



Chromium Supplementation in Diet Enhances Growth and Feed Utilization of Striped Catfish (*Pangasianodon hypophthalmus*)

Shahana Akter¹ · Nusrat Jahan¹ · Md Fazle Rohani² · Yeasmin Akter³ · Md Shahjahan¹

Received: 11 November 2020 / Accepted: 24 January 2021 / Published online: 3 February 2021
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC part of Springer Nature 2021

Abstract

Chromium (Cr) is a trace element and plays a significant role in fish nutrition and physiology. An experiment was designed to know the effects of Cr addition in the diets to growth and feed utilization in striped catfish (*Pangasianodon hypophthalmus*). Four diets with Cr (0, 2, 4, and 8 mg kg⁻¹) were fed to striped catfish in aquaria with triplicate groups for 60 days. Survival, growth parameters (weight gain, WG; %WG; specific growth rate, SGR), and feed utilization (feed intake, FI; feed efficiency, FE; protein efficiency ratio, PER; feed conversion ratio, FCR) were calculated at the end of the feeding trial. Several hemato-biochemical parameters, such as hemoglobin (Hb), red blood cell (RBC), white blood cell (WBC) and glucose level, and frequency of micronucleus (MN) formation in erythrocytes, were analyzed. The growth parameters (WG, %WG, and SGR) and feed utilization (FE and PER) increased significantly in the fish fed with 2 and 4 mg kg⁻¹ Cr supplemented diets. On the other hand, the growth parameters suppressed in the fish fed with 8 mg kg⁻¹ Cr-based diet. The polynomial regression analysis based on WG showed that 2.82 mg kg⁻¹ Cr supplementation in the diet is optimum for the tested fish species. The values of Hb (g/dL), RBC ($\times 10^6/\text{mm}^3$) and blood glucose (mg/dL) significantly decreased in the fish fed with the highest (8 mg kg⁻¹) Cr-based feed. Conversely, MN frequency was significantly increased in the fish fed with 8 mg kg⁻¹ Cr-based diet. Overall, 2.82 mg Cr kg⁻¹ can be added to the diets of striped catfish for its better growth with maximum utilization of feed.

Keywords Aquaculture · Feed · Hematological parameters · Micronucleus · Growth · Fish

Introduction

Bangladesh is a sub-tropical country, most suitable for aquaculture [1]. Fish production from natural resources has gradually been declined due to the degradation of their ecological balance. Consequently, the aquaculture industry has expanded very rapidly in the last three decades and Bangladesh ranked 5th in global aquaculture production [2]. Nevertheless, recently, the low quality as well as increased price of fish feed is alarming for aquaculturists. In aquaculture, fish feed requires around 50

to 60% of the total operational cost [3, 4]. In fact, increased price of feed ingredients (fishmeal, fish oil, cereal, etc.) complicated the easy availability of aqua-feeds to many fish farmers. On the other hand, sustainability of aquaculture depends on proper nutrition content and cost-effective feed [4].

Nutrition is one of the most important factors in aquaculture. Aquaculturists must have a clear knowledge about the actual amount of feeds with proper nutrition for better growth, health status, and reproduction of fish. Among different trace elements, chromium (Cr) plays a significant role in the fish nutrition and physiology [5, 6]. Cr has various positive impacts on human health as well as several farmed animal species [7]. Cr in the feed participates in the metabolism of various nutrients, such as protein, fat, and carbohydrate [6, 8]. It has been reported that Cr in diet improve the metabolism of carbohydrates and thus enhance the feed utilization and growth of Nile tilapia, *Oreochromis niloticus* [9], and common carp, *Cyprinus carpio* [10]. Dietary carbohydrates in association with organic Cr act as energy currency that helps in smooth operation of various biological processes and exhibits superior growth of fish [11]. It has been reported that chromodulin role of Cr amplify the process of insulin signaling and successively influence the metabolic rate of

✉ Md Shahjahan
mdshahjahan@bau.edu.bd

¹ Laboratory of Fish Ecophysiology, Department of Fisheries Management, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

² Department of Aquaculture, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

³ Department of Applied Chemistry and Chemical Engineering, Noakhali Science and Technology University, Noakhali 3814, Bangladesh

various nutrients as well as growth performance [7, 12]. Supplementation of Cr improves growth performance of animals through increasing energy metabolism. Cr supplementation in certain dosage positively stimulates the growth performance of rainbow trout (*Oncorhynchus mykiss*) [13], Indian major carp (*Labeo rohita*) [14], and hybrid tilapia (*Oreochromis niloticus*) [15]. Cr changed the serum fatty acid profile through the metabolism of fatty acid in rats [16] and finishing pigs [17, 18]. Kucukbay et al. [5] reported that Cr decreases the blood cholesterol in the rainbow trout. Cr supplementation in the diets decreased serum cholesterol, low-density lipoprotein cholesterol, and triglycerides, while increased serum high-density lipoprotein cholesterol in the broiler chicken [19, 20]. Similar result was reported in the grass carp (*Ctenopharyngodon idella*) fed with Cr-supplemented diet [6].

The health status of fish is checked by measuring different blood parameters [21–24]. Usually, the oxygen is transported to different tissues by hemoglobin (Hb). Thus, the blood Hb content is commonly used to know the abnormalities and pathological signs of fish health [25, 26]. Similarly, variations in the white blood cell count and blood glucose content are also used as a biochemical immunosuppressive sign for fish [26–28]. On the other hand, morphological alterations of blood cells are examined to assess the health condition of fish [28, 29]. For example, several authors studied the frequency of micronucleus (MN) formation in the erythrocytes to know the stress due to environmental contaminants [29–31]. The MN is a small mass of cytoplasmic chromatin created outside of the central nucleus during the nuclear division of the chromosome [32].

Striped catfish (*Pangasianodon hypophthalmus*) is an important fish species for aquaculture in Bangladesh, which was introduced from Thailand in 1989. This is a fast growing fish species with high adaptability to diverse environmental conditions. Therefore, its culture practice has been expanded throughout the country. In Bangladesh, the annual production of this fish species is 0.45 million metric tons, representing 11% of the total fish production [33]. It is considered as a good source of protein and calories. It has a high consumer value due to its availability in the market as a live condition. Recently, the profit has been decreasing day by day due to increased feed cost and improper nutrition. However, there is no available information about the role of Cr as a nutritional component in the striped catfish. Therefore, the present investigation was designed to know the effects of Cr addition in the diet to growth and feed utilization in the striped catfish.

