidant status, immune function, carcass characteristics, and meat quality, particularly under environmental or physiological stress such as heat stress. However, responses in growth performance, feed efficiency, blood biochemical parameters, carcass traits, and egg production are inconsistent and appear to depend on chromium source, dose, dietary composition, bird age, genotype, and environmental conditions. Organic and nano-formulated chromium sources have frequently shown greater bioavailability than conventional inorganic sources, although results are not uniform. This review summarizes the chemical characteristics, biological functions, absorption and metabolism, interactions with other minerals, and effects of chromium supplementation on growth, carcass traits, hematological and biochemical indices, immunity, meat quality, heat-stress tolerance, and layer performance, with emphasis on its potential applications in poultry nutrition.

Keywords: Chromium, Nano, Growth performance, Immunity, Heat stress, Poultry

1. Introduction

Chromium (Cr) is recognized as an essential trace mineral involved in carbohydrate, protein, and lipid metabolism. It also plays an important role in the activation of specific enzyme systems and in maintaining protein stability (Anderson *et al.*, 1987) [1]. Subsequent studies proposed that chromium potentiates insulin action and may facilitate cellular glucose uptake and utilization. The traditional concept of a chromium-containing glucose tolerance factor (GTF) has been widely discussed in relation to insulin activity, although the precise molecular identity and physiological significance of the native GTF remain incompletely established. Chromium has subsequently been investigated for its possible involvement in lipid and protein metabolism, nucleic-acid metabolism, antioxidant defence, and stress responses.

Chromium may also be involved in the regulation of gene expression through its interaction with chromatin. Binding of chromium to chromatin has been suggested to increase the number of transcriptional initiation sites, thereby enhancing RNA synthesis. This process may involve the induction of nuclear proteins and activation of nuclear chromatin (Okada *et al.*, 1989) [2]. Consequently, increased RNA synthesis may enhance protein availability for muscle tissue development and growth.

Chromium has additionally been associated with immunomodulatory activity. This effect has been proposed to occur indirectly through its influence on glucocorticoid secretion, as corticosteroids are known to exert immunosuppressive effects (Samantha *et al.*, 2008) [3]. In poultry nutrition, chromium is considered a potentially beneficial trace mineral, particularly under stressful environmental conditions, because of its reported antioxidant properties and its ability to reduce oxidative damage, including lipid peroxidation associated with heat stress (Rao *et al.*, 2012) [4].

The biological response to chromium is also influenced by its chemical form. Inorganic sources such as chromium chloride and chromium oxide generally have relatively low bioavailability, whereas organic forms, including chromium yeast, chromium methionine, chromium picolinate, and chromium nicotinate, may be more readily utilized. More recently, nanoparticle chromium formulations have been investigated because their small particle size and increased surface area may alter absorption, tissue distribution, and bio

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logical activity. Nevertheless, the comparative efficacy and safety of different chromium sources and supplementation levels require careful consideration.

Elsalheya *et al.* (2022) [5] observed the effect of different types of chromium supplementation (T_1 - control, T_2 - 2 mg/kg chromium chloride, T_3 - 2 mg/kg chromium yeast & T_4 - 0.2 mg/kg nano chromium) and reported significantly improvement in growth performance, immunity and biochemical attributes. Jadhav *et al.* (2026) [6] reported that dietary supplementation with 0.5 mg/kg chromium, supplied either as chromium chloride or nano chromium particles, did not significantly alter hen-house egg production, hen-day egg production, or feed conversion ratio on egg-mass and per-dozen bases but shell weight percentage and Haugh unit were significantly higher ($P < 0.05$) in T_2 than in T_1 during the 12-week summer feeding period in coloured breeder hens.

In poultry nutrition, chromium supplementation has gained particular attention because intensive production systems expose birds to nutritional, environmental, and physiological stresses. Heat stress, in particular, can impair feed intake, growth, feed efficiency, immune competence, metabolic homeostasis, and carcass quality. Several studies have reported that dietary chromium may alleviate some of these adverse effects by influencing insulin sensitivity, glucose metabolism, corticosterone responses, antioxidant mechanisms, and immune function. However, experimental findings regarding growth performance, feed conversion, carcass characteristics, serum biochemical parameters, immunity, and egg production remain inconsistent.

