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RESPONSE OF ANTIOXIDANT SYSTEM IN SOME MARINE ALGAE UNDER CADMIUM STRESS

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ABSTRACT

Ulva lactuca and *Carolina meditermean* were collected from Balteem Coast of Egypt. These two algae represented the most common species in two major divisions Chlorophycophyta and Rhodophycophyta which occur in Balteem coast. Treatment of both algae with $CdCl_2$ at various concentrations (50-250 µmol) resulted in an increase in the activities of superoxide dismutase (SOD, EC 1.15.1.1), catalase (CAT, EC 1.11.1.6), ascorbate peroxidase (APX, EC 1.11.1.11) and glutathione reductase (GR, EC 1.6.4.2). The increase in the activities of the four enzymes was proportional with the lower $CdCl_2$ concentrations. However, the higher concentrations (200 and 250 µmol) of $CdCl_2$ resulted in reduction of enzymes activities in both algae. In addition, $CdCl_2$ increased the reduced glutathione (GSH) and decreased the oxidized glutathione (GSSG) contents of both algae. Also, the contents of proline and glycine betaine (GB) as well as lipid peroxidation increased with the lower concentrations of $CdCl_2$ and decreased at the higher concentrations However, lipid peroxidation increased continuously with increasing $CdCl_2$ concentrations.

Keywords: *Ulva lactuca*, *Carolina meditermean*, Lipid peroxidation, Antioxidant enzymes, Reduced glutathione, Oxidized glutathione, Proline, Glycine betaine.

INTRODUCTION

Macroalgal communities provide nutrition, reproduction, and an accommodating environment for other living organisms in marine ecosystems (McClanahan *et al.*, 2002). Because they contain proteins, carbohydrates and other nutritional elements. Macroalgae are one of the most important organisms.

Algae contain several enzymatic and nonenzymatic antioxidant defense systems to maintain the concentration of ROS (O_2^- and H_2O_2) to protect cells from damage (Abd El-Baky *et al.*, 2004). The main cellular components susceptible to damage by these ROS are lipids, proteins, carbohydrates and nucleic acids (Susuki & Mittler, 2006). Damages in the polyunsaturated fatty acids of cell membrane under stress may result in a failure in the permeability of cell membrane and cause cell death (Gutteridge & Halliwell, 2000).

The primary scavenging enzymatic antioxidant defense system include superoxide dismutase (SOD), calalase (CAT), glutathione reductase (GR) and ascorbate peroxidase (APX) (Mittler *et al.*, 2004).

GSH is an important non-enzymatic antioxidant in macroalgae. It has been documented that GSH can remove ROS, such as OH^-, $O_2^{\cdot-}$, $^1O_2$ and alkyl peroxide, and also protect proteins from the oxidation of protein thiol groups (Noctor *et al.*, 2002).

Cd has so far unknown roles in living organisms, and are toxic even at very low concentrations (Nies, 1999). Heavy metals in general affect algae

through cell lysis, growth inhibition, reduced photosynthesis, disrupted calcification, disturbances in sexual reproduction, and changes in bioluminescence (Ku¨pper *et al.*, 2002). In addition, heavy metals induce the production of reactive oxygen species (ROS) and cause a disbalance in the cellular oxidative status (Okamoto *et al.*, 2001a & 2001b).

Heavy metals block functional groups of proteins, displace and/or substitute essential metals, induce conformational changes, denature enzymes and disrupt cells and organelle integrity (Hall, 2002). Different heavy metals have been reported to affect macroalgae by interacting with enzymes and inhibiting their normal functions (Van Assche & Clijsters, 1990).

Cadmium is one of the most toxic water pollutants which penetrate into environment mainly through industrial processes and phosphate fertilizers. The bases of Cd toxicity are still not completely understood, but it might result from its high affinity for sulfydryls (Sch¨utzend ¨ubel & Polle, 2002).

Thus, the aim of the present investigation is to study the effect of $CdCl_2$ at different concentrations (50-250 µmol) on the antioxidant enzymes and non-antioxidant compounds in *Ulva lactuca* and *Carolina mediterrnean* collected from Balteem coast of Egypt.

MATERIALS AND METHODS

Location of collection

One station along Balteem coast of Egypt was chosen for collecting the algae under investigation, the algae were taken for analysis.

Algal Material

The algae used in this study were *Ulva lactuca* and *Carolina mediterrnean.* These algae represent the most common species in the two major divisions Chlorophycophyta and Rhodophycophyta which occur in this area. Some samples of *Ulva lactuca* and *Carolina mediterrnean* were transported in ice-box directly to the laboratory. These samples were washed with distilled water several times and purified from sand and epiphytes before using in the extraction of antioxidant enzymes and non-antioxidant enzyme systems.

Identification of algae

Algal taxa were identified according to Nasr (1947), Aleem (1978) and El-Nagger (1980).

