TOXIC EFFECTS OF ZINC ON FOUR SPECIES OF FRESHWATER FISH

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Received Jan. 17, 1990

Abstract

The toxic effects of Zn^{2+} on Silver Carp (*Hypophthalmichthyps molitrix* C. et V.), Big Head Carp (*Aristrichthys nobilis* Richardson), Grass Carp (*Ctenopharyngodon ilellus* C. et V.), and Blunt Snout Bream (*Megalobrama aimbly-cephala* Yih) are studied. The test results are: (1) There are linear correlations between 24h LC_{50} and 48h LC_{50} of Zn^{2+} for Silver Carp fingerling and temperature. 24h LC_{50}, 48h LC_{50} and 96h LC_{50} of Zn^{2+} for fry of the four species are also determined; (2) There are logarithmic correlations between the growth rates of the fry and the concentrations of Zn^{2+} and between expansion of fish egg membranes after absorbing water and concentrations of Zn^{2+}; (3) The tolerance of fry of the four species to Zn^{2+} is in the following order: Grass Carp > Silver Carp > Blunt Snout Bream > Big Head Carp; (4) The safe concentrations of Zn^{2+} are: Big Head Carp: 0.008 mg/ L, Grass Carp: 0.046 mg/ L, Blunt Snout Bream: 0.010 mg/ L, Silver Carp: 0.012 mg/ L, Silver Carp fingerling: 0.09 mg/ L.

INTRODUCTION

Zn is an essential trace element for organisms, but in excessive amount is toxic for organisms. The present wide industrial use of zinc makes it one of the most common pollutants in natural waters. Excessive zinc could inhibit physiological activities of aquatic organisms and even be lethal.

Zinc can be accumulated in organisms and transmitted by the aquatic food chain and finally harm human health (Förstner and Wittmanu, 1983). Therefore, study on the toxic effects of Zn^{2+} on fish is very important for protecting human health and aquatic resources and setting water quality criteria for fisheries.

There are some published reports on the toxic effect of Zn^{2+} on fish (Xu, 1982; Huang et al., 1983 and Wu, 1983) but they did not contain information, especially on the quantitative effect of environmental factors on the toxic effect of Zn^{2+} on Silver Carp, Big Head Carp, Grass Carp and Blunt Snout Bream. Results of the present study on the relation of temperature to LC_{50} of Zn^{2+} for Silver Carp fingerling, the effects of Zn^{2+} on growth rates of fry of the four species are presented, and safe Zn^{2+} concentrations for the four fishes are proposed.

MATERIALS AND METHODS

Cleaned pond water with pH regulated with 0.1 mol/ L HCl and 0.1 mol/ L NaOH (both A.R. grade) was used. Based on the test requirements, a standard $ZnSO_4$ solution (A.R.) was added accurately into the water at equal logarithmic intervals. Each test involved at least a control group and 7 groups containing different concentrations of Zn^{2+}. Air was continuously bubbled into the water during the test. The test fish and eggs were from the Chongming Breeding Farm. The fry were measured with an OLYMPUS microscope. The test water volumes were 100 L for fingerling and 24 L for fry and egg.

1. Determination of the relationships between the LC_{50} of Zn^{2+} for Silver Carp fingerling (S-fi) and temperature

The quality indexes of the test water were: Alk = 4.31 meq/L, H_T (total hardness) = 4.51 meq/L, pH = 7.40, S-fi mean body length = 8.8 ± 0.6 cm. Twelve series (temperature 5 – 24 ℃) of the test solutions were prepared, with each series containing 7 groups of different Zn^{2+} concentrations. The fingerlings in groups of 10 were acclimated by raising temperature before the test. Test solutions were refreshed every other day to maintain a constant Zn^{2+} concentration and had temperature controlled strictly. Surviving fingerlings were counted at 24, 48 and 96 hours. The values (mg/L) of 24h LC_{50}, 48h LC_{50} and 96h LC_{50} of Zn^{2+} for S-fi were determined by linear interpolation.