Therefore, chromium represents a potentially important nutritional tool in modern poultry production, particularly where metabolic efficiency, stress tolerance, immune response, and product quality are major concerns. The present review critically summarizes the available information on chromium chemistry and biological functions, absorption and metabolism, interactions with other minerals, and the effects of different chromium sources on growth performance, carcass characteristics, hematological and biochemical responses, immunity, meat composition, heat-stress tolerance, and laying performance in poultry. It also highlights inconsistencies among published studies and identifies areas requiring further investigation to establish appropriate sources and supplementation strategies.

2. Biological functions of chromium

Chromium has been investigated for several biological functions in poultry, although the magnitude and consistency of these effects depend on chromium source, dose, physiological status, and environmental conditions.

2.1 Role in glucose metabolism

The best-established area of chromium research concerns its relationship with insulin and glucose metabolism. Chromium has traditionally been associated with the glucose tolerance factor and has been proposed to enhance insulin-mediated glucose utilization.

Insulin stimulates glucose uptake and utilization and influences carbohydrate, protein, and lipid metabolism. Chromium may support insulin signaling and consequently facilitate glucose utilization by metabolically active tissues. Evidence from poultry studies indicates that chromium supplementation can reduce circulating glucose concentrations, particularly under heat stress. A meta-analysis of heat-stressed broilers reported a significant reduction in blood glucose with increasing chromium supplementation.

Recent molecular research further suggests that chromium can affect glucose metabolism at the tissue level. Chromium picolinate supplementation under chronic heat stress increased expression of genes involved in glucose transport and insulin-related signalling, including GLUT1 and PI3K.

2.2 Role in protein metabolism

Chromium may indirectly support protein deposition by improving glucose utilization and insulin-mediated amino acid uptake. Insulin stimulates amino acid transport into tissues and promotes protein

synthesis.

Improved metabolic efficiency could therefore increase the availability of nutrients for skeletal muscle development. This mechanism has been proposed as one explanation for the improved body weight and feed efficiency observed in some chromium-supplemented broilers.

However, chromium should not be considered a direct protein-building nutrient. Its potential effect on muscle deposition is more appropriately viewed as a consequence of improved metabolic regulation and nutrient partitioning.

2.3 Role in lipid metabolism

Chromium may influence lipid metabolism through its effects on insulin sensitivity and lipid-related enzymes. Studies in broilers have reported reductions in serum triglycerides, total cholesterol, and LDL cholesterol and changes in HDL cholesterol following chromium supplementation.

Recent work has provided molecular evidence for effects on lipid metabolism. Chromium picolinate supplementation altered the expression of genes involved in fatty-acid oxidation and lipid transport, including PPAR α , CPT-1, and LPL, in breast muscle of heat-stressed broilers. These effects may contribute to alter nutrient partitioning and reduced excessive abdominal fat deposition.

2.4 Role in antioxidant defence

Chromium may also influence the antioxidant defence system. Heat stress increases reactive oxygen species production and lipid peroxidation, potentially impairing cellular function.

Chromium supplementation has been associated with increased activities of antioxidant enzymes such as glutathione peroxidase and superoxide dismutase and with reductions in oxidative stress indicators such as malondialdehyde in several poultry experiments. However, chromium should not be classified simply as a conventional antioxidant. Its effects appear to involve broader metabolic and stress-response pathways that can influence the cellular antioxidant system.

2.5 Immunomodulatory function

Chromium has been associated with modulation of both humoral and cellular immunity. Supplementation under heat stress has been reported to increase antibody responses, immunoglobulin concentrations, and lymphoid organ development while reducing stress-related changes in the Heterophil-to-lymphocyte ratio.

The immunomodulatory action may be partly indirect because chromium can influence endocrine and metabolic pathways associated with stress. Improved glucose homeostasis and reduced physiological stress may consequently support immune competence.