Treatment with $CdCl_2$

The thalli were treated with 20 ml of $CdCl_2$ at various concentrations (50, 100, 150, 200, 250 µmol) or 20 ml of distilled water (control) for 24 h. After treatment, the thalli were used for preparation of the extract for measuring enzymic and nonenzymic antioxidants. All the treatments were carried out on orbital rotating plates (60 rpm) in light (150 µmol m^{-2} s^{-1}) at 28 °C

Preparation of algal extract

Samples of *Ulva lactuca* and *Carolina mediterrnean* were used for enzyme extraction as follow. The thallus was ground in 100 mM phosphate buffer (pH 7.0), 1.0 mM DTT and then centrifuged at 5000 g for 20 min. The supernatant was collected and used for determination of the contents of non-enzymic antioxidants as well as the activities of antioxidant enzymes.

Determination of enzymes activities:

Superoxide dismutase (SOD, EC 1.15.1.1):

SOD activity was assayed by measuring the inhibition of photochemical reduction of NBT (Giannopolitis & Reis, 1997).

Catalase (CAT, EC 1.11.1.6):

Catalase activity was measured according to Kato & Shimizu (1987).

***Ascorbate peroxidase* (APX, EC 1.11.1.11):**

APX activity was determined according to the method of Nakano & Asada (1981).

Glutathione reductase (GR, EC 1.6.4.2):

Assay of GR was based on the method described by Carlberg and Mannervik (1985) and depends on the oxidation of NADPH at 340 nm.

Determination of glutathione (GSH):

The GSH content of algal cell extracts was measured by reaction with 5,5` dithiobis-2-nitrobenzoic (DTNB) according to Silber *et al.* (1992).

Estimation of proline content:

The proline content was estimated by the method of Bates *et al.* (1973).

Estimation of glycine betaine (GB) content:

GB concentration in *Ulva lactuca* and *Carolina mediterrnean* extract was determined according to the method of Wyn Jones & Storey (1977).

Determination of lipid peroxidation

The assay principle is that malondialdehyde (MDA), a secondary product of lipid peroxidation, reacts with thiobarbituric acid (TBA) in acidic medium and the absorbance was read at 532 nm (Heath & Packer, 1968).

Statistical analysis

All the data in the present study are expressed as mean ± SE obtained from three measurements.

RESULTS AND DISCUSSION

Studying the effect of various $CdCl_2$ concentrations (50-250 µmol) on SOD activities (Fig. 1) in both *U. lactuca* and *C. mediterrnean*, revealed that *U. lactuca* expressed lower activity than that expressed by *C. mediterrnean*. The Cd induction of SOD activity has also been observed in the marine microalgae *Tetraselmis gracilis* (Okamoto *et al.*, 1996). In the marine dinoflagellate *Gonyaulax polyedra*, the activity of SOD was induced by exposure to acute Cd (Okamoto & Colepicolo, 1998).

The reduction in the level of SOD activity at high concentration of $CdCl_2$ in present investigation could be due to the inhibition of the enzyme through reaction with –SH group required for enzyme catalysis. Also, the reduction could be due to the increase of superoxide anion radical during its metabolism.

$CdCl_2$ induced catalase activity in *U. lactuca* and *C. mediterrnean* at the lower concentrations (Fig 2). However, *C. mediterrnean* expressed higher catalase activity than *U. lactuca*. The induction of CAT activity by Cd has been observed in the red macroalgae *Gracilaria tenuistipitata* (Collén *et al.*, 2003).

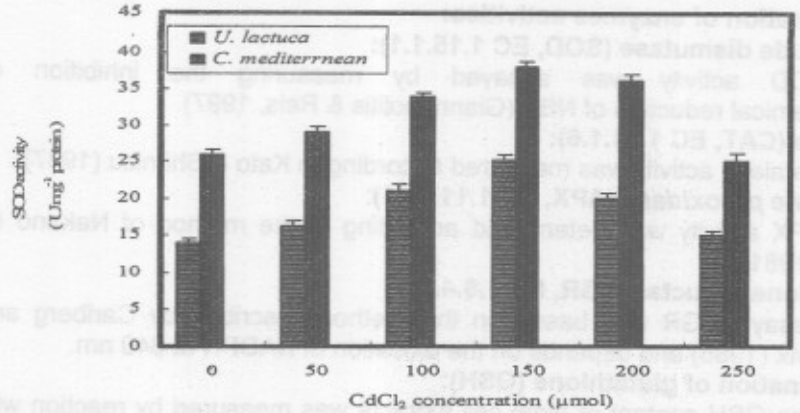

Fig.1: Effect of $CdCl_2$ on SOD activity.

