BRIEF COMMUNICATION

Effects of cadmium and gibberellin on growth and photosynthesis of *Glycine max*

M. GHORBANLI*,***, S. Hadad KAVEH**, and M. Farzami SEPEHR*

*Biology Department, Teacher Training University, 49 Mofatteh Avenue, Tehran 15, Iran**
*Biology Department, Shahid Beheshti University, Tehran 15, Iran***

Abstract

The effects of 0, 2.5, 5.0, and 10.0 mg(Cd^{2+}) m^{-3} [$Cd(NO_3)2\times4$ H_2O] and 0 and 10.0 mg m^{-3} gibberellin on certain parameters of photosynthesis and growth in soybean (*Glycine max* L. cv. Pershing) plants were studied. With increasing Cd^{2+} concentration in the Hoagland nutrient solution, the contents of chlorophyll and CO_2 compensation concentration decreased. The addition of 10 mg m^{-3} gibberellin reduced the negative effects of Cd^{2+} in shoot and root growth. With increasing of Cd^{2+} concentration in the culture medium, the dry matter production in both the roots and shoots decreased as shown by the decline in growth rate (PGR), net assimilation rate (NAR), and leaf area ratio. The addition of gibberellin caused a partial elimination of the Cd effects on the roots and shoots and the PGR and NAR and it increased leaf area and length of stem.

Additional key words: chlorophyll; CO_2 compensation concentration; dry matter production; growth rate; leaf area; net assimilation rate; root; shoot; starch.

Cadmium intake by animals has created interest in the distribution and state of this metal in plants (Rauser and Glover 1984). Low concentration of Cd is not toxic to plants, but at high concentration it is toxic to plants (Usha-Keshan and Mukher 1997) and causes leaf chlorosis accompanied by a retardation of plastid development (Ghoshroy and Nadekavukaren 1990) and degradation of their ultrastructure (Stoyanova and Tchakalova 1997), inhibition of nodule development at early stages of development (El-Kenawy *et al.* 1997), and decrease in photosynthetic rate (Collins *et al.* 1976, Baszyński *et al.* 1980, Siedlecka and Krupa 1996, Vassilev *et al.* 1997). Physiologically Cd interacts with other heavy metals thus limiting plant growth (Root *et al.* 1975, Woltz and Ghambliss 1976, Wallace *et al.* 1977, 1980, Malone *et al.* 1978).

Received 11 February 1999, *accepted* 7 October 1999.
***Author for correspondence; phone & fax: 009821-8825580; e-mail: gorbanli @ saba.tmu.ac.ir

Table 1. The interaction of Cd and gibberellin [mg m^{-3}] treatments on chlorophyll (Chl) content [g kg^{-1}(FM)], CO_2 compensation concentration, Γ [μmol mol^{-1}], leaf area, LA [cm^2 plant^{-1}], stem length, SL [cm plant^{-1}], stem fresh mass, SFM [g plant^{-1}], root fresh mass, RFM [g plant^{-1}], stem dry mass, SDM [g plant^{-1}], root dry mass, RDM [g plant^{-1}], leaf water content per unit leaf area, LMCA [g(H_2O) m^{-2}], leaf dry mass per total plant dry mass, LMR [kg kg^{-1}(DM)], relative growth rate, RGR [kg kg^{-1} d^{-1}], relative leaf growth rate, RLGR [kg kg^{-1} d^{-1}], net assimilation rate, NAR [kg m^{-2} d^{-1}], total soluble sugars, TSS [g kg^{-1}(DM)], and starch [g kg^{-1}(DM)] contents in soybean plants (means ± SE).