3. Interactions of chromium with other minerals

Mineral-mineral interactions are particularly important when considering trace-mineral supplementation because minerals can compete for absorption, form complexes, or influence common metabolic pathways.

3.1 Chromium and iron

Chromium and iron may interact because both can associate with transferrin and other metal-binding proteins. Iron status may therefore influence chromium transport and tissue distribution. Conversely, high concentrations of chromium may potentially influence iron metabolism. However, the significance of this interaction under practical poultry-feeding conditions requires further investigation. The interaction is particularly relevant because poultry diets commonly contain supplemental iron, and both minerals participate in important metabolic processes.

3.2 Chromium and zinc

Zinc is an essential component of numerous enzymes and transcription factors and plays a central role in antioxidant defence and immune function. Chromium and zinc may interact indirectly because both participate in metabolic and antioxidant pathways. Zinc also influences insulin signalling, making the biological functions of

chromium and zinc partially overlapping. Consequently, supplementation with both minerals may produce additive effects under some conditions, although excessive supplementation of either mineral should be avoided.

3.3 Chromium and copper

Copper participates in oxidative metabolism, iron utilization, connective-tissue formation, and antioxidant defense through enzymes such as copper-dependent superoxide dismutase. Chromium and copper may interact indirectly through antioxidant and metabolic pathways. However, evidence for a specific chromium–copper interaction in poultry is currently less extensive than evidence concerning individual effects of these minerals.

3.4 Chromium and calcium

Calcium is present in poultry diets at substantially higher concentrations than chromium and is essential for skeletal development, eggshell formation, muscle contraction, and cellular signalling. Changes in dietary mineral balance can influence the absorption of trace minerals. However, the specific effect of calcium on chromium absorption in poultry has not been sufficiently characterized. This represents an important research area, particularly for laying hens in which calcium concentrations are considerably higher than in broiler diets.

3.5 Chromium and phosphorus

Phosphorus is essential for energy metabolism, ATP formation, skeletal development, and cellular signalling. Because chromium is associated with energy and glucose metabolism, interactions between chromium status and phosphorus metabolism could have physiological relevance. Nevertheless, direct evidence for a significant chromium–phosphorus interaction in poultry remains limited.

4. Effects of chromium on growth performance

Dietary chromium supplementation has been investigated as a nutritional strategy to improve growth performance in poultry, particularly under environmental stress conditions. Chromium may enhance insulin activity and improve glucose and nutrient utilization, thereby supporting protein deposition and energy metabolism. Also, chromium was found to stimulate certain enzymes and stabilizes proteins and nucleic acids as well as it can increase the synthesis of fats in adipose tissues (Amatya *et al.*, 2004) [7]. Several studies have reported improvements in body weight gain, feed intake, and feed conversion ratio in broilers supplemented with chromium, especially during heat stress (Sahin *et al.*, 2002; Toghyani *et al.*, 2012) [8, 9]. In heat stressed broiler chicks growth performance were significantly increased body weight, average daily gain and feed efficiency of Cr_{Nano} and Cr_{Pic} , while the feed intake was not affected by any of the Cr sources.

Meta-analyses have also indicated that chromium supplementation can improve feed efficiency and selected growth-performance traits, although responses are variable and influenced by chromium source, dose, genotype, basal diet, and environmental conditions (Feng *et al.*, 2021; Piray *et al.*, 2022) [10, 11]. Similarly, Youssef *et al.* (2022) [12] observed effects of dietary supplementation of chromium methionine (Cr-Meth) chelate at 0 (control), 50, and 100 g/ton feed in broiler chicken and reported that 100 g/ton Cr-Meth chelate significantly improved the body weight, weight gain, feed intake, and feed conversion ratio of broilers and reduced the mortality rate of birds. Moreover, Dietary chromium supplementation resulted in a significantly ($P < 0.05$) higher average final live body weight, average daily gain (ADG), feed conversion ratio (FCR) and carcass dressing percentage of Cr-supplemented broiler chickens compared to those of control group (Habibian *et al.*, 2013; Norain *et al.*, 2013) [13, 14]. Similar results fall in agreement with several other studies, Zhang *et al.* (2024) [15], Youssef *et al.* (2022) [12], Assem *et al.* (2020) [16], Mohammed *et al.* (2014) [17], Raut *et al.* (2012) [18], Samanta *et al.* (2008) [3], Lien *et al.* (1999) [19] observed inorganic and organic chromium sup-

plementation improved body weight, feed conversion ratio in broiler chicken.