2. Determination of LC_{50} values of Zn^{2+} for the fry

Water quality indexes were: pH = 7.40, Alk = 2.61 meq/L, H_T = 3.52 meq/L. Mean body lengths of fry of Silver Carp (S-fr), Big Head Carp (Bi-fr), Blunt Snout Bream (Bl-fr) and Grass Carp (G-fr) were 8.06 ± 0.50, 8.37 ± 0.19, 7.85 ± 0.40 and 8.75 ± 0.80 mm, respectively. There were 20 fry in each group. The test method was similar to that described in Section 1.

3. Determination of effect of Zn^{2+} on fry growth

Fry lengths and water quality indexes were the same as described in 2. There were 50 fry in each group of the test solutions. The fry were reared for 17 days, and then their measured body lengths were used to determine the respective growth rates (V, mm/d) and the relationships between V and the concentration ($C_{Zn^{2+}}$, mg/L) of Zn^{2+}.

4. Determination of effect of Zn^{2+} on expansion of eggs absorbing water

One hundred newly laid eggs of Silver Carp, Big Head Carp and Grass Carp were put into each group of solutions. The amount of introduced air bubbles was controlled carefully to avoid harming the egg membranes. After the eggs had absorbed water fully, they were taken out from each group randomly. The diameters (d) of the egg balls containing embryos, perivitelline fluid and egg membranes were measured to determine the correlations between d (mm) and $C_{Zn^{2+}}$ (mg/L).

RESULTS

1. The correlation between LC_{50} values of Zn^{2+} for S-fi and temperature

Fig.1 shows the correlation between LC_{50} values of Zn^{2+} for S-fi and temperature. Statistical analysis indicates that 24h LC_{50}, 48h LC_{50} and 96h LC_{50} values and the temperature have good linear correlationship. The correlation equations are as follows:

24h $LC_{50} = 49.80 - 1.72\,t$ $\quad n = 12 \quad r = -0.984$

48h $LC_{50} = 39.23 - 1.31\,t$ $\quad n = 12 \quad r = -0.982$

96h $LC_{50} = 29.58 - 1.07\,t$ $\quad n = 12 \quad r = -0.998$

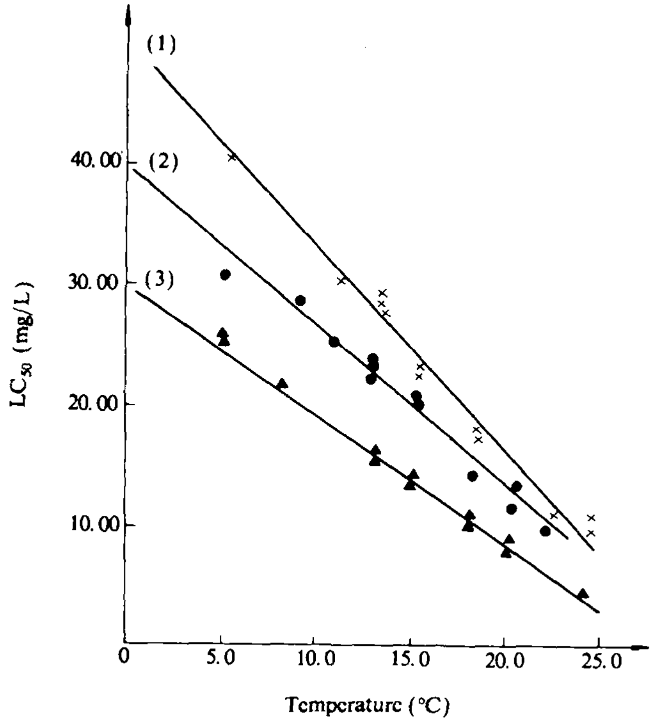

Fig.1 The relationship between the LC_{50} of Zn^{2+} for Silver Carp fingerling and temperature (1) 24h, (2) 48 h, (3) 96 h.

