

**Original Article****Protective Effects of Dietary *Spirulina platensis* against Cadmium-Induced Oxidative Stress in Gills of Rainbow Trout**

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**ABSTRACT**

**Background:** Contamination of feeds with cadmium leads to oxidative stress in vital tissues such as gills and affects the fish survival. Therefore, an increase in the capacity of the antioxidant defense system and detoxification system of fish may reduce adverse effects of pollutants. This study investigated the protective effects of microalga *Spirulina platensis* against oxidative stress in gills of cadmium-treated rainbow trout.

**Methods:** This study was conducted at Fish Farm, Almas-Dime Village, Koohrang, Charmahal & Bakhtiari Province, Iran from April to July 2016. Rainbow trout were allocated into five groups of which one group received normal feed and served as control. Fish from group II received 0.2 mg CdCl<sub>2</sub> per 1 kg feed. Groups III-V were fed with enriched diet with 2.5, 5 and 10 g *S. platensis* per 1 kg feed, respectively and simultaneously treated with 0.2 mg kg<sup>-1</sup> CdCl<sub>2</sub> for 21 d. Changes in biochemical parameters including alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP) and lactate dehydrogenase (LDH), malondialdehyde (MDA) as marker of lipid peroxidation and cellular total antioxidant capacity were evaluated.

**Results:** Oral exposure to CdCl<sub>2</sub> caused a significant increase in MDA levels and altered AST, ALT, ALP and LDH activities in gills ( $P < 0.05$ ). The cellular antioxidant capacity was significantly lowered in CdCl<sub>2</sub>-treated fish as compared to the control group ( $P < 0.05$ ). Oral administration of *S. platensis* significantly ameliorated these changes in certain biochemical parameters in gills of CdCl<sub>2</sub>-treated fish.

**Conclusion:** The findings indicate that *S. platensis* has protective effects against toxic influence of CdCl<sub>2</sub> on certain biochemical parameters in gills of fish.

**Keywords:** Biochemical Parameter, Cadmium, Microalga, Oxidative Stress.

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**INTRODUCTION**

Gills of fish are the first target organs when exposed to environmental pollutants [1]. However, many pollutants affect fish through feeds. Therefore, studying pollutants that affect target organs of fish via food chain seems essential. Cadmium, one of the nonessential metals in bio-systems, can be toxic even in very low doses and has a high potential to bio-accumulate in the food chain [2]. Contamination of main components of commercial fish feeds including cereals, fish powder, fish oil and vegetable oils with cadmium [3, 4] can transfer cadmium to farmed fish [5]. Cadmium affects the physiological activity of cells by disturbance in mitochondrial metabolic processes, disturbance in

electron transport chain, lipid peroxidation of cell membranes and influencing the cell membrane permeability, inhibiting oxidative phosphorylation and protein synthesis, as well as disturbance in cellular ion channel [2, 6, 7]. Exposure to cadmium may lead to oxidative stress-induced damages in fish [8]. Free radicals may react with biomolecules such as proteins and lipids and cause lipid peroxidation, protein carbonylation, alter the cellular antioxidant defense system [6, 9], lead to histopathological damages, change tissues, and blood biochemical parameters [6].

Accordingly, feeding fish with cadmium-contaminated diets can cause oxidative stress in gills [10]. However, the antioxidant defense system can neutralize oxygen free radicals, bind to cadmium or change the biotransformation of its

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chemical forms and remove extra cadmium from cells [9, 11]. Therefore, increasing the total antioxidant capacity of cells can be effective in creating balance, neutralizing free radicals and protecting cells.

*Spirulina platensis*, a member of cyanobacteria or blue-green algae, is rich in antioxidant compounds such as Beta-carotene, phycocyanin, tocopherol, and the antioxidant defense system enzymes that have a key role in eliminating free radicals [12]. Besides, antioxidant compounds, this microalga contain significant amounts of protein (more than 70%), long-chain polyunsaturated fatty acids (PUFA), vitamins and especially vitamin B12, as well as minerals like zinc, manganese, magnesium, selenium and iron [13]. Oral administration of *S. platensis* is reported to increase the cellular antioxidant capacity and glutathione levels in cells against iron-induced oxidative stress [14] and prevent cell death induced by increased free radicals [15-17].