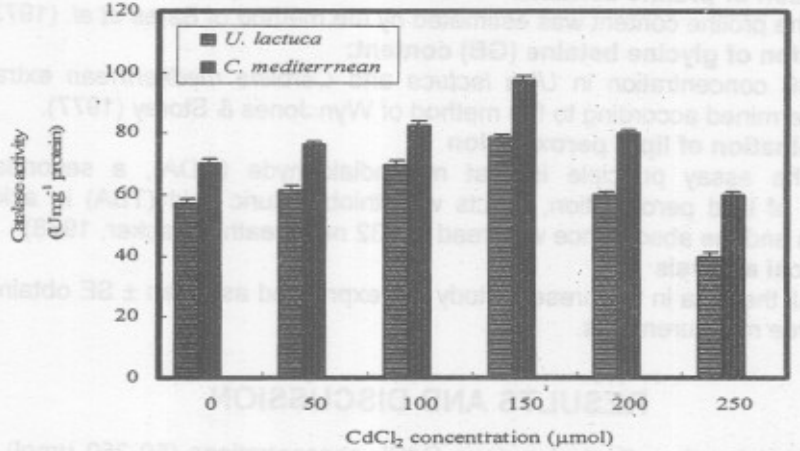

Fig.2: Effect of $CdCl_2$ on catalase activity.

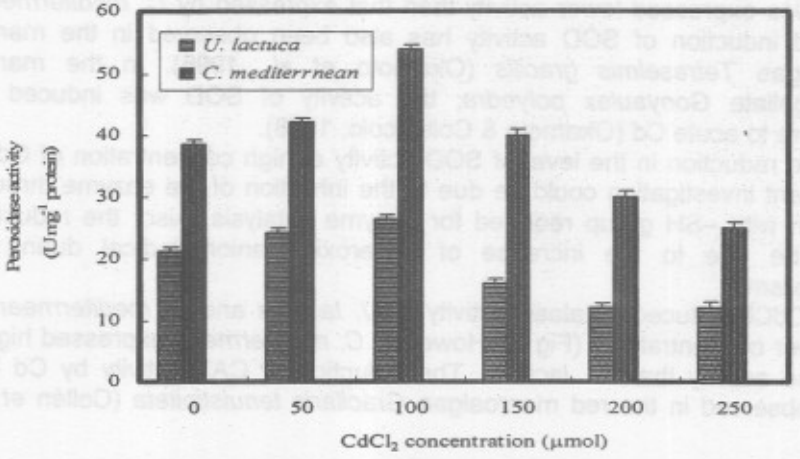

Fig.3: Effect of $CdCl_2$ on peroxidase activity

The observed reduction of catalase activity at the higher concentrations of $CdCl_2$ may be explained by insufficient supply of NADPH, which is required for the activation of catalase for its regeneration from its inactive form. Decline in the catalase activity under high stress condition may be due to increased accumulation of H_2O_2 thereby leading to augmented lipid peroxidation

The activity of peroxidase was increased in both algae progressively with increasing of $CdCl_2$ concentrations (Fig. 3). *U. lactuca* expressed lower GR activity than *C. mediterrnean* when treated with $CdCl_2$ at the various concentrations (Fig. 4).

The present data show that proline content was apparently increased at the lower concentrations of $CdCl_2$ but decreased at the higher ones. (Fig. 5). In addition, *C. mediterrnean* showed higher activity than *U. lactuca*.

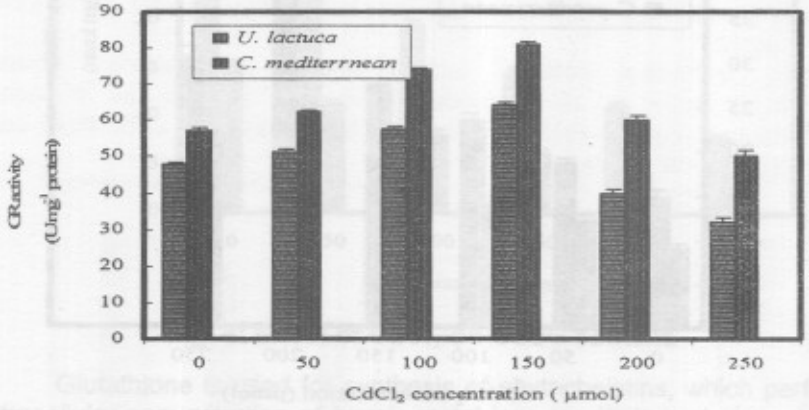

Fig.4: Effect of $CdCl_2$ on GR activity.

