Mesopotamia Journal of Agriculture

https://magrj.uomosul.edu.iq/

EVALUATION OF ADDING TWO TYPES OF ORGANIC CHROMIUM ON ENHANCING GROWTH AND CHEMICAL COMPOSITION CRITERIA OF COMMON CARP *Cyprinus carpio* L.

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Article information
Article history:
Received: 23/6/2024
Accepted: 27/8/2024
Published: 31/12/2024

Keywords:
Feed efficiency ratio, nicotinate, picolinate, protein productive value.

DOI:
https://doi.org/10.33899/mja.2024.150878.1477

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ABSTRACT

The study aims to indicate the effect of two types of organic chromium added on growth criteria, namely chromium picolinate, at an amount of 0.3, 0.4, and 0.5 mg/kg feed (T2, T3, and T4), and 0.3, 0.4, and 0.5 mg/kg feed of chromium nicotinate (T5, T6, and T7), besides the standard diet without additives (T1). Results of the statistical analysis showed that T4 and T7 were significantly superior ($P \leq 0.05$) in the criteria of final weight, total weight gain, daily growth rate, relative growth rate, specific growth rate, food intake, feed conversion ratio, and feed efficiency ratio over all other experimental treatments, including standard diet. Results of the protein retention and protein productive value criteria showed that T2 and T3 were significantly superior to the remaining experimental therapies. At the same time, T4 and T7 were significantly superior to the remaining experimental treatments in the protein efficiency ratio. The fish-fed diets T1, T3, T4, and T7 outperformed the other experimental treatments regarding protein intake criterion. The fish fed T4, which differed significantly from the different treatments, had the highest level of protein retention, according to the results. Compared to the standard diet, the amount of ether extract in the edible portion was positively lowered upon adding both forms of organic chromium. As mentioned earlier, the findings demonstrate that adding both forms of organic chromium improved growth, food utilization, protein sedimentation, protein productive value, and the reduction of fat percentage in the edible portion.

INTRODUCTION

Aquatic products are among the significant sources of food and animal protein produced worldwide (Al-Kattan and Al-Bassam, 2024), and it is the fastest-growing, nutrient-producing, and food-delivery sector on Earth (Mizory and Altaee, 2023). Modern trends in the field of fish farming take into account that the quality of these feeds is as much as possible, causing the lowest level of pollution in the aquatic environment (F. A. O., 2022), to the addition of enzymes, vitamins, body required elements for animal health (Ameen *et al*., 2023) and other sources to make the most of the feed ingredients and subtract the minimum of Nutrients into the aquatic environment (Moreira *et al*., 2020).

Chromium is described as a contributing element in the mechanism of amplifying cellular signals for insulin; it contributes to increasing the sensitivity of insulin receptors on the plasma membrane (Al-Niaeemi and Dawood, 2023). The effect of chromium and thyroid hormones on the production and action of growth hormone through IGF-1 (insulin-like growth factor) stimulates glucose absorption and transport to cardiac and skeletal muscles. In addition to lactate production, from an anabolic or synthetic point of view, IGF-1 stimulates the synthesis of DNA and protein (Moreira *et al*., 2020 and Maty *et al*., 2024). The metabolism of carbohydrates, fats, and proteins affects insulin action (Amata, 2013 andAhmed and Abdul-Rahman, 2023).

Researchers have found that organic forms of chromium are less toxic and more accessible to absorb than inorganic forms of chromium (Saha *et al*., 2011); however, high levels of dietary chromium have adverse effects on growth and feed utilization efficiency (Wang *et al*., 2014). Common carp are omnivores whose natural food consists of many complex carbohydrates (Al-Taee, 2024) Therefore, the efficiency of their utilization of this type of food as energy is expected. In addition, the energy ratio represented by the fat and carbohydrate content is close to 2.25:1, respectively (Moatt *et al*., 2017). The percentage of carbohydrate digestibility in common carp was 30–40%, while it was less than 20% in Atlantic salmon (Kiron *et al*., 2017). Carp fish are distinguished by their ability to benefit from high-carbohydrate foods, and adding organic chromium will enhance this type of fish's benefit from carbohydrate sources and thus reduce feeding costs. The current research study aims to add two types of organic chromium, picolinate, and nicotinate, to the growth, food utilization, and the main chemical composition of the body criteria.

MATERIALS AND METHODS

Ethical Approve

The Scientific Ethical Committee approved the research at the College of Veterinary Medicine at the University of Mosul, with its letter numbered UM.VET. 2023.095.25/2/2023.

Experience location

The experiment was conducted in the Department of Animal Production Sciences at a fish laboratory in the College of Agriculture and Forestry/University of Mosul.

Experience fish

147 common carp, *Cyprinus carpio* L., were brought from one of the local fish farms for culturing and hatching fish in the Tajran area, located in the Al-Gower district of Nineveh Governorate. The experimental fish were sterilized for five minutes with salt food at a concentration of 3% for sterilization and elimination external parasite, if present, with an average weight of 27.65 ± 2 g/fish. They were distributed in the 21 aquariums, with three replicates for each treatment and a ratio of seven fish per tank. The feeding experiment lasted for 56 days and preceded acclimatization by three weeks.

Breeding water quality

Chlorine is removed from the water, and the temperature in laboratory tanks is similar to the temperature of aquariums. A mercury thermometer fixed to each glass tank revealed that the rearing water's temperature ranged from 23 to 26 °C. A specialized RS-200W heater was installed inside each glass tank to heat the water and regulate the temperature via a thermostat. Fish waste and dissolved metabolites were eliminated by partially siphoning off aquarium water at a rate of 20–25% per day and replacing it with filtered water from the main tank. A dissolved oxygen meter HD 3030 field device was used to measure the amount of dissolved oxygen, and throughout the experiment, its results varied between 4.6 and 4.8 mg/L. The pH levels, which were determined, ranged from 7.3 to 7.4 using a pH meter from Eutech Instruments, Singapore. These requirements are acceptable for warm-water fish growth and reproduction (Todd *et al*., 2017).

Diet preparation

Common carp were fed with a combination of seven experimental treatments, where organic chromium powder, namely chromium picolinate and chromium nicotinate, was added at different levels to the components of the experimental diets. The experimental diets were prepared by dissolving both types of organic chromium in water and adding them as a spray to the ground other feed ingredients to ensure that these chromium additions were as homogeneous as possible, and the mixture was stirred repeatedly before the feed manufacturing process. Warm water was added to moisten the feed and make it into 3 mm pellets using a meat grinder. The samples were dried while stirring in the laboratory. The fish were fed 3% of the live weight of the fish at the beginning of the experiment, three meals a day. The amount of feed provided to the fish was changed every fourteen days, depending on the live weight. The percentage of feed provided increased to 4% after the third week until the end of the experiment. The experimental fish were weighed on a sensitive balance Chinese origin. Three levels of chromium picolinate and chromium nicotinate were addition to the components standard diet, as shown below and in Table (1).