Parameter	Gibberellin	Cd 0 (control)	2.5	5.0	10.0
Chl *a*	0	1.77±0.89	1.55±0.76	1.15±0.48	0.55±0.30
	10	1.70±0.62	1.25±0.50	1.42±0.45	1.27±0.54
Chl *b*	0	0.85±0.36	0.96±0.4	0.63±0.03	0.47±0.07
	10	0.92±0.15	0.67±0.01	0.80±0.20	0.63±0.04
Γ	0	109.89±2.8	203.10±5.36	300.00±0.95	334.88±4.19
	10	89.50±6.8	76.40±2.71	233.10±1.88	259.74±7.51
LA	0	14.20±1.42	4.13±1.00	3.16±0.64	3.26±1.04
	10	21.50±1.51	15.69±1.72	7.42±0.67	7.76±0.65
SL	0	13.12±2.28	71.12±1.03	10.00±1.08	9.75±0.64
	10	28.01±4.25	25.25±3.79	19.37±4.26	16.25±2.62
SFM	0	0.47±0.12	0.43±0.01	0.45±0.08	0.42±0.03
	10	0.67±0.01	0.56±0.12	0.44±0.01	0.28±0.06
RFM	0	0.36±0.05	0.36±0.02	0.36±0.09	0.34±0.06
	10	0.30±0.02	0.26±0.05	0.25±0.05	0.23±0.05
SDM	0	0.06±0.01	0.06±0.02	0.09±0.01	0.88±0.00
	10	0.05±0.01	0.07±0.01	0.06±0.02	0.04±0.01
RDM	0	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01
	10	0.02±0.01	0.01±0.00	0.01±0.00	0.01±0.00
LMCA	0	172.5	163.0	146.0	133.0
	10	196.2	168.0	148.0	142.0
LMR	0	0.62	0.49	0.48	0.35
	10	0.83	0.40	0.46	0.46
RGR	0	0.213	0.145	0.126	0.086
	10	0.231	0.182	0.131	0.109
RLGR	0	0.159	0.142	0.123	0.115
	10	0.192	0.162	0.149	0.142
NAR	0	0.080	0.003	0.003	0.002
	10	0.030	0.004	0.003	0.002
TSS	0	66.29±7.07	55.17±1.16	50.64±19.21	20.71±0.00
	10	64.25±5.37	52.43±4.28	41.17±18.60	27.99±4.35
Starch	0	227.02±24.68	121.05±5.76	106.32±11.95	108.29±15.55
	10	206.00±15.22	102.01±14.42	86.77±4.47	75.62±7.39

When plant growth substances are applied to the roots of plants grown hydroponically, their maximal uptake and low concentrations are required to affect photosynthesis (Arteca and Dong 1981, Dong and Arteca 1982, Arteca *et al.* 1985a,b, Tsai and Arteca 1985, Arteca and Tsai 1988, Arteca *et al.* 1991). Because there are only a few studies on the effect of gibberellin and Cd on growth and photosynthesis in *Glycine max* L., we studied these effects.

Seeds of soybean were germinated for 7 d in petri dishes with distilled water at 27 °C. Young seedlings were transferred to 1000 cm^3 plastic containers (3 plants per container) with nutrient solution containing 5 mM KNO_3, 5 mM $Ca(NO_3)\times 4\ H_2O$, 2 mM $MgSO_4\times 4\ H_2O$, 1 mM KH_2PO_4, 0.09 mM $NH_4Fe(SO_4)$, and micronutrients. The plants were treated with 0 (controls), 2.5, 5.0, or 10.0 mg (Cd^{2+}) m^{-3} either with or without adding 10 mg m^{-3} gibberellin. All solutions were kept at a pH 5.8 and aerated throughout the experimental period. The amount of water was adjusted daily using distilled water, and renewed every 10th d. The environment conditions were 16 h photoperiod [irradiance of *ca.* 700 W m^{-2}], 57 % relative air humidity, ambient temperature of 25±2 °C. The plants of four container sets (replicates), each container holding three plants, were harvested for growth analysis after 12 d of experimental growth using the methods of Evans and Hughes (1962) and Watson (1952).

