International Journal of Pharmacology

ISSN 1811-7775

International Journal of Pharmacology 10 (7): 357-367, 2014
ISSN 1811-7775 / DOI: 10.3923/ijp.2014.357.367

Modes of Action and Beneficial Applications of Chromium in Poultry Nutrition, Production and Health: A Review

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Abstract: Trace elements supplementation is now widely considered not only essential but also beneficial to avian species. In the last few decades, chromium (Cr) has been considered to play important role in livestock and poultry nutrition, production and health and also as a potent toxin depending on the dosage levels. It has been documented that chromium may enhance growth rate and egg quality in meat and egg type chickens, respectively. Chromium is identified as an essential nutritional supplement and it has been utilized for weight gain, to improve Feed Conversion Ratio (FCR), increase relative organ weight, muscle development and relative breast mass, that's why Cr has been a popular mineral supplement. It is also a potent antioxidant and hypocholesterimic agent. It increases the retention of other essential elements in blood and decreases their excretion. The beneficial effects of Cr have been linked with improved nutrient digestion and enhanced metabolism. Chromium (Cr) supplementation may improve function of various digestive organs such as liver and pancreas with regards to secretion of digestive enzymes. Supplementation of Cr has promising effects on the immune system by way of relative increase in lymphoid organ weight (bursa of Fabricius, spleen and thymus), decreased heterophil:lymphocyte ratio, enhanced antibody response against infectious diseases and increased Cell-Mediated Immune (CMI) response. In the current review some of the beneficial aspects of Cr in poultry nutrition and their possible mechanisms of actions are discussed with a view to explore and promote its optimum utilization in poultry production and health.

Key words: Chromium, poultry, mechanism of action, nutrition, production, immunity, health

INTRODUCTION

In recent years, there is a considerable research interest in the utilization of Chromium (Cr) in the animal feed. Since intake of Cr is usually low in feed and diets therefore, attention of researchers is focussed and gaining momentum for exploring the possible beneficial aspects of Cr supplementation on biological activities, body composition and health of animals and humans (Mertz, 1993; Jeejeebhoy, 1999; Racek, 2003; Lukaski, 1999; Vincent, 2004; Sahin *et al.*, 2005; Moeini *et al.*, 2011; Rao *et al.*, 2012; Rajalekshmi *et al.*, 2014). Chromium (Cr) has been considered to play important role in nutrition and treatment and also as a potent toxin. Nearly fifty years ago, the element chromium was considered to be an essential element for mammals. It plays an important role in keeping up proper carbohydrate and lipid metabolism. It is a potent biological modifier of insulin

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action and so has been suggested for treatment or prevention of insulin resistance cases. As nutritional supplement it has been utilized for weight loss and muscle development and has been a popular mineral supplement. However, the biomolecules(s) that bind it as well as their mechanisms of action are to be elucidated. Reliable supporting evidences are also need to be documented for its various pharmacological and biological activities as well as nutritional biochemistry and molecular mechanisms of actions. Also concerns over its safety exist as it has potential toxic effects too. Presently, a debate is there regarding essential need of this useful element to be formally readdressed and high possibility may be there that chromium could no longer be positioned as an essential trace element in humans (Levina and Lay, 2008; Vincent, 2010, 2013, 2014; Yoshida, 2012).

In fact, many increasing evidences have supported that Cr supplemental diet may show multiple beneficial effects on health and nutritional/production aspects of poultry. Several varieties of Cr exist, but Cr from yeast (Cr-yeast), Cr picolinate (Cr Pic) and chromium chloride ($CrCl_3$) have been cited mostly for their biological activities. Chromium (Cr) is one of the transition element and occurs in valancies of +2, +3 and +6. The hexavalent Cr is inorganic and found to be toxic with poor absorption while trivalent Cr is organic with better bioavailability (Mowat, 1994). Chromium is an essential micromineral, not only required for digestion of carbohydrate, protein, fat, nucleic acid, but also activating certain enzyme system and protein stabilization (Anderson, 1987). There is no recommendation of Cr in poultry diet (NRC, 1997). As reported in many studies, the dietary intake of Cr is often suboptimal and the absorption is very low (Prasad, 1978; Anderson, 1993; Uyanik *et al*., 2005). Moreover, Cr content of poultry feed is very low, because the ingredients used for feed formulation is naturally low in Cr. Additionally, the requirement of Cr also increases in specific conditions like fatigue, trauma and stress (nutritional, metabolic, physical and environmental). Such circumstances demand for supplementation of this essential trace element to optimize productive performance in poultry.

