TOXIC EFFECTS OF CYANOBACTERIA BLOOM EXTRACT CONTAINING MICROCYSTINS ON ANTIOXIDANT ENZYMES IN MICE

BAO Xiao-Feng[1], LU Yan, ZHU Tong-Yang and SHEN Ping-Ping
(*State Key Laboratory of Pharmaceutical Biotechnology, Department of Biochemistry, Nanjing University, Nanjing* 210093, *China*)

Abstract: Cyanobacteria blooms that appear in eutrophic freshwaters around the world are contaminating water seriously. The toxic compound microcystins (MCs), a family of monocyclic hepta-peptide, generated by cyanobacteria blooms have been reported to have harmful effects on human being and domestic animals. In this paper, we collected cyanobacteria blooms from Taihu Lake, China and employed three sublethal dosages of cyanobacteria bloom extract (CBE) (16, 32 and 64 mg lyophilized algae cells/ kg body weight, with contents of 4.97, 9.94 and 19.88 μg MCs equivalents/ kg body weight) to assay its effects on the antioxidant enzymes in mice's liver. The mice received CBE treatment every day via i.p. injection for 14 days and were sacrificed on day 3, 5, 7, 9, 11, 13 and 15. Three main antioxidant enzymes: superoxide dismutase (SOD), catalase (CAT) and glutathione-S-transferase (GTS) were examined. Inhibition effects of CBE on SOD and CAT activities were presented. Obvious changes of GST activity were also observed. To further determine the degree of peroxidation induced by CBE, the level of lipid peroxidation was analyzed by testing malondialdehyde (MDA) concentration. A significant dose-dependent increase of MDA level was found after 14 days of CBE exposure. Our results showed that CBE possessed the deleterious effects on antioxidant enzymes and caused the increase of lipid peroxidation level in mice's liver.

Key words: Taihu Lake; Cyanobacteria; Microcystins; Antioxidant enzymes
CLC number: X174 **Document code**: A **Article ID**: 100-3207(2007)06-0874-06

During the past years, with a rapid economic development and urbanization along Taihu Lake, growing amounts of domestic, industrial and agricultural waste are discharged into the lake. These pollutions lead to eutrophic in some parts of the water system of the lake[1], and heavy cyanobacteria blooms often occur in those regions[2, 3]. Our previous work has indicated the presence of MCs, a family of monocyclic hepta-peptide, in cyanobacteria bloom collected from Taihu Lake and showed that the main toxic component of cyanobacteria bloom extract (CBE) is MC-LR[4].

It is well known that the main target of MCs is liver, where they are taken up into the hepatocytes via multispecific bile acid transport systems[5, 6], and the toxicity of MCs is initiated by inhibition of the activity of serine/ threonine protein phosphatase 1 and 2A[7, 8]. The consequent protein phosphorylation imbalance causes disruption of the liver cytoskeleton, which leads to the loss of cell morphology and the increase of progressive liver fibrosis in human being and animals[7, 9]. In acute toxicosis with high doses of MCs, the massive hepatic haemorrhage is presented in livers. In 1996, the most severe health case that MCs caused the death of 60 of the patients at a hemodialysis clinic was happened in Caruaru, Brazil, in which massive hepatomegaly was the most striking finding in these patients[10]. In Chronic toxicity with long time and lower level of MCs, tumorigenesis can be led. It was reported that the incidence of primary liver cancer in certain areas of China was related to the presence of MCs in drinking water[11, 12]. Recently, studies have been carried out to elucidate the peroxidant damage mechanism related to MCs hepatotoxicity. Ding, *et al*.[13] suggested

Received date: 2005-11-21; **Accepted date**: 2006-12-28
Foundation item: the National Natural Science Foundation of China (Project No. 20477016)
Corresponding author: Shen Ping-Ping, Fax: +86-25-83324605, E-mail: ppshen@nju.edu.cn

that free radicals induced by MCs were responsible for the hepatotoxicity. Li, *et al*.[14] found that the toxicity of raw MCs purified from *Microcysis* caused the increase of reactive oxygen species (ROS) contents and the depletion of GSH in hepatocytes. In this study, to clarify the effect of MCs on antioxidant system in liver, the effects of CBE on three antioxidant enzymes, SOD, CAT and GST were first assayed. These enzymes play a primary role in the maintenance of redox balance[15-17] and the changes of their activities imaged the oxidative stress that the liver underwent. To further determine the degree of peroxidation induced by CBE, the level of MDA in mice's liver, as an index of lipid peroxidation, was also analyzed.