Materials and Methods

Experimental Diets

The ingredients (Table 1) used to formulate the diets were procured from the local market. In the experimental diets, rice

Table 1 Formulation and proximate composition experimental diet (% dry matter basis)

| Formulation | Diet 1 | Diet 2 | Diet 3 | Diet 4 |
|----------------------------------------------|--------|--------|--------|--------|
| Ingredients (%) | | | | |
| Fish meal | 40 | 40 | 40 | 40 |
| Soybean meal | 25 | 25 | 25 | 25 |
| Rice bran | 15 | 15 | 15 | 15 |
| Wheat bran | 15 | 15 | 15 | 15 |
| Molasses | 4 | 4 | 4 | 4 |
| Vitamin-mineral premix | 1 | 1 | 1 | 1 |
| Chromium (mg kg ⁻¹) supplemented | 0 | 2 | 4 | 8 |
| Proximate composition analysis | | | | |
| Moisture (%) | 11.23 | 10.33 | 10.90 | 11.78 |
| Crude lipid (%) | 7.35 | 7.80 | 7.36 | 7.46 |
| Crude protein (%) | 38.50 | 38.97 | 38.58 | 38.79 |
| Ash (%) | 12.71 | 12.86 | 12.65 | 12.00 |
| Crude fiber (%) | 4.14 | 4.20 | 3.90 | 4.20 |
| NFE | 25.87 | 25.84 | 26.61 | 25.77 |

and wheat brans were used as a source of carbohydrate. Four experimental diets were formulated containing 0, 2, 4, and 8 mg kg⁻¹ of chromium (Cr). For preparation of the test diets, dry ingredients were mixed thoroughly with molasses and cold distilled water. Then, wet extrusion of the pellets was done with the help of a pelletizer. Finally, the diets were air-dried and stored at -20°C in airtight polythene bags until use in the experiment. The proximate composition (Table 1) of the formulated diets was analyzed following standard protocol [34]. A flame atomic absorption spectrophotometer (Model Shimadzu AA-7000) was used to determine the final concentrations of Cr in the basal diets and the concentrations of Cr in the basal diets were found as per the desired level.

Experimental Fish

Apparently, healthy and active striped catfish (*P. hypophthalmus*) fingerlings of body weight (18.48 ± 1.67 g) and total length (13.81 ± 0.83 cm) were collected from a private hatchery of Sadar Upazila, Mymensingh. The fingerlings were transported to the Fish Ecophysiology Laboratory, Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh. In the laboratory, fish were kept in aquaria (75 × 45 × 45 cm) containing 100 L of clean tap water. Before starting the experiment, fish were acclimatized for 21 days to the laboratory conditions. During the acclimatization process, the fish were fed twice daily with commercial grower feed (CP Bangladesh Co., Ltd.) and each aquarium was monitored daily to check fish mortality and dead fish were removed from each aquarium. We maintained all guidelines provided by the Animal Welfare and Ethical Committee, Bangladesh

Agricultural University, Mymensingh 2202, Bangladesh (approval number: BAU-FoF/2019/003).

Experimental Design

Four diets with chromium (0, 2, 4, and 8 mg kg⁻¹) were fed to striped catfish in aquaria with triplicate groups for 60 days. After acclimatization, fish were distributed into 12 glass aquaria (75 × 45 × 45 cm) filled with 100 L of water. In each aquarium, 15 fingerlings of striped catfish were stocked. Aerators were used to provide sufficient aeration to the aquaria throughout the experiment that help to balance the dissolved oxygen level. The aquaria were divided into four dietary treatment groups, each with three replications. Throughout the experimental period, fish was fed with diets at 5% of their body weight two times in a day (9 am and 5 pm). After determining the new body weights of the fish, the rations were adjusted in every week. Uneaten feed and feces in each aquarium were siphoned in every morning before feeding.

Survival, Growth, and Feed Utilization

Total number of the survived fish was counted and weighed from each aquarium at the end of experiment. Survival, growth parameters (weight gain, WG; %WG; specific growth rate, SGR), and feed utilization (feed intake, FI; feed efficiency, FE; protein efficiency ratio, PER; feed conversion ratio, FCR) were calculated using the following formulae:

Survival rate (%)

$$= \left[\frac{\text{number of fish harvested}}{\text{number of fish stocked}} \right] \times 100$$

Weight gain (WG) = final weight – initial weight

Percentage weight gain (%WG)

$$= \left[\frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \right] \times 100$$

Specific growth rate (SGR)

$$= \frac{\ln \text{ final weight (g)} - \ln \text{ initial weight (g)}}{\text{number of days reared}} \times 100$$

Feed intake (FI, g/100g/BW/day)

$$= \text{dry feed fed} \times 100 / \left[\frac{\text{final weight} + \text{initial weight}}{2} \right] \times \text{experimental duration in days}$$

Feed efficiency (FE)

$$= \frac{\text{final weight (g)} - \text{initial weight (g)}}{\text{dry feed intake (g)}}$$

Feed conversion ratio (FCR)

$$= \frac{\text{dry feed fed}}{\text{live weight gain}}$$

Protein efficiency ratio (PER)

$$= \frac{\text{live weight gain}}{\text{crude protein fed}}$$

Hemato-biochemical Study

To assess the hemato-biochemical parameters, ten fish ($n = 10$) from each treatment were sacrificed at the end of the feeding trial. The hemoglobin (Hb; g/dL) and glucose content (mg/dL) of blood were directly measured by using a digital EasyMate® GHb double monitoring system (Model ET 232, Bioptic technology Inc., Taiwan 35057) with hemoglobin and glucose strips, respectively. For counting red blood cell (RBC) and white blood cell (WBC), blood was collected from the caudal vein and preserved in the tubes containing 20-mM EDTA anticoagulants. The preserved samples were further used for counting RBC and WBC using a Neubauer hemocytometer under a microscope.

Frequency Analysis of Micronucleus Formation

The procedures for analysis of frequency of micronucleus (MN) formation were described in detail by Islam et al. [35]. In brief, blood was smeared on glass slides immediately after collection. The slides were air-dried for 10 min, fixed in methanol for 10 min, and finally stained 5% Giemsa stain. The MN was scored blindly on randomized coded slides under a light microscope (MICROS MCX100LED, Austria) connected to a camera (AmScope 1000). Three slides were prepared from the blood of each fish and 2000 cells were scored from each slide.

