Biological Trace Element Research (2023) 201:2546–2554
https://doi.org/10.1007/s12011-022-03326-z

Investigation of Different Nutritional Effects of Dietary Chromium in Fish: A Literature Review

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Received: 16 February 2022 / Accepted: 9 June 2022 / Published online: 2 August 2022

Abstract

The supply of food for the world population that is increasing is one of the concerns of governments. The Food and Agriculture Organization of the United Nations assessment shows that the aquaculture industry could help meet food needs for human communities. The aquaculture industry also relies on providing a feed of high quality. Minerals are one essential component of an aquatic diet. Chromium (Cr) is a trace element that finds the form of Cr^{+3} (trivalent) and Cr^{+6} (hexavalent) in nature and food items. Studies show that exposure to Cr waterborne have toxicity effects on fish. However, oral exposure to Cr has a different impact on fish. Cr is usually involved in the metabolism of fats, carbohydrates, proteins, growth function, enzyme functions, etc. This element could play a significant role in fish nutrition and physiology. Cr as a dietary supplement can improve growth performance and adjust the metabolism of carbohydrates and lipids. However, high concentrations of Cr can be toxic to fish. Although the physiological effects of Cr on aquatic organisms are well known, there are still ambiguities in determining the appropriate concentration in the diet of some species. Maybe, the physiological response of fish depends on the concentration, origin, and chemical composition of Cr, as well as the biological and individual characteristics of the fish. Therefore, it is necessary to estimate the appropriate concentration of Cr in fish diets. This article aims to summarize the available information about the effect of Cr on various physiological indicators and fish growth. Therefore, this information may help to find the appropriate concentration of Cr in the diet.

Keywords Chromium · Dietary supplement · Nutritional effects · Metabolism · Aquatic organisms

Introduction

Heavy metals are a group of metals and metalloids that have a relatively high density and are very toxic to plants and animals [1]. If the heavy metals enter a body of organisms through the food chain, they can have a toxic effect on the body of animals [2]. Some heavy metals, such as chromium (Cr), are also known as trace elements [3, 4]. This metal finds in different forms, divalent (Cr^{+2}), trivalent (Cr^{+3}), and hexavalent (Cr^{+6}) forms. Although Cr^{+3} and Cr^{+6} are the most dominant and stable forms [5], Cr + 3 is a natural and stable form of chromium that find in living organisms [6]. Also, Cr^{+3} as a cofactor could affect the metabolism of glucose, lipids, and proteins in various animal species [7]. Cr binds to an oligopeptide to form chromodulin, a low molecular weight. Next, chromodulin conjugates to insulin receptors and enhances insulin affinity for its receptor [8, 9]. The role of chromium in carbohydrate metabolism has been reported for turkeys [10] and humans [11]. Furthermore, Cr has an important role in the metabolism of protein, nucleic acid, and lipids [12]. Cr also reduces cholesterol and triglyceride [13, 14] and enhances the concentration of insulin and high-density lipoprotein (HDL) in serum [15, 16]. However, there is little information about the nutritional effects of dietary chromium on various fish (Tables 1, 2, 3, and 4).

In fish, Cr may be absorbed through the gills and gastrointestinal tract and then enter the tissues through the

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Table 1 The effects of chromium on growth performance

Species	Diet	Duration	Effects	References
Common carp(*C.carpio)*	0.5 mg kg^{-1}Of Cr Supplementation 2 mg kg^{-1} Of chromium supplementation	65 days 30 days	Increased growth performance Decreased growth performance	[17]
Herbivorous carp(*C. idellus)*	0.8 mg kg^{-1}Of chromium Supplementation 1.6 mg kg^{-1} Of chromium supplementation	10 weeks	Increased growth performance Decreased growth performance	[15]
Nile tilapia *(O. niloticus)*	1200 µg L^{-1} of (Cr-Pic) supplementation	–	Had no significant effect on the growth performance	[18]
Gilthead seabream (*S. aurata*) & Rainbow trout (*O. Mykiss*)	(Cr-Pic) supplementation	–	Did not improve growth performance	[19–21]
Nile tilapia(*O. niloticus)*	1.2–1.8 mg kg^{-1} of Cr supplementation	–	Significantly improved final body weight, WG, SGR, protein efficiency, and feed intake	[22]
Young golden pompano (*T. ovatus*)	20 mg kg^{-1} or more (Cr-Nic) supplementation	–	Decreased growth performance	[23]
Striped catfish (*P. lineatus*)	2 and 4 mg kg^{-1} of Cr supplementation 8 mg kg^{-1} of chromium supplementation	–	Increased growth and feed intake Decreased growth and feed intake	[24]
Rohu (*Labeo. Rohita)*	800 μ g kg^{-1} of (Cr-Pic) supplementation	–	Significantly improved WG, SGR, FER, and PER	[25]
Rohu *(L. Rohita)*	0. 3 mg kg^{-1} of Cr supplementation	–	Showed better survival	[26]