Prior to harvest at the end of experimental growth period, CO_2 compensation concentration (Γ) was measured in plant shoots using an infrared CO_2 analyser (*225 MKS, Analytical Development Co.*, UK) (Khavari-Nejad 1986). The contents of chlorophyll (Chl) *a* and *b* were measured spectrophotometrically using the method of Arnon (1949). The contents of total soluble sugars and starch were measured by the method of Kochert (1978).

Interaction of Cd and gibberellin positively affected growth rate (expansion growth of leaf, shoot, and roots) and reduced poisonous effects of Cd on soybean plants. Decreased cell wall extensibility may cause reduced cell expansion (Poschenrieder *et al.* 1989). The Γ, NAR, and contents of total soluble sugars (TSS) and starch decreased in Cd-treated plants: our results agree with those of Singh and Singh (1987). The gibberellin effect on Cd-treated plants was positive. Chl *a* is more susceptible to Cd than Chl *b* (Stobart *et al.* 1985). The inhibitory action of Cd is probably in structural and ultrastructural disorders in thylakoids (Barcélo *et al.* 1988).

The enhancement of growth rate by gibberellin might result from an increase in effective leaf area, stimulation of photosynthetic rate, modification in partitioning of photosynthates, or from their cooperative effect (Arteca 1995). In the present work, gibberellin decreased poisonous effects of Cd. In plants treated with gibberellin and Cd, increases in LA, LS, RGR, and RLGR were demonstrated.

References

Arnon, D.I.: Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. - Plant Physiol. **24**: 1-15, 1949.

Arteca, R.N.: Plant Growth Substances. 1st Ed. - Chapman and Hall, London 1995.

Arteca, R.N., Dong, C.-N.: Increased photosynthetic rates following gibberellic acid treatments. - Photosynth. Res. **2**: 243-249, 1981.

Arteca, R.N., Holcomb, E.J., Schlagnhaufer, C., Tsai, D.S.: Effect of root applications of gibberellic acid on photosynthesis and growth of geranium plants grown hydroponically. - HortScience **20**: 925-927, 1985a.

Arteca, R.N., Schlagnhaufer, C.D., Arteca, J.M.: Effects of root application of gibberellic acid on growth of seven different *Pelargonium* cultivars. - HortScience **26**: 555-556, 1991.

Arteca, R.N., Tsai, D.S.: Effects of abscisic acid on photosynthesis, transpiration and growth of tomato plants. - Crop Res. **27**: 91-96, 1988.

Arteca, R.N., Tsai, D.-S., Schlagnhaufer, C.: Abscisic acid effects on photosynthesis and transpiration in geranium cuttings. - HortScience **20**: 370-372, 1985b.

Barcélo, J., Vázquez, M.D., Poschenrieder, C.: Structural and ultrastructural disorders in cadmium-treated bush bean plants (*Phaseolus vulgaris* L.). - New Phytol. **108**: 37-49, 1988.

Baszyński, T., Wajda, L., Król, M., Wolińska, D., Krupa, Z., Tukendorf, A.: Photosynthetic activities of cadmium-treated tomato plants. - Physiol. Plant. **48**: 365-370, 1980.

Collins, F.W., Cunningham, L.M., Hutchinson, T.C.: Physiological and biochemical aspects of cadmium toxicity in soybean. Part II. Toxicity, bioaccumulation and subcellular fractionation of cadmium in soybean plants grown at subchromic to accute cadmium levels. - In: Trace Substances in Environ. Health. Proc. 10thAnnu. Conf. Univ. Missouri. Pp. 145-166. 1976.

Dong, C.-N., Arteca, R.N.: Changes in photosynthetic rates and growth following root treatments of tomato plants with phytohormones. - Photosynth. Res. **3**: 45-52, 1982.

El-Kenawy, Z.A, Angle, J.S, Gewaily, E.M., El-Wafai, N.A., Chaney, R.L., Ibekwe, M.A., Van Berkum, P.: Zinc and cadmium effects on the early stages of nodulation in white clover. - Agron. J. **89**: 875-880, 1997.