Therefore, oral administration of *S. platensis* may improve the capacity and performance of cellular antioxidant defense system against cadmium-induced free radicals. This study was conducted to investigate the protective effects of microalga *Spirulina* against oxidative stress in gills of cadmium-treated rainbow trout.

## MATERIALS AND METHODS

### Fish Treatment

Two hundred rainbow trout, *Oncorhynchus mykiss*, weighting  $200 \pm 10$  gr were used in the present study according to National Ethical Framework for Animal Research in Iran [18]. This study was conducted at Fish Farm, Almas-Dime Village, Koohrang, Charmahal & Bakhtiari Province, Iran from April to July 2016. Specimens were randomly distributed in 5 concrete raceway (10000 L) and acclimatized in aerated freshwater ( $16 \pm 2$  °C; pH,  $7.4 \pm 0.2$ ; 100% water exchange rate/day and natural photoperiod) for two weeks before use. During the acclimatization period, fish were fed two times per day with commercial diet from Faradaneh Company, Sharkourd, Iran.

This experiment was done in a completely randomized design with 5 experimental treatments: group I or control fish; Group II fed with 0.2 mg of CdCl<sub>2</sub> per kg of commercial fish feed; group III simultaneously fed with 0.2 mg L<sup>-1</sup> of CdCl<sub>2</sub> [6] and 2.5 g of *Spirulina* [19] per kg of commercial fish feed; group IV, simultaneously

fed 0.2 mg L<sup>-1</sup> of CdCl<sub>2</sub> and 5 g *Spirulina* per kg of commercial fish feed and group V simultaneously fed with 0.2 mgL<sup>-1</sup> of CdCl<sub>2</sub> and 10 g of *Spirulina* per kg of commercial feed. Water exchange rate/day was 100% and CdCl<sub>2</sub> was orally administered to fish.

After 21 d of exposure to CdCl<sub>2</sub> and treatment with *Spirulina*, 12 fish from each group were caught and anesthetized. Fish were euthanized and then their gills, liver and kidney were removed, washed with physiological serum and homogenized for 2 min in cold phosphate buffer solution (pH: 4.7). The resulting homogenized solution was centrifuged at 150000 rpm for 15 min at 4 °C. The supernatant was collected to measure biochemical parameters and was stored at -25 °C until biochemical analysis.

### Biochemical Parameters Analysis

Aspartate aminotransferase (AST) was assayed in a coupled reaction with malate dehydrogenase in the presence of NADH. In alanine aminotransferase (ALT) assay, the enzyme reacts with alanine and α-ketoglutarate to form glutamate and pyruvate. Lactate dehydrogenase converts pyruvate to lactate and NAD<sup>+</sup>. AST and ALT activities were recorded by measuring changes in absorbance during 3 min at 340 nm. Lactate dehydrogenase (LDH) activity was measured based on the conversion of pyruvate to L-lactate by monitoring the oxidation of NADH. LDH activity was monitored during 3 min at 340 nm Alkaline phosphatase (ALP) assay is based on the enzyme-mediated conversion of p-nitrophenol phosphate to nitrophenol in an alkaline buffer at 405 nm [20]. Protein levels in tissues were determined by standard procedures used in clinical biochemistry laboratories according to the biochemical kits user manuals (ParsAzmun Co, Iran) [21]. CAT activity was determined [22], although with some modifications. Catalase activity was measured by hydrogen peroxidase assay based on the formation of its stable complex with ammonium molybdate. 200 μL of the supernatant was incubated in working solution including 1000 μL hydrogen peroxide and 500 μL phosphate buffer (pH: 7.4) at

$$\text{Catalase activity (kU.L}^{-1}\text{)} = \frac{A(\text{sample}) - A(\text{blank 1})}{A(\text{blank 2}) - A(\text{blank 3})} \times 271$$

Blank 1 contained 1.0 mL substrate, 1.0 mL molybdate and 0.2 mL distilled water; blank 2 contained 1.0 mL substrate, 1.0 mL molybdate and 0.2 mL buffer; blank 3 contained 1.0 mL buffer, 1.0 mL molybdate and 0.2 mL buffer.

