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Effect of Cadmium Stress in the Presence and Absence of Gibberellic Acid on Mineral Nutrition of *Cowpea (Vigna unguiculata L.*) During Ontogenesis

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Abstract. The effect of cadmium (Cd) stress on mineral nutrition of cowpea, *Vigna unguiculata* L., plants in the presence or absence of gibberellic acid (GA_3) was studied using Atomic Absorption Spectroscopy. Application of different concentrations (0, 20, 40, 80, 160 ppm) of cadmium chloride ($CdCl_2$) resulted in an increased accumulation of Cd in shoots and roots, and a large proportion of the absorbed Cd was retained in roots. Cadmium chloride treatment decreased the Ca, K, Fe and Mn contents of *Vigna unguiculata* shoots and roots progressively in a dose dependent manner. However, the level of Mg increased in the roots and decreased in the shoots. Changes in Cd and mineral nutrient levels were related to the plant growth stage, being maximum when Cd was applied at the early vegetative stage, and the intensity of these changes was less significant when the heavy metal was applied at a later stage.

When the Cd-treated plants were sprayed with GA_3, the hormone was partially effective in decreasing the Cd concentration of both roots and shoots. Furthermore, GA_3 treatment increased the mineral nutrient levels of *Vigna unguiculata* roots and shoots. This effect was most significant at 20 and 40 ppm $CdCl_2$ concentrations and during the intermediate growth stage followed by the early stage, and roots were less affected than shoots.

Keywords: Cadmium, mineral nutrient, toxicity, gibberellic acid, *Vigna unguiculata*.

Introduction

During the last few decades the toxicity of heavy metals to plants has drawn the attention of many environmental scientists. Increased investigation of environmental Cd concentration has been undertaken, since many reports have shown that excessive accumulation of this heavy metal adversely affects human health [1].

Soil pollution with heavy metals, including Cd, was recorded in some industrial areas in Saudi Arabia by many investigators, among them Hashem [2] for Jubail Industrial City and Arif and Hashem [3] for Jizan City. Cadmium ions enter the soil with phosphate fertilizers, sewage sludge and air pollutants, and are taken up in varying degrees by plants [4]. Its uptake and accumulation depends on plant species and plant organs involved [5]. Inspite of the mobility of heavy metals in plants, the root system accumulates them to a significantly higher extent than do the overground organs [6]. Furthermore, the Cd level in plant tissues depends on the concentration of available Cd in the growth medium [7]. Greger and Lindberg [8] reported 4 – 10 times increase in Cd content of sugar beet, *Beta vulgaris* L., roots when Cd concentration was raised from 5 to 50 uM. They also reported that the Cd content in shoots was only 10-20% of that in roots.

One of the most important factors of heavy metals which influences plant metabolism are their relationships with other mineral nutrients. It has been reported that uptake, transport and subsequent distribution of other elements by the plant can be affected by the presence of Cd ions [9]. It was shown that heavy metals may interfere with the uptake of nutrients and/or induce leakage of nutrients by affecting the permeability of plasma membranes [10].

The involvement of plant growth regulators in plant responses to different stresses has been postulated. It has been shown that heavy metals alter the hormone content in plants [11], and the application of hormones to heavy metal stressed plants reduces the uptake of these metals [12]. In addition, many studies have pointed out to the regulatory role of hormones in selective ion uptake and distribution in plants through their effect on membrane properties and in consequence transport of various substances, including assimilates [13].

The aim of the present work was to investigate the effect of different concentrations of $CdCl_2$, applied at different developmental stages on mineral content of shoots and roots of *Vigna unguiculata*, and to determine the role of gibberellins in overcoming the Cd-induced alteration of the mineral levels.

Materials and Methods

Surface sterilized *Vigna unguiculata* seeds were sown (3 seeds in each pot) in the green house under natural light conditions at 25^0 C - 30^0C in 216 pots (15cm in diameter) containing a mixture of peat moss and sand (1:1), irrigated with distilled water for 15 days. At emergence thinning was done leaving one seedling per pot. The seedlings were then divided into three groups (72 pots each). Plants of the first, the second and the third group were allowed to grow for 15, 30 and 45 days prior to any treatment and were called early, intermediate and late stages, respectively. The pots of each group were subdivided into two sets. Pots of the first set were irrigated with distilled water containing 20, 40, 80 and 160 ppm $CdCl_2$, and the pots of the second set were irrigated with the same concentrations of $CdCl_2$, and in addition, 100 ppm GA_3 was sprayed on each strategy. The control group was irrigated only with distilled water. Plants were allowed to grow for a period of two weeks following treatment, after which they were harvested for growth measurements (30, 45, 60 days old).