Table (1): Dietary ingredients and chemical composition (%DM) of the experimental diets containing different percentages of diets.

Ingredients / Diets	T1 standard	T2 0.3 pic	T3 0.4 pic	T4 0.5 pic	T5 0.3 nic	T6 0.4 nic	T7 0.5 nic
Animal protein*	12	12	12	12	12	12	12
Soybean meal	30	30	30	30	30	30	30
Local Barley	20	20	20	20	20	20	20
Yellow corn	16.5	16.5	16.5	16.5	16.5	16.5	16.5
Wheat bran	19	19	19	19	19	19	19
Mix (Vits. and Minerals)	1	1	1	1	1	1	1
Salt	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Lime stone	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Binder (Bentonite)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Chromium pic	-	0.3	0.4	0.5	-	-	-
Chromium nic	-	-	-	-	0.3	0.4	0.5

* mg/kg, **Calculated according to Smith's (1971), equation: ME (MJ\Kg) = Protein x 18.5 + Fat x 33.5 + NFE x 13.8

- Standard diet (free of additives).
- Standard diet + 0.3 mg chromium picolinate /kg diet.
- Standard diet + 0.4 mg chromium picolinate /kg diet.

- Standard diet + 0.5 mg chromium picolinate /kg diet.
- Standard diet + 0.3 mg chromium nicotinate /kg diet.
- Standard diet + 0.4 mg chromium nicotinate /kg diet.
- Standard diet + 0.5 mg chromium nicotinate /kg diet.

Chemical composition of experimental diets

The fish used in the experiment were fed with seven experimental diets balanced in terms of protein and metabolic energy. Table 2 shows the chemical composition of the experimental diets that were analyzed based on standard methods (A.O.A.C, 2000).

Table (2): Chemical composition (%) of the experimental diets.

Chemical composition	%
Dry matter	92.42
Moisture	7.58
Crude protein	25.60
Either extract	6.34
Ash	5.66
NFE	54.80
ME (MJ/KG)*	14.36

*Based on the Smith's equation (1971): Fat × 33.5+ Protein × 18.5 + NFE × 13.8.

Food additives

The first type of organic chromium was used: chromium picolinate, (Cr-pic), produced by the Canadian company Isura and manufactured in the form of tablets (500 micrograms per tablet). The second type is chelated chromium, called chromium nicotinate, (Cr-nic), produced by the American company Now. It is also manufactured in tablet form (200 micrograms per tablet). Both types of organic chromium were obtained from one of the scientific offices in Baghdad Governorate.

Criteria used in evaluating growth performance and food utilization criteria

Growth criteria

The following growth standards were used to demonstrate the effect of adding Chromium (picolinate and nicotinate) to the experimental diets under study: Weight Gain WG, Daily Growth Rate, Relative Growth Rate, and Specific Growth Rate (Hepher, 1988).

Food utilization criteria

The following criteria were used: Feed Conversion Ratio, Feed Efficiency Ratio, Protein Efficiency Ratio, Protein Consumption, Protein retention, and Protein Productive Value to demonstrate the effect of adding chromium picolinate and nicotinate to fish diets on food utilization (Hepher, 1988).

Chemical analysis

The main chemical components of feed and body components of fish-fed experimental diets were estimated in both the fish laboratories and the central laboratory located at the College of Agriculture and Forestry/University of Mosul, based on the AOAC (2000).

Statistical analysis

The data were statistically analyzed using a completely randomized design (CRD). The data were analyzed using the ready-made statistical program Statistical Package for Social Science (SPSS, 2017), version 25, in analyzing the effect of experimental parameters on the studied criteria. The significant differences between the means of the studied traits were tested with Duncan's multiple range test (Duncan, 1955).

RESULTS AND DISCUSSION

Initial weight, daily gain, total gain, and final body weight

The initial weight criterion, which ranged from 27.50 to 27.77 gm/fish, it did not exhibit any significant differences ($P \geq 0.05$) between the treatments, according to the statistical analysis results in Table 3. The fish fed the seventh diet (0.5 mg/kg chromium picolinate feed) and the fourth diet (0.5 mg/kg chromium picolinate feed) outperformed significantly ($P \leq 0.05$) according to the final weight criteria results, which equaled out to 62.53 and 62.83 g/fish, respectively. The third treatment (0.4 mg/kg chromium picolinate feed) resulted in 59.24 g/fish with the first group's (standard diet, 58.98 g/fish) was significantly higher than second treatments (0.3 mg/kg chromium picolinate feed, 57.42 g/fish) and sixth treatments (0.4 mg/kg chromium nicotinate feed), which reached to 56.60 g/fish. The lowest final weight was for the fish in the fifth treatment fed a diet supplemented with 0.3 mg/kg feed of chromium nicotinate, which reached a final weight of 55.20 g/fish, which was significantly behind all other experimental treatments.

Table (3): Effect of organic chromium picolinate and nicotinate on final weight, daily growth rate and weight gain criteria of common carp fish (Means ±SE).

Criteria / Treatment diets	Initial weight (gm\fish)	Final weight (gm\fish)	Total weight gain (gm\fish)	Daily weight gain (gm/fish/day)
T1 (standard)	27.51± 0.05 a	58.98 ± 0.10 b	31.47 ± 0.10 b	0.55 ± 0.03 b
T2 (0.3 chr-pic.)	27.67 ± 0.07 a	57.42 ± 0.38 c	29.74 ± 0.43 c	0.52 ± 0.08 c
T3(0.4 chr-pic)	27.50 ± 0.03 a	59.24 ± 0.16 b	31.74 ± 0.13 b	0.56 ± 0.03 b
T4 (0.5 chr-pic)	27.50 ± 0.08 a	62.83 ± 0.61 a	35.14 ± 0.57 a	0.62 ± 0.08 a
T5 (0.3 chr-nic)	27.77 ± 0.07 a	55.20 ± 0.36 d	27.43 ± 0.29 d	0.48 ± 0.06 d
T6 (0.4 chr-nic)	27.61 ± 0.04 a	56.63 ± 0.42 c	29.03 ± 0.37 c	0.51 ± 0.06 c
T7(0.5 chr-nic)	27.66 ± 0.16 a	62.53 ± 0.67 a	34.86 ± 0.30 a	0.62 ± 0.00 a

Significant differences are present when there are different letters in a column at $P \leq 0.05$.