Several feed supplements and additives are now gaining significance in poultry production and health due to their multidimensional beneficial aspects to be used as growth promoters, augmenting production, immunomodulators and protecting health of livestock animals and poultry (Dhama *et al*., 2011, 2013a, b, 2014a, b; Mahima *et al*., 2012, 2013; Rahal *et al*., 2014). The present review is an updated compilation describing the beneficial applications of dietary chromium supplementation in poultry nutrition, growth and production performances, its various modes of action viz., improving nutrient digestion and consumption, enhancing food metabolism, positive effects on egg quality, potent antioxidant, hypocholesterimic and anticholesteremic activity, helping retention of other essential elements in the body and other useful health-effects. The present study will be highly useful for researchers, scientists, pharmacists, veterinary professionals, pharmaceutical industries, poultry industry and enrich the knowledge in promoting chromium usage.

ABSORPTION AND EXCRETION

According to Vincent (2000), Cr is present in the blood as free Cr^{+3} or bound to proteins or complexes like Glucose Tolerance Factor (GTF). Once absorbed, Cr circulates in the free states and binds to transferrin or to the other plasma proteins (β-globulin protein). The dietary sources influencing Cr absorption from the gut include amino acids, ascorbic acid and oxalate (Amatya *et al*., 2004). Organic Cr gets absorbed in a better way into the gut as compared to inorganic Cr salt and thus has higher bioavailability (Lukaski, 1999). Inorganic Cr binds irreversible to the undigested materials in the intestines and thus their absorption is reduced from the small intestines (Underwood and Suttle, 2001; Amatya *et al*., 2004). The absorption of Cr absorption in the gut is enhanced by ascorbic acid by chelates formations, which prevents its precipitation at the alkaline pH of poultry gut (Mertz, 1969; Ahmed *et al*., 2005). According to NRC (1997), the Cr picolinate (CrPic) form is a distinctive molecule (Cr combined with picolinic acid) which helps the body to absorb it.

It is excreted primarily in urine either freely or bound to low molecular weight organic transporters (Ducros, 1992). The retention of Cr may relate to absorption patterns of various organic/inorganic sources of Cr. According to Amatya *et al*. (2004) Cr-yeast complex might be absorbed better than K-chromate and Cr-chloride. Cr is mainly accumulated in kidney, liver and muscle (Uyanik *et al*., 2005). Sahin and Sahin (2002) reported that supplement of a combination of Cr and ascorbic acid in the laying hen's diet decreases the Cr excretion. One of the reasons of the enhanced retention may be the unavailability of Cr in the basal diet of the birds which triggers the retention of the essential element in the gut. On the other hand, stressors cause depletion of Cr through altered glucose metabolism (Anderson, 1987; Ahmed *et al*., 2005).

