Metabolic, Bioproductive and Reproductive Effects of Aquatic Exposure to Cadmium in Fish- A Review

Bogdan GEORGESCU¹, Daniel MIERLIȚĂ², Dănuț STRUȚI¹, Hermina KISS¹, Anca BOARU^{1*}

¹ University of Agricultural Sciences and Veterinary Medicine, Faculty of Animal Science and Biotechnologies, Cluj-Napoca, Romania, EU.

² Department of Animal Science, University of Oradea, Romania, EU.

* corresponding author: anca.boaru@usamvcluj.ro

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Abstract

Cadmium (Cd) exposure in fish is the result of aquatic pollution with heavy metals, which is mainly caused by anthropic interventions. Rarely, Cd mobilization from natural resources takes place. Bioaccumulation in tissues and organs is a property of this heavy metal, to generate various pathological effects and major risks due to bio-propagation within the human food chain. We hereby reviewed the main circumstances and levels of exposure to Cd in the aquatic environment, and effects on growth, development and reproduction induced by its bioaccumulation in fish, as well as the possible ramifications for food security in humans.

Keywords: *cadmium (Cd), fish, food, production.*

INTRODUCTION

Aquatic organisms exposure to heavy metals has been extensively studied starting with the second half of the twentieth century. Effects of exposure, the capacity of bioconcentration and bio-propagation of Cd within the aquatic trophic chains is of wide interest, as all these combined involve important food security risks to humans. It is well-known that aquatic organisms, particularly various fish species, consistently react to water pollution; therefore, they represent reliable bioindicators of water quality.

SOURCES OF CADMIUM POLLUTION IN AQUATIC SYSTEM

Cadmium is a common element, ubiquitous distributed in the environment in concentrations varying between 0.1-25 ppm. Cadmium concentrations depend on the nature of the rock structure of origin (Cook *et al.*, 1995). In agricultural land areas, the high Cd concentration originates from

phosphate-rich fertilizers that may be found in concentrations up to 10-200 ppm, but also from Cd-containing pesticides and other fertilizers such as natural manure and slurries, which may contain significant amounts of Cd (Cook *et al.*, 1995; Wuana *et al.*, 2011).

Freshwater pollution is commonly the consequence of elutriation of agricultural soils, mine extracts deposits and industrial waste by rainfall water. The Cd load in these waters depends on the location and sources of pollution found in each area, explaining why reported concentrations may vary largely between 10-4000 ng/mL (OECD, 1996; WHO, 1992). In sea and ocean waters, mean Cd concentration is 5-20 ng/mL, but the level is significantly higher in industrialized coastal areas where it may reach 100 ng/L (Cook *et al.*, 1995; OECD, 1994).

CADMIUM BIOACCUMULATION IN FISH

Normal ranges of Cd concentration in fish meat should not surpass 5-40 ppb (ATSDR, 1997). Cadmium enters the animal body by intestinal absorption in most cases or, alternatively, by branchial respiration or transdermal passage.

Several mechanisms of transdermal penetration are possible: simple diffusion, transport channels of calcium ions, aminoacids transmembrane passage and metallothioneins, which exhibit high affinity for Cd (Olsson and Hogstrand, 1987; Olsson, 1998).

From the circulation, Cd is bioaccumulative by the kidneys, the liver and the branchial arches (De Smet *et al.*, 2001; Kumar *et al.*, 2005). After 9-months exposure to 5.0 pg/L of Cd in the trout species *Salvelinus namaycush*, the highest Cd concentration (2.5 pg/g wet weight) was detected in the posterior kidney (Scherer *et al.*, 1997).

Exposure to Cd stearate-containing forage (100 mg Cd/kg) was associated in the rainbow trout (*Oncorhynchus mykiss*) with high Cd levels and specific histological changes in the liver and the kidney (Kumada *et al.*, 1980).

Simultaneous exposure of fish species *Liza vaigiensis* and *Johnius carutta* to several heavy metals (Cd, Cr, Pb and Ni) resulted in highest Cd concentrations in the liver, of 0.68 mg/g wet weight in *Liza vaigiensis* and 0.58 mg/g wet weight in *Johnius carutta*, respectively. The content of Cd in branchial arches was of 0.30 mg/g wet weight in *Liza vaigiensis* and 0.29 mg/g wet weight in *Johnius carutta*, respectively. The lowest Cd concentration was evidenced in the muscles, of 0.16 mg/g in both species. Differences in Cd concentrations between different types of tissues were highly significant ($p < 0.001$) in both species. In most cases, females presented significantly higher content of heavy metals in tissues than males, however, no statistical significance was reached (Mohsen *et al.*, 2012).