Relative growth rate, specific growth rate, and survival rate

It is clear from Table (4) that the best results about the relative growth criterion were obtained in the fourth and the seventh treatments, which reached 126.90 and 126.03%, respectively, and which were significantly ($P \leq 0.05$) superior to the standard diet (114.39%). Adding two types of chromium supplements (chromium picolinate and nicotinate) to the standard diet resulted in higher specific growth in the fourth and seventh treatments, which reached 1.46 and 1.44 %g/day, respectively, higher than the standard diet (1.35 %g/day) and the rest of the other experimental treatments.

The superiority of diets supplemented with organic chromium supplements (chromium picolinate and nicotinate) is likely to be explained by the fact that organic chromium is an essential mineral for the physiological and vital functions of fish and that it affects the vital activity of insulin, the flow of glucose in the blood, and thus the rate of glucose metabolism in the blood. By increasing blood glucose metabolism, dietary carbohydrates will be used more efficiently as the main source of energy (Abbi and Qasim, 2024) and thus, dietary protein can be efficiently retained for body growth (Subandiyono and Hastuti, 2016). The results of our current study are consistent with the findings of (Wang *et al*. 2014) in their study on yellow croaker fish *Larmichthys crocea*, where they noted that the highest specific growth rate was in fish fed a diet supplemented with chromium nicotinate. They indicated the possibility of chromium in enhancing the activities of carbohydrate-specific enzymes, enhancing the glucose tolerance factor (GTF), facilitating the glycolysis pathway, and ultimately improving fish’s utilization of carbohydrates. Other studies indicated that there is no significant effect when adding organic chromium to fish diets (Pan *et al*., 2002; El-Sayed *et al*., 2010) in Nile tilapia fish. The survival rate criterion (%) results recorded in Table 4 showed no significant differences, as no deaths occurred within the different experimental treatments throughout the experiment, which lasted eight weeks. This implies that the fish's breeding environment and the various treatments had no negative effects on the fish

Table (4): The effect of organic chromium picolinate and nicotinate on parameters of relative growth rate, specific growth rate, and survival rate of common carp fish (Means ±SE).

Criterion / Treatment	Relative Growth Rate (RGR) (%)	Specific Growth Rate (SGR)	Survival Rate (%)
T1 (standard)	114.39 ± 0.37 b	1.35 ± 0.00 b	100 %
T2 (0.3 chr-pic.)	107.48 ± 1.79 c	1.29 ± 0.01 c	100 %
T3(0.4 chr-pic)	115.41 ± 0.35 b	1.36 ± 0.00 b	100 %
T4 (0.5 chr-pic)	126.90 ± 1.96 a	1.46 ± 0.01 a	100 %
T5 (0.3 chr-nic)	98.77 ± 0.88 d	1.22 ± 0.01 d	100 %
T6 (0.4 chr-nic)	105.32 ± 1.21 c	1.28 ± 0.01 c	100 %
T7(0.5 chr-nic)	126.03 ± 0.26 a	1.44 ± 0.00 a	100 %

Significant differences are present when there are different letters in a column at $P \leq 0.05$.

Food intake, feed conversion ratio and feed efficiency ratio

The results of the statistical analysis shown in Table (5) showed that the fourth and the seventh treatments were significantly ($P\leq 0.05$) superior to the total consumed feed standard, as they reached 65.02 and 65.60 g/fish, respectively, over the fish fed in the second, fifth, and sixth treatments, as the amount of feed consumed reached 63.05, 62.89, and 62.75 g/fish, respectively. While the group fed the standard diet, which amounted to 64.25 g/fish, did not differ significantly from all experimental groups. The results of the statistical analysis of the food conversion factor standard indicated that the fish fed the treatment (the fourth treatment) were significantly ($P\leq 0.05$) superior to the standard group and all other experimental treatments, as the food conversion factor for both treatments 7 and 4 reached 1.73 and 1.83, respectively.

The results of the statistical analysis indicated a significant decrease in the feed conversion ratio for the fourth treatments (1.73), which is the best and differed significantly from the rest of the other experimental treatments, including the standard treatment (1.91), while there are no significant differences were recorded between the standard and the fish fed the second and third treatments, which amounted to 1.98 and 1.89, respectively. The results that we reached were consistent with the results of the feed efficiency ratio criterion, which confirmed that the common carp that fed the fourth and seventh treatments, which amounted to 57.50 and 56.52%, were significantly superior to the standard group 52.10% and to all other experimental treatments. The results also indicated that the third treatments, which amounted to 52.89%, and the standard group were significantly superior to the second, fifth, and sixth treatments, as the feed efficiency ratio for the three treatments was 50.20, 46.40, and 49.29%, respectively.

Because it stimulates increased production of digestive enzymes, which positively enhances nutritional response, organic chromium, an essential micronutrient, may be responsible for these positive results obtained in food utilization criteria. Additionally, fish that obtain these diets benefit from them. This makes using essential nutrients to improve insulin function and utilizing carbohydrates as an energy source necessary for the metabolism of proteins, fats, and nucleic acids to build tissues (Ibrahim *et al*., 2010; Khan *et al*., 2014).

Table (5): The effect of organic chromium picolinate and nicotinate on the feed conversion ratio, feed efficiency ratio, and amount of feed consumed for common carp fish (Means ±SE) .

Criteria / Treatments	Food intake (g/fish)	Feed conversion ratio (FCR)	Feed efficiency ratio (%)
T1 (standard)	64.25 ± 0.36 ab	1.91 ± 0.02 c	52.10 ± 0.39 b
T2 (0.3 chr-pic.)	63.05 ± 0.65 b	1.98 ± 0.03 bc	50.20 ± 0.95 c
T3(0.4 chr-pic)	63.85 ± 0.58 ab	1.89 ± 0.02 bc	52.89 ± 0.58 b
T4 (0.5 chr-pic)	65.02 ± 0.46 a	1.73 ± 0.01 a	57.50 ± 0.55 a
T5 (0.3 chr-nic)	62.89 ± .075 b	2.15 ± 0.02 e	46.40 ± 0.43 d
T6 (0.4 chr-nic)	62.75 ± .061 b	2.02 ± 0.00 d	49.29 ± 0.18 c
T7(0.5 chr-nic)	65.60 ± .036 a	1.83 ± 0.05 ab	56.52 ± 0.35 a

Significant differences are present when there are different letters in a column at $P \leq 0.05$.