Water Quality Parameters

Dissolved oxygen (DO), pH, free CO₂, total alkalinity, and ammonia were measured fortnightly during the experimental period. Temperature, DO, and pH were monitored using a mercury thermometer, DO meter (DO5509, Lutron, Taiwan), and portable pH meter (RI 02895, HANNA Instruments Co.), respectively. Titrimetric method with phenolphthalein indicator and 0.0227N sodium hydroxide (NaOH) titrant was used to assess the free CO₂ of water. Total alkalinity of water was also assessed by titrimetric method where methyl orange was used as indicator and 0.02N standard sulfuric acid (H₂SO₄) was used as titrant. Ammonia was determined by ammonia test kit solution. For these, the test vital was rinsed with a water sample and filled up to the 5mL of measuring cylinder. Then, 5 drops of ammonia test kits solution-1 was added, mixed, and waited for 1 min. After sometimes, 1 spoon of ammonia test kit powder-2 was added and mixed until dissolved. Then, 5 drops of solution

ammonia test kit solution-3 were added, mixed, and waited for 3–5 min. Finally, it was compared with the standard color chart for ammonia (ppm).

Data Analysis

All values are presented as mean \pm standard deviation (SD). One-way analysis of variance (ANOVA) was used to test the statistical variation ($p < 0.05$) of growth parameters, feed utilization, hemato-biochemical parameters, and frequency of micronucleus (MN) of fish fed with different Cr supplemented feed. The polynomial regression analysis based on WG and FE was used to determine the optimum dietary Cr requirement. The SPSS version 14 for Windows (SPSS Inc., Chicago, IL, USA) was statistical analysis.

Results

Survival, Growth, and Feed Utilization

The survivability of fish was very high (98 to 99%), not affected by dietary treatments (Table 2). Weight gain (WG), %WG, and specific growth rate (SGR) were significantly ($p < 0.05$) higher in the fish fed with 2 and 4 mg Cr kg⁻¹ containing diets compared to those in fish fed with 0 and 8 mg Cr kg⁻¹ containing diets (Table 2). These growth parameters were decreased in the fish fed with 8 mg Cr kg⁻¹ containing diets. In case of feed intake (FI), no distinct change was observed among different dietary treatments. On the other hand, the feed efficiency (FE) and protein efficiency ratio (PER) were significantly ($p < 0.05$) higher in the fish fed with 2 and 4 mg kg⁻¹ Cr-based diets (Table 2). Consequently, the feed conversion ratio (FCR) was significantly ($p < 0.05$) lower in case of fish fed with 2 and 4 mg kg⁻¹ Cr-based diets

(Table 2). Based on WG and FE, the polynomial regression analysis showed the optimum dietary Cr requirements for striped catfish 2.82 and 2.75 mg Cr kg⁻¹, respectively (Fig. 1). During the analysis of the polynomial regression, the equations were $y = -344.89x^2 + 310.4x + 94.06$ ($R^2 = 0.99$) and $y = -1.7394x^2 + 1.528x + 0.4892$ ($R^2 = 0.99$), respectively.

Hematological Parameters

At the end of the feeding trial, Hb, RBC, and WBC were measured in the blood of fish. The values of Hb (g/dL), RBC ($\times 10^6/\text{mm}^3$), and WBC ($\times 10^3 \text{ mm}^3$) ranged from 10.5 ± 0.8 to 12.7 ± 0.9 , 1.30 ± 0.09 to 2.51 ± 0.19 , and 1.67 ± 0.18 to 1.87 ± 0.23 , respectively, in the fish blood exposed to different concentrations of Cr. The values of Hb and RBC significantly ($p < 0.05$) decreased in the fish fed with 8 mg kg⁻¹ Cr-based diet compared to others (Fig. 2A and B), while the value of WBC did not vary among the different Cr-based diets fed fish (Fig. 2C).

Biochemical Parameters

At the end of the feeding trial, glucose levels (mg/dL) were measured in the blood of fish. There was a significant ($p < 0.05$) reduction in the levels of blood glucose in the fish fed with 8 mg kg⁻¹ Cr-based diet compared to others (Fig. 3). The highest levels of blood glucose were observed in the fish fed with 4 mg kg⁻¹ Cr-based diet followed by 2 and 0 mg kg⁻¹ Cr-based diets (Fig. 3).

Formation of Micronucleus

There was a significant ($p < 0.05$) increase in the frequency of formation of MN in the blood of fish fed with 8 mg Cr kg⁻¹ based diet. No change in the frequency of forma-

Table 2 Growth performances of striped catfish fed diets containing various concentrations of chromium for 60 days

| Growth parameters | Chromium added (mg kg ⁻¹) | | | |
|-------------------|---------------------------------------|---------------------------------|---------------------------------|--------------------------------|
| | 0 | 2 | 4 | 8 |
| Initial BW (g) | 19.48 \pm 0.79 | 19.23 \pm 1.43 | 19.29 \pm 1.27 | 19.27 \pm 0.98 |
| Final BW (g) | 40.12 \pm 2.92 ^{ab} | 47.98 \pm 2.66 ^b | 49.03 \pm 1.53 ^b | 37.24 \pm 1.39 ^a |
| Weight gain (g) | 20.58 \pm 1.04 ^a | 29.38 \pm 2.37 ^b | 29.69 \pm 1.94 ^b | 17.97 \pm 1.56 ^a |
| % weight gain | 105.65 \pm 9.07 ^a | 158.03 \pm 15.09 ^b | 154.28 \pm 17.49 ^b | 93.64 \pm 11.63 ^a |
| SGR (%/day) | 0.95 \pm 0.09 ^a | 1.35 \pm 0.10 ^b | 1.37 \pm 0.08 ^b | 1.04 \pm 0.06 ^a |
| FI | 2.10 \pm 0.01 | 2.15 \pm 0.01 | 2.15 \pm 0.01 | 2.13 \pm 0.01 |
| FE | 0.55 \pm 0.05 ^a | 0.79 \pm 0.03 ^b | 0.78 \pm 0.07 ^b | 0.45 \pm 0.04 ^a |
| PER | 1.47 \pm 0.01 ^{ab} | 1.74 \pm 0.01 ^b | 1.75 \pm 0.01 ^b | 1.28 \pm 0.01 ^a |
| FCR | 1.82 \pm 0.01 ^{ab} | 1.47 \pm 0.01 ^b | 1.48 \pm 0.01 ^b | 2.01 \pm 0.01 ^a |
| Survival (%) | 98.00 \pm 0.00 | 99.00 \pm 0.00 | 99.00 \pm 0.00 | 98.00 \pm 0.00 |