Plant tissues were oven dried at 70°C until a constant weight was achieved. Each sample was digested with a mixture of acids HNO_3:H_2SO_4:$HClO_4$ (5:1:2) at low temperature. The Cd, Ca, K, Fe, Mg and Mn were analyzed by using an Atomic Absorption Spectrophotometer**:** Shimadzu AA-6701F [14].
Three samples of 10 replicates of *Vigna unguiculata* root and shoot tissues were used for each treatment.

Data were subjected to analysis of variance using Minitab Program. Means and standard deviations were obtained, and the LSD at $p \leq 0.01$ and $p \leq 0.05$ were calculated to compare the significance of the difference between any two groups as described by Snedecor and Cochran [15].

Results and Discussion

The results presented in Table 1 revealed that Cd content of *Vigna unguiculata* roots and shoots were positively correlated with the concentration of Cd in the growth medium. Thus, it was confirmed that the Cd level in plant tissues depends on the concentration of available Cd in the growth medium. Petterson [16] indicated that shoot and root content of Cd in tomato, *Lycopersicom esculentum* L., plants increased 5 –10 times when Cd concentration was increased 10 times. Furthermore, the response of *Vigna unguiculata* to Cd treatment was strongly dependent on the plant growth stage at which $CdCl_2$ was applied, with more significant accumulation of the heavy metal at the early stage, and decreasing with further development. The results of the present study also showed that *Vigna unguiculata* roots absorb Cd from the soil and transport it to shoots to different degrees, but most of the absorbed Cd remains in roots or is redistributed to roots from shoots. These observations confirm the finding of Ernst *et al*. [6] who reported that Cd ions are mainly retained in roots, and only small amounts are transported to the shoots.

This behavior is one of several strategies of tolerance to Cd[17] .Cadmium retention in the root may be attributed to cross linkage of Cd to carboxyl groups of the cell walls, and/or to its interaction with thiol residues of soluble proteins, which could be considered as a protective mechanism to avoid accumulation and transport of Cd to the photosynthetic and reproductive tissues [18].

Table 1. The effect of various concentrations of $CdCl_2$ in the presence or absence of GA_3 on cadmium content of *Vigna unguiculata* L. shoots and roots at the three studied developmental stage

Treatment (ppm)		Cadmium (µg/g) (Mean ± SD)					
		Early vegetative		Intermediate		Late vegetative	
Cd	GA_3	Shoot	Root	Shoot	Root	Shoot	Root
0	0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
20	0	41.66 ± 6.10**	67.18 ± 6.48**	26.32 ± 4.09**	46.91 ± 5.61**	4.46 ± 3.60	8.75 ± 2.62
20	100	25.58 ± 5.63^{++}	40.19± 10.06^{++}	10.64 ± 0.76^{++}	31.77 ± 0.16^{++}	2.97 ± 1.68	6.36 ± 1.72
40	0	66.82 ± 6.24**	94.89 ± 3.07**	36.64 ± 5.18**	54.66 ± 3.37**	7.24 ± 4.88	13.57 ± 2.69*
40	100	52.16 ± 3.81^{+}	84.39 ± 5.90^{+}	23.35 ± 0.94^{++}	48.06 ± 0.18^{+}	5.78 ± 1.61	11.39 ± 1.14
80	0	103.30±7.25**	168.00 ± 3.81**	53.54 ± 3.58**	70.78 ± 2.59**	22.54 ± 4.20**	39.26 ± 8.06**
80	100	92.02 ± 2.99^{+}	160.33 ± 4.86	44.19 ± 1.66^{++}	65.15 ± 0.30^{+}	21.10 ± 1.33	37.27 ± 1.51
160	0	174.78 ± 6.21**	266.72 ± 2.15**	84.82 ± 4.81**	114.48 ± 2.05**	31.14 ± 5.15**	69.77 ± 13.60**
160	100	165.81 ± 6.71	260.52 ± 5.91	78.13 ± 1.72^{+}	109.88 ± 0.22	29.89 ± 1.65	68.86 ± 0.39
Cd	LSD at 5%	10.83	6.82	7.25	5.95	7.32	13.21
	LSD at 1%	15.40	9.71	10.31	8.46	10.41	18.79
Cd + GA_3	LSD at 5%	10.50	10.45	5.98	4.71	6.13	11.04
	LSD at 1%	14.95	14.86	8.50	6.70	8.71	15.71

** and * denote significant differences between Cd-treated plants and controls at the 0.01 and 0.05% levels, respectively.