2. The toxic effect of Zn^{2+} on the fry

LC_{50} values of Zn^{2+} for the four species of fish fry are listed in Table 1.

Table 1 LC_{50} (mg/L) of Zn^{2+} for fish fry

Fish	24h LC_{50}	48h LC_{50}	96h LC_{50}
Grass Carp	6.47	6.04	4.60
Silver Carp	3.56	2.63	1.23
Blunt Snout Bream	2.58	2.15	0.95
Big Head Carp	1.48	1.47	0.80
Big Head Carp[1)]	5.24	4.22	2.82

1) Hatched 6 days in advance, water temperature 20 ℃.

3. The effect of Zn^{2+} on fry growth

Fig.2 giving curvilinear correlations between the growth rates (mm/d) of fry of the four species and the concentration of Zn^{2+} shows that the curves are very well correlated. The correlation equations are as follows:

G-fr: $V=0.101-2.10\times10^{-2}\ \ln C_{Zn^{2+}}$ $n=7$ $r=-0.973$ $S_V=5.13\times10$

S-fr: $V=3.10\times10^{-2}-1.26\times10^{-2}\ \ln C_{Zn^{2+}}$ $n=7$ $r=-0.979$ $S_V=2.65\times10$

Bl-fr: $V=-1.56\times10^{-3}-4.68\times10^{-2}\ \ln C_{Zn^{2+}}$ $n=7$ $r=-0.993$ $S_V=4.60\times10$

Bi-fr: $V=-3.62\times10^{-3}-2.75\ \ln C_{Zn^{2+}}$ $n=7$ $r=-0.996$ $S_V=2.50\times10$

where, n, number of sample; r, correlation coefficients, S_V, the standard deviations of the regressive equations.

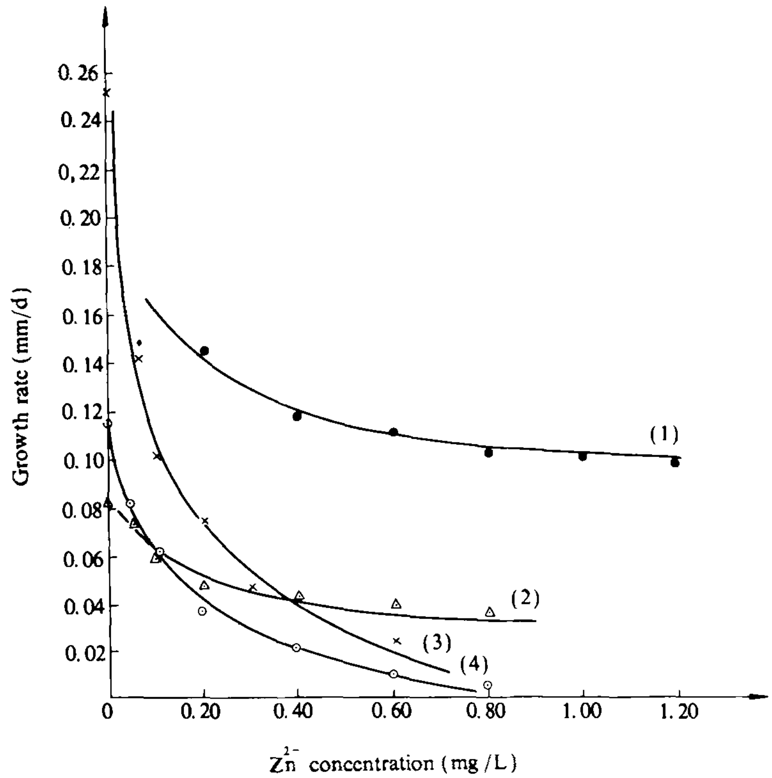

Fig.2 The growth rates (V) of fry of the four species as a function of the concentration ($C_{Zn^{2+}}$)
(1) Grass Carp, (2) Silver Carp, (3) Blunt Snout Bream, (4) Big Head Carp.