Values with different alphabetical superscripts in a row differ significantly ($p < 0.05$) among different diets. All values expressed as mean \pm SD

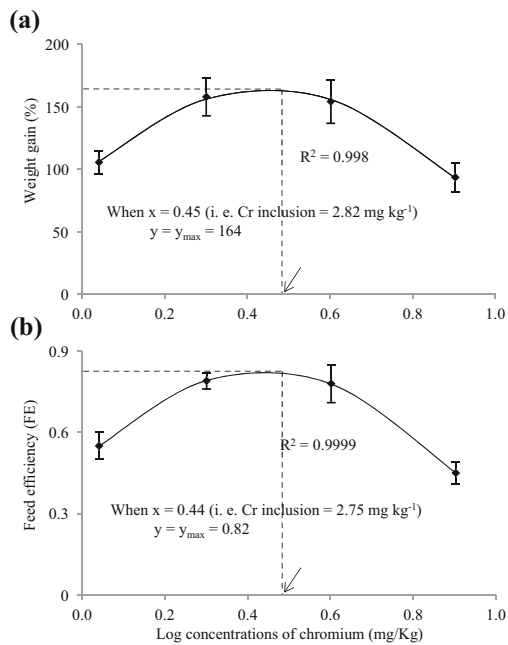


Fig. 1 The effect of dietary Cr on (a) weight gain (WG) and (b) feed efficiency (FE) in striped catfish. Each point represents the mean (\pm SD) of three groups of fish ($n = 3$), with 15 fish per group. The analyzed dietary Cr concentrations were log-transformed for better visualization. Requirement derived with the polynomial regression method for WG and FE was 2.82 and 2.75 mg kg⁻¹ Cr, respectively

on of MN was observed in the blood of fish fed with 0, 2 and 4 mg kg⁻¹ Cr-based diets (Fig. 4).

Water Quality Parameters

Water quality parameters (mean \pm SD), dissolved oxygen (mg L⁻¹), free CO₂ (mg L⁻¹), pH, total alkalinity (mg L⁻¹), and ammonia (mg L⁻¹) values are presented in Table 3. There were no distinct changes recorded for any water quality parameters irrespective of any treatments throughout the experimental period. All the parameters were within suitable range for the growth of fish.

Discussion

Chromium (Cr) plays an important role in the metabolism of fat, protein, and carbohydrate. Cr-supplemented diets (2 and 4 mg kg⁻¹) in the present study significantly enhanced WG, %WG, SGR, FCR, FE, and PER of striped catfish fingerlings. It has been reported that diets containing Cr improved the growth of the rohu, *Labeo rohita* [14], tilapia, *Oreochromis niloticus* \times *Oreochromis aureus* [15], grass carp, *Ctenopharyngodon idellus* [6], yellow croaker, *Larimichthys crocea* [36], and golden pompano, *Trachinotus ovatus* [37]. In pigs, Cr-supplemented diets improved carcass composition, quality, and weight of muscle [38]. Considering the previous reports, the present study indicates that the growth might be enhanced due to the increased utilization of feed.

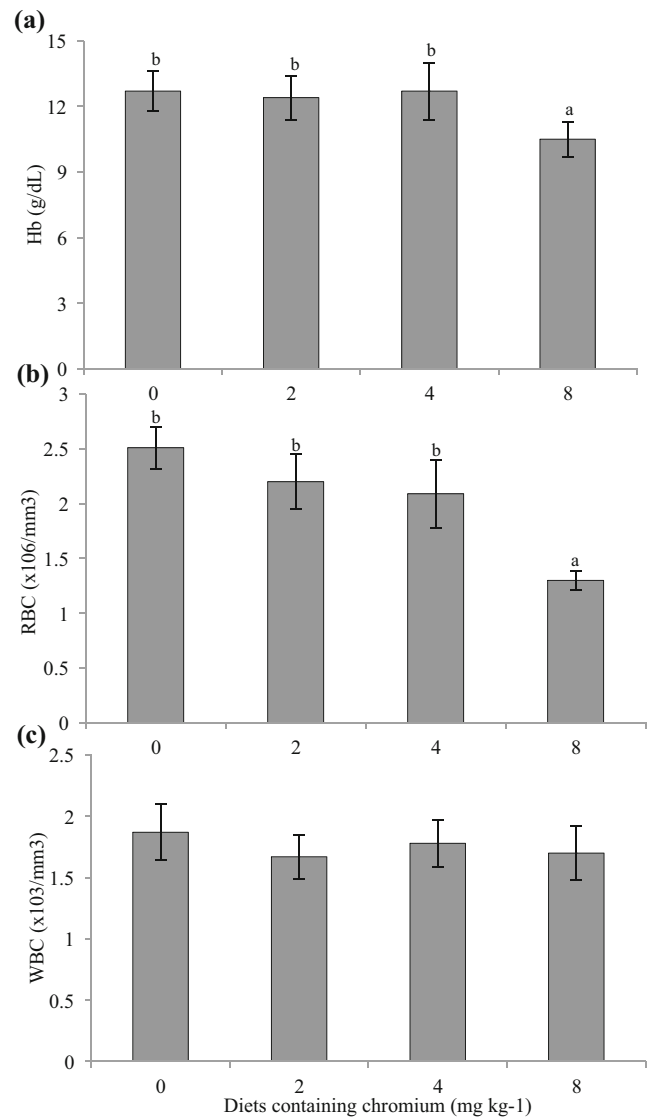


Fig. 2 Changes in hematological parameters of striped catfish-fed diets containing various concentrations of chromium after 60 days. A. hemoglobin levels (g/dL); B. number of RBC ($\times 10^6/\text{mm}^3$); and C. number of WBC ($\times 10^3/\text{mm}^3$). Values accompanied by different alphabets are indicating statistically significantly different ($p < 0.05$) among treatments. All values expressed as mean \pm SD ($n = 10$)