GROWTH IN BROILER, JAPANESE QUAIL AND TURKEYS

A plenty of literature suggest that supplementation of Cr at different levels of supplementation and experimental conditions in non-ruminants species increases the carcass quality and decreased the body fat content (Ahmed *et al*., 2005). In a study, Lien *et al*. (1999) observed that weight gain of broilers to be increased when the diet was supplemented with 1600 or 3200 μg kg^{-1} of diet. A 16% increase in the rate of glucose utilization has been observed with chromium (Cupo and Donaldson, 1987). The dietary supplementation of CrPic has been shown to increase the growth of broiler birds without affecting their feed intake (Sands and Smith, 1999). Supplementation of Cr at 200 and 400 μg kg^{-1} did not show any affect on feed intake, weight gain, as well as Feed Conversion Ratio (FCR) (Ward *et al*., 1993). Hossain *et al*. (1998) found higher body weight and improved feed intake and feed efficiency in broilers with 300 or 400 μg kg^{-1} Cr-yeast. Moreover, the study of Kim *et al*. (1996) also revealed that 1600 or 3200 CrPic supplementation increased the weight gain and feed efficiency without affecting feed consumption in broilers. $CrCl_3$ supplementation in chicks showed no effect on gain in weight, but reduced feed consumption and improved feed efficiency, decreased serum glucose and increased protein, activity of Alkaline phosphatase (ALP), along with a slight decrease in cortisol levels (Uyanik *et al*., 2002a). Jackson *et al*. (2008) stated that Cr improved feed efficiency in broilers. Kroliczewska *et al*. (2004) found that 500 μg kg^{-1} of Cr supplementation in broiler chickens boosted their body weight gain and feed efficiency during the growing phase. Samanta *et al*. (2008) reported 0.5 mg kg^{-1} of Cr to improve the FCR, hot and dress carcass weight and weight of the wholesale cut compared to the control unsupplemented birds.

Many studies support Cr supplementation in the poultry diet to improve performances during heat stress (Sahin *et al*., 2002a, b, 2005; Moeini *et al*., 2011). Dietary supplementation of Cr (Cr nicotinate and Cr chloride) in heat-stressed broilers showed positive effects on productivity, carcass traits and enhanced the oxidative stability of refrigerated meat (Toghyani *et al*., 2012). Supplementing Cr (1500 ppb) to broilers in heat stress showed positive effects on weight gain and feed efficiency (Toghyani *et al*., 2006). Addition of Cr (500 μg kg^{-1}) nano-composite in broilers reared under heat-stress resulted in increased weight gains, improved feed efficiency, carcass yield and lean muscle and reduced abdominal fat (Zha *et al*., 2009). Chromium and copper, along with nicotinic acid treatments, have been found to modulate meat of broilers under tropical environment, cholesterol and crude fat contents decreased while crude protein increased significantly (Javed *et al*., 2010). Rao *et al*. (2012) reported that the dietary supplementation of organic chromium in commercial broiler chickens have no effect on body mass gain and feed efficiency at 21 and 42 days of age and relative mass of liver, abdominal fat and ready to cook yields at 42 days of age. However, body mass loss during pre-slaughter holding period (12 h) reduced and relative breast mass increased nonlinearly. However, in a study conducted by Habibian *et al*. (2013), dietary chromium supplementation could not show positive effects on growth performances, serum insulin, glucose and lipoprotein levels in broilers kept under heat stress condition. Recently, peppermint essential oil combined with CrPic dietary additions showed beneficial effects on blood biochemical parameters in broiler chicks maintained under heat stress (Akbari and Torki, 2014). Regarding mode of action of CrPic dietary supplement, a role of microRNA (miRNA) target genes has been shown to effect protein synthesis in skeletal muscles of broiler birds (Pan *et al*., 2013).