1 Material and Methods

1.1 Chemicals Standard MC-LR was obtained from Alexis Inc. (Carlsbad, CA). Nitro blue tetrazolium (NBT), H_2O_2, glutathione (GSH), 1-chloro-2, 4-dinitrobenzene (CDNB) and thiobarbituric acid (TBA) were purchased from Sigma Chemical Inc. (St. Louis, MO). All other reagents were purchased from Promega Inc. (Madison, WI).

1.2 Preparation of samples The surface cyanobacteria blooms were collected from Meiliang Bay, the hypertrophic area in the northern part of Taihu Lake. Microscopic examination revealed that the *Microcystis aeruginosa* was the dominating genus (more than 80%). According to the method we used previously[4], dried algae that had been processed by ultrasonic were extracted three times with aqueous acetic acid. The supernatant was pooled together and applied directly to ODS-C18 cartridges, and then CBE was obtained. HPLC with DAD detector showed that the main component of CBE was MC-LR[4].

1.3 Animals and CBE treatment Virus-free BALB/c mice, 6 weeks of age, were purchased from the Animal Center of Nanjing General Hospital of Chinese People's Liberation Army. On arrival, randomized mice were transferred to plastic cages containing saw dust bedding which was changed every 3 days, 5 mice per cage and allowed to acclimatized for 1 week. Mice were given food and water ad libitum and used for experimentation when their body weight was between 16 and 20 g. Animal holding rooms were kept at 21—24℃ and 40%—60% relative humidity with a regime of 12 h light/dark cycle.

Mice were randomly separated into four groups. A first group of 3 mice (T0 group) were immediately killed. Other 63 mice in three CBE treatment groups were administered at three independent doses respectively (16, 32 and 64 mg lyophilized algae cells/kg body weight, with contents of 4.97, 9.94 and 19.88 μg MCs equivalents/kg body weight). The doses were based mainly on the LD_{50} of CBE (230 mg dry algae cells/kg body weight, with 71.30 μg MCs equivalents/kg body weight)[18]. These mice received CBE treatment every day for 14 days via i.p. injection. 3 mice of each group were sacrificed on day 3, 5, 7, 9, 11, 13 and 15, 24 hours after the last treatment of CBE. Livers of mice were excised and weighted. 0.2 g individual liver was homogenized in 10 mL physiological saline and centrifuged at 5000 r/min, 4℃ for 10 min. The supernatant was kept on ice for later test of antioxidant enzymes.

1.4 Antioxidant enzymes activity determination

1.4.1 Superoxide dismutase assay The SOD activity was measured by the method described by Oberley and Spitz[19]. A 50 μg sample of each extract was assayed. One unit of enzyme was defined as the quantity of SOD required to produce 50% inhibition of NBT oxidated. The change of absorbance in control group at 550 nm was used to obtain the rate of change in absorbance inhibited by the sample. This rate was used to measure the activity of SOD and the activity was expressed as units per gram liver sample.

1.4.2 Catalase assay The CAT activity was determined by measuring the catalyzed decomposition of H_2O_2[20]. To determine the activity of CAT, 2.9 mL phosphate buffer (50 mmol/L, pH 7.0) and 100 μL H_2O_2 (final concentration about 35 mmol/L) were added to the quartz cuvette. The initial absorbance was measured at 240 nm. After a 50 μL sample was added to the mixture, the change was detected in 60 seconds. Activity was expressed as μmol H_2O_2 decomposed/sec per gram liver sample.

1.4.3 Glutathione-S-transferase assay The GST aetivity was assayed by the modified method according to Habig, *et al*[21]. The reaction mixture consisted of 0.8 mL 0.1 mol/L potassium phosphate buffer (pH 6.5) containing 1 mmol/L EDTA, 50 μL 20 mmol/L GSH, and 50 μL 20 mmol/L CDNB. The change of absorbance at 340 nm was recorded as a baseline. After a 100 μL sam-

ple was added to the mixture, the reaction was initiated and the change of absorbance was detected in 2 min. Results were expressed as μmol GSH oxidized/min per gram liver sample.