These results agreed with the study conducted by (Mubeen *et al*. 2022) when adding chromium picolinate to Indian carp diets. The results of the study showed that the best feed efficiency ratio and feed conversion factor were when adding chromium picolinate, as they indicated that the absorption of organic forms of chromium is very effective, less toxic, and more beneficial in carbohydrate metabolism and insulin flow compared to the inorganic form of chromium. The results were confirmed by (Khaeriyah and Haryati 2018) in the presence of a significant effect of organic chromium on aspects of food utilization in snakehead fish, where the treatments to which organic chromium was added were significantly superior. Organic chromium has a positive effect in increasing the potential performance of insulin in the flow of glucose in the blood to the cells, which enables insulin to enhance the transfer of glucose from the blood into living cells more quickly and then convert it into energy, as well as for improving the number of proteins needed for growth purposes (Mehrim, 2014). On the contrary, if carbohydrates are not utilized for growth purposes, the trend is towards using proteins as energy sources, negatively affecting growth rates. (Mehrim 2014) and (Selcuk *et al*. 2010) did not notice any effect of organic chromium on feed conversion standards and feed efficiency ratio in Nile tilapia and rainbow trout.

Protein intake protein retention, protein production value, and protein efficiency ratio

The results of the statistical analysis of the protein intake criterion (g/fish) listed in Table (6) showed significant superiority in the standard, the fourth, and the seventh treatments, whose values reached 16.12, 16.32, and 16.48, respectively, over the second treatment (15.82), the third (16.02), the fifth (15.79), and the sixth (15.75). The results of this criterion were linked to the amount of food consumed, which came as a result of the positive effect of adding organic chromium in general on the metabolism of nutrients, which in turn affected the growth above criterion positively, as it was reflected in the health and well-being of the fish, which increased the amount of food intake. As for the protein retention criterion, gm/fish, the results showed that the addition of chromium picolinate at different levels, represented by the second, third, and fourth treatments, recorded significant differences compared to the standard diet, whose values reached 8.34, 8.19, and 7.67, respectively, followed by the effect of this criterion. Treatments added to chromium nicotinate (except for the sixth treatment), the fifth and seventh treatments recorded values of 7.09 and 6.63, which differed significantly from the standard diet. It was shown from what was mentioned above that adding chromium picolinate had the best effect, which differed considerably from the fish fed the diet in which chromium nicotinate was added in the fifth, sixth, and seventh treatments. Picolinates are sources of organic chromium manufactured by companies. They are considered to have the best effect on the growth of organisms other than fish, such as livestock (Bernhard *et al*., 2012), poultry (Debski *et al*., 2004), and goats. (Paul *et al*., 2005).

The Protein Efficiency Ratio (PER) is one of the important criteria in evaluating foods, as it is noted from Table 7 that the fish fed the fourth treatments (0.5 mg/kg chromium picolinate feed) and the seventh treatments (0.5 mg/kg chromium nicotinate feed) outperformed significantly. This criterion is different from the rest of the experimental diets, including the standard diet (1.95), which amounted to 2.14 and 2.11, respectively. This explains why increasing the addition of both types of organic chromium (picolinate and nicotinate) had the greatest effect on increasing the protein efficiency ratio .

The Protein Productive Value (PPV) criterion is one of the most important criteria in evaluating protein-rich diets because it takes into account the percentage of protein intake that can be deposited in the fish’s body, through which it is known whether the weight gain results from the deposited protein or from an increase in moisture or body fat (Hepher, 1988). The results shown in Table 6 showed that the fish fed the second and third treatments were significantly superior to chromium picolinate in amounts of 0.3 and 0.4 mg/kg feed, which recorded values of 52.72 and 52.13% over the standard diet.(%38.45)

The fish fed the fourth treatments and the fifth, sixth, and seventh values reached 47.01, 44.90, 38.99, and 44.22, respectively, which means that the addition of picolinate had the best effect on these standard and other previous standards, as chromium picolinate, which represents the organic form and is low in toxicity. It is trivalent chromium (Cr^{+3}) which is an essential element that is best for obtaining optimal metabolism of carbohydrates, fats, proteins, and nucleic acids (Swaroop *et al*., 2019), and for activating some enzymes, stable proteins, and nucleic acids (Genchi *et al*., 2021).

Table (6): Effect of Organic Chromium picolinate and nicotinate on criteria of protein intake, protein retention, protein efficiency ratio, protein productive value of common carp fish (Means ±SE).

Criteria / Treatment	Protein Consumption (g/fish)	Protein Retention (g/fish)	Protein Efficiency Ratio (PER)	Protein Productive Value (PPV%)
T1 (standard)	16.12± 0.09 a	6.04 ± 0.02 e	1.95 ± 0.01 b	38.45 ± 0.01 e
T2 (0.3 chr-pic.)	15.82± 0.16 b	8.34 ± 0.09 a	1.87± 0.03 c	52.72 ± 0.03 a
T3(0.4 chr-pic)	16.02 ± 0.14 a	8.19 ± 0.02 a	1.97± 0.02 b	51.13± 0.02 a
T4 (0.5 chr-pic)	16.32± 0.11 a	7.67± 0.11 b	2.14± 0.02 a	47.01 ± 0.02 b
T5 (0.3 chr-nic)	15.79± 0.19 b	7.09± 0.06 c	1.73± 0.01 d	44.90± 0.01 c
T6 (0.4 chr-nic)	15.75± 0.16 b	6.14± 0.07 e	1.84± 0.00 c	38.99 ± 0.00 de
T7(0.5 chr-nic)	16.48± 0.08 a	6.63± 0.00 d	2.11± 0.01 a	44.22 ± 0.01 c

Significant differences are present when there are different letters in a column at $P \leq 0.05$.

These results came about as a result of increasing the efficiency of the utilization of carbohydrates in the fish diet, which works to reduce the consumption of protein and fats for energy purposes and also works to create metabolic intermediates through which other biologically essential compounds are formed. These results were consistent with what was indicated by (Ahmed *et al*. 2012) in a study they conducted on mirror carp fish, where they attributed these results to the chromomodulin Cr-LMW, which acts as part of the materials associated with chromium, which are low-molecular-weight compounds that were found to play a vital role. In the mechanism of automatic amplification of insulin signals, it thus affects the metabolism of glucose, fats, and proteins. It enhances growth performance, as chromodulin works to convert glucose into carbon dioxide or fats mediated by lipocytes (Penque, 2013) .