$^{++}$ and $^{+}$ denote significant differences between plants treated with GA_3 + Cd and plants treated with Cd alone at the 0.01 and 0.05% levels, respectively.

An interesting finding in the present study was the influence of Cd on the uptake of other cations. Levels of Ca, Fe, K and Mn of *Vigna unguiculata* roots and shoots decreased with increasing the Cd concentration in the growth medium, while the level of Mg increased in roots and decreased in shoots (Tables 2-6). Changes in mineral nutrient levels induced by Cd treatment were observed at all studied growth stages and at all Cd concentrations, but to different degrees. During the late growth stage, Cd only slightly affected the mineral nutrient levels. However, these changes were more distinct in plants treated with Cd at the intermediate stage, and the strongest effect was noted at the early growth stage. The decrease in Mg content of *Vigna unguiculata* shoots relative to roots under Cd treatment may indicate that Mg transport from roots to shoots was reduced. Greger and Lindberg [19] reported higher Mg levels in roots of sugar beet, *Beta vulgaris* L., suggesting that Cd interrupts the long distance transport of Mg.

Table 2. The effect of various concentrations of $CdCl_2$ in the presence or absence of GA_3 on calcium content of *Vigna unguiculata* L. shoots and roots at the three studied developmental stages

Treatment (ppm)		Calcium (mg/g) (Mean ± SD)					
		Early vegetative		Intermediate		Late vegetative	
Cd	GA_3	Shoot	Root	Shoot	Root	Shoot	Root
0	0	8.94 ± 0.32	3.62 ± 0.16	11.60 ± 0.56	4.98 ± 0.42	12.75 ± 0.37	6.27 ± 0.36
20	0	8.33 ± 0.52	3.17 ± 0.23**	11.12 ± 0.11	4.58 ± 0.22	12.46 ± 0.66	5.91 ± 0.39
20	100	10.27 ± 0.41^{++}	3.74 ± 0.11^{+}	14.18 ± 0.41^{++}	5.74 ± 0.02^{++}	14.94 ± 1.06^{++}	6.76 ± 0.59^{+}
40	0	7.82 ± 0.51*	2.88 ± 0.15**	10.67 ± 0.37*	4.16 ± 0.16**	12.17 ± 0.41	5.74 ± 0.37
40	100	9.47 ± 0.59^{++}	3.34 ± 0.23^{+}	13.14 ± 0.10^{++}	5.06 ± 0.04^{++}	14.21 ± 1.18^{+}	6.45 ± 0.48
80	0	6.56 ± 0.53**	2.18 ± 0.14**	10.35 ± 0.58**	3.92 ± 0.30**	11.94 ± 0.38	5.61 ± 0.33*
80	100	7.72 ± 0.78^{+}	2.45 ± 0.28	12.48 ± 0.14^{++}	4.60 ± 0.03 $^{++}$	13.34 ± 1.46	6.14 ± 0.42
160	0	4.61 ± 0.48**	1.53 ± 0.16**	9.18 ± 0.49**	3.50 ± 0.36**	11.38 ± 0.48**	5.14 ± 0.37**
160	100	5.15 ± 0.97	1.68 ± 0.38	10.47 ± 0.11^{++}	3.94 ± 0.02^{+}	12.12 ± 1.19	5.38 ± 0.63
Cd	LSD at 5%	0.874	0.307	0.823	0.552	0.855	0.661
	LSD at 1%	1.242	0.437	1.170	0.784	1.216	0.940
Cd + GA_3	LSD at 5%	1.137	0.408	0.616	0.346	1.704	0.832
	LSD at 1%	1.617	0.580	0.875	0.492	2.423	1.183

** and * denote significant differences between Cd-treated plants and controls at the 0.01 and 0.05% levels, respectively.
$^{++}$ and $^{+}$ denote significant differences between plants treated with GA_3 + Cd and plants treated with Cd alone at the 0.01 and 0.05% levels, respectively.