1.4.4 Lipid peroxidation assay MDA was determined by the double heating method of Draper and Hadley[22]. 1 mL freshly prepared 0.67 % (w/v) TBA solution was added to 1 mL of each sample, and then the mixtures were incubated in boiling water for 10 min. After cooling, the absorbance was measured at 532 nm. MDA concentration was calculated by the absorbance coefficient of MDA-TBA complex and expressed in μmol MDA per gram liver sample.

1.5 Statistical analysis Data for antioxidant enzymes activities were expressed as the mean ± standard error (SE). Statistical analysis was performed by students' *t*-test. $p < 0.05$ or $p < 0.01$ was considered statistically significant and indicated by * or **, respectively.

2 Results

The effects of CBE on SOD activity were presented in Fig. 1. Different doses of treatment, 16, 32 and 64 mg/kg body weight respectively, made differences. With low dose treatment, SOD activity decreased significantly on day 2, reached the bottom level on day 6 and then gradually returned to about its T0 level on day 10. Compared with the T0 group, SOD activity at the bottom level decreased 27.72%. Moderate dose treatment showed a transient increase (7.67 %) of SOD activity on day 2 and then the enzyme activity attenuated. The maximum reduction was 25.21 % compared with the T0 group, which was obtained on day 8. After day 8, SOD activity reverted with time and the reduction ratio was 11.71 % on day 14. In high dose group, a 14.62 % enhancement in SOD activity was observed on day 2. From day 2, SOD activity decreased remarkably and reached the lowest level on the day 14, which was only 69.04 % of the T0 group. No obvious activity recovery was found with this high dose treatment.

The effects of CBE on CAT activity in different dose groups were displayed in Fig. 2. With low dose treatment, CAT activity decreased significantly from day 2, reached the bottom level on day 6 and then gradually returned to its T0 level on day 10, which was similar to the SOD. CAT activity at the bottom level decreased 43.69 %. In moderate and high dose groups, CAT activity was decreased with time and no observable recovery trend was found. The minimum enzymatic activity was, respectively, 71.68 % and 65.94 % of the T0 level.

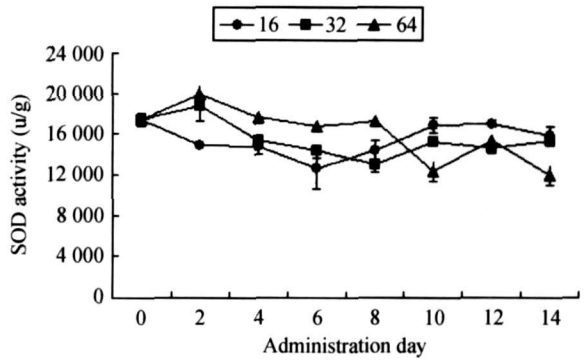

Fig. 1 Effects of 14 days of i.p. injection three doses of CBE (16, 32 and 64 mg lyophilized algae cells/kg body weight) on SOD activity in mice's liver

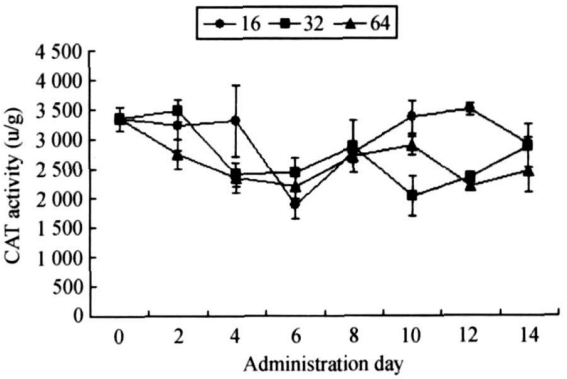

Fig. 2 Effects of 14 days of i.p. injection three doses of CBE (16, 32 and 64 mg lyophilized algae cells/kg body weight) on CAT activity in mice's liver

Based on the data from Fig. 3, in low dose group evident variation of GST activity was also observed throughout the 14 days except the day 10. Moderate dose treatment showed no variation of GST activity in the first 10 days and then a significant increase until day 14. Similar to moderate dose treatment, no obvious change was found during the first 8 days in high dose group, and then a remarkable increase was noted on day 10. But a kinetic falling was found from day 12 and a significant decrease was shown on day 14.