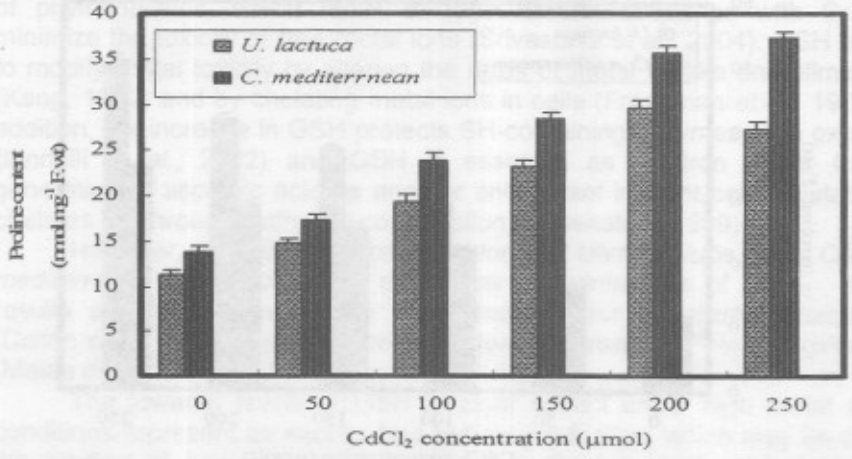

Fig.5: Effect of $CdCl_2$ on proline content

The observed reduction of catalase activity at the higher concentrations of $CdCl_2$ may be explained by insufficient supply of NADPH, which is required for the activation of catalase for its regeneration from its inactive form. Decline in the catalase activity under high stress condition may be due to increased accumulation of H_2O_2 thereby leading to augmented lipid peroxidation

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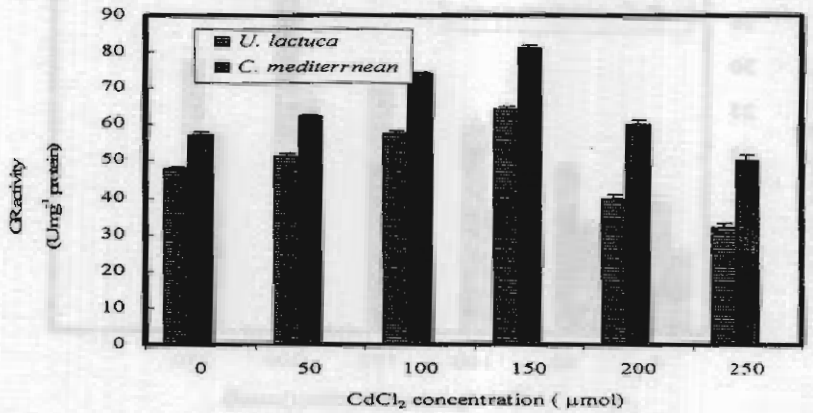

Fig.4: Effect of $CdCl_2$ on GR activity.

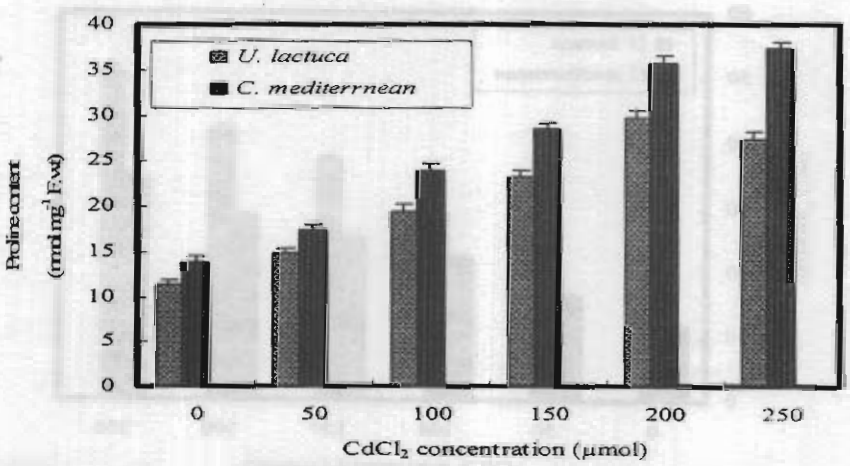

Fig.5: Effect of $CdCl_2$ on proline content

C. mediterrnean expressed higher content of GB compared to that of *U. lactuca* (Fig. 6) and there was corresponding increase in GB content on treatment with the lower $CdCl_2$ concentrations. However, there was a decrease in its content at the higher concentrations.

The content of GSH as antioxidant was increased in both *U. lactuca* and *C. mediterrnean* (Fig. 7) under treatment with various concentrations of $CdCl_2$. On the other hand, GSSG content was reduced particularly with *C. mediterrnean* (Fig. 8). It was remarkable that the reduction of GSSG content in both algae was dependent on $CdCl_2$ concentration. Under metal stress conditions seaweeds may use GSH primarily to counter oxidative stress from exposure to a mixture of toxic metals.