Sahin *et al*. (2001a) also reported, improved feed intake, weight gain, feed efficiency when Japanese quails were fed 200-1200 μg kg^{-1} CrPic. Onderci *et al*. (2005) observed that addition of Cr in the feed of Japanese quail increased feed intake, body weight, feed efficiency and carcass traits. Sahin *et al*. (2004) noted that increasing Cr supplementation (200, 400, 800 or 1200 μg kg^{-1}) led to more feed intake and improve body weight and feed efficiency in Japanese quail. Chromium (Cr) supplementation at 400 μg kg^{-1} level increased the live weight gain, feed efficiency and carcass traits in heat-stressed quails (Sahin *et al*., 2005). Moreover, El-Hommosany (2008) stated, increased body weight, weight gain and FCR in Japanese quail fed different levels of dietary Cr (125, 250, 375, 500 μg kg^{-1} diet, respectively). Recently, Sahin *et al*. (2010) described that CrPic supplemented at 400 and 800 μg kg^{-1} resulted in better feed intake, FCR and weight gain compared to control in Japanese quail. Chromium supplementation has been found to show positive effects on weight of turkey poults, carbohydrate metabolism (liver glycogen, active glycogen synthetase) but not on feed consumption of poults (Rosebrough and Steele, 1981). In growing turkeys, chromium nicotinate dietary supplementation showed dose dependant effects on growth performance, carcase characteristics and blood parameters. A dose rate of 1 mg kg^{-1} Cr significantly increased weight gain and feed intake at 9-18 weeks of age but not at 19-22 weeks; breast and thigh muscle got significantly increased at 1 mg kg^{-1}

dose but decreased at 3 mg kg^{-1}; serum triacylglycerol (TG) and uric acid concentrations increased but glycerol and alpha-globulin reduced at 3 mg kg^{-1}; serum cholesterol and glycerol reduced at 18 weeks while glucose increased and uric acid decreased by 1 mg kg^{-1} Cr at 22 weeks of age; creatinine got increased and beta-globulin decreased at 3 mg kg^{-1} dose (Chen *et al*., 2001). Rajalekshmi *et al*. (2014) investigated the effect of supplementation of chromium propionate at different dosage levels (100-3,200 μg kg^{-1}) in male broiler chickens (Cobb 400). The weight gain, feed intake, FCR and lymphoid organ weights were not significantly affected during the whole study period of 42 days. However, with increased chromium dosage, the breast meat yield increased linearly.

LAYING BIRDS' PERFORMANCE

The CrPic at the level of 1200 ppb has been found to improve egg weight, shell thickness, albumen index and weight as well as yolk weight and index in Japanese quail (Sahin *et al*., 2001a). Chromium (Cr) supplementation given at the rate of 400 and 800 μg kg^{-1} of feed in laying hens improved their egg weight, specific gravity, shell thickness, weight and Haugh unit (Sahin and Sahin, 2001). Sahin and Sahin (2002) noted, in laying hens that feeding Cr at the level of 400 μg kg^{-1} increased feed efficiency and consequently the egg production and weight were improved. Sahin *et al*. (2004) observed that Cr supplementation increased egg weight, shell thickness, specific gravity and Haugh unit in Japanese quail. Sahin *et al*. (2001b) also reported that Cr supplementation improved feed efficiency and subsequently the egg production was enhanced in laying hens. Recently, Hanafy (2011) found improved egg production, egg weight, albumen percentage, shell percentage, shell thickness, Haugh unit and yolk index in Bandarah laying hens. According to Hossain *et al*. (1998), Cr augments egg quality by acting as a structural component of egg albumin or in cross linking of protein, necessary for the synthesis of ovomucin and facilitates the transfer of cation into the albumin of egg during the plumping process in the uterus. Increasing egg shell thickness may be due to the action of Cr which stimulates and control insulin action or indirectly empowers the ascorbic acid transportation which has significant role in formation of eggshell (Anderson, 1994; Mowat, 1994; Hanafy, 2011). Jensen *et al*. (1978) suggested that Cr has a favourable effect on albumin quality and postulated that this element is necessary to maintain the physical state of albumin.