Remarkably, the growth parameters and feed utilization were declined in the fish fed with the diet containing more than 4 mg Cr kg⁻¹, which indicated that high Cr supplementation probably led to toxicity and depressed the growth of striped catfish. In common carp (*Cyprinus carpio*), growth increased at 0.5 mg kg⁻¹ dietary Cr supplementation, while growth decreased at 2 mg Cr kg⁻¹ diet [39]. The palatability of feed reduces when the concentrations of Cr nanoparticles cross the optimum levels that may cause decrease of growth on higher levels of supplementation [40]. It is noted that several fish species, such as gilthead seabream [41], rainbow trout [42], and Nile tilapia [43], did not show any response to Cr-based diets. These variations are not surprising as many

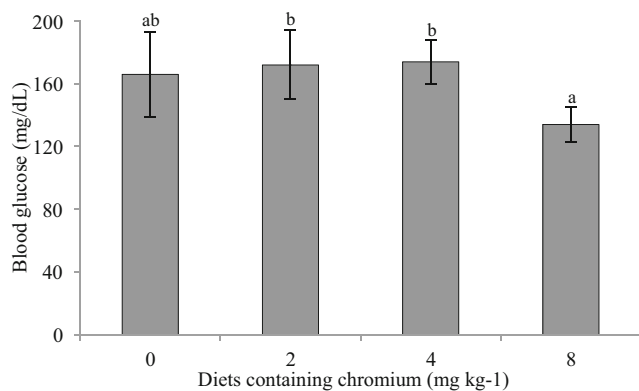


Fig. 3 Changes in blood glucose levels (mg/dL) of striped catfish-fed diets containing various concentrations of chromium after 60 days. Values accompanied by different alphabets are indicating statistically significantly different ($p < 0.05$) among treatments. All values expressed as mean \pm SD ($n = 10$)

factors, such as form and dose of Cr, duration of experiment, and behavior of concerned species, determined the actions of supplemented Cr in the diets.

Health conditions, as well as the physiological status of fish, are frequently evaluated by the hematological studies. Hence, the obtained results revealed that Hb and RBC significantly decreased in the highest (8 mg kg⁻¹) Cr in diets. There was a significant change in Hb content and RBC in broiler birds supplemented with vitamin E, zinc (Zn), and Cr [44] are good agreement with our study. Cr-picolinate-supplemented diet increased Hb values in Japanese quail [45]. The changes of RBC and Hb content may have resulted from degeneration of the erythropoietic tissues by Cr, which obstructs the viable condition of the cell. Cr impairs the metabolism and storage of iron that leads to a significant reduction in the iron-binding capacity of the serum, and ferritin and hemoglobin content of fish blood [46]. In this study, blood glucose levels were increased significantly in the fish fed with up to 4 mg Cr kg⁻¹ diets, whereas significantly declined in the fish fed with 8 mg Cr kg⁻¹ diet.

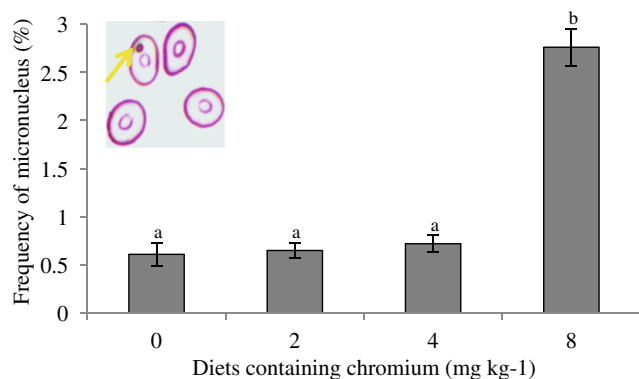


Fig. 4 Frequency of micronucleus (MN) in the erythrocytes of striped catfish-fed diets containing various concentrations of chromium after 60 days. Values with different alphabetical superscripts differ significantly ($p < 0.01$) among different diets. All values are expressed as mean \pm SD. Three slides were prepared from blood of each fish and 2000 cells were scored from each slide. MN is shown by an arrow

Increased Cr-based diet reduced the blood glucose levels in rainbow trout [5], hybrid tilapia [47], and Nile tilapia [43] which supported the findings of the presents study.

Significantly increased formation of micronucleus (MN) at 8 mg kg⁻¹ Cr-based diet also indicates that increased Cr level causes toxicity and depressed the growth performance of striped catfish. The frequency of MN increased significantly in the erythrocytes of fish after exposure to cadmium (Cd), copper (Cu), and lead (Pb) [48]. MN as well as other erythrocytic abnormalities was observed in the erythrocytes of common carp exposed to Cu [49]. The frequency of nuclear abnormalities significantly increased in the erythrocytes of mosquitofish (*Gambusia affinis*) as a result of Cd and Cu toxicity [50]. MN frequency increased in the erythrocytes of tilapia, *Oreochromis mossambicus* [51], and spotted snakehead, *Channa punctatus* [52], exposed to arsenic. There was a linear connection among different heavy metals (Ni, Cd, Cu, and Pb), MN, and other nuclear abnormalities of the erythrocytes in mullet, *Mugil cephalus*, and catfish, *Clarias gariepinus* [53]. Therefore, high Cr supplementation probably led to toxicity and depressed the growth of striped catfish.

Cr supplementation in the feed enhances the metabolism of protein, fat, and carbohydrate [6, 8]. Basically, energy from carbohydrate depends on its digestibility, metabolic enzymes, and finally absorption [54]. It has been reported that dietary Cr increased the carcass crude protein content of Nile tilapia [43, 55]. Cr significantly influences the activities of several enzymes. For instant, Cr supplementation through diet enhances the liver enzymes such as glycolytic enzyme and lipogenic enzyme that are related with the preliminary step of glycolysis and lipogenesis pathways [10] which clarify the mechanisms regulating the utilization of carbohydrates [56, 57]. It has been reported that dietary Cr supplementation positively enhanced the growth and homeostasis of blood glucose levels through influencing the expression of glucose metabolism related genes (pyruvate kinase PK, phosphoenolpyruvate carboxykinase PEPCK, glucose-6-phosphatase G6Pase, and glycogen synthase GS) and lipogenesis-related genes (sterol regulatory element binding protein-1 SREBP1 and fatty synthase FAS) in Juvenile Blunt Snout Bream, *Megalobrama amblycephala* [58]. However, the role of dietary Cr on the enzymatic activities in striped catfish warrants further investigation.