This stimulation occurs to activate insulin without changing the required insulin concentration by less than half, indicating that chromodulin plays an essential role in adipocytes. The stimulation also depends directly on the chromium content of the chromodomain (O'Hagan, 2014), and no other natural chromium-containing species stimulates insulin action in this way. Many other studies also confirmed our findings, including a study on grass carp by (Liu *et al*. 2010) and on red tilapia (*Coptodon rendalli*) (Rakhmawati *et al*., 2018). While our results differed from those of researchers (Pan *et al*., 2003) in red tilapia fish, (Gatta *et al*., 2001) in gilthead seabream (Sparus aurata), (El-Sayed *et al*., 2010), and (Mehrim *et al*. 2012) in Nile tilapia. The discrepancy between the results obtained in this study and various other studies is due to several factors, such as the form of organic chromium used, the source of carbohydrates, the diet, the concentration used for organic chromium, and the duration of its use, as well as the nutritional behavior of the target fish species used in the experiment. It has been proven that sufficient levels of energy sources non-proteins (carbohydrates and fats) in the diet can reduce protein catabolism through the property of reducing protein intake, which may be due to the use of carbohydrates as an energy source instead of protein in the diet, which requires the use of carbohydrates more efficiently, which reflects positively on the growth and health of fish due to chromium supplements of organic additives (Giri *et al*., 2014).

Chemical composition of the edible portion of the fish

The results shown in Table 7 show that the standard, second, fifth, and sixth treatments were significantly superior (P≤0.05) in moisture percentage, which reached 70.74, 71.23, 71.51, and 70.14%, respectively. Over the third, fourth, and seventh treatments, whose values were recorded as 66.76, 63.24, and 64.93%, respectively. The results of the analysis in Table 7 also showed that the values of the fourth group were significantly lower (P≥ 0.05) among the rest of the different experimental diets, including the standard diet.

The results of the analysis of the dry matter (DM) criterion for the edible portion, showed that fish fed the fourth treatments reached 36.76%. outperformed all other experimental diets, including the standard diet (29.26%). As for the crude protein criterion, the results of the statistical analysis Table (7) showed that the highest value was recorded when feeding the fish, the fourth treatments (22.82%), which differed significantly compared to all other experimental diets, including the standard diet (17.45%). Adding both types of organic chromium had a positive effect on raising the percentage of crude protein in the edible portion of the body above the standard diet. Adding picolinate at a level of 0.3 and 0.4 mg/kg feed, the second and third treatments, led to an increase in the percentage of protein retention, reaching 18.25 and 21.49%, respectively.

This is also the case when adding chromium nicotinate to the fifth, sixth, and seventh treatments, which led to an increase in the percentage of protein retention by 19.21, 19.79, and 21.81, respectively. Adding both types of organic chromium had a positive effect on increasing the percentage of protein and dry matter when adding organic chromium.

These results were consistent with (Ahmed *et al*. 2012) in common carp, (Asad *et al*. 2017), marigal fish, *Cirrhinus mrigala, Magzoub et al*. (2010) and (Pires *et al*. 2015) in Nile tilapia. These positive results were in contrast to the results obtained by (Dias *et al*. 2001) in European seabass (*Dicentrarchus labrax*). The results mentioned in Table 7 also showed that the standard treatment was significantly superior (P≤ 0.05) to the various experimental treatments to which picolinate and chromium nicotinate were added in ether extract criterion, which amounted to 7.15%, followed in effect by the second and fourth treatments, which amounted to 6.01 and 5.96%, respectively. They outperformed the third, fifth, and sixth treatments, with the percentage of ether extract for each treatment reaching 5.24, 5.39, and 5.40%, respectively, while the fish of the seventh treatment lagged behind all other tested treatments in the same criterion, reaching 4.51%.

The results obtained statistically confirmed that the fish from the fifth treatments were significantly superior to all other experimental treatments, reaching a value of 6.93%. While the results did not show significant differences between the rest of the other experimental treatments represented by the standard group and the second, third, fourth, sixth, and seventh treatments, where the percentage of deposited fat reached 4.96, 4.63, 4.80, 4.71, 5.03, and 5.96, respectively, adding both types of organic chromium led to a decrease in the retention fat criterion compared to the standard diet.(%7.15)

Table (7): Effect of Organic Chromium picolinate and nicotinate on chemical composition (%) of the edible portion of common carp fish (Means ±SE).

Criterion / Treatment	Moisture	Dry matter	Ether extract	Crude protein	Ash
T1 (standard)	70.74± 1.12 a	29.26± 0.12 c	7.15 ± 0.07 a	17.45 ± 0.19 f	4.96 ± 0.14 b
T2 (0.3 chr-pic.)	71.23± 0.70 a	28.77± 0.70 c	6.01 ± 0.13 b	18.25 ± 0.23 e	4.63 ± 0.26 b
T3(0.4 chr-pic)	66.76± 1.04 b	33.24± 1.04 b	5.69 ± 0.15 c	22.10± 0.92 b	5. 38± 0.34 b
T4 (0.5 chr-pic)	63.24± 0.65 c	36.76 ± 0.65a	6.46 ± 0.10 b	24.07± 0.19 a	5.96 ± 0.30 b
T5 (0.3 chr-nic)	71.51± 0.57 a	29.99± 0.57 c	5.01 ± 0.15 c	19.02± 0.18 d	6.23± 0.27 a
T6 (0.4 chr-nic)	70.14± 0.13 a	29.86 ± 0.13c	5.10 ± 0.19 c	19.49± 0.19 c	4.95 ± 0.21 b
T7(0.5 chr-nic)	64.93± 0.14 b	34.07±0.14ab	4.92 ± 0.24 d	22.83± 0.18 b	6.11 ± 0.24 b

Significant differences are present when there are different letters in a column at $P \leq 0.05$.