A combination of Cu (125 mg kg^{-1}) and CrPic (800-1600 μg kg^{-1}) dietary supplement showed significant reduction of egg yolk cholesterol, while egg traits (production, weight, shell strength and thickness) were not affected. Cu decreased serum cholesterol while both Cu and Cr significantly reduced Very Low-Density Lipoprotein (VLDL) and increased High-Density Lipoprotein (HDL) (Lien *et al*., 2004). A combination of CrPic and biotin revealed beneficial effects in terms of feed intake, feed efficiency, egg production and quality, Haugh unit, antioxidant status, cholesterol and mineral (Cr, Zn and Fe) contents of egg yolk in heat-distressed laying Japanese quails, the negative effects of high ambient temperature thus could be reduced (Sahin *et al*., 2004). Dietary CrPic (400 μg of Cr/kg diet) and ascorbic acid (250 mg of L-ascorbic acid) supplementation showed increased digestibility of nutrients (DM, OM, CP and EE), serum vitamin C and E (antioxidant vitamins) in laying hens kept at a low ambient temperature (6.8°C). The synergistic effects observed by combinations of CrPic and L-ascorbic acid may be helpful in preventing cold-stress-related problems in laying hens performances (Sahin *et al*., 2002c). Chromium (Cr) addition can alleviate negative effects of heat stress on egg production and quality as well as serum metabolites of laying Japanese quail (Sahin *et al*., 2002d). Also, dietary supplementation of CrPic and Vitamin C in heat-stressed laying hens showed feed intake to be increased with Cr or Vitamin C, produced eggs with higher shell mass and thickness; Cr lowered serum glucose, total cholesterol and triglycerides but increased serum albumin and total proteins; however revealed no effect on egg production, mass and volume, as well as feed conversion ratio and body masses (Torki *et al*., 2014). Addition of chromium propionate at a dose rate of 400 μg kg^{-1} diet improved egg production but reduced the egg quality (albumen height, yolk color score, Haugh unit), while 600 μg kg^{-1} improved shell thickness and 200 μg kg^{-1} reduced uric acid contents in hens under late-phase laying (Ma *et al*., 2014).

DIGESTION OF NUTRIENTS

Sahin and Sahin (2002) reported that Cr supplementation may improve functioning of pancreas with regards to secretion of digestive enzymes, which improves the retention of nitrogen and minerals. A reduced utilization of dry matter, crude protein and ether extract is observed in laying hens reared under low temperature (6.2°C) conditions, interestingly the supplementation of Cr was found to compensate these negative values (Sahin and Sahin, 2001). Metabolizability of the organic nutrients was better in the Cr supplemented group compared with the control (Amatya *et al*., 2004). Sahin and Sahin (2002) observed that magnitude of the increase and decrease in retention and excretion of N, ash and minerals was greater when Cr was supplemented in combination with ascorbic acid. Sahin and Sahin (2001) found that Cr supplementation increased the digestibility of dry matter, ash, organic matter, crude protein and ether extract in laying hens. Chromium (Cr) is believed to play a role in the metabolism of nucleic acid and stimulates amino acids incorporation in the liver (Weser and Koolman, 1969). Sahin *et al.* (2001b) registered higher digestibility of dry matter, organic matter, ether extract, crude protein, crude fibre and nitrogen free extract in laying hens. Ahmed *et al.* (2005) suggested that due to the antioxidative role of Cr, it is possible that Cr may exert a protective effect on pancreatic tissue which results in increased pancreatic functions comprising of the release of digestive enzymes and an enhanced nutrient utilization.