Table 2 The effects of chromium on carbohydrate

Species	Diet	Effects	References
Common carp (*C. carpio*)	chromium chloride supplementation	Decreased glucose levels	[27]
Young golden pompano (*T. ovatus*) Common carp (*C. carpio*) and Nile tilapia (*O. niloticus*)	chromium poly nicotinate supplementation chromium supplementation	Increased growth performance and carbohydrate intake Can improve glucose utilization and inhibit gluconeogenesis	[23]
Rohu (*L. Rohita)*	low levels of Cr-Pic supplementation High levels of Cr-Pic supplementation	Significantly increased liver glycogen levels Significantly decreased liver glycogen levels	[25]
Herbivorous carp(*C.idellus)*	High levels of Cr-Pic supplementation	Significantly decreased liver glycogen levels	[15]

Table 3 The effects of chromium on fat

Species	Diet	Effects	References
Nile tilapia (*O. niloticus)*	Chromium supplementation	High body fat content was observed	[28, 29]
Goldfish (*C. auratus)*	High concentrations of chromium supplementation	Fish body crude fat was significantly reduced and no significant difference in the activity of glucose-6-phosphate dehydrogenase (G6PDH) enzyme was observed	[30–32]
Herbivorous carp (*C.idellus*)	Cr-Pic supplementation	Carcass fat content was significantly reduced	[15]
Rohu (*L. Rohita)*	Cr-Pic supplementation	High lipid content in carcasses was observed	[25]

blood. However, its absorption and excretion mechanisms are unclear. Studies showed that Cr could be uptake from water and diet [35]. Although Cr could affect fish's nutritional and physiological responses [36], Cr is not an essential biological element [37]. Previous studies showed that oral administration Cr-picolinate (Cr-Pic) increased the crude protein content in the carcass of Nile tilapia (*Oreochromis niloticus*), while decreasing crude fat [18]. A significant decrease was reported in the carcass fat content in the herbivorous carp (*Ctenopharyngodon idellus*) fed Cr-Pic dietary supplementations [15]. However, feeding zebrafish (*Danio rerio*) breeders with chromium-rich

Table 4 The effects of chromium on enzymes

Species	Diet	Effects	References
African catfish (*Clarias gariepinus*)	Chromium supplementation	Creatine kinase activity insignificantly reduced in serum, but reduced significantly in kidney and liver with enhancing chromium concentration	[33]
Young blunt snout bream (*Megalobrama amblycephala*)	Chromium supplementation	Growth and homeostasis blood glucose were increased positively	[34]
Young golden pompano (*Trachinotus ovatus*)	Cr-Nic supplementation	Activities of GK and PFK enzymes were not significantly different from the control groups, and HK and PK activities were increased compared to control groups	[23]
Rohu (*L. Rohita*)	Cr-Pic supplementation	Amylase, protease, and lipase activity in intestinal tissue were significantly increased	[25]

un-encapsulated Artemia cyst reduced larval survival rates [38].

Compared to birds and mammals, fish often rely on protein sources to supply energy and use fewer carbohydrates as energy sources. Therefore, fish need Cr much less than mammals and poultry [39–41]. Previous studies showed that Cr is involved in the metabolism of carbohydrates [4, 42] and act as a cofactor for insulin in transporting glucose from the bloodstream to peripheral tissues [43]. Consequently, Cr dietary supplementation can increase protein-sparing efficiency and make it possible to replace carbohydrates as an energy source for fish.

Moreover, studies revealed that fish's physiological response to Cr supplements might depend on species, age, gender, concentrations of Cr, and Cr supplement origin. Furthermore, biological conditions, physicochemical quality of water and the breeding system, and test duration may also affect the results [44–46].

Research on the effects of Cr on fish health and growth is very limited and often includes studies on the toxicity of Cr. Therefore, there is a gap in information about the effects of Cr on fish. Therefore, in the present paper, a literature review on the impacts of Cr on fish has been done. Hence, studying its effects on aquatic health seems necessary to better understand the advantages and disadvantages of using Cr supplements in fish diets.