4. The effect of Zn^{2+} on expansion of fish eggs absorbing water

Fig.3 gives the relationship between the egg ball diameter (d) of the fish and

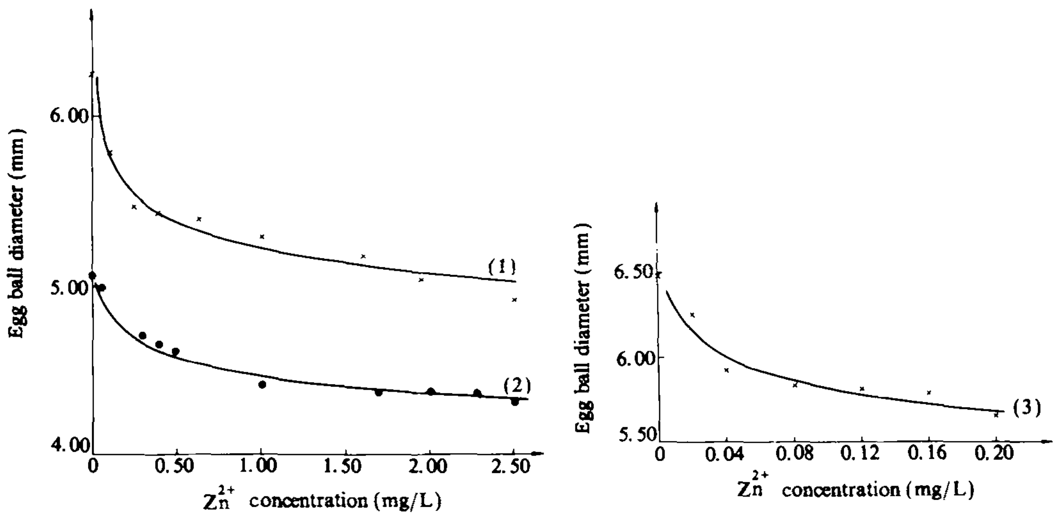

Fig.3 Egg ball diameter (d) of the fishes as functions of the concentration of Zn^{2+}
(1) Grass Carp, (2) Silver Carp, (3) Big Head Carp.

the concentration of Zn^{2+}, and shows their good correlation. The correlation equations are as follows:

Grass Carp egg: $d=5.32-0.214\ln C_{Zn}^{2+}$ $n=9$ $r=-0.960$ $S_d=0.067$

Silver Carp egg: $d=4.47-0.154\ln C_{Zn}^{2+}$ $n=10$ $r=-0.982$ $S_d=0.040$

Big Head Carp egg: $d=5.23-0.136\ln C_{Zn}^{2+}$ $n=7$ $r=-0.921$ $S_d=0.116$

where, n and r, ditto; S_d, the standard deviations of regressive equations.

DISCUSSION

1. The toxic effect of Zn^{2+} on fish and the factors affecting toxicity of Zn^{2+} to the animals

Table 1 shows that LC_{50} values of Zn^{2+} for the four species of fry were different, and that their tolerances to Zn^{2+} are in the following order: G−fr > S−fr > Bl−fr > Bi−fr. The LC_{50} values for two groups of Big Head Carp fry of different ages were different. It was also found that the LC_{50} value difference between Silver Carp fingerling and the fry was much bigger (higher LC_{50} values for fingerlings, lower LC_{50} values for fry). These indicate that the tolerance of the fish to Zn increases with age. This agrees with the results of other researchers (Alabaster, 1982; Riberling and Migaki, 1975).

Fig.1 shows that LC_{50} values decreased with rising temperature. 96h LC_{50} of Zn^{2+} for S-fi dropped by 83 percent when temperature rose from 5 ℃ to 24 ℃, though S-fi can live normally in unpolluted water between 5 ℃ and 24 ℃. The above observation that toxicity of Zn^{2+} to the fishes increases with temperature agrees completely with the toxic character of general poisons (Tamura, 1977; Wu, 1981; Wang, 1983).