METABOLIC FUNCTION

Chromium is an essential element useful for metabolism of food in the body. Being a part of GTF, the prime role of chromium regarding metabolism is mediated through activating insulin (Anderson, 1987) and helps insulin to progress glucose into the cell for energy production (Sahin *et al.*, 2001a). Insulin controls the metabolism of carbohydrate, protein, fats and stimulates the uptake of amino acids and protein synthesis and also the glucose utilization (Linder, 1991; Vincent, 2000). Sahin *et al.* (2001a) found that serum glucose and total protein level decreased of Japanese quail decreased with CrPic supplementation. Also, serum insulin linearly increased and corticosterone decreased indicating metabolic role of this essential mineral. Linder (1991) documented that insulin and corticosterone has anabolic and catabolic functions, respectively, being opposite to each other in nature. Steele and Rosebrough (1981) stated that Cr acts as cofactor of insulin activity and the presence of this mineral is needed for maintaining proper glucose metabolism and growth in animals. Birds receiving Cr supplementation have registered decreased serum glucose and now it is proven that Cr is necessary for normal glucose metabolism (Lien *et al.*, 1999; Ahmed *et al.*, 2005; Moeini *et al.*, 2011). Steele and Rosebrough (1981) documented greater liver glycogen level in turkey poults by supplementation of Cr which resulted in increased activity of glycogen synthetase enzyme and higher glucose transport through increased activity of insulin. Sahin *et al.* (2001a) suggested that increased liver weight gain, feed efficiency and egg production may be due to the action of Cr which stimulates insulin production. Sahin and Onderci (2002) documented reduced serum glucose and corticosterone and increased insulin level in laying hens in response to Cr supplementation (200, 400 and 800 μg kg^{-1} of diet). Sahin and Sahin (2002) confirmed that Cr supplementation (400 μg kg^{-1}) increased serum insulin and decreased corticosterone and glucose concentration in laying hens. Onderci *et al.* (2005) observed that feed of Japanese quail supplemented with 1, 2 or 4 mg kg^{-1} resulted in lower serum glucose concentration. Sahin *et al.* (2001a, c, 2004, 2005) found that serum insulin increased and glucose and corticosterone decreased in laying hens and Japanese quail after supplementation of Cr in their diet. Uyanik *et al.* (2005) found that serum glucose decreased when $CrCl_3$ was supplemented in the diet of Japanese quail. According to Vincent (2000, 2001), chromodulin binds strongly four chromic binding ion before this olgipeptide acquires a conformation needed for binding to the insulin receptor via the tyrosine kinase active site. Thus, it appears that chromodulin plays a function in auto-amplification of insulin signalling. Ahmed *et al.* (2005) hypothesized that addition of Cr in poultry diet may boost the utilization of dietary energy through stimulation of insulin action and thus could help maintain productivity of birds even if the dietary energy level is lowered. Trivalent chromium (Cr(III)-chromium chloride as a yeast or as aminoniacinate, 50 ppm) supplementation has been reported to modulate hepatic cytochrome P-450 (CYP)-dependant monooxygenases enzymes in laying hens, which indicates that Cr at high levels can considerably blight CYP-catalysed drug metabolisms (Guerra *et al.*, 2002). The supplementation of chromium propionate at different dosage levels (100-3,200 μg kg^{-1}) in male broiler chickens (Cobb 400) reduced the serum glucose levels and increased the total protein levels (Rajalekshmi *et al.*, 2014).

ROLE IN ALLEVIATING LIPID PEROXIDATION

Chromium (Cr) has been postulated to enhance defence machinery of antioxidants. Sahin *et al.* (2010) reported that serum and liver MDA (malondialdehyde) (a pointer of lipid peroxidation), TNF-α, IL-6 and CRP (C-reactive protein) were decreased when CrPic was supplemented in the diet of Japanese quail. Onderci *et al.* (2005) found that feed of Japanese quail supplemented with 1, 2 or 4 mg kg^{-1} reduced serum, muscle and liver MDA and enhanced serum vitamin E and C concentration. Sahin and Sahin (2002) suggested that antioxidant effect of Cr is not less than vitamin C (Khan, 2011). Sahin *et al.* (2005) reported that supplementation of Cr alleviated peroxidation by decreasing MDA concentration and improved serum vitamin E and C concentration in Japanese quail. Toghyani *et al.* (2010) reported that lipid peroxidation in thigh meat was decreased after Cr supplementation in broilers. Onderci *et al.* (2005) suggested that antioxidant effect of Cr is related to inhibition of epinephrine resulting from the insolinotropic effect of Cr. Rao *et al.* (2012) reported that the dietary supplementation of organic chromium in commercial broiler chickens ameliorates oxidative stress by reducing lipid peroxidation and increasing the activities of plasma glutathione peroxidase and glutathione reductase.