In contrast, growth performance on dietary supplementation of Cr as chromium chloride ($CrCl_3$), chromium picolinate (Cr_{Pic}) and nanoparticle chromium picolinate ($NanoCr_{Pic}$) were not influenced by any of the Cr sources (Han *et al.*, 2020; Lu *et al.*, 2019; Lin *et al.*, 2015) [20, 21, 22]. Similarly, Habibian *et al.* (2013) [13] evaluated that 600 and 1,200 ppb Cr in the form of Cr chloride ($CrCl_3$) and Cr L-methionine in broilers did not affect the body mass, feed intake and feed conversion ratio.

These findings indicate that chromium should not be regarded as a universally growth-promoting additive. Rather, its effects may be more apparent when birds experience metabolic or environmental stress.

5. Effects of chromium on immune response

Heat stress can suppress immune function and impair vaccine responses in poultry. Chromium has therefore been studied as a potential immunomodulatory trace mineral. Chromium supplementation has been associated with changes in lymphoid organ development, antibody responses, immunoglobulin concentrations, and the heterophil-to-lymphocyte ratio. The heat-stress meta-analysis reported positive linear associations between chromium supplementation and bursa and thymus relative weights, vaccine antibody titers, cutaneous basophil hypersensitivity, and serum IgG, together with a reduction in the heterophil-to-lymphocyte ratio. Kashyap *et al.* (2018) [23] who reported that there was no significant difference among the various treatment groups but the response to 1% SRBC (log2 titre) was apparently better in group consuming 800 ppb chromium picolinate as compared to the other treatment groups. According to Norain *et al.* (2013) [14] inclusion of $CrCl_3$ (2 mg kg⁻¹) in the diet of broiler chickens potentiates the immune response by significantly increasing ($P < 0.05$) antibody titre to NDV vaccine determined by haemagglutination test (HA). Similarly, Patil *et al.* (2008) [24], Kheiri and Toghyani (2007); Singh *et al.* (2009) [25]; Naela *et al.* (2008) [26] determine the effect of chromium on the humoral immune response and recorded significantly ($P < 0.05$) higher antibody titres against ND virus. Assem *et al.* (2020) [16] noted that concentrations of IgG and IgM were higher for all chromium supplementation treatments than the control group, with markedly improved values ($P < 0.05$) recorded for the organic chromium treatments. According to Uyanik *et al.* (2002) [27] supplementation of $CrCl_3$ increased the cell-mediated immune response to phytohemagglutinin as compared to control group. However, Kashyap *et al.* (2018) [23] reported there was no significant difference recorded in the response to PHA-P among the various treatment groups.

In poultry, Heterophil-to-Lymphocyte (H/L) ratio serves as a primary haematological indicator of physiological stress, disease resistance and immune system balance. Chromium supplementation reduces circulating serum corticosterone. This directly prevent corticosteroid induced lymphopenia and heterophillia, resulting in a lower H/L ratio. Bahrani *et al.* (2012) [28]; Ebrahimzadeh *et al.* (2012) [29] and Uyanik *et al.* (2002) [27] noticed that Heterophil-to-lymphocyte ratios decreased in broilers receiving the Cr supplements compared with those in other treatments. While, Kheiri *et al.* (2009) [30] reported heterophils to lymphocyte ratio were unaffected by Cr supplementation. Stress leads to regression of primary and secondary lymphoid organs due to apoptosis caused by high corticosteroid exposure. Chromium supplementation significantly increases the relative weight of bursa of fabricius, thymus and spleen relative to body weight. Valera *et al.* (2021) [31] supplemented Cr at the rate of 200 ppb/kg diet (T_2) and 400 ppb/kg diet and observed that increase ($P < 0.05$) in the relative weight of all studied organs viz., liver, spleen, thymus, bursa and spleen Cr supplemented broilers as compared to broilers of control group. Similarly, Lu *et al.* (2019) [21]; Ghazi *et al.* (2012) [32]; Naghieh *et al.* (2010) [33] noted that, supplementation of Cr in heat stressed broilers showed improved relative weight of lymphoid organs i.e. spleen and thymus. However in contrast to above results,