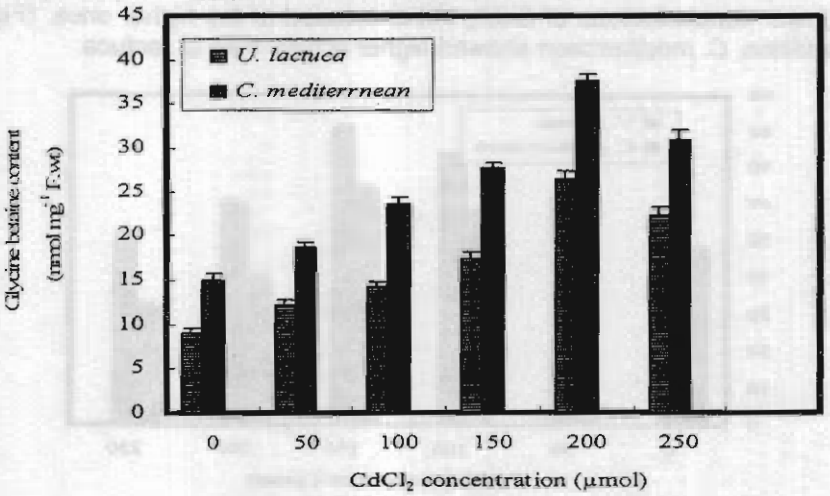

Fig.6: Effect of $CdCl_2$ on glycine betaine content.

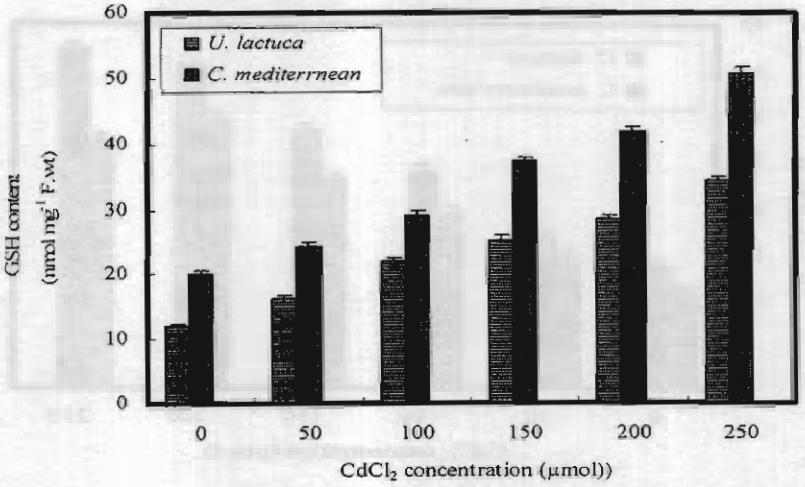

Fig. 7: Effect of $CdCl_2$ on GSH content.

Cd-induced increase of GSH was also observed in hyphomycetes (Miersch *et al.*, 1997). The increase in GSH content has been reported also for plant and algal cells subjected to stress by metals (Okamoto *et al.*, 2001 a;Lavoie *et al.*, 2009). Such increase in GSH content might be an important defense response to stresses as has been found in Cd-stressed plants (Pietrini *et al.*, 2003) although defense against stress situation sometimes occurs irrespective of the GSH concentration (Potters *et al.*, 2004).

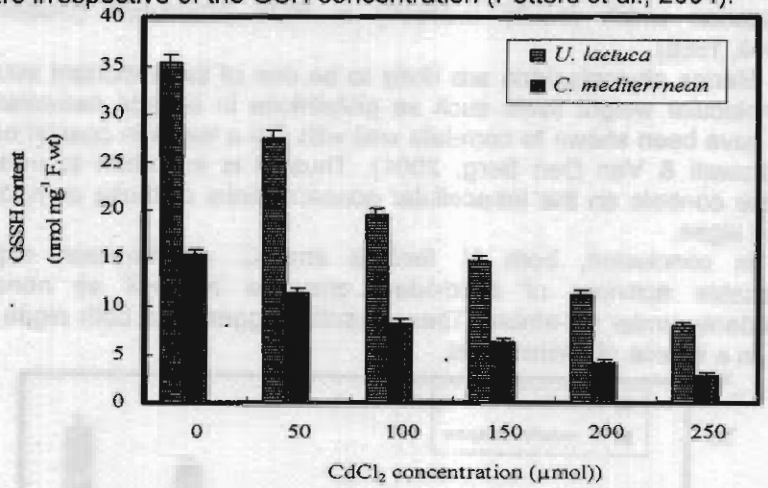

Fig. 8: Effect of $CdCl_2$ on GSSG content.

Glutathione is used for synthesis of phytochelatins, which perform the intracellular sequestration of heavy metal ions in plants and algae (Ahner & Morel, 1995; Cobbett & Goldsbrough, 2002). Furthermore, the increase in GSH content under Cd stress was reported to be essential for the synthesis of phytochelatins, which tends to form stable complexes with Cd and minimize the toxicity of free metal ions (Srivastava *et al.*, 2004). GSH is able to modify metal toxicity by altering the rates of metal uptake and elimination (Kang, 1992) and by chelating metal ions in cells (Freedman *et al.*, 1989). In addition, the increase in GSH protects SH-containing enzymes from oxidation (Iannelli *et al.*, 2002) and GSH is essential as electron donor for the generation of ascorbic acid as another antioxidant in plant cells. Glutathione chelates Cd through sulfhydryl coordination (Rabenstein, 1989).