The Effects on Growth Rate

The effect of Cr on fish growth is highly contradictory and depends on the concentration of Cr in the diet, a chemical form of Cr, and species of fish. Feeding *Cyprinus carpio* with 0.5 mg kg^{-1} Cr increased growth performance after 65 days, while oral administration of 2 mg kg^{-1} Cr reduced growth after 30 days [17]. A significant increase was observed in the growth performance of grass carp (*Ctenopharyngodon idellus*) fed with dietary supplements containing 0.8 mg kg^{-1} for 10 weeks, while growth indexes decreased when Cr concentration increased [15]. Improvement in growth indices and an increase in hepatic glycogen stores were also observed in Nile tilapia [22], and hybrid tilapia (*Oreochromis niloticus* × *O. aureus*) [28] fed Cr supplementation. Feeding fingerlings *L. rohita* and grass carp, *C. idellus* with 800 µg kg^{-1} Cr-Pic significantly improved growth performance indexes. Results showed that alterations in growth performance were related to increasing protein assimilation [25].

Furthermore, Giri et al. [13] and Liu et al. [15] found that Cr-Pic could improve the efficiency of consuming carbohydrates as an energy source. Therefore, Cr-picolinate supplementation could affect the protein-sparing action of carbohydrates. Similarly, increased survival and growth rates were reported in fish fed with Cr supplementation [26, 47].

In contrast, oral administration of Cr-Pic dietary supplement did not have a significant effect on the growth performance of *O. niloticus* [18], gilthead seabream (*Sparus aurata*) [19], and rainbow trout (*O. mykiss*) [20, 21].

Growth performance decreased after young golden pompano (*Trachinotus ovatus*) fed 20 mg kg^{-1} Cr-nicotinate (Cr-Nic) supplementation [23]. Decreased growth was observed in Crocker (*Larimichthys crocea*) [47], tilapia [15, 48], and rainbow trout [49] fed with diets containing relatively high levels of Cr. A decrease in growth performance and feed efficiency may be due to the toxic effect of Cr. Oral administration of dietary supplements containing 8 mg kg^{-1} caused toxicity and reduced the growth performance of striped catfish [24]. In common carp (*Cyprinus carpio*), the concentration of 0.5 mg kg^{-1} of Cr supplement in the diet increased growth, while the concentration of 2 mg kg^{-1} decreased growth [17]. Previous studies showed that increasing concentrations of Cr could affect the feed taste [24]. Therefore, the administration of high concentrations of Cr supplementation could reduce fish's appetite and growth performance [24].

The Effects of Cr on Carbohydrate Metabolism

Cr can affect glucose metabolism and helps insulin transport glucose into cells for energy production. Cr-Pic dietary supplements can regulate urea and glucose levels. Feeding *C. carpio* with CrCl2 supplementation decreased glucose levels in the serum [27]. The use of Cr-poly nicotinate in the diet of juvenile *T. ovatus* could increase the protein-sparing effect of carbohydrates [23]. A significant decrease in gluconeogenesis in the liver of *Labeo rohita* indicated that the administration of Cr could change the carbohydrate metabolism pathway [25]. Change in the enzyme activities involved in carbohydrate metabolism was observed in *Catla catla* [50], *C. carpio* [27], and hybrid tilapia [51] fed with Cr supplement. Increasing the catecholamine levels affect glycogenolysis in the liver of *Anabas scandens* fed with Cr supplement [52]. The effect of Cr on insulin functions may accelerate the assimilation of amino acids and protein biosynthesis [26, 53].

The Effects on Fat Metabolism

Chromium salts can accelerate the process of lipogenesis and affect glycogen accumulation in the presence of insulin [10, 54–56]. Insulin reduces fat lipolysis by reducing the adenylate cyclase activity and hormone-sensitive lipase [57]. The high body fat content of tilapia was significantly observed in glucose-containing diets in which chromium supplementation was used compared to chromium-free diets [28, 29]. The liver glycogen content of Atlantic salmon (*Salmo salar L*) increased at different levels of the presence of corn starch in the diet.

The reduction of crude fat in fish carcasses fed with high concentrations of Cr supplementation may be due to the toxicity of Cr [58]. However, administration of low levels of Cr-Pic supplementation (800 μg kg^{-1}) could increase the fat content of fish carcasses [15]. It is hypothesized that the administration of low levels of Cr-Pic supplement may cause fish to use carbohydrates for energy and dietary lipids to accumulate in fish tissue [51].

