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Effects of Water Borne Iron on Toxicity and Path Physiology of Indian Major Carp – A Review

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ABSTRACT

Extensive studies have been carried out for the influences of toxic metals on aquatic organisms worldwide. Ferrous iron is considered to be the most toxic form of iron (Fe). Indian major carps (IMC) are most important cultured species in India and it is essential to protect them against metal toxicity. Several studies have been taken up for spawn and fry whereas in case of fingerlings it is scanty. Among the IMC spawn, Mrigal showed least tolerance to Fe followed by Catla and Rohu. In case of Catla fingerling highest mortality was observed at 13 mg l-1 and 15 mg l-1 concentrations. Rohu fingerlings had the lowest mean LC50 concentration for 30-days fish, followed by 60 and 90-days respectively. Physiological evidences indicated that ferrous form of Fe preferentially crosses the apical membrane of both gill and intestine (Ilavazhahan et al., 2010). Accumulation of Fe in liver and kidney was highest in case of Rohu fry compared to Catla and Mrigal. Mrigal showed highest accumulation of Fe in muscle followed by Catla and Rohu. Among spawn, Catla growth was affected most by the Fe concentration followed by Mrigal and Rohu (Debnath, 2011)

KEYWORDS : IMC, pathophysiology, toxicity, water borne iron

INTRODUCTION

Heavy metals consist less than one percent of living mass organisms, and their different density cause to some disorders. Fish is one of the sources of biologically valuable protein, fats and fat-soluble vitamins (Belitz and Grosch, 1987). Fish are used to determine the effect and threshold of heavy metal accumulation and toxicity in aquatic organisms. Increased concentrations of essential or non essential metals devastates the ecological balance of recipient fish, resulting in growth reduction, increased mortality, mutagenic changes, adverse biochemical processes, including (reproductive, physiological and morphological) abnormalities. The presence of this metal in aquaculture fish species varies between fish species; depend on age, developmental stage and other physiological factors.

WHAT ARE THE HEAVY METALS?

Heavy metals have variously been used to denote the metals with atomic number 23(i.e. Vanadium) onwards except Rb, Y, Cs, Ba, and Fr; these are the metals with density greater than 5; and are generally toxic to man and other life forms when found in the environment. Iron is one of the most abundant metals on the earth and is essential to almost all organisms. Consequently, in excess, iron can be detrimental to health. In addition, excess water borne iron may be toxic to fish, due to formation of iron 'flocs' on gills, resulting in gill clogging and respiratory perturbations (Peuranen et al., 1994).

Maximum desirable limit of iron (as Fe) in drinking water should be 0.3 mg l^{-1} as per EPA (1986) and BIS (1991). On the other hand, the maximum total iron concentration should not exceed 1.0 mg l^{-1} to protect aquatic systems from detrimental effects of iron as per EPA (1986) and for aquaculture less than 0.01 (Meade, 1989).

METALS COMMONLY TOXIC TO FISH

As a result of increased industrialization, contamination of natural freshwater by heavy metals, such as iron, zinc, lead, nickel and manganese, has become a global problem. In case of essential trace elements e.g., copper, zinc and nickel, the optimal concentration ranges for fish growth and reproduction are narrow and both excess and deficiency are harmful to the fish. Some non-essential trace metals such as mercury, lead and cadmium are toxic at concentrations observed in natural waters (Javed and Mahmood, 2001). Cadmium is highly toxic to wildlife; it is cancer causing and teratogenic and potentially mutation causing, with severe sub-lethal and lethal effects at low environmental concentrations (Eisler, 1985). It is associated with increased mortality, and it affects respiratory functions, enzyme levels, muscle concentrations, growth reduction, and reproduction. It bio-accumulates at all trophic levels, accumulating in the livers and kidneys of fish (Sindayigaya et al., 1994). Nickel toxicity is generally low (Khangarot and Ray, 1990) but elevated concentration can cause lethal effects in the aquatic ecosystems. The lead is known to accumulate the tissue of fish including the bone, gills, kidneys, liver and scales (Dallas and Day, 1993). Excess copper is toxic. Form a dietary perspective the primary toxic action is predominantly the production of free radicals in tissues where copper accumulates. In addition, dietary copper toxicity can occur at several other loci in the gut and includes inhibition of digestive enzymes and reduced gut motility (Woodward et al., 1995). Zinc may, however, generate toxicity to fish by interfering with calcium homeostasis (Hogstrand and Wood, 1996).