MDA levels were shown in Fig. 4. The T0 value was 0.36 ± 0.08 μmol MDA/g liver. In different dose groups, MAD concentrations were increased to 0.97 ± 0.34, 2.53 ± 0.52 and 2.98 ± 0.83 μmol/g liver respee-

tively after 14 days of CBE treatment; which was 2.7, 7.0 and 8.3 fold increase respectively compared with T0 group.

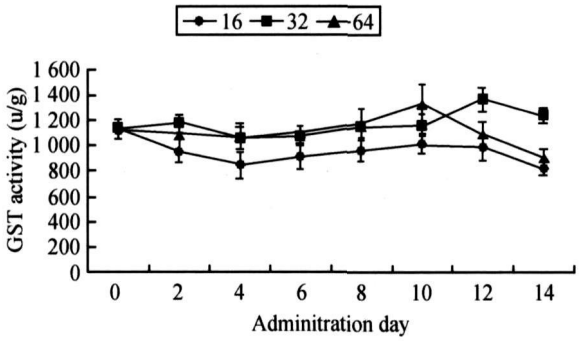

Fig. 3 Effects of 14 days of i.p. injection three doses of CBE (16, 32, 64 mg lyophilized algae cells/kg body weight) on GST activity in mice's liver

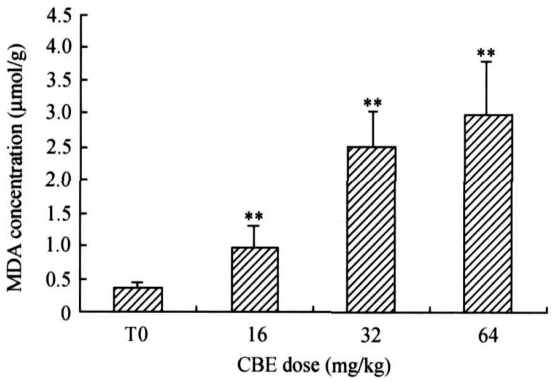

Fig. 4 Effects of three doses of CBE via i.p. injection on MDA content on day 14 in mice's liver. The differences between the T0 group and treated groups were determined by students' *t*-test. $p < 0.01$ was considered statistically significant and indicated by * *

3 Discussion

Cyanobacteria extract containing MCs was able to enhance intracellular production of ROS in primary culture rat hepatocytes[13], providing experimental evidence that oxidative damage was involved in cyanobacteria extract-induced hepatotoxicity. However, exact mechanism leading to oxidant damage in liver by MCs has not been clarified thoroughly yet. In this study, we set up a batch of enzymological assays to assess the subacute effects of intraperitoneal administration of CBE on the activities of antioxidant enzymes in mice's liver including SOD, CAT and GST. The concentrations of MDA were also detected to reflect the level of lipid peroxidation. Our work was the first report that clarified the noxious effects of CBE on the antioxidant system of mammal.

Activities of both SOD and CAT in mice's liver were found to be down regulated after CBE exposure (Fig. 1, 2). SOD, a potential antioxidant enzyme, mediated enzyme-catalyzed decomposition of superoxide anion, and converted it to peroxide that could in turn be destroyed by CAT reactions[23]. The reduction of activities of SOD and CAT would lead to their degressive abilities of detoxifying H_2O_2. H_2O_2 could rapidly diffuse across biological membranes, thus gave rise to more reactive radicals inside the cell[24], which indicated that the negative effects of CBE on both enzymes might result in cellular and tissue damage by causing peroxidation *in vivo*. Similar to our finding, Pinho, *et al.*[25] reported that CAT activity in the estuarine crab *Chasmagnathus granulatus* decreased over the 7 days of exposure of MG-LR. Their work exhibited that MG-LR could affect invertebrate antioxidant defense system. Fig. 1, 2 revealed that the enzymatic activities in the low dose groups reverted and were quite similar to the T0 group after the day 10, suggesting that the repair system in mice had probably been started and counteracted the effect induced by CBE shock. However, the SOD activity in high dose group got a transitory increase on day 2 and then significantly decreased, implying that high dose treatment could activate the emergency response in the first few days, but then some irreversible damage was likely done to the animals.