METABOLIC, BIOPRODUCTIVE AND REPRODUCTIVE EFFECTS OF CADMIUM EXPOSURE

Both absorption rate and amount of absorbed Cd in *Cirrhinus mrigala* is potentiated by concomitant absorption of nickel (Ni), the two acting synergistically. In fact, bioaccumulation of the two heavy metals in case of simultaneous exposure is significantly higher in comparison

to individual exposure to each contaminant (Palaniappan *et al.*, 2009).

Studies on various fish species, experimentally exposed to sublethal Cd concentrations, indicate a reduction of food intake and significant decrease in metabolic processes rates. The silver carp, *Hypophthalmichthys molitrix*, when exposed to water with Cd levels of 0.01 mg/L for 96 hours resulted in significant increase of plasmatic concentrations of cortisol, lactate, glucose and red blood cells. In addition, a decrease in glycogen and muscle ATP levels was noticed and an increase in the muscle lactate concentration was obtained, the later being there after maintained constant throughout the exposure period.

The data indicate significant physiological changes in the muscle metabolism, possibly linked to alterations in gas exchanges at the branchial arches level (Zhang *et al.*, 2013). Offspring from species *Catostomus commersonii* and *Luxilus cornutus*, when were exposed to aquatic contamination with cadmiu, have presented a significantly higher food intake compared to the control groups and the individual growth rate was with 67-100% lower. The efficiency of food conversion was below 50% (Borgmann *et al.*, 1986).

Exposure of crucians (*Carassius auratus gibelio*) to 20 mg/L Cd for 15 days resulted in significant reduction fo the superoxiddismutase activity (SOD) in erythrocytes after the first day of exposure, followed by an increase in the enzymatic activity during days 7-15. The red blood cells catalase also increased after 15 days of exposure as well as the serum transaminases (GOT and GPT). At the same time, the hemoglobin level and hematocryte significantly decreased. Glucose levels constantly increased during exposure. These data suggest generation of oxidative stress and tissue lesions in exposed fish (Zikić *et al.*, 2001).

Similar results were reported in the species *Oncorhynchus mykiss* exposed to sublethal Cd concentrations of 1 and 3 pg/L, respectively, for 30 days, which resulted in a significant dose- and time-dependent increase in alkaline phosphatase and aminotransferases. In contrast, triglycerides and cholesterol levels decreased up to exposure day 15 but raised afterwards, whereas serum glucose levels increased up to exposure day 15 and decreased thereafter reaching levels similar to those observed in controls. The total protein

concentration levels rised, reaching at end of experiments significantly higher values in exposed animals compared to controls. Exposed trouts ingested less food and exhibited decreased growth rates (Saeed *et al.*, 2013).

Exposure of the tench (*Tinca tinca*) for 3 hours to a water concentration of Cd of 4.5 mg/dm³ resulted in notable changes of hematological parameters, a significant decrease in oxygen demand, a decrease in the metabolic rate and alteration of the immune response. The number of red blood cells constantly increased for 96 hours after exposure, when the experiment reached its end, whereas the white blood cell number progressively decreased without changes in the lymphocytes/neutrophils ratio, both parameters being significantly modified in comparison to the control group. With regard to blood cells, the numbers of structural abnormalities significantly increased, for instance abnormally shaped cells, intracellular vacuolation, cell swelling and disintegration of nuclear chromatin (Witeska *et al.*, 2006).

Exposure to Cd induces several effects on the endocrine status and on carbohydrates metabolism in fish. Acute effects of 0.4, 0.8 and 2.4 mg/L Cd exposure for 2, 4, 24 and 96 hours on young rainbow trout populations (*Oncorhynchus mykiss*) consisted of increased T₄ levels and an elevation of plasma cortisol, whereas T₃ concentration remained unchanged. Subacute exposure (0.4 and 0.8 mg/L Cd) for 1 week resulted in a decrease of liver glycogen combined to an increase in glucose and serum cortisol levels, while T₄ decreased and T₃ remained stable (Hontella *et al.*, 1996).