FISH VERSES IRON

In fish there are two potential sites for iron uptake, across the intestinal (i.e. dietary borne) or branchial epithelium (i.e. water borne) (Bury and Grosell, 2003). The nutritional value of water borne iron compared to dietary iron has not been elucidated, but the gills may play a vital role in iron homeostasis at time of developmental need, for example, after yolk-sac absorption and prior to feeding. How fish acquire this iron, despite the constraint of unfavourable water chemistry, has not been determined and require further investigation (Bury et al., 2003). To prevent iron deficiency or to avoid excess toxic iron fish need to judge their iron needs, assess the availability levels of iron in the water or diet and then import accordingly to meet

demand. But the fact that there have been considerable differences between different fish species in sensitivity and ability to accumulate metals in their body on the basis of their environment. The Indian Major Carps (IMCs), catla, *Catla catla* (Ham.), rohu, *Labeo rohita* (Ham.) and mrigal, *Cirrhinus mrigala* (Ham.) are mostly cultured, preferred and as well as high priced fish in India. Previously, no such work has been reported on the effects of water borne iron on toxicity and pathophysiological aspects of IMC.

IRON REQUIREMENT FOR FISH

Minerals are required for the normal life processes in all animals, including fish. Fish may derive these minerals from the diet and also from ambient water. Characteristic concentrations and functional forms of the minerals need to be maintained within narrow ranges for ordinary metabolic activities in cells and tissues. This is facilitated by the homeostatic mechanisms operating in the animal, catering for the fluctuations in dietary intake. The minerals are responsible for skeletal formation, maintenance of colloidal systems, regulation of acid-base equilibrium and for biologically important compounds such as hormones and enzymes. Iron requirement ranges for fish is 30-170 mg kg^{-1} dry diet (Watanabe et al., 1997). The iron requirements have also been reported for catfish, atlantic salmon (Lall and Hines, 1987), and eel (Nose and Arai, 1979), and they are 30, 60, and 170 mg kg^{-1} of diet, respectively.

IRON DEFICIENCY ANAEMIA IN FISH

Deficiency of iron causes several types of anaemia. Iron deficiency anaemia is a common type of anaemia, and is known as sideropenic anaemia. It is the most common cause of microcytic anaemia. Iron deficiency anaemia occurs when the dietary intake or absorption of iron is insufficient, and haemoglobin, which contains iron, cannot be formed (Brady, 2007). Deficiency of iron induces anaemia in brook trout (Kawatsu, 1972), yellowtail, red sea bream and carp (Sakamoto and Yone, 1978). In carp, the anaemic condition was the same, but there was no growth retardation. Gatlin and Wilson (1986) additionally noted poor feed utilization and lowering of plasma iron level and transferrin saturation in channel catfish.

EFFECT OF EXCESS IRON IN FISH

Excess iron is toxic, acting as a catalyst in the Fenton reaction generating free radicals (Crichton et al., 2002) which is detrimental to health. In addition, excess water borne iron may be toxic to fish, due to the formation of iron 'flocs' on the gills, resulting in gill clogging and respiratory perturbations. Iron occurs primarily as a free ferrous form in acidic water (pH < 5.8) when the water oxygen concentration is low. This iron form is deleterious to fish (Amelung, 1982). The harmful effects of iron will decrease if ferrous iron has time to oxidize into the ferric form before it comes into contact with the fish. In 10 °C sea water, half of the ferrous iron will oxidize into a ferric form within eight days at pH 6, while at pH 5; it may take over two years (Roekens and van Griegen, 1983). Consequently, organisms have to regulate balanced iron uptake to prevent the detrimental effects of tissue iron loading.

A possible mechanism for dissolved iron toxicity involves a disruption of the sodium balance. At higher pH values (above about pH 5.0, where iron is less soluble), one possible mechanism of iron toxicity is the precipitation of ferric hydroxide directly onto the gills in the form of a brown slime (Doudoroff and Katz, 1953). Damage can result either from the clogging action of the precipitate or from injury to the tissues by corrosive action. Iron has also been shown to cause cell membrane damage (Dandapat et al., 1999), and damage DNA of fish. The precipitation of ferric hydroxide can also affect fish according to their life stage. Higher concentrations of iron (up to 52.9 mg l^{-1}) can reduce visibility in the water and cause impaired food perception to fry and juvenile stages, resulting in prolonged stress and reduced growth. Ferrous iron (Fe^{+2}) is considered to be more toxic to fish than the ferric (Fe^{+3}) form (Decker and Menendez, 1974). Because the pH at the gill micro environment may differ from that of the surrounding body of water, the precipitation of metals on gills is possible. Dissolved iron at a concentration of 0.005 mg l^{-1} had an unfavourable effect.