However, glutathione concentration in *Ulva lactuca* and *Carolina mediterrnean* was declined at the higher concentrations of $CdCl_2$. These results are in agreement with those reported for *Gracilaria tenuistipitata* (Collén *et al.*, 2003) and in the marine green macroalgae *Enteromorpha linza* (Malea *et al.*, 2006) under heavy metal stress.

The lowered levels of GSH in algal extract under high metal stress conditions represent as excess free radical production, which may be due to the binding of heavy metal with various sulfhydryls that exist in the cell (Vijayavel *et al.*, 2006).

The effect of $CdCl_2$ on lipid peroxidation of *U. lactuca* and *C. mediterrnean* at various concentrations (50-250 µmol) was investigated and

the results are illustrated in Fig. 9. The results indicate that there was a correlation between $CdCl_2$ concentrations and lipid peroxidation in both algae. The results also show that lipid peroxidation was higher in *C. mediterrnean* than *U. lactuca*. It has been reported that Cd treatment resulted in an increase of membrane integrity loss (Sch¨utzend ¨ubel & Polle, 2002). Cd does not appear to generate free radicals, but it does elevate lipid peroxidation which results indirectly in ROS production (Gutteridge & Halliwell, 1988).

Marine phytoplankton are likely to be one of the important sources of low molecular weight thiols such as glutathione in surface seawater, since thiols have been shown to correlate well with Chl *a* levels in coastal seawater (Al-Farawati & Van Den Berg, 2001). Thus, it is important to understand possible controls on the intracellular concentrations of these compounds in marine algae.

In conclusion, both *U. lactuca* and *C. mediterrnean* expressed appreciable activities of antioxidant enzymes as well as nonenzymic antioxidants under Cd-stress. These results suggest that both algae can be used as a source of antioxidants.

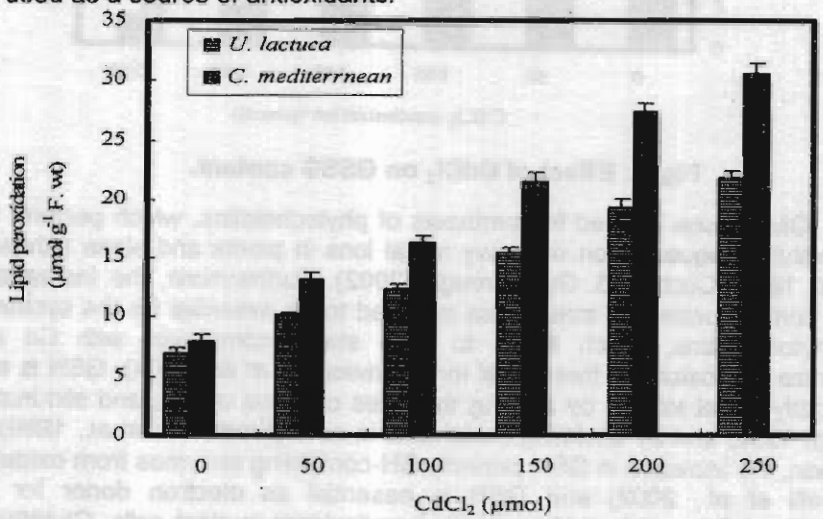

Fig. 9: Effect of $CdCl_2$ on lipid peroxidation..

REFERENCES

Abd El-Baky, H. H., El Baz, F. K. and El-Baroty, G. S. (2004). Production of antioxidant by the green alga *Dunaliella salina*. Int. J. Agri. Biol. 6: 49-57.

Ahner, B. A. and Morel, F, M. M. (1995). Phytochelatin production in marine algae: II. Induction by various metals. Limnol. Oceanogr. 40: 658-665.

AL-Farawati, R. and Van Den Berg, C. M. G. (2001). Thiols in coastal waters of the western North Sea and English Channel. Environ. Sci. Technol. 35: 1902–1911.

Aleem, A. A. (1978). Contributions to the study of the marine algae of the Red Sea. III. Marine algae from Obhur, in the vicinity of Jeddah, Saudi Arabia. Bull. Fac. Sci., K.A.U., Jeddah, 2: 123-130.

Bates, L. S., Waldern, R. P. and Teare, I. D. (1973). Rapid determination of free proline for water stress studies. Plant Soil. 39: 205–207.

Carlberg, I. and Mannervik, B. (1985): Glutathione reductase assay. Meth. Enzymol. Acad. Press, Orlando FL. 113: 484–495.

Cobbett, C. and Goldsbrough, P. (2002). Phytochelatins and metallothioneins: roles in heavy metal detoxification and homeostasis. Annu. Rev. Plant Biol. 53: 159–182.

Collén, J., Pinto, E., Pedersen, M. and Colepicolo, P. (2003). Induction of oxidative stress in the red Macroalga *Gracilaria tenuistipitata* by pollutants metals. Arch. Environ. Contam. Toxicol. 45: 337–342.