Studies showed that high levels of Cr can reduce lipid storage by regulating lipogenesis [58]. However, there is no report on the effect of Cr supplementation on the activity of glucose-6-phosphate dehydrogenase (G6PDH), one of the enzymes involved in lipolysis [30–32]. Therefore, there was insufficient evidence to support the involvement of G6PDH in lipogenesis [25]. Cr supplementation may accelerate the conversion of glucose to Acetyl-CoA (necessary in the process of lipogenesis) [55, 56], possibly by increasing pyruvate dehydrogenase [59], Acetyl-CoA carboxylase, and citrate lyase activity [60] followed by promoting lipogenesis.

The Effect on Protein Metabolism

The fact that chromium is involved in protein metabolism has been well established [61] and improves the function of insulin to regulate amino acid metabolism [62]. Due to its lipophilic nature, Cr-Pic supplementation used in the diet can increase cell membrane fluidity and insulin uptake to accelerate insulin activity, and therefore amino acid transfer and protein synthesis may increase [63, 64]. Previous studies have shown that Cr in the diet positively affects crude carcass protein [65]. Cr-Pic dietary supplementation (up to 1200 μg L^{-1}) significantly increased crude protein content and decreased ether extract content in Nile tilapia *O. niloticus* [18]. Moreover, a significant increase was reported in the crude protein content of Nile tilapia carcasses fed Cr supplement [18, 34]. Laboratory studies showed that Cr is involved in nucleic acid metabolism and biosynthesis of proteins in the liver [66]. Cr supplementation could reduce blood urea nitrogen content, indicating improved protein synthesis in fish [22].

The Effects on Enzymes

Enzymes are large biochemical molecules that monitor metabolic processes in living organisms, so a slight change in enzyme activity in the body can affect the condition of an organism [67]. Accordingly, by assessing the enzymatic activity in an organism, a metabolic disorder can be easily recognized. Enzymatic activities also prepare rapid screening methods to assess the health of various fish and can be used to estimate the initial lethal concentration of a toxin. Creatine kinase is found in various body tissues containing bones and muscles. It must catalyze the conversion reaction of creatine to phosphocreatine by dividing itself in the conversion of adenosine triphosphate (ATP). In one study, chromium supplementation in the diet significantly decreased creatine kinase activity under cold stress conditions [22]. Although Cr could not significantly affect creatine kinase activity in serum, its activity decreased in the kidney and liver of catfish [33].

Cr is a metal element that significantly affects the activity of various enzymes in the body. Cr supplementation in the diet increases liver enzymes such as glycolytic enzymes and lipogenic enzymes associated with an early section of glycolysis and lipogenesis pathways [68], which elucidate the mechanisms regulating carbohydrate intake [69, 70]. Cr supplementation could significantly affect blood glucose homeostasis by regulating the gene expression of enzymes involved in glucose regulation (phosphoenolpyruvate carboxykinase PEPCK, pyruvate kinase PK, glycogen synthase GS, and glucose-6-phosphatase G6Pase) [34]. Moreover, Cr dietary can also regulate lipid levels in mRNA levels of lipogenesis genes in Blunt Snout Bream (*Megalobrama amblycephala*) [34].

In a previous study, the effect of Cr on glucokinase (GK), pyruvate kinase (PK), hexokinase (HK) and 6-phosphofructokinase (PFK) activities, which are key enzymes in the glycolysis process, were assessed [23]. GK is the first glycolytic pathway enzyme that plays an essential role in catalyzing the conversion of glucose to glucose-6-phosphate, which is an intermediate metabolite and can be used in various catabolic metabolic pathways (glycogenesis and pentose phosphate) [71–74]. In some fish, such as rainbow trout, carp, goldfish, and gilthead seabream, liver GK enzyme activity is strongly provoked after the use of carbohydrates, and this action is communicated to the high expression of the liver GK enzyme gene [71–74]

In one analysis, the activities of GK and PFK enzymes in the groups that received Cr-Nic in their diet were not significantly different from the control groups. On the other hand, Cr-Nic in the diet naturally increased HK and PK activities compared to control groups [23]

Glycolysis is the only pathway for glucose catabolism in various organisms, including fish [75], and involves the progressive oxidation of one molecule of glucose (6C) to two molecules of pyruvate (3C). HK and PK are key enzymes that regulate the glycolytic pathway. The HK enzyme catalyzes the first glycolysis reaction, which involves the phosphorylation of glucose to glucose-6-phosphate, a molecule that may be used in other metabolic and catabolic pathways such as glycogenesis and the pentose-phosphate pathway [76–78]