2. The inhibitory effect of Zn^{2+} on fry growth and expansion of fish egg after absorbing water

Fig.2 shows that the growth rates of the fry decreased with increasing concentration of Zn^{2+} and decreased faster at the low concentration range, implying that Zn^{2+} inhibits fry growth, and that its toxicity to the fishes strengthens with concentration. Alabaster, Conner and Wisely of the United States Environmental Protection Agency suggested that excessive Zn^{2+} can cause various pathological changes of fish tissues and retard growth and maturity. Fig.2 also shows that the growth rates of Bi-fr and Bl-fr decreased with C_{Zn}^{2+}, faster than that of G-fr and S-fr, and that $V_{G\text{-}fr} > V_{S\text{-}fr} > V_{Bl\text{-}fr} > V_{Bi\text{-}fr}$ when C_{Zn}^{2+} was about 0.36 mg/L. This order is the same as the order of tolerance of the fishes to Zn^{2+}. This result agrees with our deduction from the LC_{50} values.

Fig.3 shows that expansion of fish eggs after absorbing water was inhibited strongly by Zn^{2+}. The strengthened inhibition with increasing Zn^{2+} concentration indicates that the toxic effect of Zn^{2+} on the fish eggs is strengthened with increasing concentration of Zn^{2+}.

To sum up, temperature and Zn^{2+} concentration are important factors which strongly affect the toxicity of Zn^{2+} to the fishes.

3. The symptoms and mechanisms of Zn^{2+} poisoning

Zn^{2+} is the most toxic form of zinc for aquatic organisms (Wang, 1983). The test showed that the fish were highly sensitive to Zn^{2+}. The fish swam wildly and jumped about after they were put into the test solution ($C_{Z_n}^{2+} > 10$ mg / L). After a while, the gills and the body surface excreted a large amount of mucus; then the fish swam slowly, dashed intermittently against the container walls; the chest fins shivered, the scales dropped off. The fish spat out big bubbles; the respiratory frequency decreased; haemorrhage spots were observed in the eye sockets and gill cover; gill strands became white and were covered with mucus; the fish gradually lost equilibrium, and then died.

The mechanism and chain of reactions in fish to zinc poisoning could possibly be: Zn^{2+} could have damaged the gill tissues, thus disturbing gas exchange, waste excretion, and osmotic pressure regulation; and could also have reacted harmfully with protein, and therefore prevented the normal function of protein and enzymic activity (Nomiyama, 1981; Pringle et al., 1986; Skidmore, 1970; Ribelin and Migaki, 1975).

4. Zn^{2+} content as water quality criterion for fishery

At present, the safe concentrations of heavy metal ions for fish are commonly based on 0.01×96 h LC_{50}. The concentration of Zn^{2+} in fishery water in the U.S.A. and Japan are limited to less than 0.01 and 0.1 mg / L, respectively (J.F.R.C.A., 1965, 1972; United States Enviromental Protection Agency, 1978). In China it is temporarily limited to less than 0.1 mg/L (Wu, 1981). The values of 0.01×96 h LC_{50} calculated from the present test results are listed in Table 2. The readers will easily find that values calculated from the results of the present study for the fishes are close to those of the U.S.A..

Table 2 The safe concentrations of Zn^{2+} for some fresh water (20 ℃) fishes

	0.01×96 h LC_{50}
Big Head Carp fry	0.008
Grass Carp fry	0.046
Blunt Snout Bream fry	0.010
Silver Carp fry	0.012
Silver Carp fingerlings	0.028

ACKNOWLEDGEMENT

We thank the Chongming Breeding Farm for providing test fish and laboratory facilities, Professor Wang Daozun for his many constructive comments and suggetions, and Zou Xiaoming et al. for their helpful cooperation.

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