Total antioxidant capacity was estimated according to the ferric reducing ability of plasma (FRAP). Briefly, the FRAP reagent contained 5 mL of a (10 mmol/L) TPTZ (2, 4, 6- tripyridyl-s-triazine) solution in 40 mmol/L HCL plus 5 mL of  $\text{FeCl}_3$  (20 mmol/L) and 50 mL of acetate buffer, (0.3 mol/L, pH=3.6) and was prepared freshly. One hundred  $\mu\text{L}$  aliquots of the supernatant were mixed with 3 mL FRAP reagent. The conversion rate of ferric tripyridyl-s-triazine ( $\text{Fe}^{3+}$ -TPTZ) complex to ferrous tripyridyl-s-triazine ( $\text{Fe}^{2+}$ -TPTZ) at pH 3.6 and 25 °C is directly proportional to the concentration of total antioxidant in the sample.  $\text{Fe}^{2+}$ -TPTZ has an intense blue color that can be monitored for up to 5 min at 593 nm by a UV/VIS spectrophotometer. Calculations were performed using a calibration curve of  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  (100 to 1000  $\mu\text{M/L}$ ) [23].

Malondialdehyde (MDA) content was assessed by modified thiobarbituric acid assay and was expressed as  $\mu\text{mol/g}$  tissue [24]. Briefly, 500  $\mu\text{L}$  of the supernatant was transferred to a Pyrex tube and mixed with 2500  $\mu\text{L}$  trichloroacetic acid (20%) and 1000  $\mu\text{L}$  thiobarbituric acid (67%). The tubes were then placed in boiling water (100 °C) for 15 min. After cooling, the chromogenic substrate was extracted into the organic phase with 1000  $\mu\text{L}$  of distilled water and 5000- $\mu\text{L}$  *n*-butanol: pyridine (15: 1). The mixture was then centrifuged at 2000 gr for 15 min at 4 °C. The pink color produced by these reactions was measured spectrophotometrically at 532 nm to measure MDA levels. MDA concentration was calculated using MDA standard. Tetraethoxypropane and absolute ethanol were used to prepare the MDA standards. Concentrations of MDA in tissue samples are expressed in  $\mu\text{M}$  per g protein. All biochemical parameters were measured by UV/VIS spectrophotometer (model Biochrom Libra S22, England).

### Data Analysis

Kolmogorov-Smirnov Normality Test was done with SPSS, ver. 22 (Chicago, IL, USA), to test the normality of data. Data analysis was conducted by one-way ANOVA. Means

comparison was performed using Duncan's test at a confidence level of 95% ( $\alpha=0.05$ ). Significant differences between values when compared with control groups were showed by alphabet letters ( $P<0.05$ ), similar alphabet letters indicated no significant difference between experimental groups.

### RESULTS

The activity level of AST in CdCl<sub>2</sub>-treated fish was significantly higher than its level in the gills of the control. Despite a decrease in AST activity in gill cells of fish treated with different concentrations of *S. platensis* and 0.2 mg of CdCl<sub>2</sub> compared with fish solely treated with CdCl<sub>2</sub>, AST activity was significantly higher than that of the control group (Figure 1).

Feeding fish with CdCl<sub>2</sub>-contaminated diets significantly decreased ALT activity in gill cells. However, administering different doses of *S. platensis* maintained ALT activity in gills of fish treated with CdCl<sub>2</sub> at a normal level (Figure 2).

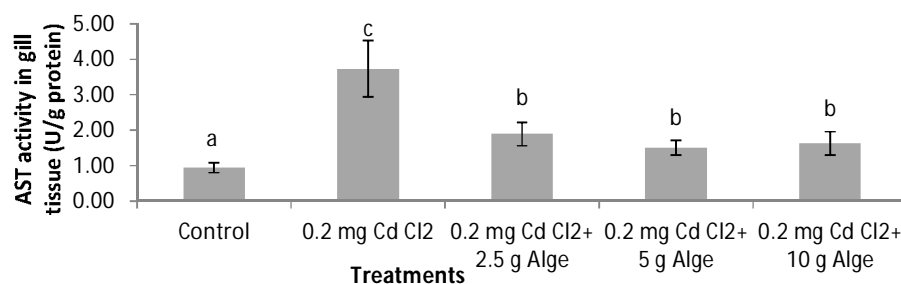
ALP activity in gills of fish treated with CdCl<sub>2</sub>-contaminated diets decreased significantly. Feeding fish with different doses of *S. platensis* was effective in regulating ALP to the normal level (Figure 3).