El-Naggar, M. E. (1980). Studies on the natural products of some marine algae. Ph.D. Thesis, Faculty of science, Mansoura University, Egypt.

Freedman, J. H., Ciriolo, M. R. and Peisach, J. (1989). The role of glutathione in copper metabolism and toxicity. J. Biol. Chem. 264: 5598-5605.

Giannopolitis, C. N. and Reis, S. K. (1997). Superoxide dismutase I. Occurrence in higher plants. Plant Physiol. 59: 309-314.

Gupta, M., Tripathi, R. D., Rai, U. N. and Chandra, P. (1998). Role of glutathione and phytochelatin in *Hydrilla verticillata* and *Vallisneria spiralis* under mercury stress. Chemosphere. 37: 785-800.

Gutteridge, J. M. C. and Halliwell, B. (1988). The deoxyribose assay: an assay both for free hydroxyl radical and for site-specific hydroxyl radical production. Biochem. J. Lett. 253: 932-933.

Gutteridge, J. M. C. and Halliwell, B. (2000). Free radicals in biology and medicine. Ann. N.Y. Acad. Sci. 899: 136–147.

Hall, J. L. (2002). Cellular mechanisms for heavy metal detoxification and tolerance. J. Exp. Bot. 53: 1–11.

Heath, R. L. and Packer, L. (1968). Photoperoxidation in isolated chloroplast I. Kinetics and stoichiometry of fatty acid peroxidation. Arch. Biochem. Biophys. 125: 189–198.

Iannelli, M. A., Pietrini, F., Fiore, L., Petrilli, L. and Massacci, A. (2002). Antioxidant response to cadmium in *Pragmites australis* plants. Plant Physiol. Biochem. 40: 977–82.

Kang, Y. J. (1992). Exogenous glutathione decreases cellular cadmium uptake and toxicity. Drug Metab. Dispos. 20: 714-718.

Kato, M. and Shimizu, S. (1987). Chlorophyll metabolism in higher plants. VII. Chlorophyll degradation in senescing tobacco leaves: phenolic-dependent peroxidative degradation. Can. J. Bot. 65: 729-735.

Ku¨pper, H. S., etlı´k, I., Spiller, M., Ku¨pper, F.C. and Pra´s˘il, O. (2002). Heavy metal-induced inhibition of photosynthesis: Targets of *in vivo* heavy metal chlorophyll formation. J. Phycol. 38: 429–441.

Lavoie, Séverine Le Faucheur, Claude Fortin, Peter, G.C. and Campbell (2009). Cadmium detoxification strategies in two phytoplankton species: Metal binding by newly synthesized thiolated peptides and metal sequestration in granules, Aquat. Toxicol. 92: 65–75

Malea, P., Rijstenbil, J. W. and Haritonidis, S. (2006). Effects of cadmium, zinc and nitrogen status on non-protein thiols in the macroalgae *Enteromorpha* spp. Mar. Environ. Res. 62: 45–60.

Miersch, J., Ba¨rlocher, F., Bruns, I. and Kraus, G. J. (1997). Effects of cadmium, copper, and zinc on growth and thiol content of aquatic hyphomycetes. Hydrobiol. 346: 77–84.

Mittler, R., Vanderauwera, S., Gollery, M. and Van Breusegem, F. (2004). The reactive oxygen gene network of plants. Trends Plant Sci. 9: 490–498.

McClanahan, T. R., Cokos, B. A. and Sala, E. (2002). Algal growth and species composition under experimental control of herbivory, phosphorus and coral abundance in Glovers Reef, Belize. Mar. Poll. Bull. 44: 441-451.

Nakano, Y. and K. Asada. (1981). Hydrogen peroxide is scavenged by ascorbate-specific peroxidase in spinach chloroplasts. Plant Cell Physiol. 22: 867-880.

Nasr, A. H. (1947). Synopsis of the marine algae of the Egyptian Red Sea coast. Bull. Fac. Egypt. Univ. pp. 26-65.

Nies, D. H. (1999). Microbial heavy metal resistance. Appl. Microbiol. Biotechnol. 51: 730–750.

Noctor, G., L. Gomez, H. Vanacker, and C. Foyer. (2002). Interactions between biosynthesis, compartmentation and transport in the control of glutathione homeostasis and signaling. J. Exp. Bot. 53: 1283-1304.

Okamoto, O. K. and Colepicolo, P. (1998). Response of superoxide dismutase to pollutant metal stress in the marine dinoflagellate *Gonyaulax polyedra*. Comp. Biochem. Physiol. 119C: 67-73.

Okamoto, O. K., Asano, C. S., Aidar, E. and Colepicolo, P. (1996). Effects of cadmium on growth and superoxide dismutase activity of the marine microalga *Tetraselmis gracilis* (Prasinophyceae). J. Phycol. 32: 74-79.

Okamoto, O. K., Pinto. E., Latorre, L. R., Bechara, E. J. H. and Colepicolo, P. (2001a). Antioxidant modulation in response to metal-induced oxidative stress in algal chloroplasts. Arch. Environ. Contam. Toxicol. 40: 18–24.