In another study, exposure of the rainbow trout (*Oncorhynchus mykiss*) to sublethal concentrations of Cd altered the physiological state by changes in endocrine and metabolic activities, in both adults and young animals, to result in decreased calcium and low T₃ and T₄. Exposure of adults to 10 and 25 mg/L Cd and exposure of the youth to 1 and 5 mg/L Cd, respectively, for 30 days resulted in a significant reduction of the liver volume and glycogen levels, in addition to a lower growth rate (Ricard *et al.*, 1998).

Endocrine-disrupting effects of Cd were noticed in tilapia (*Oreochromis mossambicus*) exposed for 150 days to 1, 10, 50, 100 and 150 ppt of CdCl₂. Reproductive parameters such as spawns, the somato-gonadal index, reproductive hormone

levels (estradiol, progesterone, testosterone) and gonadotropins (GtH-I, GtH-II) significantly differed in comparison to those seen in controls (Amutha *et al.*, 2013). Nevertheless, each species may react differently to Cd exposure. Rainbow trout (*Oncorhynchus mykiss*) and yellow perch (*Perca flavescens*) adrenocortical cells cultures were exposed to Cd for 60 days. Cultures were stimulated with physiological stimuli such as ACTH, dbcAMP and pregnenolon, and effects on adrenal steroidogenesis and the cortisol levels were assessed. Cadmium resulted in inhibition of cortisol production, which was observed in both species but more expressed in rainbow trout cells compared to perch cells. In agreement to these study, Cd appears to affect glucocorticoid synthesis pathways at an early stage, before the biosynthesis of pregnenolone (Lacroix *et al.*, 2004). Exposure of the yellow perch (*Perca flavescens*) to heavy metals (Cd, Zn, Cu, Pb and Ni) led to changes in T₃, T₄ and 17 β -estradiol levels and to an altered Na⁺/K⁺-ATP-ase activity. The study authors concluded that longterm exposure to sublethal heavy metals contamination will change physiological functions and delay reproductive activity (L'evesque *et al.*, 2003).

Concomitant exposure of young rainbow trout to forage with high calcium (Ca) content (*e.g.* 30 and 60 mg Ca²⁺/g forage in the form of CaCl₂·H₂O) and Cd (50 mg/L CdNO₃) for 3 hours was associated to marked branchial absorption of Cd. The data suggest that the two ions use a common transmembrane transporter and may act in a competitive manner. Under the same experimental conditions, body Ca²⁺, Na⁺ and Cl⁻ levels remained stable (Baldisserotto *et al.*, 2004). A similar effect was observed after aquatic exposure of the catfish species *Clarias batrachus* to sublethal Cd concentrations (5 and 10 ppm CdCl₂·H₂O) for 45 days simultaneously to natural antioxidants such as ascorbic acid, dry garlic extract and taurine (2-aminoethansulphonic acid) at 5 ppm in water. The presence of antioxidants significantly reduced the oxidative stress rate in exposed fish, which was demonstrated by lower levels of lipid peroxides and increased catalase and SOD activity in the liver, kidney and erythrocytes in comparison to controls. Experimental data indicate that use of natural antioxidants significantly lowered Cd levels in tissues. Ascorbic acid acted most

efficiently, while taurine had the weakest effect (Kumar *et al.*, 2009).

A Canadian study on the implication of pollution with heavy metals (Cd, Cu and Zn) of aquatic ecosystems on ecosystems productivity and energy efficiency in fisheries reported a threefold lower capacity of energy conversion and storage in the yellow perch (*Perca flavescens*) in comparison to perches originating from unpolluted systems (4.2% vs 10.8%). This demonstrates that significantly higher energy costs are reported in fish populations exposed to heavy metals. Moreover, the adult population was increasingly represented in contaminated aquatic ecosystems, thus, suggesting reproductive problems and a high mortality rate among young individuals. Heavy metals-contaminated aquatic biocenosis featured lower numbers of population structure of species as well as simplified trophic chains to demonstrate global effects affecting the entire biocenosis (Sherwood *et al.*, 2011).

CONCLUSIONS

Exposure to Cd results in morphological, biochemical and physiological changes in fish, irrespective of the fish species. All together will interfere with the metabolic rate, eventually leading to a reduced growth rate by lowering the energy efficiency at increased energy costs. Both endocrine-disrupting effects of Cd and Cd-induced alterations in the immune response exert deleterious effects on the reproductive function. As fish products and subproducts represent important components of the human diet, longterm exposure of fish to Cd may cause food insecurity in humans. Natural antioxidants and calcium may act protective by decreasing cadmium bioaccumulation in fish.

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