Fish exposure to CdCl<sub>2</sub> through the food chain significantly increased LDH activity compared to that of the control. However, oral administration of *S. platensis* prevented an increase in LDH activity in gills of CdCl<sub>2</sub>-treated fish (Figure 4).

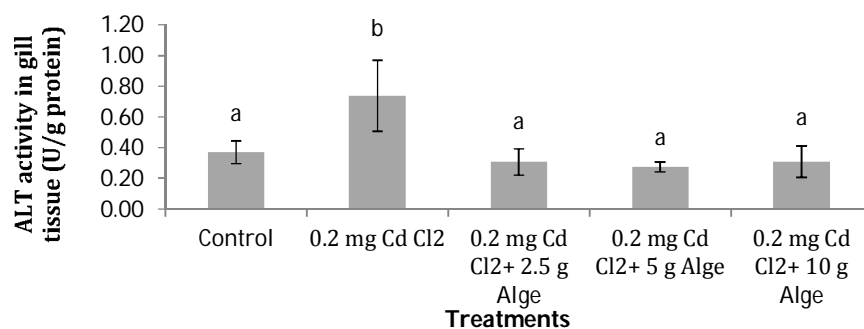
CAT activity in gills of CdCl<sub>2</sub>-treated fish was significantly higher than that in gills of the control group. In contrast, oral administration of *S. platensis* in different doses maintained CAT activity at a normal level in fish treated with .2 mg of cadmium per gr of feed (Figure 5).

Cellular total antioxidant level in gills of fish exposed to CdCl<sub>2</sub> decreased significantly compared with that of the control group. Although administration of 2.5 and 5 gr *S. platensis* led to a slight decrease in total antioxidant level, this is significantly less than the antioxidant level of the control group. Feeding fish with 10 gr of *S. platensis* increased cellular total antioxidant level in gills of fish treated with CdCl<sub>2</sub> (Figure 6).

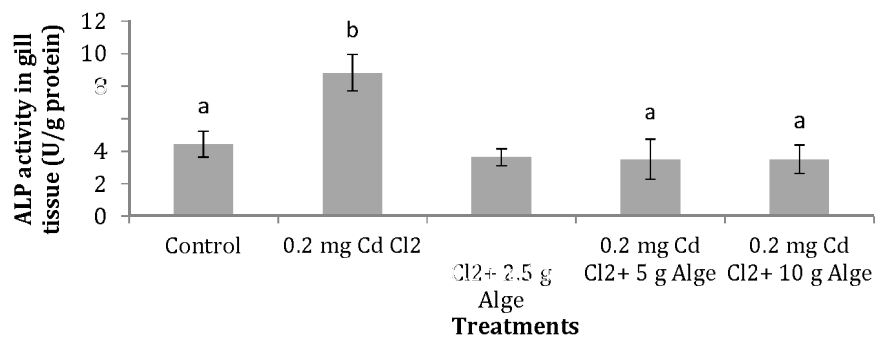
MDA level in gills of CdCl<sub>2</sub>-treated fish was significantly higher than that of the control group. Feeding fish with different doses of *S. platensis* cannot reduce MDA levels as much as MDA levels in the control (Figure 7).



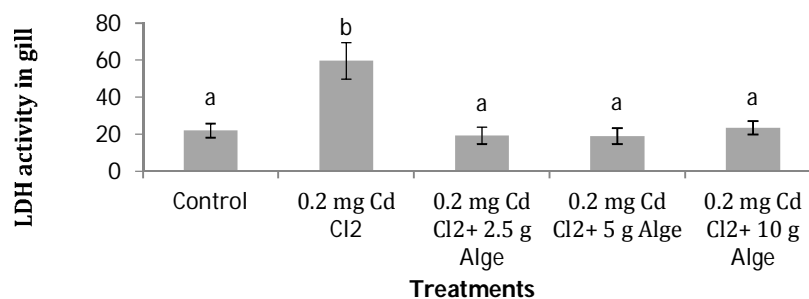
**Figure 1.** Alterations in AST activity in gills of fish ( $U\ g^{-1}$  protein tissue). Significant differences between values when compared with control groups were showed by alphabet letters ( $P < 0.05$ ), similar alphabet letters indicated no significant difference between experimental groups.