After CBE exposure, the obvious kinetic changes of GST activity were observed (Fig. 3). GST enzymes are a class of phase II metabolic enzymes presenting in virtually all organs and tissues, which protect against the reactive toxicants. They scavenge these toxicants through catalyzing the conjugation with reduced GSH[26, 27]. Pflugmacher, *et al.*[28] have shown the existence of a MG-LR-GSH conjugate formed through GST catalysis in various aquatic organisms. Pietsch, *et al.*[29] also observed the higher GST activity after MG-LR exposure. The enhancement of GST activities during the 14 days exposure of CBE was found after moderate and high doses treatment, assuming that the increased GST activity might be either due to a high rate of MCs conjugation with GSH and/or detoxification of endogenous molecules like peroxides. However, the GST activity fell from the day 12 at high dose treat-

ment, indicating that excessive treatment of CBE broke the production mechanism of GST.

MDA level was up regulated significantly and in dose-dependent manner after 14 days of CBE exposure (Fig. 4), which meant an underlying increase of the lipid peroxidation. Lipid peroxidation was one of the main manifestations of oxidative damage, and the increased lipid peroxidation found in our experiment indicated that the deleterious effects of CBE on antioxidant enzymes led to the oxidative stress in mice's liver. Consistent with our findings, Ding, *et al*. [13] observed that cyanobacteria extract containing MCs caused oxidative stress and increased lipid peroxidation in primary rat hepatocytes.

Water quality of Taihu Lake has become increasingly worse with the development, with increases the risk of toxicity to human being and animal health. The average contents of MCs in cyanobacteria blooms in this area are very high, and in some sites, sometimes about ten times of the guideline made by WHO (1.0 μg/L)[18]. Because MCs are very stable undergoing proteolytic or hydrolytic attack[9], they can accumulate in the food chain and have a long-term impact to the aquatic ecosystem and public health. Mu, *et al*. [30] have reported that hepatopathy occurred in Taihu Lake and nearby areas was associated with the polluted drinking water containing cyanobacteria blooms, and MCs were responsible for the deleterious effects of the blooms[9, 31]. In present experiments, CBE has been proved to cause obvious disruption of the antioxidant defense system in mice's liver. The results suggested that consumption of water heavily contaminated by cyanobacteria blooms might be of oxidative stress in the liver concern. Our work evaluated that the cyanobacteria contamination in Taihu Lake was a big health hazard to human being and gave an indication for *in vivo* study of toxicity of MCs, which was related to the hepatopathy caused by cyanobacteria contamination.

References:

[1] Cai Q M, Gao X Y, Chen Y W, Ma S W, Dokulil M. Dyamic variation of water quality in Taihu Lake and multivariate analysis of its influential factors [J]. *The Journal of Chinese Geography*, 1997, **7**: 72—82

[2] Yang Q X. Algal bloom in Taihu Lake and its control [J]. *Journal of Lake Science*, 1996, **8** (1): 67—74

[3] Liang W, Jia Q F, Hua Y J. Influence of alga contamination on the quality of drinking water in the Tai Lake area [J]. *Jiangsu Journal of Preventive Medicine*, 2001, **12** (1): 1—2

[4] Shen P P, Shi Q, Hua Z C, Kong F X, Wang Z G, Zhuang S X, Chen D C. Analysis of microcystins in cyanobacteria blooms and surface water samples from Meiliang Bay, Taihu Lake, China [J]. *Environment International*, 2003, **29** (5): 641—647

[5] Runnegar M T, Falconer I R, Silver J. Deformation of isolated rat hepatocytes by a peptide hepatotoxin from the blue-green alga microcystis aeruginosa [J]. *Naunyn-Schmiedebergs Archives of Pharmacology*, 1981, **317**(3): 268—72