ANTICHOLESTEREMIC AND HYPOLIPIDEMIC EFFECT

In non ruminant diets, reduction of blood cholesterol with addition of Cr is observed as the main response regarding lipid metabolism, which may be on account of an enhanced activity of insulin that decreases lipolysis and increases fatty acids assimilation in the adipocytes (Anderson, 1987; Vincent, 2000, 2001). Sahin *et al.* (2001a) found that serum cholesterol concentration decreased with dietary supplemented of 1200 μg kg^{-1} of CrPic in Japanese quail. Similarly, the lipid and cholesterol levels were found to be decreased by dietary Cr supplementation in laying hens (Lien *et al.*, 1999). Recently, Moeini *et al.* (2011) reported that serum HDL cholesterol was slightly improved when broilers were supplemented with Cr. Sahin and Onderci (2002) reported reduction in serum of triglyceride and cholesterol in laying hens in response to different levels of Cr supplementation. Onderci *et al.* (2005) observed that feed of Japanese quail supplemented with 1, 2 or 4 mg kg^{-1} resulted in reduced serum cholesterol level. Uyanik *et al.* (2005) found that $CrCl_3$ fed at different levels decreased fat percentage and serum LDL cholesterol. Sahin and Sahin (2002) and Sahin *et al.* (2005) also confirmed decrease in cholesterol concentration in laying hens and Japanese quail after Cr supplementation. Du *et al.* (2005) reported that addition of 600 μg kg^{-1} Cr improved abdominal fat, liver triglyceride, serum triglyceride and serum free fatty acid in laying hens at the end of the experiment. Liver is the key organ of cholesterol synthesis in laying hens and Cr improves the cholesterol profile through accelerating the activity of Lecithin Cholesterol Acyltrasnferase (LCAT), cholesterol esterification and excretion (Du *et al.*, 2005). Chromium (Cr) can increase liver LDL receptors and could decrease the LDL levels and in parallel activity the HDL fraction gets increased (Lien *et al.*, 1999).

EFFECT ON SERUM MINERALS

Sahin and Onderci (2002) reported increased serum concentration of Calcium (Ca), Phosphorous (P) and Potassium (K) and decreased level of Sodium (Na). Uyanik *et al.* (2005) documented that feeding $CrCl_3$ did not affect serum Ca and P, but increased magnesium (Mg) concentration at the level of 100 mg kg^{-1} of feed. Sahin and Sahin (2002) noted that Cr supplementation in the form of CrPic (400 μg kg^{-1} of diet) improved the retention of minerals and decreased the excretion of Ca, P, Cr, Nitrogen (N), zinc (Zn) and iron (Fe) in laying hens. Sahin *et al.* (2005) observed that Cr supplementation reduced the excretion rate of Zn and Fe in Japanese quail. According to Ahmed *et al.* (2005) the superior retention of Zn and copper (Cu) in the body may be due to the supplemental Cr which might have reduced urinary losses of these elements. Amatya *et al.* (2004) found that Cu, Zn, Fe and manganese (Mn) retention was better when Cr was supplemented in the feed of broilers in the form of Cr-yeast, whereas Uyanik *et al.* (2002b) reported that 20 ppm $CrCl_3$ increased serum Ca and Mg in laying hens. $CrCl_3$ supplementation in chicks showed decreased serum Ca and Mg levels and increased Zn and Cu levels (Uyanik *et al.*, 2002a). Effects of different levels of organic and inorganic chromium (chromium chloride, chromium L-methionine) showed an increase in serum Cr and Zn concentrations but decrease in Cu contents (Ghazi *et al.*, 2012). Dietary CrPic and ascorbic acid supplementation showed increased concentrations of Fe, Zn, Mn and Cr in laying hens at a low ambient temperature (Sahin *et al.*, 2002c), while CrPic and Vitamin C supplementation in heat-stressed laying hens increased Ca and P concentrations (Torki *et al.*, 2014).