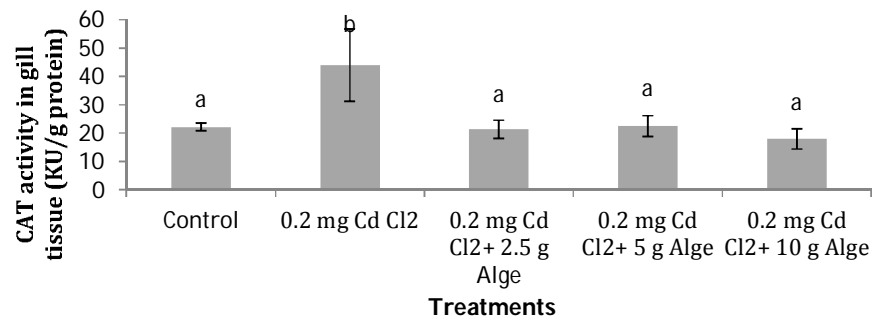
**Figure 2.** Alterations in ALT activity in gills of fish ( $U\ g^{-1}$  protein tissue).



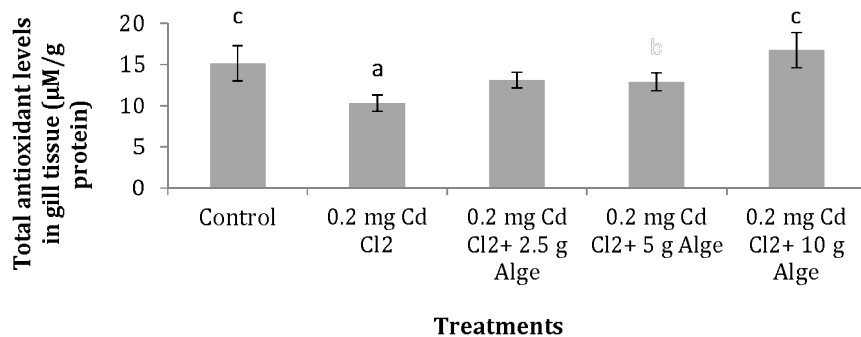
**Figure 3.** Alterations in ALP activity in gills of fish ( $U\ g^{-1}$  protein tissue).



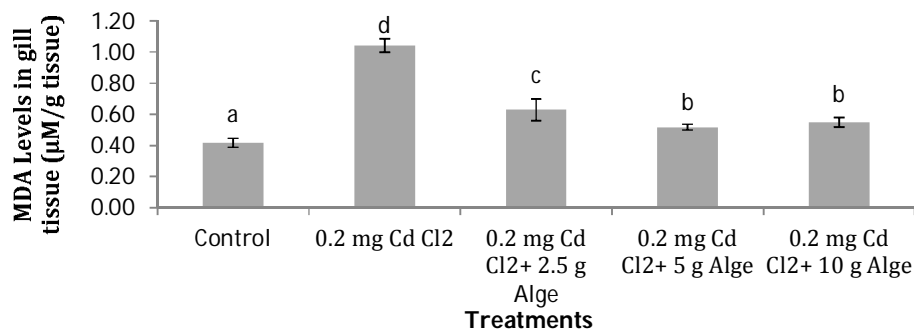
**Figure 4.** Alterations in LDH activity in gills of fish ( $U\ g^{-1}$  protein tissue).



**Figure 5.** Alterations in CAT activity in gills of fish (KU g<sup>-1</sup> protein tissue).



**Figure 6.** Alterations in cellular total antioxidant level in gills of fish (µM g<sup>-1</sup> protein tissue).



**Figure 7.** Alterations in cellular malondialdehyde (MDA) level in gills of fish (µM g<sup>-1</sup> tissue).

## DISCUSSION

Gills of bony fish are vulnerable to exposure to toxic compounds [25]. Although damage to gills is often attributed to a direct contact with contaminants, transfer of the compounds through food chain can also cause severe damages to target tissues [26]. Damage to gills of fish exposed to environmental pollutants disturbs osmoregulation, gas exchange and ammonia excretion [27].