In summary, the striped catfish fed with 2 and 4 mg kg⁻¹ Cr-based diets had substantial higher growth and utilization of feed. In contrast, a diet with 8 mg Cr kg⁻¹ suppressed the growth and feed utilization. The values of hemato-biochemical parameters and formation of MN also indicated that 8 mg Cr kg⁻¹ supplementation causes toxicity, which decreased growth performance of striped catfish. Polynomial regression analysis based on WG showed that 2.82 mg Cr kg⁻¹ is optimum for the diet of striped catfish. This level of Cr may be recommended as a feed supplementation for striped catfish farming as well as the factories involved in the

Table 3 Water quality parameters (mean \pm SD) during the study periods

| Parameters | Chromium (mg kg ⁻¹) | Days of feeding trial | | | |
|-----------------------------|---------------------------------|-----------------------|-----------------|-----------------|-----------------|
| | | 15 | 30 | 45 | 60 |
| Dissolved oxygen (mg/L) | 0 | 7.2 \pm 0.5 | 7.0 \pm 0.28 | 6.5 \pm 0.14 | 7.0 \pm 0.27 |
| | 2 | 6.8 \pm 0.37 | 6.5 \pm 0.19 | 6.7 \pm 0.47 | 6.8 \pm 0.51 |
| | 4 | 6.2 \pm 0.14 | 6.5 \pm 0.42 | 6.3 \pm 0.14 | 6.5 \pm 0.42 |
| | 8 | 6.5 \pm 0.30 | 6.8 \pm 0.17 | 6.5 \pm 0.42 | 6.8 \pm 0.31 |
| Free CO ₂ (mg/L) | 0 | 6.0 \pm 0.07 | 7.0 \pm 0.07 | 8.0 \pm 0.07 | 7.0 \pm 0.14 |
| | 2 | 7.0 \pm 0.08 | 8.0 \pm 0.14 | 9.0 \pm 0.07 | 9.0 \pm 0.09 |
| | 4 | 8.0 \pm 0.12 | 9.0 \pm 0.07 | 7.0 \pm 0.21 | 8.0 \pm 0.07 |
| | 8 | 6.0 \pm 0.09 | 8.0 \pm 0.07 | 8.0 \pm 0.21 | 7.0 \pm 0.08 |
| pH | 0 | 8.60 \pm 0.28 | 8.85 \pm 0.15 | 7.25 \pm 0.07 | 7.15 \pm 0.07 |
| | 2 | 8.60 \pm 0.06 | 8.65 \pm 0.11 | 7.55 \pm 0.21 | 7.90 \pm 0.14 |
| | 4 | 8.45 \pm 0.70 | 8.50 \pm 0.10 | 7.35 \pm 0.07 | 7.20 \pm 0.14 |
| | 8 | 8.55 \pm 0.04 | 8.70 \pm 0.12 | 7.85 \pm 0.21 | 7.90 \pm 0.14 |
| Total alkalinity (mg/L) | 0 | 113.0 \pm 9.1 | 105.0 \pm 7.1 | 108.0 \pm 8.1 | 112.0 \pm 9.6 |
| | 2 | 105.0 \pm 7.2 | 95.0 \pm 8.7 | 122.0 \pm 7.2 | 112.0 \pm 8.3 |
| | 4 | 112.0 \pm 8.3 | 115.0 \pm 7.1 | 115.0 \pm 7.8 | 110.0 \pm 9.7 |
| | 8 | 103.0 \pm 9.1 | 105.0 \pm 5.1 | 118.0 \pm 8.1 | 114.0 \pm 8.6 |
| Ammonia (mg/L) | 0 | 0.25 \pm 0.05 | 0.25 \pm 0.05 | 0.32 \pm 0.06 | 0.35 \pm 0.02 |
| | 2 | 0.30 \pm 0.04 | 0.35 \pm 0.06 | 0.45 \pm 0.07 | 0.30 \pm 0.04 |
| | 4 | 0.30 \pm 0.06 | 0.35 \pm 0.17 | 0.40 \pm 0.04 | 0.30 \pm 0.06 |
| | 8 | 0.25 \pm 0.04 | 0.25 \pm 0.04 | 0.35 \pm 0.04 | 0.35 \pm 0.05 |

preparation of fish feed. More studies are needed to know the role of Cr on reproductive physiology as well as stages of maturation to enlarge the scopes of Cr to be used as an efficient nutrient.

Acknowledgements We are grateful to SM Majharul Islam and Rayeda Jannat for their help in sampling and technical assistance.

Author contribution Shahana Akter and Nusrat Jahan conceived, designed and performed the experiments, analyzed data, and drafted the manuscript. Fazle Rohani and Yeasmin Akter were assisted in data analysis and drafting the manuscript. Md Shahjahan assisted in the experimental design and edited the manuscript. All authors reviewed and approved the final manuscript.

Funding National Agricultural Technology Program-Phase II Project (CRG-364), Bangladesh Agricultural Research Council, Dhaka, Bangladesh.

Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval The Animal Welfare and Ethical Committee, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh (Approval Number: BAU-FoF/2019/003).

Conflict of interest The authors declare no competing interests.

References

- Ahmed N, James AY, Madan MD, James FM (2012) From production to consumption: a case study of tilapia marketing systems in Bangladesh. *Aquac Int* 20:51–70
- FAO (2018) The state of world fisheries and aquaculture: opportunities and challenges. Food and Agriculture Organization of the United Nations, Rome
- Mzengereza K, Msiska OV, Kapute F, Kang'ombe J, Singini W, Kamangira A (2014) Nutritional value of locally available plants with potential for diets of *Tilapia rendalli* in pond aquaculture in Nkhata Bay, Malawi. *J Aquac Res Dev* 5(6):1
- Daniel N (2018) A review on replacing fish meal in aqua feeds using plant protein sources. *Int J Fish Aquat Stud* 6(2):164–179
- Kucukbay FZ, Yazlak H, Sahin N, Cakmak MN (2006) Effect of dietary chromium picolinate supplementation on serum glucose, cholesterol and minerals of rainbow trout (*Oncorhynchus mykiss*). *Aquac Int* 14:259–266
- Liu T, Wen H, Jiang M (2010) Effect of dietary chromium picolinate on growth performance and blood parameters in grass carp fingerling, *Ctenopharyngodon idellus*. *Fish Physiol Biochem* 36:565–572
- Vincent JB, Stallings D (2007) Introduction: a history of chromium studies (1955–1995). In: The nutritional biochemistry of chromium (III). Elsevier, Amsterdam, pp 1–40
- Aslam S, Yousafzai AM (2017) Chromium toxicity in fish: a review article. *J Entomol Zool Stud* 5(3):1483–1488
- Pires KA, Dalinne Chrystian CDS, Decio SG, Benito S (2015) Effect of two sources of chromium on performance, blood and liver lipid levels in Nile tilapia (*Oreochromis niloticus*). *Acta Sci Vet* 43(1302):1679–1685