EFFECT ON IMMUNE RESPONSES

Effects of dietary $CrCl_3$ supplementation on immune response in broilers revealed an increase in ratio of bursa of Fabricius and liver to body weight, reduced the counts of heterophil and monocyte as well as ratio of heterophil/lymphocyte (H/L), while lymphocyte counts, total antibody, antibody titers (IgG and IgM) increased along with an increase in the Cell-Mediated Immunity (CMI) to phytohemagglutinin (PHA) (Uyanik *et al.*, 2002b). The dietary use of organic and inorganic chromium (chromium chloride, chromium L-methionine) showed a significant increase in antibody responses, improved H/L ratio, CMI (Cutaneous Basophil Hypersensitivity (CBH) response test to PHA-P) as well as relative weights of thymus and spleen in broilers reared under heat stress. The organic form was found to be better in reducing heat stress-related immunodepression in broiler chicks (Ghazi *et al.*, 2012). The CrPic supplementation through feed or drinking water enhances the immune response by up-regulating interferon-gamma

(IFN-γ) expression after vaccination with R_2B strain of Newcastle Disease (ND) in broiler chicken. On day 1, IFN-γ expression in spleen was about 2-4 times higher than control and on day 3 post-immunization, IFN-γ expression was about 27-40 times higher. However, on day 7 post-immunization IFN-γ expression reached basal level in all the vaccinated groups. Interestingly, other groups exhibited down-regulation of IFN-γ expression (Bhagat *et al*., 2008). Rao *et al*. (2012) reported that the dietary supplementation of organic chromium in commercial broiler chickens has no effect on ratio between heterophyl and lymphocyte and relative mass of lymphoid organs such as bursa, spleen and thymus and antibody production against Newcastle disease vaccination. However, CMI (lymphocyte proliferation ratio) increased nonlinearly with dietary Cr supplementation. Rajalekshmi *et al*. (2014) investigated the effect of supplementation of chromium propionate in male broiler chickens (Cobb 400) and found that the lymphoid organ weights were not significantly affected during the whole study period of 42 days. However, with increased dose of chromium, the antibody response against ND vaccination and CMI response (lymphocyte proliferation ratio) enhanced quadratically. Furthermore, heterophil: lymphocyte ratio decreased which indicated decreased stress levels.

CONCLUSION

In conclusion, the present literature review showed that the dietary chromium (Cr) has useful effects on feed consumption, nutrient digestibility, antioxidant machinery, growth and production performances and egg qualitative traits. Chromium is an essential mineral element that plays important role in livestock and poultry nutrition and treatment at appropriate dosage levels and recently it has gained considerable public attention. It is also very helpful especially in poultry under heat-stress environmental conditions. Exploring the possible mechanism of action of Cr such as its various pharmacological and biological activities, nutritional biochemistry and molecular mechanisms of actions are crucial for successful farm animal management that may provide further understanding of the health and performance ramifications of immune-endocrine interactions in agricultural species. Poultry fed diet supplemented with chromium significantly revealed higher levels of chromium and other trace elements compared to those without any supplementation. Recently, chromium is used in the poultry diet because of its anti-stress effects during stress conditions and other various pharmacological, growth and immune enhancing effects. Moreover, beneficial effects of lowered serum levels of glucose, total cholesterol, as well as triglycerides have been observed in poultry fed diets with chromium, indicating the positive health-effects of chromium dietary supplementation. Therefore, the chromium plays a key-role in poultry nutrition. There is a need to study combined effects inorganic, biochemical and nutritional effects of chromium (III) to better understand the beneficial effects of chromium supplementation in livestock and poultry production and health. The requirements of different classes of poultry and the quality of the different trace minerals used are the areas that warrant attention. Further, the bioavailability of minerals to the poultry is limited due to natural factors; hence the role of trace minerals to improve mineral availability in modern high producing poultry may be examined.

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