This study investigated the protective effects of *S. platensis* against oxidative stress and biochemical alterations in gills of rainbow trout. Naturally and during metabolism, reactive oxygen species are produced which can react with major macromolecules such as lipids, proteins, and nucleic acids. In normal conditions, there is a balance between production and removal of oxygen free radicals. An imbalance in this process leads to oxidative stress and pathological changes in varied cells. Lipid peroxidation of the cell

membrane is the main factor in damaging gills and other organs due to exposure to CdCl<sub>2</sub> [27]. An increase in malondialdehyde (MDA) in gills could be the result of cadmium accumulation in this tissue and consequently, an increase in the production rate of reactive oxygen species (ROS). MDA, as a marker of oxidative stress, is the final product of lipids catabolism and an increase in MDA represents damage to cell membranes. Besides, MDA is highly inclined to react with thiol and amine groups in the biochemical structure of peptides, enzymes, and nucleic acids, thus providing a highly toxic environment for cells [28]. Cadmium is known to increase oxygen free radicals, change the activity of oxidant enzymes and reduce non-enzymatic antioxidant activities in biological systems [6]. An increase in lipid peroxidation and an imbalance between oxidants and antioxidants are the main factors in causing oxidative stress in fish exposed to cadmium [6]. A significant decrease in the cellular total antioxidant level in gills, as well as a significant increase in MDA in CdCl<sub>2</sub>-treated fish, suggests oxidative stress. An increase in MDA was along with a decrease in total antioxidant level in gills of CdCl<sub>2</sub>-treated fish. These changes are the result of an overproduction of free radicals and final products of lipid peroxidation that cause oxidative stress. Similar results were reported in olive flounder (*Paralichthys olivaceus*), and African sharp-tooth catfish (*Clarias gariepinus*) exposed to CdCl<sub>2</sub> and demonstrated an increase in MDA levels [29]. Feeding fish with different doses of *S. platensis* significantly decreased MDA level compared to that of the control group.

An increase in the cellular total antioxidant level in gills of fish (treated with 10 gr of microalga) can decrease toxic effects of CdCl<sub>2</sub>. An increase in the cellular antioxidant capacity and a decrease in MDA in fish treated with both cadmium and *S. platensis* can be attributed to  $\beta$ -carotene, vitamin C, vitamin E, selenium and manganese in *S. platensis* [13, 15]. Moreover, the presence of phycocyanin in *S. platensis* can inhibit peroxy radicals including lipid peroxidation [30], reduce the bioavailability of metals in the diet [15], and thus decrease cadmium toxicity.

Therefore, the cellular antioxidant defense system, whether enzymatic or non-enzymatic, can effectively eliminate ROS in different tissues and decrease damages caused by oxidative stress. Catalase is one of the most important enzymes

that can help cells get rid of ROS. Catalase (CAT) is also a major enzyme of the antioxidant system. CAT participates in hydrogen peroxide decomposition to water and oxygen in order to prevent oxidative stress and maintain cellular homeostasis. The activity of CAT in gills increased significantly. An increase in CAT activity in gills indicates a kind of physiological response to increased hydrogen peroxide in the same cells. Administering different doses of *S. platensis* had a significant effect in maintaining normal levels of CAT in gills of fish treated with CdCl<sub>2</sub>.

An increase in AST activity in gills of fish solely treated with CdCl<sub>2</sub> may suggest a metabolic mechanism provide energy [31]. This energy is used to cope with CdCl<sub>2</sub> toxicity. However, a significant decrease in ALT activity in gills could be due to disturbance in the biosynthesis of this enzyme or inhibition of its activity in cadmium-treated fish. Oral administration of *S. platensis* to CdCl<sub>2</sub>-treated fish had no impacts on returning AST to normal levels. On the other hand, *S. platensis* balanced ALT activity in gills (2.5, 5 and 10 gr of microalga) and approximate to its level in the control group. This is because of the antioxidant properties and the important role of photochemical compounds in *S. platensis* in removing free radicals and returning these enzymes to the normal level.

ALP activity in gills of fish treated with CdCl<sub>2</sub>-contaminated diets decreased significantly. Feeding fish with different concentrations of *S. platensis* balanced ALP activity to the normal state.

An increase in lactate dehydrogenase (LDH) in gills of CdCl<sub>2</sub>-treated fish is a response to disturbance in physiological processes of cells, such as inhibition of oxidative phosphorylation in mitochondria, development of cell hypoxia, and reduced production of adenosine triphosphate (ATP) [32]. An increase in LDH, in the absence of oxygen, prepares the ground for continuing glycolysis and reoxidation of NADH by lactate [32]. *S. platensis* administration prevented an increase in LDH in gills and regulated the enzyme to the normal level.