Okamoto, O. K., Robertson, D. L., Fagan, T. F., Hastings, J. W. and Colepicolo, P. (2001b). Different regulatory mechanisms modulate the expression of a dinoflagellate iron-superoxide dismutase. J. Biol. Chem. 276: 19989–19993.

Pietrini, F., Iannelli, M. A., Pasqualini, S. and Massacci, A. (2003). Interaction of cadmium with glutathione and photosynthesis in developing leaves and chloroplasts of *Phragmites australis*. Plant Physiol. 133: 829-837.

Potters, G., De Gara, L., Asard, H. and Horemans, N. (2004). Ascorbate and glutathione: guardians of the cell cycle, partners in crime? Plant Physiol. Biochem. 40: 537–548

Rabenstein, D. L. (1989). Metal complexes of glutathione and their biological significance. (In: Dolphin, D, Avramovic, O. and Poulson, R. eds.), Glutathione: Chemical, Biochemical, and Medical Aspects. Wiley, pp. 147–186.

Sch¨utzend ¨ubel, A. and Polle, A. (2002). Plant responses to abiotic stresses: heavy metal-induced oxidative stress and protection by mycorrhization. J. Exp. Bot: 53: 1351–1365.

Silber, R., Farber, M., Papopoulos, E., Nervla, D., Liebes, L. Bruch, M. and Bron, R. (1992). Glutathione depletion in chronic lymphocytic leukemia blymphocytes. Blood, 80: 2038-2040.

Srivastava, S., Tripathi, R. D. and Dwivedi, U. N. (2004). Synthesis of phytochelatins and modulation of antioxidants in response to cadmium stress in *Cuscuta reflexa*-an angiospermic parasite. J. Plant Physiol. 161: 665–674.

Suzuki, N. and Mittler, R. (2006). Reactive oxygen species and temperature stresses: A delicate balance between signaling and destruction. Plant Physiol. 126: 45-51.

Van Assche, F. and Clijsters, H. (1990). Effects of metals on enzyme activity in plants. Plant Cell. Environ. 13: 195–206.

Vijayavel, K., Anbuselvam, C. and Balasubramanian, M. P.(2006). Free radical scavenging activity of the marine mangrove *Rhizophora apiculata* bark extract with reference to naphthalene induced mitochondrial dysfunction. Chem.Biol Inter. 163(1-2): 170-175.

Wyn Jones, R. G. and Storey, R. (1977). Salt stress and comparative physiology in the gramineae. II. Glycine betaine and proline accumulation in two salt- and water-treated barley cultivars. Aust. J. Plant Physiol. 5: 817 – 829.

إستجابة النظام المضاد للأكسدة في بعض الطحالب البحرية تحت اجهاد الكادميوم

حامد محمد الشوري ، محمد السيد النجار و عبد الحميد علي الزغلوفي
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تم جمع عينات من ألفا لاكتوكا وكارولينا مديترنيان من ساحل بلطيم بمصر وهذان الطحلبان ينتميان إلي الطحالب الخضراء الطحالب الحمراء بالتتابع. تم معاملة الطحلبين بتركيزات مختلفة من محلول كلوريد الكادميوم (٥٠، ١٠٠، ١٥٠ ، ٢٠٠، ٢٥٠ ميكرومول) ثم تم تعيين أنشطة الإنزيمات المضادة للأكسدة مثل ديسميوتيز سوبر أكسيد، الكاتاليز، بيروكسيديز والاسكوربات ريدكتيز الجلوتاثيون بالإضافة إلي قياس محتوى كل من الجلوتاثيون المختزل والمؤكسد، البرولين،الجليسين بيتان. وتم كذلك تقدير أكسدة الدهون .ولوحظ أن التركيزات المنخفضة من محلول كلوريد الكادميوم أدت إلي زيادة نشاط الإنزيمات الأربعة السالف ذكرها بينما التركيزات المرتفعة أدت إلي إنخفاض أنشطة الإنزيمات بمعدل مختلف. كذلك أدت المعاملة إلي زيادة محتوي كل من الجلوتاثيون المختزل والبرولين والجليسين بيتان بمعدلات مختلفة إلا أن التركيزات المرتفعة من محلول كلوريد الكادميوم أدت إلي إنخفاض محتويات المركبات الثلاثة. أبدى محتوى الجلوتاثيون المؤكسد إنخفاضا مستمرا بزيادة تركيز محلول كلوريد الكادميوم وهذا على النقيض من الجلوتاثيون المختزل. كذلك أظهرت النتائج وجود علاقة طردية بين تركيز محلول كلوريد الكادميوم وزيادة أكسدة الدهون ومن هذه النتائج يستنتج أن الطحلبين محل الدراسة يمثلان مصدرا هاما لمضادات الأكسدة.

قام بتحكيم البحث

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