The result may be because organic chromium has an insulin-simulating property, as it enhances the entry of glucose into the body's cells and converts it into energy or stores it for later use (Stapleton, 2000). This chromium stimulation increases the hormone insulin's activity, which ultimately increases the use of protein in the formation of protein tissue. The essential ingredients used in feed formulations were enriched with plant protein sources that increase the availability of nutrients and allow them to be digested more efficiently in the presence of the organochrome compound (Qamer *et al*., 2019). These results were consistent with the study conducted by (Asad *et al*. 2017), who indicated that chromium has beneficial effects on reducing fat deposition in marine fish meat. As for the ash standard, no significant differences were recorded between the different experimental diets, except for the fifth treatment (6.93%), which was superior to all other treatments, including the standard diet (4.96%). The high ash content in fish-fed organic chromium nicotinate likely leads to an increase in chromium deposition in the muscles, as (Qamer *et al*. 2019) in Rohu found that adding organic chromium compounds leads to an increase in chromium concentration in the muscles, while other results were recorded by (Liu *et al*. 2010) in grass carp had no positive effect on ash retention in fish.

CONCLUSIONS

The results show that the feed additives represented by organic chromium have positive effects on promoting growth, utilizing food, and supporting the nutritional value of the edible part of the fish body, especially when adding organic chromium (both types) 0.5 mg/kg of feed.

ACKNOWLEDGMENT

The researcher wishes to thank the University of Mosul and the College of Agriculture and Forestry for their support and provide the requirements for the completion of this research.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

تقييم إضافة نوعين من الكروم العضوي لتعزيز معايير النمو والتركيب الكيميائي لأسماك الكارب الشائع *Cyprinus carpio* L.

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الخلاصة

هدفت هذه الدراسة إلى تقييم إضافة نوعين من الكروم العضوي على معايير النمو وهما بيكولينات الكروم بكمية 0.3 و0.4 و0.5 ملغم/كغم علف (T2 وT3 وT4) و0.3 و0.4 و0.5 ملغم/كغم علف من نيكوتينات الكروم (T5 وT6 وT7) بالإضافة إلى عليقة السيطرة بدون إضافات (T1). أظهرت نتائج التحليل الإحصائي تفوق T4 وT7 بشكل معنوي (P≤ 0.05) في معايير الوزن النهائي والزيادة الوزنية الكلية ومعدل النمو اليومي ومعدل النمو النسبي والنوعي والغذاء المتناول ومعامل التحويل الغذائي ونسبة كفاءة التغذية على جميع المعاملات التجريبية الأخرى بما في ذلك عليقة السيطرة. أظهرت نتائج معيار البروتين المترسب والقيمة المنتجة للبروتين تفوق T2 وT3 بشكل معنوي على بقية المعاملات التجريبية بينما تفوقت T4 وT7 بشكل معنوي على بقية المعاملات التجريبية في نسبة كفاءة البروتين. وقد تفوقت الأسماك التي تغذت على العلائق T1 وT3 وT4 وT7 على المعاملات التجريبية الأخرى في معيار تناول البروتين. ووفقًا للنتائج، فإن الأسماك التي تغذت على T4، والتي اختلفت بشكل كبير عن المعالجات الأخرى، كان لديها أعلى مستوى من الاحتفاظ بالبروتين. وعند مقارنتها بالنظام الغذائي الضابط، انخفضت كمية مستخلص الأثير في الجزء الصالح للأكل بشكل إيجابي عند إضافة كلا الشكلين من الكروم العضوي. وتوضح النتائج المذكورة أعلاه أن إضافة كلا الشكلين من الكروم العضوي أدى إلى تحسين النمو والاستفادة من الغذاء وترسيب البروتين والقيمة المنتجة للبروتين وتقليل نسبة الدهون في الجزء الصالح للأكل.

الكلمات المفتاحية: القيمة المنتجة للبروتين، بيكولينات الكروم، كفاءة التحويل الغذائي، نيكوتينات الكروم.

REFERENCES

Abbi, S., and Qasim, A. (2024). Impact Of Zinc Supplementation On Nutrients Digestibility And Blood Minerals Concentration During Hot Season Of Local Growing Lambs. *Mesopotamia Journal of Agriculture*, *52*(1), 79-93. https://doi.org/10.33899/mja.2024.146430.1364

Ahmed, A. R., Jha, A. N., and Davies, S. J. (2012). The efficacy of chromium as a growth enhancer for mirror carp (*Cyprinus carpio* L): an integrated study using biochemical, genetic, and histological responses. *Biological trace element research*, *148*, 187-197. https://2u.pw/EaSfmPR6

Ahmed, S. J., and Abdul-Rahman, S. Y. (2023). Effects of castration and sex hormones on antioxidant status and some biochemical parameters of male rabbits exposed to oxidative stress. *Mesopotamia Journal of Agriculture*, *51*(1), 92-114. https://doi.org/10.33899/magrj.2023.138538.1220

Al-Kattan, H. A., and Al-Bassam, N. H. (2024). Evaluation Of Adding Sweet Bean Seed (Foeniculum Vulgare) And Roselle (Hibiscus Sabdariffa) Seed On Enhancing Growth And Performance Of Common Carp Cyprinus Carpio. *Mesopotamia Journal of Agriculture*, *52*(2). https://doi.org/10.33899/mja.2024.146824.1374

Al-Niaeemi, B. H., and Dawood, M. H. (2023). Bioaccumulation of heavy metals in Bothriocephalus acheilognathi cestoda and the definitive host, Cyprinus carpio (L. 1758). Iraqi Journal of Veterinary Sciences, 37(4), 899-905. https://doi.org/10.33899/ijvs.2023.137615.2715

Al-Taee, S. K. (2024). Immunohistochemically and semi-quantities analysis of carp gills exposed to sodium thiosulfate. Iraqi Journal of Veterinary Sciences, 38(1), 191-198 https://doi.org/10.33899/ijvs.2023.140746.3086

Amata, I. A. (2013). Chromium in livestock nutrition: A review. *Global Advanced Research Journal of Agricultural Science*, *2*(12), 289-306. https://short-link.me/Koju

Ameen, M. H., Wahhab, M. A., Muhammad, S. S., and Salih, S. A. (2023). Impact Of Mixed Dietary Vitamin E-Selenium Powder on Reproductive Hormones' concentration Of Males and Females in Japanese Quail Bird (Coturnix Coturnix Japonica). *Mesopotamia Journal of Agriculture*, *51*(3). http://doi.org/10.33899/magrj.2023.139953.1233

AOAC (2000). Official Methods of Analysis, 17th Ed. Association of Official Analytical Chemists, Gaithersburg, USA. Broihier (1999). The Phyto-chemical Renaissance. *Food Processing*. 44:46-48. https://law.resource.org/pub/us/cfr/ibr/002/aoac.methods.1.1990.pdf