TOXICITY AND PATHOPHYSIOLOGICAL CHANGES IN IMC

Toxicity tests are classified as short-term toxicity tests (range-fining toxicity tests and short-term definitive tests) and long-term, partial-or complete-life-cycle toxicity tests. In range-fining toxicity tests, materials of unknown toxicity is conducted (24 h or 48 h), to determine approximate concentration range to include in definitive short-term tests. The overall objective of the long-term, partial-life-cycle toxicity test is to determine no-observed-effect concentration (NOEC) or chronic value (ChV) of toxicants. This test is also used to determine the effects on growth, survival of spawn or fry, behaviour, bioaccumulation etc. (APHA, 2005). The NOEC is defined as the highest tested toxicant concentration that yields no significant deviation from a control. The determination of NOEC is highly dependent on the testy design, e.g., the selection of test concentrations, the number and spacing of tested doses, the endpoints measured, and the number of replicates (Koolijman et al., 1996). The LC_{50} values are used to measure the acute toxicity but they do not represent concentrations that were safe or harmless in aquatic habitat. In case of Catla fingerling 50% mortality was recorded in 8 and 9 mg l^{-1} concentration and 50% of mortality line intercepted the graph to show 8.4 mg l^{-1} as corresponding LC_{50} for the toxicant (Ilavazhahan et al., 2010). Rohu had the lowest mean iron LC_{50} concentration of 49.75 ± 2.78 mg l^{-1} for 30-days fish, followed by that of 60- and 90-days that had the average values of 53.18 ± 2.74 and 58.18 ± 2.74 mg l^{-1}, respectively. Abdullah and Javed (2006) found LC_{50} value of iron for 30, 60 and 90 days old Catla as 114.67 ± 4.65 104.17 ± 5.47 and 91.68 ± 4.65 mg l^{-1} respectively. Sykora et al. (1972) suggested that ferric iron is not particularly dangerous to fish, although the soluble iron species may have been considerably toxic. Iron is acutely toxic to freshwater fish and invertebrates at concentrations ranging from 0.03 mg l^{-1} to 2.0 mg l^{-1}. It is reported in case of Catla fingerling the highest mortality of 100% was observed at 13 mg l^{-1} and 15 mg l^{-1} concentrations. 50% mortality was recorded in 8 and 9 mg l^{-1} concentration and 50% of mortality line intercepted the graph to show 8.4 mg l^{-1} as corresponding LC_{50} for the toxicant (Ilavazhahan et al., 2010). It was also found Mrigal spawn showed least tolerance to iron followed by Catla and Rohu. Mrigal showed the lowest value of 96hour LC_{50} value of and Rohu showed the highest value for both spawn and fry. 96 h LC_{50} values of Fe for Catla, Rohu and Mrigal spawn was found as 0.59 ± 0.067 mg l^{-1}, 0.73 ± 0.057 mg l^{-1} and 0.30 ± 0.057 mg l^{-1}, respectively. And for fry the values were 13.68 ± 0.569 mg l^{-1}, 16.75 ± 0.957 mg l^{-1} and 11.21 ± 0.530 mg l^{-1} respectively for Catla Rohu and Mrigal (Debnath, 2011). The reason for less tolerance of Mrigal to iron might be due to bottom feeder Mrigal exposes itself most to the iron precipitate, hence ingest a large quantity of iron compared to Catla and Rohu. However no significant difference of mortality of Catla and Rohu spawn was observed. Among IMC considerable differences in iron sensitivity have been reported (Javed and Abdullah, 2001).

According to Anderson and Nyberg (1984) the gill is the target organ for all metals, and iron accumulated ten times faster than other metals. They also expected that iron accumulation in gill is probably the primary cause of mortality. Accumulation of iron in higher concentrations in both spawns and fry body was significantly higher compared to the control group. Fe contents in gills, kidney and skin increased with fish age (Javed and Muhammad, 2010). In case of fry gill showed highest uptake of iron followed by kidney, liver and body muscle in both short term definitive and long term partial life cycle test. In IMC fry in case of gill Rohu showed the highest accumulation of Fe followed by Mrigal and Catla. In case of fry kidney Mrigal showed the highest accumulation of iron followed by Catla and Rohu. In case of liver also Rohu showed the highest accumulation of Fe followed by Mrigal and Catla. When iron accumulation test for muscle was conducted Mrigal showed the highest accumulation followed by Catla and Rohu (Debnath, 2011). It is also reported that among spawn Catla growth was affected most by the iron concentration followed by Mrigal and Rohu. Although Mrigal is most sensitive to mortality, in case of fry Rohu growth was affected most by the iron concentration followed by Catla and Mrigal. In long term partial life cycle test a decrease in growth rate was observed in both spawn and fry of IMC. Although the main reason for reduced growth rate in the experiment is due to iron toxicity, the role of some other factor in reduced growth of the fishes also cannot be denied (Debnath, 2011). Gross changes in the architecture of gill morphology like loss, fusion, clubbing of secondary gill lamellae, and detachment of gill rakers following softening of gill shaft in fish under lethal exposures indicating reduced respiratory surface area.

CONCLUSION

The present report reveals that excess of iron concentration in culture water can severely affect the fish growth, feeding rate, spawn and fry survival of IMC. The accumulation of heavy metals in the tissues of or-

ganisms can result in chronic illness and cause potential damage to the population. The development of biological monitoring techniques based on fish offers the possibility of checking water pollution with heavy metals as iron.

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