## CONCLUSION

Although the greatest damage to gills of fish can be the result of environmental pollutants, feeding fish with CdCl<sub>2</sub>-contaminated diets also

caused oxidative stress in gills. Using *S. platensis* as a supplement not only improved the cellular antioxidant capacity and detoxification system, but also prevented certain adverse changes in the biochemical parameters of gill cells.

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## REFERENCES

- Zeitoun MM, Mehana E-SE. Impact of water pollution with heavy metals on fish health: overview and updates. *Global Vet* 2014;12(2):219-31.
- Pereira F, Azevedo F, Parachin NS, Hahn-Hägerdal Br, Gorwa-Grauslund MF, Johansson Br. Yeast Pathway Kit: A Method for Metabolic Pathway Assembly with Automatically Simulated Executable Documentation. *ACS Synth Biol* 2016;5(5):386-94.
- Yang Y, Li H, Peng L, Chen Z, Zeng Q. Assessment of Pb and Cd in seed oils and meals and methodology of their extraction. *Food Chem* 2016;197:482-8.
- Bodin N, Lesperance D, Albert R, Hollanda S, Michaud P, Degroote M, et al. Trace elements in oceanic pelagic communities in the western Indian Ocean. *Chemosphere* 2017;174:354-62.
- Heshmati A, Momtaz JK, Nili-Ahmadabadi A, Ghadimi S. Dietary exposure to toxic and essential trace elements by consumption of wild and farmed Carp (*Cyprinus carpio*) and Caspian kutum (*Rutilus frisii kutum*) in Iran. *Chemosphere* 2017;173:207-15.
- Mehrpak M, Banaee M, Nematdoost Haghi B, Noori A. Protective Effects of Vitamin C and Chitosan against Cadmium-Induced Oxidative Stress in the Liver of Common Carp (*Cyprinus carpio*). *Iran J Toxicol* 2015;9(30):1360-7.
- Onukwufor JO, Stevens D, Kamunde C. Combined effects of cadmium, temperature and hypoxia-reoxygenation on mitochondrial function in rainbow trout (*Oncorhynchus mykiss*). *Aquatic Toxicol* 2017;182:129-41.
- Zheng J-L, Yuan S-S, Wu C-W, Lv Z-M. Acute exposure to waterborne cadmium induced oxidative stress and immunotoxicity in the brain, ovary and liver of zebrafish (*Danio rerio*). *Aquatic Toxicol* 2016;180:36-44.
- Zheng J-L, Yuan S-S, Wu C-W, Lv Z-M, Zhu A-Y. Circadian time-dependent antioxidant and inflammatory responses to acute cadmium exposure in the brain of zebrafish. *Aquatic Toxicol* 2017;182:113-9.
- Manera M, Dezfuli BS, DePasquale JA, Giari L. Multivariate approach to gill pathology in European sea bass after experimental exposure to cadmium and terbuthylazine. *Ecotoxicol Environ Saf* 2016;129:282-90.
- Yuan S-S, Lv Z-M, Zhu A-Y, Zheng J-L, Wu C-W. Negative effect of chronic cadmium exposure on growth, histology, ultrastructure, antioxidant and innate immune responses in the liver of zebrafish: Preventive role of blue light emitting diodes. *Ecotoxicol Environ Saf* 2017;139:18-26.
- Adel M, Yeganeh S, Dadar M, Sakai M, Dawood MA. Effects of dietary *Spirulina platensis* on growth performance, humoral and mucosal immune responses and disease resistance in juvenile great sturgeon (*Huso huso* Linnaeus, 1754). *Fish Shellfish Immunol* 2016;56:436-44.
- K. The antioxidant, immunomodulatory, and anti-inflammatory activities of *Spirulina*: an overview. *Arch Toxicol* 2016;90(8):1817-40.
- Abdel-Daim MM, Abuzead SM, Halawa SM. Protective role of *Spirulina platensis* against acute deltamethrin-induced toxicity in rats. *PLoS ONE* 2013;8(9):e72991-2.
- Bashandy SA, El Awdan SA, Ebaid H, Alhazza IM. Antioxidant potential of *Spirulina platensis* mitigates oxidative stress and reprotoxicity induced by sodium arsenite in male rats. *Oxid Med Cell Longev* 2016;2016.
- Perez-Juarez A, Chamorro G, Alva-Sánchez C, Paniagua-Castro N, Pacheco-Rosado J. Neuroprotective effect of *Arthrospira* (*Spirulina*) *platensis* against kainic acid-neuronal death. *Pharm Biol* 2016;54(8):1408-12.
- Yigit F, Gurel-Gurevin E, Isbilen-Basok B, Esener O, Bilal T, Keser O, et al. Protective effect of *Spirulina platensis* against cell damage and apoptosis in hepatic tissue caused by high fat diet. *Biotech Histochem* 2016;91(3):182-94.
- Mobasher M, Aramesh K, Aldavoud S, Ashrafganjooei N, Divsalar K, Phillips C, et al. Proposing a national ethical framework for animal research in Iran. *Journal of Medical Ethics and History of Medicine* 2008;37(1 Sup):39-46.
- Yeganeh S, Teimouri M, Amirkolaie AK. Dietary effects of *Spirulina platensis* on hematological and serum biochemical parameters of rainbow trout (*Oncorhynchus mykiss*). *Res Vet Sci* 2015;101:84-8.
- Moss DV, Henderson AR. Clinical enzymology. In: Burtis CA, Ashwood ER. *Tietz Textbook of Clinical Chemistry*. 3<sup>rd</sup>ed. Philadelphia: W.B. Saunders Company; 1999. p. 617-721.