Evans, G.C., Hughes, A.P.: Plant growth and aerial environment. III. On the computation of unit leaf rate. - New Phytol. **61**: 322-327, 1962.

Ghoshroy, S., Nadakavukaren, M.J.: Influence of cadmium on the ultrastructure of developing chloroplasts in soybean and corn. - Environ. exp. Bot. **30**: 187-192, 1990.

Khavari-Nejad, R.A.: Carbon dioxide enrichment preconditioning effects on chlorophylls contents and photosynthetic efficiency in tomato plants. - Photosynthetica **20**: 315-317, 1986.

Kochert, G.: Carbohydrate determination by the phenosulfuric acid method. - In: Helebust, J.A., Craig, J.S. (ed.): Handbook of Phycological Methods. Pp. 96-97. Cambridge Univ. Press, Cambridge 1978.

Malone, C.P., Miller, J., Koeppe, D.E.: Root growth in corn and soybean: effect of cadmium and lead on lateral root initiation. - Can. J. Bot. **55**: 277-281, 1978.

Poschenrieder, C., Gunsé, B., Barceló, J.: Influence of cadmium on water relations, stomatal resistance, and abscisic acid content in expanding bean leaves. - Plant Physiol. **90**: 1365-1371, 1989.

Rauser, W.E., Glover, J.: Cadmium-binding protein in roots of maize. - Can. J. Bot. **62**. 1645–1650, 1984.

Root, R.A., Miller, R.J., Koeppe, D.E.: Uptake of cadmium – its toxicity and effect on the iron ratio in hydroponically grown corn. - J. environ. Qual. **4**: 473-476, 1975.

Siedlecka, A., Krupa, Z.: Interaction between cadmium and iron and its effects on photosynthetic capacity of primary leaves of *Phaseolus vulgaris*. - Plant Physiol. Biochem. **34**: 833-841, 1996.

Singh, D.P., Singh, S.P.: Action of heavy metals on Hill activity and O_2 evolution in *Anacystis nidulans*. - Plant Physiol. **83**: 12-14, 1987.

Stobart, A.K., Griffiths, W.T., Ameen-Bukhari, I., Sherwood, R.P.: The effect of Ca^{2+} on the biosynthesis of chlorophyll in leaves of barley. - Physiol. Plant. **63**: 293-298, 1985.

Stoyanova, D.P., Tchakalova, E.S.: Cadmium-induced ultrastructural changes in chloroplasts of the leaves and stems parenchyma in *Myriophyllum spicatum* L. - Photosynthetica 34: 241-148, 1997.

Tsai, D.-S., Arteca, R.N.: Effects of root applications of gibberellic acid on photosynthesis and growth in C_3 and C_4 plants. - Photosynth. Res. **6**: 147-157, 1985.

Usha-Keshan, Mukher, J.-S.: Phytotoxic effect of cadmium as foliar spray on mung bean plant. - Indian J. Toxicol. **4**: 15-22, 1997.

Vassilev, A., Yordanov, I., Tsonev, T.: Effects of Cd^{2+} on the physiological state and photosynthetic activity of young barley plants. - Photosynthetica **34**: 293-302, 1997.

Wallace, A., Romney, E.M., Alexander, G.V., Soufi, S.H.: Some interaction of cadmium with other elements in plants. - Commun. Soil Sci. Plant Anal. **8**: 765-772, 1977.

Wallace, A., Romney, E.M., Alexander, G.V.: Zinc–cadmium interaction on the availibility of each to bush bean plants grown in solution culture. - J. Plant Nutr. **2**, 51, 1980.

Watson, D.T.: The physiological basis of variation in yield. - Adv. Agron. **4**: 101-145, 1952.

Woltz, S.S., Ghambliss, G.G.: Cadmium toxicity in some vegetable and test plant species. - Proc. Florida State hort. Soc. **92**: 110-112, 1976.