10. Ahmad AR, Awadesh NJ, Simon JD (2012) The effect of dietary organic chromium on specific rate, tissue chromium concentration, enzymes activities and histology in common carp (*Cyprinus carpio*). *Biol Trace Elem Res* 149(3):362–370
11. Asad F, Mubarik MS, Ali T, Zahoor MK, Ashrad R, Qamer S (2019) Effect of organic and in-organic chromium supplementation on growth performance and genotoxicity of *Labeo rohita*. *Saudi J Biol Sci* 26:1140–1145
12. Vincent JB (2000) The biochemistry of chromium. *J Nutr* 130:715–718
13. Tacon AGJ, Beveridge MM (1982) Effects of dietary trivalent chromium on rainbow trout. *Nutr Rep Int* 25:49–56
14. Jain KK, Sinha A, Srivastava PP, Berendra DK (1994) Chromium: an efficient growth enhancer in Indian major carp (*Labeo rohita*). *J Aquac Tropics* 9:49–54
15. Pan Q, Liu S, Tan YG, Bi YZ (2003) The effect of chromium picolinate on growth and carbohydrate utilization in tilapia, *Oreochromis niloticus* × *Oreochromis aureus*. *Aquaculture* 225:421–429
16. Zha LY, Wang MQ, Xu ZR, Gu LY (2007) Efficacy of chromium (III) supplementation on growth, body composition, serum parameters, and tissue chromium in rats. *Biol Trace Elem Res* 119:42–50
17. Wang MQ, Xu ZR, Zha LY, Lindemann MD (2007) Effects of chromium nanocomposite supplementation on blood metabolites, endocrine parameters and immune traits in finishing pigs. *Anim Feed Sci Technol* 139(1-2):69–80
18. Wang MQ, He YD, Lindeman MD, Jiang ZG (2009) Efficacy of Cr (III) supplementation on growth, carcass composition, blood metabolites and endocrine parameters in finishing pigs. *Asian-Australas. J Anim Sci* 22(10):1414–1419
19. Krocizewska B, Zawadzki W, Dobrzanski Z, Kaczmarek-Oliwa A (2004) Changes in selected serum parameters of broiler chicken fed supplemental chromium. *J Anim Physiol Anim Nutr* 88(11-12):393–400
20. Patil A, Palod J, Singh VS, Kumar A (2008) Effect of graded levels of chromium supplementation on certain serum biochemical parameters in broilers. *Indian J Anim Sci* 78(10):1149–1152
21. Elahee KB, Bhagwant S (2007) Hematological and gill histopathological parameters of three tropical fish species from a polluted lagoon on the west coast of Mauritius. *Ecotoxicol Environ Saf* 68:361–371
22. Sharmin S, Salam MA, Haque F, Islam MS, Shahjahan M (2016) Changes in hematological parameters and gill morphology in common carp exposed to sub-lethal concentrations of malathion. *Asian J Med Biol Res* 47(5):1495–1498
23. Jahan A, Nipa TT, Islam SMM, Uddin MH, Islam MS, Shahjahan M (2019) Striped catfish (*Pangasianodon hypophthalmus*) could be suitable for coastal aquaculture. *J Appl Ichthyol* 35:994–1003
24. Islam MA, Uddin MH, Uddin MJ, Shahjahan M (2019a) Temperature changes influenced the growth performance and physiological functions of Thai pangas *Pangasianodon hypophthalmus*. *Aquacult Rep* 13:100179
25. Hesser EF (2011) Methods for routine fish hematology. *Prog Fish Cult* 22:164–171
26. Shahjahan M, Uddin MH, Bain V, Haque MM (2018) Increased water temperature altered hemato-biochemical parameters and structure of peripheral erythrocytes in striped catfish *Pangasianodon hypophthalmus*. *Fish Physiol Biochem* 44:1309–1318
27. Kopp R, Palíková M, Navrátil S, Kubiček Z, Ziková A, Mareš J (2010) Modulation of biochemical and haematological indices of silver carp (*Hypophthalmichthys molitrix* Val.) exposed to toxic cyanobacterial water bloom. *Acta Vet Bmo* 79:135–146
28. Ashaf-Ud-Doulah M, Shahjahan M, Islam SMM, Al-Emran M, Rahman MS, Hossain MAR (2019) Thermal stress causes nuclear and cellular abnormalities of peripheral erythrocytes in Indian major carp rohu *Labeo rohita*. *J Therm Biol* 86:102450
29. Shahjahan M, Rahman MS, Islam SMM, Uddin MH, Al-Emran M (2019) Increase in water temperature increases acute toxicity of sumithion causing nuclear and cellular abnormalities in peripheral erythrocytes of zebra fish *Danio rerio*. *Environ Sci Pol* 26:36903–36912
30. Bolognesi C, Hayashi M (2011) Micronucleus assay in aquatic animals. *Mutagenesis* 26:205–213
31. Sadiqul MI, Zannatul F, Tanvir ANM, Mostakim GM, Rahman MK (2016) Acute exposure to a quinalphos containing insecticide (convoy) causes genetic damage and nuclear changes in peripheral erythrocytes of silver barb, *Barbonymus gonionotus*. *Environ Pollut* 219:949–956
32. Fenech M, Kirsch-Volders M, Natarajan AT, Surrallés J, Crott JW, Parry J (2011) Molecular mechanisms of micronucleus, nucleoplasmic bridge and nuclear bud formation in mammalian and human cells. *Mutagenesis* 26:125–132
33. Fisheries Resources Survey System (2016) Fisheries statistical report of Bangladesh, Department of Fisheries, Bangladesh. 32: 1-57
34. AOAC (2000) Association of Official Analytical Chemists. Official Methods of Analysis. Kenneth, H. (Editors). Arlington, Virginia, USA. pp. 1298
35. Islam SMM, Rahman MA, Nahar S, Uddin MH, Haque MM, Shahjahan M (2019b) Acute toxicity of an organophosphate insecticide sumithion to striped catfish *Pangasianodon hypophthalmus*. *Toxicol Rep* 6:957–962
36. Wang J, Ai Q, Mai K, Xu H, Zuo R (2014) Dietary chromium polynicotinate enhanced growth performance, feed utilization and resistance to Cryptocaryon irritans in juvenile large yellow croaker (*Larimichthys crocea*). *Aquaculture* 432:321–326
37. Wang J, Gatlin DM, Li L, Wang Y, Jin N, Lin H, Zhou C, Huang Z, Yu W, Guo Y (2019) Dietary chromium polynicotinate improves growth performance and feed utilization of juvenile golden pompano (*Trachinotus ovatus*) with starch as the carbohydrate. *Aquaculture* 505:405–411
38. Wang MQ, Xu ZR (2004) Effect of chromium nanocomposite supplementation on blood metabolites, endocrine parameters and immune traits in finishing pigs. *Anim Feed Sci Technol* 139:69–80
39. Lin YH, Liu JM, Fu HG, Liang ZL, Zhao SM, Ma JJ (2003) Effect of chromium on growth and plasma biochemical indexes of *Cyprinus carpio* juveniles. *J Dalian Fish Univ* 18:48–51
40. Onugebu UC, Aggarwal A, Singh BN (2018) ZnO nanoparticles as feed supplementation on growth performance of cultured African catfish fingerlings. *J Sci Ind Res* 77:213–218
41. Gatta PP, Piva A, Paolini M, Testi S, Bonaldo A, Antelli A, Mordenti A (2001) Effects of dietary organic chromium on gilthead seabream (*Sparus aurata* L.) performances and liver microsomal metabolism. *Aquac Res* 32:60–69
42. Selcuk Z, Tiril SU, Alagil F, Belen V, Salman M, Cenesiz S, Muglali OH, Yagci FB (2010) Effects of dietary L-carnitine and chromium picolinate supplementations on performance and some serum parameters in rainbow trout (*Oncorhynchus mykiss*). *Aquac Int* 18:213–221
43. El-Sayed EH, Hassanein EI, Soliman MH, El-Khatib NR (2010) The effect of dietary chromium picolinate on growth performance, blood parameters and immune status in Nile tilapia (*Oreochromis niloticus*). *Proceedings of the 3rd Global Fisheries and Aquaculture Research Conference*, November 29 - December 1, 51-63
44. Al-Zahrani Kandeal S, Mohanty M, Badr G (2011) Effects of vitamin E and thymoquinone on physiological and histological characteristics of heat-stressed, male mice. *Afr J Pharm Pharmacol* 5(19):2174–2183
45. Askar AA, El-Hindawy MM, Sonbol SM, El-Kholy MS (2008) Effect of ambient temperature and some dietary supplementations