21. Johnson AM, Rohlf EM, Silverman LM. Proteins. In: Burtis CA, Ashwood ER. Tietz Textbook of Clinical Chemistry. 3<sup>rd</sup>ed. Philadelphia: W.B. Saunders Company; 1999. p. 477-540.
22. Goth L. A simple method for determination of serum catalase activity and revision of reference range. Clinica Chimica Acta 1991;196(2-3):143-51.
23. Benzie IF, Strain JJ. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. Anal Biochem 1996;239(1):70-6.
24. Placer ZA, Cushman LL, Johnson BC. Estimation of product of lipid peroxidation (malonyl dialdehyde) in biochemical systems. Anal Biochem 1966;16(2):359-64.
25. Griffith MB. Toxicological perspective on the osmoregulation and ionoregulation physiology of major ions by freshwater animals: Teleost fish, crustacea, aquatic insects, and Mollusca. Environ Toxicol Chem 2016.
26. Mohisani M, Asayesh S, Shafiee Bazarnoie S, Mohseni F, Moradi N, Matouri M, et al. Biochemical Alteration Induced by Cadmium and Lead in Common Carp via an Experimental Food Chain. Iran J Toxicol 2016;10(4):25-32.
27. Mehrepek M, Banaie M, Nematdoste Haghi B, Noori A. The protective effect of vitamin C and chitosan on oxidative biomarkers in gills of common. Iran Sci Fisheries J 2016;24(4):31-45.
28. Oropesa A-L, García-Camero JP, Soler F. Glutathione and malondialdehyde levels in common carp after exposure to simazine. Environ Toxicol Pharmacol 2009;27(1):30-8.
29. Cao L, Huang W, Liu J, Yin X, Dou S. Accumulation and oxidative stress biomarkers in Japanese flounder larvae and juveniles under chronic cadmium exposure. Comp Biochem Physiol Part C: Toxicol Pharmacol 2010;151(3):386-92.
30. Finamore A, Palmery M, Bensehaila S, Peluso I. Antioxidant, Immunomodulating, and Microbial-Modulating Activities of the Sustainable and Ecofriendly *Spirulina*. Oxid Med Cell Longevity 2017;2017.
31. Rehman H, Aziz AT, Saggu S, VanWert AL, Zidan N, Saggu S. Additive toxic effect of deltamethrin and cadmium on hepatic, hematological, and immunological parameters in mice. Toxicol Ind Health 2017.
32. Kiran Kumar K, Naveen Kumar M, Patil RH, Nagesh R, Hegde SM, Kavya K, et al. Cadmium induces oxidative stress and apoptosis in lung epithelial cells. Toxicol Mech Methods 2016;26(9):658-66.