Asad, F., Qamer, S., Behzad, A., Ali, T., and Ashraf, A. (2017). Growth performance and chemical composition of *Cirrhinus mrigala* (mori) under the effect of chromium chloride hexahydratre. *Pure and Applied Biology (PAB)*, *6*(4), 1226-1233.http://dx.doi.org/10.19045/bspab.2017.600130

Bernhard, B. C., Burdick, N. C., Rounds, W., Rathmann, R. J., Carroll, J. A., Finck, D. N., ... and Johnson, B. J. (2012). Chromium supplementation alters the performance and health of feedlot cattle during the receiving period and enhances their metabolic response to a lipopolysaccharide challenge–. *Journal of animal science*, *90*(11), 3879-3888. https://doi.org/10.2527/jas.2011-4981

Debski, B., Zalewski, W., Gralak, M. A., and Kosla, T. (2004). Chromium-yeast supplementation of chicken broilers in an industrial farming system. *Journal of Trace Elements in Medicine and Biology*, *18*(1), 47-51 https://doi.org/10.1016/j.jtemb.2004.02.003

Dias, J., Arzel, J., Corraze, G., and Kaushik, J. (2001). Effects of dietary L-carnitine supplementation on growth and lipid metabolism in European seabass (Dicentrarchus labrax). *Aquaculture research*, *32*, 206-215.https://doi.org/10.1046/j.1355-557x.2001.00016.x

Duncan, D. B. (1955). Multiple range and multiple F tests. *biometrics*, *11*(1), 1-42. https://www.jstor.org/stable/3001478

El-Sayed, E. H., Hassanein, E. I., Soliman, M. H., and El-Khatib, N. R. (2010). The effect of dietary chromium picolinate on growth performance, blood parameters and immune status in Nile tilapia, *Oreochromis niloticus 27*(1), 51-63. cabidigitallibrary.org/doi/full/10.5555/20113072504

FAO, R. (2022). The state of world fisheries and aquaculture 2022. Towards blue transformation. *The State of World Fisheries and Aquaculture (SOFIA)*, 266. https://n9.cl/be6ir

Gaber, M. (2002). effects of dietary carbohydrate-to-lipid ratios on growth performance and body coposition of nile tilapia, *oreochromis niloticusl*. fingerlings. *Egyptian Journal of Aquatic Biology and Fisheries*, *6*(2), 25-40. https://dx.doi.org/10.21608/ejabf.2002.1737

Gatta, P. P., Piva, A., Paolini, M., Testi, S., Bonaldo, A., Antelli, A., and Mordenti, A. (2001). Effects of dietary organic chromium on gilthead seabream (*Sparus aurata* L.) performances and liver microsomal metabolism. *Aquaculture Research*, *32*, 60-69. https://doi.org/10.1046/j.1355-557x.2001.00005.x

Genchi, G., Lauria, G., Catalano, A., Carocci, A., and Sinicropi, M. S. (2021). The double face of metals: The intriguing case of chromium. *Applied Sciences*, *11*(2), 638. https://doi.org/10.3390/app11020638

Giri, A. K., Sahu, N. P., Saharan, N., and Dash, G. (2014). Effect of dietary supplementation of chromium on growth and biochemical parameters of *Labeo rohita* (Hamilton) fingerlings. *Indian Journal of Fisheries*, *61*(2), 73-81. http://eprints.cmfri.org.in/id/eprint/10156

Hepher, B. (1988). *Nutrition of pond fishes*. Cambridge university press England 1-84. https://short-link.me/KodS

Ibrahim, D. K., Al-Mashhadani, E. H., and Al-Bandr, L. K. (2010). Effect of supplementing different levels of chromium yeast to diet on broiler chickens on some physiological traits. *International Journal of Poultry Science*, *9*, 376–381 http://dx.doi.org/10.3923/pjn.2010.942.949

Khaeriyah, A., and Haryati and Karim, Y. (2018). Optimization of feeding with organic chromium supplement in different concentrations on the ammonia excretion and the growth of snakehead fish seeds (*Channa striata*). *Scientific Research Journal*, *6*(4), 11-18. https://www.scirj.org/papers-0418/scirj-P0418520.pdf

Khan, R. U., Naz, S., Dhama, K., Saminathan, M., Tiwari, R., Joen, G. J., ... Tufarelli, V. (2014). Modes of action and beneficial application of chromium in poultry nutrition, production and health: Review. *International Journal of Pharmacology*, *10*, 357–367. https://hdl.handle.net/11586/66364

Kiron, V., Phromkunthong, W., Huntley, M., Archibald, I., and De Scheemaker, G. (2012). Marine microalgae from biorefinery as a potential feed protein source for Atlantic salmon, common carp and whiteleg shrimp. *Aquaculture Nutrition*, *18*(5), 521-531. https://doi.org/10.1111/j.1365-2095.2011.00923.x

Liu, T., Wen, H., Jiang, M., Yuan, D., Gao, P., Zhao, Y., and Liu, W. (2010). Effect of dietary chromium picolinate on growth performance and blood parameters in grass carp *fingerling*, Ctenopharyngodon idellus. *Fish physiology and biochemistry*, *36*, 565-572. https://n9.cl/nkuom

Magzoub, M. B., Al-Batshan, H. A., Hussein, M. F., Al-Mufarrej, S. I., and Al-Saiady, M. Y. (2010). The effect of source and level of dietary chromium supplementation on performance, chemical composition and some metabolic aspects in hybrid tilapia fish (*Oreochromis niloticus*× *O. aureus*). *Research Journal of Biological Sciences*, *5*(2), 164-170 http://docsdrive.com/pdfs/medwelljournals/rjbsci/2010/164-170.pdf

Maty, H. N., Hameed, H. M., and Hassan, A. A. (2024). Potency of nano-zinc oxide on caspase-3 of male quail exposed to lipopolysaccharide. Iraqi Journal of Veterinary Sciences, 38(1), 163-171. https://doi.org/10.33899/ijvs.2023.141585.3121

Mehrim, A. I. (2012). Effect of dietary chromium picolinate supplementation on growth performance, carcass composition and organs indices of Nile tilapia (*Oreochromis niloticus* L.) fingerlings. *Journal of Fisheries and Aquatic Science*, *7*(3), 224-232. https://short-link.me/Komb

Mehrim, A. I. (2014). Physiological, biochemical and histometric responses of Nile tilapia (*Oreochromis niloticus* L.) by dietary organic chromium (chromium picolinate) supplementation. *Journal of advanced research*, *5*(3), 303-310.https://doi.org/10.1016/j.jare.2013.04.002