Rajlakshmi *et al.* (2014) [34]; Moeini *et al.* (2011) [35]; Ibrahim *et al.* (2010) [36] reported that relative weights of lymphoid organs (i.e. thymus, bursa, and spleen) were not affected by the supplementation of organic chromium.

6. Effects of chromium on heat-stress tolerance

Heat stress is one of the most critical environmental challenges in modern poultry production, triggering oxidative damage, endocrine disruption, and hyperthermia. Chromium is recognized as a key nutritional intervention to alleviate heat stress due to its ability to modulate plasma corticosterone concentration and upregulate antioxidant enzyme activities, such as superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px). By downregulating stress-induced corticosteroid secretion, chromium helps restore metabolic homeostasis, reduces core body temperature elevation, and prevents respiratory alkalosis. Extensive literature reports that chromium supplementation during high ambient temperatures significantly reduces serum cortisol/corticosterone levels, lowers heat-shock protein expression (e.g., HSP70), and mitigates lipid peroxidation ($P < 0.05$) (Sahin *et al.*, 2002, 2017; Toghyani *et al.*, 2012) [8, 37]. Furthermore, heat-stressed broilers supplemented with organic chromium exhibit better thermoregulation, restored feed intake, and lowered mortality rates (Habibian *et al.*, 2013; Feng *et al.*, 2021) [13, 10]. In contrast, under comfortable or thermo-neutral rearing conditions, chromium supplementation generally fails to demonstrate significant heat-stress mitigative benefits. Studies by Lin *et al.* (2015) [22] and Lu *et al.* (2019) [21] indicated that physiological markers of stress, heat-shock proteins, and body temperature regulation remained unchanged when chromium was fed to birds not exposed to thermal discomfort. These findings reinforce that chromium functions primarily as an *anti*-stress nutritional additive whose physiological benefits are conditionally triggered by environmental heat challenge.

7. Effects of chromium on hematological and biochemical indices

Chromium plays a vital role as a trace mineral in modulating blood metabolites, serum biochemistry, and hematological profiles in poultry. Biologically, chromium functions as a constituent of the chromodulin complex, which potentiates insulin signaling pathways, thereby regulating blood glucose levels, lipid metabolism, and protein synthesis. Furthermore, chromium modulates the hypothalamic-pituitary-adrenal axis, resulting in suppressed serum corticosterone levels during stress. Research indicates that chromium supplementation significantly lowers blood glucose, total cholesterol, triglycerides, and low-density lipoprotein (LDL) cholesterol, while elevating high-density lipoprotein (HDL) cholesterol and serum total protein concentrations ($P < 0.05$) (Ebrahimzadeh *et al.*, 2012; Toghyani *et al.*, 2012; Habibian *et al.*, 2013) [29, 9, 13]. Regarding hematological parameters, chromium supplementation has been reported to improve packed cell volume (PCV), red blood cell count (RBC), and hemoglobin levels in birds subjected to environmental stressors (Bahrami *et al.*, 2012) [28]. However, some investigations have indicated that baseline hematological and biochemical parameters remain unaltered by chromium inclusion. Studies by Lu *et al.* (2019) [21] and Lin *et al.* (2015) [22] reported no significant alterations in serum glucose, total cholesterol, or liver enzyme activities (such as AST and ALT) in broilers receiving various organic and inorganic chromium sources. Similarly, Kheiri *et al.* (2009) [30] observed that routine serum biochemical indices were unaffected when birds were housed under non-stressful environmental conditions. Overall, chromium acts primarily as a metabolic regulator whose hematological and biochemical benefits are most pronounced during periods of physiological or environmental stress.