PK catalyzes the last stage of glycolysis, which converts phosphoenolpyruvate to pyruvate [79–83]. A study found that Cr-Nic supplementation possibly regulated glycolytic processes by increasing HK and PK activity, thereby increasing growth performance and feed efficiency in fish-fed diets containing chromium supplements. In addition, hepatic glycogen was significantly lower in the food groups that have Cr-Nic supplements than in the control group. The various digestive organs of the body are highly sensitive to food composition and cause immediate changes in the activity of digestive enzymes [84–86]. Increased activity of digestive enzymes indicates better utilization of nutrients in the diet and thus better growth. The study found that amylase, protease, and lipase activity in intestinal tissue was significantly increased in diets containing 800 μg kg^{-1} of Cr-Pic supplementation, indicating an improvement in nutrient utilization, and the result is higher growth performance [25].

The Effect of Chromium on Cortisol

Cr supplement could decrease stress by reducing cortisol in serum [87–92]. Stressors increase plasma cortisol levels, including cold exposure [88] and short-term heat exposure [89]. How chromium affects cortisol production is unknown. Glucocorticoids inhibit insulin excretion [93]. Because chromium boosts insulin function, it may inhibit cortisol secretion reversely. In a study on tilapia, serum cortisol levels decreased following dietary chromium supplementation [22].

Toxicity of Chromium

High levels of Cr in diet and water cause tissue changes in the intestine, gills, liver, and kidneys, but the mechanism of toxicity is not yet known [35, 94]. The toxicity of Cr^{+3} is very low. However, Cr^{+6} is more toxic than the Cr^{+3} form due to its easy permeability through cell membranes [95]. Toxic Cr^{+6} readily crosses cell membranes and then decreases when converted to the trivalent form. The Cr^{3+} form combines with numerous macromolecules, including genetic material, within the cytosol, eventually resulting in changes due to the toxic and mutagenic form of chromium [96].

Kim and Kang [97] found that dietary chromium (Cr^{+6}) exposure could induce oxidative damage and block the catalytic domain of acetylcholine esterase [97]. The bioaccumulation capacity of Cr in fish has been studied [98–101]. Kumar et al. [102] showed that the toxicity of Cr in fish depends on the pH and temperature of the water [102]. Also, Lunardelli et al. [103] detected a significant correlation between Cr concentrations in the environment and alteration in oxidative biomarkers in the Neotropical fish, *Prochilodus lineatus* [103]. Similar changes in the antioxidant enzymes were reported in the liver of eel fish (*Anguilla anguilla*) [104].

Moreover, Mohamed et al. [105] reported histopathological and hematological changes in *O. niloticus* exposed to Cr^{+6} [105]. Similarly, growth performance and a decrease in CYP450 and GST gene expression. Furthermore, the metallothionein gene expression increased in the liver of juvenile rockfish *Sebastes schlegelii* after oral exposure to Cr [6].

Histopathological damage to gills, increased mucus secretion, and increased blood lactate were observed in *Colisa fasciatus* following exposure to Cr [106].

Conclusion

Although Cr is not the essential biological element, it can affect the physiology and health of fish. Fish can uptake Cr from diet and water. However, oral administration of Cr may have contradictory impacts on fish. Exposure to waterborne Cr could have toxicity effects on fish. Literature reviews showed that Cr could play a role in the metabolism of fats, carbohydrates, and proteins and affect the function of enzymes and some parameters. Also, the suitable levels of Cr in fish diets could improve growth performance. In contrast, high concentrations of Cr could have toxic effects on fish and decrease fish carcasses' growth rate and quality.

Overall, the chemical structure, origin, concentration, and bioavailability of Cr play a decisive role in its effects on fish. Furthermore, individual characteristics, species, gender, and environmental conditions also play a role in the physiological response of fish exposed to Cr. This information suggests that knowledge of the non-toxic concentrations of Cr in the food and environment is essential for different fish species. As a result, this report may help to design a complete diet containing chromium supplements.

Author Contribution Bagheri and Gholamhosseini collected manuscripts data and wrote the manuscript. Banaee contributed to the final manuscript.

Data Availability The data that support the findings of this study are available from Shiraz University but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Shiraz University.

Declarations

Conflict of Interest The authors declare no competing interests.

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