[6] Hooser S B, Kuhlenschmidt M S, Dahlem A M, Beasley V R, Carmichael W W, Haschek W M. Uptake and subcellular localization of tritiated dihydro-microcystin-LR in rat liver [J]. *Toxicon*, 1991, **29** (6): 589—601

[7] Mackintosh C, Beattie K A, Klumpp S, Cohen P, Codd G A. Cyanobacterial microcystin-LR is a potent and specific inhibitor of protein phosphatases 1 and 2A from both mammals and higher plants [J]. *FEBS Letters*, 1990, **264**: 187—192

[8] Yoshizawa S, Matsushima R, Watanabe M F, Harada K I, Ichihara A, Carmichael W W, Fujiki H. Inhibition of protein phosphatases by microcystins and nodularin associated with hepatotoxicity [J]. *Journal of Jancer Research and Clinical Oncology*, 1990, **116**: 609—614

[9] Dawson R M. The toxicology of microcystins [J]. *Toxicon*, 1998, **36** (7): 953—962

[10] Pouria S, A de Andrade A, Borbosa J, Cavalcanti R L, Barreto V T, Ward C J, Preiser W, Poon G K, Neild G H, Codd G A. Fatal microcystin intoxication in haemodialysis unit in Caruaru, Brazil [J]. *Lancet*, 1998, **352**: 21—26

[11] Yu S Z. Primary prevention of hepatocellular carcinoma [J]. *Journal of Gastroenterology and Hepatology*, 1995, **10** (6): 674—682

[12] Ueno Y, Nagata S, Tsutsumi T, Hasegawa A, Watanabe M F, Park H D, Chen G C, Chen G, Yu S Z. Detection of microcystins, a blue-green algal heptatotoxin in drinking water sampled in Haimen and Fusui, endemic areas of primary liver cancer in China, by highly sensitive immunoassay [J]. *Carcinogenesis*, 1996, **17**: 1317—1321

[13] Ding W X, Shen H M, Zhu H G, *et al*. Studies on oxidative damage induced by cyanobacteria extract in primary cultured rat hepatocytes [J]. *Environmental Research*, 1998, **78**: 12—18

[14] Li X, Liu Y, Song L, Liu J. Responses of antioxidant systems in the hepatocytes of common carp (Cyprinus carpio L.) to the toxicity of microcystin-LR [J]. *Toxicon*, 2003, **42** (1): 85—89

[15] Wispe J R, Warner B B, Clark J C. Human Mn superoxide dismetase in pulmonary epithelial cells of transgenic mice confers protection from oxygen injury [J]. *Journal of Biological Chemistry*, 1992, **267**: 23937—23941

[16] Werns S W, Lucchesi B R. Free radicals and ischemic tissue injury [J]. *Trends in Pharmacological Sciences*, 1990, **11** (4): 161—166

[17] Coyle J T, Puttfarcken P. Oxidative stress, glutamate, and neurodegenerative disorders [J]. *Science*, 1993, **262** (5134): 689—695

[18] Shen P P, Zhao S W, Zheng W J, Hua Z C, Shi Q, Liu Z T. Effects of cyanobacteria bloom extract on some parameters of immune function in mice [J]. *Toxicology Letters*, 2003, **143** (1): 27—36

[19] Oberley L W, Spitz D R. Assay of superoxide dismutase activity in tumor tissue [J]. *Methods in Enzymology*, 1984, **105**: 457—464

[20] Escobar J A, Rubio M A, Lissi E A. Sod and catalase inactivation by singlet oxygen and peroxyl radicals [J]. *Free Radical Biology and Medicine*, 1996, **20** (3): 285—290

[21] Habig W H, Pabst M J, Jakoby W B. Glutathione S-transferases: The first enzymatic step in marcapturic acid formation [J]. *Journal of Biological Chemistry*, 1974, **249**: 7130—7139

[22] Draper H H, Hadley M. Malondialdehyde determination as index of lipid peroxidation [J]. *Methods in Enzymology*, 1990, **186**: 421—431