8. Effects of chromium on carcass traits

Dietary chromium supplementation has been explored as an effective nutritional strategy to enhance carcass traits and yield in poultry, particularly by altering body composition through nutrient partitioning.

Chromium enhances insulin sensitivity, which facilitates glucose uptake and amino acid transport into muscle cells, thereby promoting protein synthesis while suppressing lipogenesis in adipose tissue. Consequently, chromium supplementation often results in higher dressing percentages and improved lean meat yield. Several studies have demonstrated that chromium supplementation significantly ($P < 0.05$) increases carcass yield, breast muscle proportion, and thigh yield while reducing abdominal fat pad percentage in broiler chickens (Toghyani *et al.*, 2012; Sahin *et al.*, 2017; Zhang *et al.*, 2024) [9, 37, 15]. Additionally, Youssef *et al.* (2022) [12] reported that dietary inclusion of chromium methionine (Cr-Meth) improved dressing percentage and reduced relative abdominal fat weight compared to control groups, especially under heat-stress conditions. Similar favorable effects on carcass composition and reduced abdominal fat accumulation have been observed by Huang *et al.* (2016) [38] and Habibian *et al.* (2013) [13]. In contrast, other studies have reported that carcass parameters were not significantly influenced by dietary chromium supplementation. For instance, Lu *et al.* (2019) [21] and Han *et al.* (2020) [20] observed no significant differences in dressing percentage, breast yield, or abdominal fat content among broilers fed diets supplemented with various chromium sources compared to unsupplemented controls. Similarly, Rajlakshmi *et al.* (2014) [34] evaluated organic chromium sources and found that carcass traits remained largely unaffected under thermo-neutral conditions. These mixed findings suggest that the impact of chromium on carcass traits depends heavily on environmental temperature, dietary energy levels, and the underlying metabolic state of the birds.

9. Effects of chromium on meat quality

Meat quality is an important physiological and economic parameter in poultry production, influencing customer acceptability, shelf life, and processing traits. Chromium supplementation contributes to improved meat quality largely through its antioxidant properties, which help reduce lipid peroxidation and cell membrane damage post-mortem. By mitigating oxidative stress, chromium improves cellular membrane integrity, thereby decreasing drip loss and liquid exudation during meat storage. Dietary supplementation with organic chromium (such as Cr-picolinate or Cr-methionine) has been shown to significantly reduce malondialdehyde (MDA) content—a key marker of lipid oxidation—in breast and thigh muscles ($SP < 0.05$) (Sahin *et al.*, 2002; Zhang *et al.*, 2024) [8, 15]. Furthermore, improved muscle pH, reduced drip loss, and enhanced meat color parameters have been documented following chromium inclusion under heat-stress conditions (Huang *et al.*, 2016; Youssef *et al.*, 2022) [38, 12]. Conversely, several studies have found no substantial effect of chromium supplementation on post-mortem meat characteristics. Investigations by Lu *et al.* (2019) [21] and Han *et al.* (2020) [20] demonstrated that muscle pH, cooking loss, shear force, and drip loss were not significantly affected by dietary chromium chloride or chromium picolinate. Likewise, Moeini *et al.* (2011) [35] reported that meat quality attributes remained unaffected in broilers raised under thermo-neutral environments. These results demonstrate that while chromium can preserve meat quality and oxidation status under stress conditions, its influence is minimal in well-managed, non-stressed environments.

10. Effects of chromium on layer performance

In laying hens and breeder flocks, maintaining egg production, shell quality, and reproductive efficiency under stress is essential for economic viability. Chromium enhances insulin action and nutrient utilization, supporting the metabolic demands of yolk precursor synthesis in the liver and albumen secretion in the oviduct. Additionally, chromium supplementation helps preserve calcium and phosphorus metabolism during stress, which is vital for eggshell formation. Numerous studies have demonstrated that dietary supplementation with chromium significantly improves hen-day egg production, egg weight, egg mass, and feed conversion ratio per dozen eggs ($P < 0.05$), particularly in laying hens exposed to high environmental temperatures (Sahin *et al.*, 2002; Youssef *et al.*, 2022) [8, 12].