Mizory, F. A., and Altaee, N. T. (2023). Evaluation the growth performance and feed utilization of *Cyprinus carpio* L. fed on Moringa oleifera leaves floating on water as supplemented diet. *Mesopotamia Journal of Agriculture*, *51*(1), 66-78. http://10.33899/magrj.2023.137303. 1210

Moatt, J. P., Hambly, C., Heap, E., Kramer, A., Moon, F., Speakman, J. R., and Walling, C. A. (2017). Body macronutrient composition is predicted by lipid and not protein content of the diet. *Ecology and Evolution*, *7*(23), 10056-10065. https://doi.org/10.1002/ece3.3529

Moreira, D. K. T., de Pádua Gandra, R. L., Zuin, J. C., Ract, J. N. R., Ribeiro, A. P. B., Macedo, J. A., ... and Macedo, G. A. (2020). Synthesis and characterization of structured lipid rich in behenic acid by enzymatic interesterification. *Food and bioproducts processing*, *122*, 303-310. https://doi.org/10.1016/j.fbp.2020.06.005

Mubeen, S., Bibi, S., Zahra, M., Jahan, S., Iqbal, S., and Iftikhar, I. (2022). Effect of chromium supplementation, both organic and inorganic, on the growth capacity and genotoxicity of *Labeo rohita*. *International Journal of Multidisciplinary Sciences and Arts*, *1*(1), 72-79.https://doi.org/10.47709/ijmdsa.v1i1.1682

O'Hagan, H. M. (2014). Chromatin modifications during repair of environmental exposure-induced DNA damage: A potential mechanism for stable epigenetic alterations. *Environmental and molecular mutagenesis*, *55*(3), 278-291. https://doi.org/10.1002/em.21830

Pan, Q., Bi, Y.Z., Yan, X.L., Pu, Y.Y., Zheng, C., (2002). Effect of organic chromium on carbohydrate utilization in hybrid tilapia (*Oreochromis niloticus* × *O. aureus*). *Acta Hydrobiol. Sin. 26* (4), 393–399. https://2u.pw/Y9vvcVem

Pan, Q., Liu, S., Tan, Y. G., and Bi, Y. Z. (2003). The effect of chromium picolinate on growth and carbohydrate utilization in tilapia, *Oreochromis niloticus*× *Oreochromis aureus*. *Aquaculture*, *225*(1-4), 421-429. https://2u.pw/LGgMHIyB

Paul, T. K., Haldar, S., and Ghosh, T. K. (2005). Growth performance and nutrient utilization in black Bengal bucks (*Capra hircus*) supplemented with graded doses of chromium as chromium chloride hexahydrate. *Journal of Veterinary Science*, *6*(1), 33-40. https://2u.pw/1TomKEpx

Penque, B. A. (2013). Mechanisms of hexosamine-induced cholesterol accumulation and therapeutic actions of chromium. Indiana University. https://short-link.me/Ko3e

Pires, K. A., Santos, D. D., Graça, D. S., Melo, M. M., Barbosa, F. A., and Soto-Blanco, B. (2015). Effects of two sources of chromium on performance, blood and liver lipid levels in Nile Tilapia (*Oreochromis niloticus*). https://www.cabidigitallibrary.org/doi/full/10.5555/20163045082

Qamer, S., Asad, F., Faiz, A., Arshad, R., Shaheen, Z., and Yasmin, T. (2019). Supplemental organic and inorganic chromium effects on feed digestibility and muscle composition in labeo rohita (*Rohu*). *Pakistan Journal of Agricultural Research*, *32*(3), 474-479. http://dx.doi.org/10.17582/journal.pjar/2019/32.3.474.479

Rakhmawati, R., Suprayudi, M. A., Setiawati, M., Widanarni, W., Junior, M. Z., and Jusadi, D. (2018). Bioefficacy of dietary chromium picolinate and chromium yeast on growth performance and blood biochemical in Red Tilapia, *Oreochromis niloticus* (Linnaeus). *Aquaculture Research*, *49*(2), 839-846 https://doi.org/10.1111/are.13527

Saha, R., Nandi, R., and Saha, B. (2011). Sources and toxicity of hexavalent chromium. *Journal of Coordination Chemistry*, *64*(10), 1782-1806. https://doi.org/10.1080/00958972.2011.583646

Selcuk, Z., Tiril, S. U., Alagil, F., Belen, V., Salman, M., Cenesiz, S., ... and Yagci, F. B. (2010). Effects of dietary L-carnitine and chromium picolinate supplementations on performance and some serum parameters in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture international*, *18*, 213-221. https://2u.pw/ZiqfD7En

Smith, R. R. (1971). A method for measuring digestibility and metabolizable energy of fish feeds. *The Progressive Fish-Culturist*, *33*(3), 132-134. https://doi.org/10.1577/1548-8640(1971)33[132:AMFMDA]2.0.CO;2

SPSS. (2017). Statistical Package for Social Science. Version 25, SPSS Inc, U.S.A

Stapleton, S. R. (2000). Selenium: an insulin mimetic. *Cellular and Molecular Life Sciences CMLS*, 57(13), 1874-1879. https://2u.pw/wHFC0aQj

Subandiyono, S., and Hastuti, S. (2016). Trivalent Chromium (Cr+ 3) In Dietary Carbohydrate And Its Effect On The Growth Of Commonly Cultivated Fish. *Jurnal Teknologi (Sciences and Engineering)*, *78*(4–2), 233-237. https://doi.org/10.11113/jt.v78.8214

Swaroop, A., Bagchi, M., Preuss, H. G., Zafra-Stone, S., Ahmad, T., and Bagchi, D. (2019). Benefits of chromium (III) complexes in animal and human health. In The nutritional biochemistry of chromium (III) (pp. 251-278). Elsevier. https://doi.org/10.1016/B978-0-444-64121-2.00008-8

Todd, A. S., Coleman, M. A., Konowal, A. M., May, M. K., Johnson, S., Vieira, N. K., and Saunders, J. F. (2008). Development of new water temperature criteria to protect Colorado's fisheries. Fisheries, 33(9), 433-443. https://doi.org/10.1577/1548-8446-33.9.433

Wang, J., Ai, Q., Mai, K., Xu, H., and Zuo, R. (2014). Dietary chromium polynicotinate enhanced growth performance, feed utilization, and resistance to Cryptocaryon irritans in juvenile large yellow croaker (*Larmichthys crocea*). *Aquaculture*, *432*, 321-326. https://doi.org/10.1016/j.aquaculture.2014.05.027