[23] Mao G D, Thomas P D, Lopaschuk G D, Poznansky M. Superoxide dismutase (SOD)-catalase conjugates. Role of hydrogen peroxide and the Fenton reaction in SOD toxicity [J]. *Journal of Biological Chemistry*, 1993, **268**, 416—420

[24] Mauro M, Maria V C, Stefano I, Gerry M, Alessandro F A. A survey of reactive oxygen species and their role in dermatology [J]. *Journal of the European Academy of Dermatology and Venereology*, 1997, **8**: 185—202

[25] Pinho G L L, Moura da Rosa C, Yunes J S, Luquet C M, Bianchini A, Monserrat J M. Toxic effects of microcystins in the hepatopancreas of the estuarine crab *Chasmagnathus granulatus* (Decapoda, Grapsidae) [J]. *Comparative Biochemistry and Physiology C*, 2003, **135**: 459—468

[26] Hartley D P, Ruth J A, Petersen D R. The hepatocellular metabolism of 4-hydroxynonenal by alcohol dehydrogenase, aldehyde dehydrogenase and glutathione S-transferase [J]. *Archives of Biochemistry and Biophysics*, 1995, **316**: 197—205

[27] Siems W G, Zollner H, Grune T, Esterbauer H. Metabolic fate of 4-hydroxynonenal in hepatocytes: 1, 4-dihydroxynonene is not the main product [J]. *Journal of Lipid Research*, 1997, **38**: 612—622

[28] Pflugmacher S, Wiegand C, Oberemm A, Beattie K A, Krause E, Codd G A, Steinberg C E W. Identification of an enzymatically formed glutathione conjugate of the cyanobacterial hepatoxin microcystin-LR: the first step of detoxication [J]. *Biochimica et Biophysica Acta*, 1998, **1425**: 527—533

[29] Pietsch C, Wiegand C, Ame M V, Nicklisch A, Wunderlin D, Pflugmacher S. The effects of cyanobacterial crude extract on different aquatic organisms: evidence for cyanobacterial toxin modulating factors [J]. *Environmental Toxicology*, 2001, **16**: 535—542

[30] Mu L N, Chen C W, Yu S Z, Liu J N, Wu Y Y, Zhu W C. Investigation study on the content of microcystin in Tai lake and methods for microcystin treatment [J]. *Zhongguo Gonggong Weisheng*, 2000, **16** (9): 803—804

[31] Codd G A, Word C J, Bell S G. Cyanobacterial toxins: occurrence, modes of actions, health effects and exposure routes [J]. *Archives of Toxicology*, 1997, (Suppl. 19): 399—410

含微囊藻毒素的蓝藻水华提取物对小鼠抗氧化酶的毒性作用

包小峰　卢　彦　朱彤阳　沈萍萍

(南京大学生物化学系, 医药生物技术国家重点实验室, 南京　210093)

摘要: 在世界范围内发生的富含营养的废水中生长蓝藻水华已经造成了严重的水污染。已有报道显示水华中的有毒成分是一类单环七肽微囊藻毒素, 它们对人和家畜有严重的毒害作用, 本文所使用的蓝藻水华采集于我国的太湖地区。我们采用三个亚致死计量(16、32、64 mg 冻干藻细胞/kg 体重, 相当于4.97、9.94、19.88 μg 藻毒素/kg 体重)的蓝藻水华提取物(CBE), 分析它们对小鼠肝脏抗氧化酶的影响。经过连续 14d 每天腹腔注射 CBE, 小鼠分别在第3、5、7、9、11、13、15 天处死并检测三种主要的抗氧化酶: 超氧化物歧化酶(SOD)、过氧化氢酶(CAT)和谷胱甘肽巯基转移酶(GST)的活性。SOD 和 CAT 的活性均呈现了抑制效应, GST 的活性也发生了明显的变化。为了进一步确定过氧化的程度, 我们又通过检测丙二醛的含量分析了脂质过氧化的程度。经过 14d CBE 处理后脂质过氧化表现出了明显的浓度依赖性的上升趋势。我们的结果表明, CBE 对小鼠的抗氧化酶有严重毒害作用, 并且能够引起脂质的过氧化。

关键词: 太湖; 蓝藻; 微囊藻毒素; 抗氧化酶