Furthermore, improvements in eggshell quality traits—including shell thickness, shell breaking strength, and Haugh unit scores—have been widely reported following chromium picolinate or yeast inclusion (Piva *et al.*, 2003; Ma *et al.*, 2014) [40, 39]. Conversely, under optimal microclimatic conditions, dietary chromium inclusion does not always yield positive layer performance responses. In coloured breeder hens subjected to a 12-week summer thermal challenge, dietary supplementation with 0.5 mg/kg chromium administered as either chromium chloride or chromium nanoparticles exhibited no significant effect ($P > 0.05$) on production efficiency parameters, including hen-house egg production, hen-day egg production, and feed conversion ratios (expressed per egg mass and per dozen eggs); however, organic/nanoparticle chromium supplementation (T_2) resulted in a statistically significant enhancement ($P < 0.05$) in eggshell proportion and Haugh unit values compared to the control group (T_1) (Jadhav *et al.*, 2026) [6].

Research by Lin *et al.* (2015) [22] observed that egg production rate, average egg weight, shell ratio, and internal egg quality parameters were unaffected by chromium supplementation in non-stressed laying

hens. Thus, chromium supplementation serves as an effective nutritional tool to sustain egg production and eggshell integrity primarily when laying hens face thermal, metabolic, or age-related physiological stress.

11. Dose–response relationship

One of the most important issues in chromium nutrition is the determination of an appropriate supplemental level. The literature contains a wide range of supplementation concentrations, partly because different chromium sources contain different percentages of elemental chromium.

The heat-stress *meta*-analysis identified nonlinear responses for several performance and carcass parameters and estimated approximately 1,100 µg/kg supplemental chromium as an overall optimum under the conditions represented in that analysis. However, the estimated optimum differed according to the response variable (Piray and Foroutanifar, 2021).

For example, estimated concentrations associated with maximum responses were approximately:

Parameter	Estimated Cr concentration
Body-mass gain	~1,200 µg/kg
Feed intake	~1,100 µg/kg
Carcass yield	~900 µg/kg
Breast yield	~800 µg/kg
Leg yield	~800 µg/kg
Lowest FCR	~1,100 µg/kg
Lowest abdominal fat	~1,000 µg/kg

These values should not be interpreted as universal dietary recommendations because they are derived from pooled experimental data and depend on source, stress intensity, basal diet, genotype, and other factors.

The inorganic chromium *meta*-analysis estimated beneficial growth responses within approximately 1.6–2.3 mg/kg supplemental inorganic chromium, whereas the chromium-picolinate *meta*-analysis estimated maximum ADG at approximately 1.81 mg/kg (Piray and Foroutanifar, 2021). The difference between these estimates further demonstrates that chromium source and experimental conditions are important.

12. Factors affecting the response to chromium

The inconsistent results reported in chromium studies can be attributed to several factors.

12.1 Chromium source

Organic and inorganic chromium sources differ in chemical structure and biological availability. Consequently, the same nominal chromium concentration may not produce the same physiological response.

12.2 Supplementation level

The relationship between chromium concentration and response is frequently nonlinear. Both insufficient and excessive supplementation may produce little measurable benefit.

12.3 Environmental conditions

The physiological response to chromium appears to be strongly influenced by environmental stress. Benefits are generally more apparent under heat stress than under thermoneutral conditions.

12.4 Bird genotype

Broiler strain and genetic background can influence chromium responses. *Meta*-analyses have identified differences among commercial strains, suggesting that genotype should be considered when interpreting experimental results

12.5 Age and production stage

The chromium requirement and response may differ between young broilers, finishing broilers, laying hens, and breeders because nutrient metabolism changes substantially with age and production intensity.

12.6 Basal diet

The composition of the basal diet can affect chromium responses. Dietary energy, protein, amino acid balance, mineral composition, antioxidant concentration, and background chromium content may all influence the magnitude of the response.