- on some physiological traits of laying Japanese quail. *J Agric Sci Mansoura Univ* 33:75–87
46. Ani M, Moshtague AA (1992) The effect of chromium on parameters related to iron metabolism. *Biol Trace Elem Res* 32:57–64
 47. Magzoub MB, Al-Batshan HA, Hussein MF, Al-Mufarrej SI, Al-Saiady MY (2009) The effect of source and level of dietary chromium supplementation on humoral antibody response and blood chemical parameters in hybrid tilapia fish (*Oreochromis niloticus* × *O. aureus*). *Curr Res J Biol Sci* 4:821–827
 48. Jiraungkoorskul W, Kosai P, Sahaphong S, Kirtputra P, Chawlab J, Charucharoen S (2007) Evaluation of micronucleus test's sensitivity in freshwater fish species. *Res J Environ Sci* 1(2):56–63
 49. Zhu Y, Wang J, Bai Y, Zhang R (2004) Cadmium, chromium and copper induce polychromatocyte micronuclei in carp (*Cyprinus carpio*). *Bull Environ Contam Toxicol* 72:78–86
 50. Guner U, Dilek F, Muranl G (2011) Micronucleus test, nuclear abnormalities and accumulation of Cu and Cd on *Gambusia affinis* (Baird & Girard, 1853). *Turk J Fish Aquat Sci* 11:615–622
 51. Ahmed MK, Habibullah-Al-Mamun M, Hossain MA, Arif M, Parvin E, Akter MS, Khan MS, Islam MM (2011) Assessing the genotoxic potentials of arsenic in tilapia (*Oreochromis mossambicus*) using alkaline comet assay and micronucleus test. *Chemosphere* 84:143–149
 52. Patowary K, Hazarika NS, Goswami M (2012) Studies on the toxic impact of arsenic on some enzymes and chromosomes of *Channa punctatus*. *Clarion* 1:148–153
 53. Ergene S, Cavas T, Celik A, Koleli N, Kaya F, Karahan A (2007) Monitoring of nuclear abnormalities in peripheral erythrocytes of three fish species from the Goksu Delta (Turkey): genotoxic damage in relation to water pollution. *Ecotoxicology* 16:385–391
 54. Stone DAJ, Allan GL, Anderson AJ (2003) Carbohydrates utilization by juvenile silver perch (*Bidyanus bidyanus*). III. Digestibility and growth using meat meal products. *Aquac Res* 34:109–121
 55. Mehrim AI (2012) Effect of dietary chromium picolinate supplementation on growth performance, carcass composition and organs indices of Nile tilapia (*Oreochromis niloticus* L.) fingerlings. *J Fish Aquat Sci* 7(3):224–232
 56. Enes P, Peres H, Couto A, Oliva-Teles A (2010) Growth performance and metabolic utilization of diets including starch, dextrin, maltose or glucose as carbohydrate source by gilthead sea bream (*Sparus aurata*) juveniles. *Fish Physiol Biochem* 36:903–910
 57. Carvalho CS, Fernandes MN (2008) Effect of copper on liver key enzymes of anaerobic glucose metabolism from freshwater tropical fish *Prochilodus lineatus*. *Comp Biochem Physiol A Mol Integr Physiol* 151:437–442
 58. Ren M, Mokrani A, Liang H, Ji K, Xie J, Ge X, Liu B (2018) Dietary chromium picolinate supplementation affects growth, whole-body composition, and gene expression related to glucose metabolism and lipogenesis in Juvenile Blunt snout bream, *Megalobrama amblycephala*. *Biol Trace Elem Res* 185(1):205–215

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.