13. Safety and limitations

Despite promising results, chromium supplementation should be approached with appropriate caution. Not all studies have demonstrated improvements in growth or production, particularly in unstressed birds. A systematic review published by White and Vincent concluded that the chicken literature available at that time was too inconsistent to support a general recommendation for chromium supplementation across poultry diets. The review also noted that chromium supplementation generally resulted in increased tissue chromium concentrations. More recent *meta*-analyses have provided stronger evidence for specific outcomes, especially under heat stress, but substantial heterogeneity remains among studies.

Therefore, supplementation should consider:

- Chromium chemical form; particularly because of its involvement in insulin-related signalling, carbohydrate and lipid metabolism, antioxidant defence, and immune regulation. Available evidence indicates that the effects of chromium are highly dependent on chromium source, dose, bird genotype, production stage, basal diet, and
- Elemental chromium concentration;
- Bird type and genotype;
- Environmental temperature;
- Duration of supplementation;
- Background dietary chromium;

- Total mineral balance; and
- Regulatory requirements for feed additives.

Importantly, nutritional chromium should be distinguished from hexavalent chromium, which has markedly different toxicological properties.

14. Recommended areas for future research

Although considerable research has been conducted, several important questions remain unresolved.

Future research should focus on:

- **Source-specific bioavailability:** Direct comparisons of chromium chloride, chromium picolinate, chromium propionate, chromium-methionine, chromium yeast, chromium histidinate, and nano-chromium using equivalent elemental chromium concentrations.
- **Precision supplementation:** Establishment of optimum chromium concentrations for different poultry categories rather than applying a single supplementation level across all production systems.
- **Mechanistic studies:** Greater emphasis on insulin signalling, glucose transporters, lipid metabolism, mitochondrial function, and molecular responses to chromium.
- **Gut health:** Investigation of intestinal barrier integrity, microbiota, nutrient transporters, and chromium-microbiome interactions.
- **Heat-stress physiology:** Identification of how chromium interacts with corticosterone, oxidative stress, inflammatory pathways, and thermoregulation.
- **Long-term safety:** Evaluation of chromium accumulation in edible tissues, eggs, liver, and other organs during prolonged supplementation.
- **Precision nutrition:** Investigation of interactions between chromium and vitamin E, vitamin C, selenium, zinc, methionine, and other functional nutrients.
- **Commercial-scale validation:** Results obtained from controlled experiments should be validated under practical farm conditions with different climatic regions, genotypes, diets, and management systems.

15. Conclusion

Chromium is a biologically active trace mineral with potential applications in poultry nutrition, particularly because of its involvement in insulin-related signalling, carbohydrate and lipid metabolism, antioxidant defence, and immune regulation. Available evidence indicates that the effects of chromium are highly dependent on chromium source, dose, bird genotype, production stage, basal diet, and environmental conditions.

The most consistent evidence for beneficial effects appears under heat-stress conditions, where chromium supplementation has been associated with improvements in growth performance, feed efficiency, glucose and lipid metabolism, antioxidant status, and selected immune responses. Meta-analyses also suggest that responses under thermoneutral conditions are less consistent.

Recent research further indicates that chromium may influence intestinal function and skeletal-muscle glucose and lipid metabolism, providing additional mechanisms through which it could support poultry performance during environmental stress. Nevertheless, chromium should not be considered a universal growth promoter. The considerable variation among studies emphasizes the importance of source, dose, bioavailability, environmental stress, genotype, and dietary composition when evaluating its nutritional value. Future research should therefore move toward source-specific and precision-based chromium nutrition, supported by mechanistic studies and large-scale commercial validation.

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Ethics statement

Since the current study is a review article and involves no live animals, ethical approval was not sought.

Declaration of competing interest

All persons listed as authors have read and contributed to preparing the manuscript attest to the validity and legitimacy of the data and its interpretation, and agree to its submission to *Aquaculture*. The manuscript has not been published nor is being considered for publication elsewhere. We have read and understood your journal's policies, and we believe that neither the manuscript nor the study violates any of these. There are no conflicts of interest to declare.

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