On the other hand, the observed reduction in essential nutrient levels(Ca, Fe, K, Mn) of *Vigna unguiculata* seedlings may be related to Cd ion competition with divalent cations during their absorption by the root. In this respect, Cd may displace some of the investigated cations in metalo-enzymes from the absorption sites in the cell walls- especially during the early growth stage and at higher Cd doses – and such competition may result in the reduction in their level. This finding confirms the report of Greger and Bertell [20] which indicated that Cd may compete with Ca or prevent it from being utilized in Ca-dependent processes leading to diminished growth. Cadmium interference with plant growth was reported by Al-Rumaih [21] and this paralleled the decline in calcium content observed in the present study. An earlier study by Greger and Lindberg [19] showed that the uptake area was diminished by Cd treatment, as root growth of sugar beet, *Beta vulgaris* L. was depressed, consequently reducing the number of absorption sites available for nutrients on the cell walls and membranes, thereby inhibiting uptake.

Table 3. The effect of various concentrations of $CdCl_2$ in the presence or absence of GA_3 on potassium content of *Vigna unguiculata* L. shoots and roots at the three studied developmental stages

Potassium (mg/g) (Mean ± SD)							
Treatment (ppm)		**Early vegetative**		**Intermediate**		**Late vegetative**	
Cd	**GA_3**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**
0	0	20.82 ± 1.32	17.46 ± 1.17	18.34 ± 1.28	15.73 ± 0.72	17.66 ± 1.20	15.19 ± 0.81
20	0	18.23 ± 1.38	14.63 ± 1.27*	17.36 ± 1.42	14.50 ± 0.85	17.19 ± 1.07	14.52 ± 0.74
20	100	23.90 ± 1.18^{++}	18.47 ± 1.36^{++}	24.15 ± 1.00^{++}	19.10 ± 1.81^{++}	21.54 ± 2.82^{+}	17.28 ± 2.74
40	0	16.95 ± 1.46**	12.11 ± 1.09**	16.54 ± 1.27	13.83 ± 0.89*	16.99 ± 1.13	13.77 ± 0.86
40	100	21.42 ± 1.58^{++}	14.66 ± 1.39^{+}	22.16 ± 0.91^{++}	17.54 ± 2.76^{+}	20.36 ± 1.7	16.10 ± 2.45
80	0	12.81 ± 1.50**	9.70 ± 1.10**	15.32 ± 1.49*	12.55 ± 0.74**	16.20 ± 0.94	13.29 ± 0.93*
80	100	15.36 ± 1.28^{+}	11.43 ± 1.53	19.24 ± 0.74^{++}	15.22 ± 2.42	18.59 ± 2.75	14.97 ± 2.66
160	0	9.93 ± 1.52**	5.82 ± 0.93**	13.98 ± 1.47**	10.71 ± 0.75**	15.47 ± 0.92*	12.10 ± 0.97**
160	100	11.13 ± 0.88	6.44 ± 1.31	16.36 ± 0.87^{+}	12.28 ± 2.21	16.75 ± 2.65	12.75 ± 1.72
Cd	LSD at 5%	2.62	2.02	2.53	1.44	1.92	1.57
	LSD at 1%	3.72	2.88	3.60	2.05	2.74	2.24
Cd + GA_3	LSD at 5%	2.48	2.33	2.14	3.17	3.50	3.32
	LSD at 1%	3.52	3.31	3.05	4.51	4.97	4.72

** and * denote significant differences between Cd-treated plants and controls at the 0.01 and 0.05% levels, respectively.
$^{++}$ and $^{+}$ denote significant differences between plants treated with GA_3 + Cd and plants treated with Cd alone at the 0.01 and 0.05% levels, respectively.

Our results also showed leaf margin necrosis and chlorotic yellowing of *Vigna unguiculata* induced by the highest studied Cd concentration (160 ppm) during the early vegetative stage, which could be considered as symptoms of multiple element deficiency. These symptoms corresponded with the decreased rates of uptake and distribution of these nutrients in plants. This confirms the finding of Greger and Lindberg [19], which revealed a range of nutritional disorders in response to Cd treatment.

The results of the present investigation further showed that when GA_3 was applied simultaneously with different concentrations of $CdCl_2$ the content of Cd in

Vigna unguiculata shoots and roots decreased. The reduction was significantly more in the shoot during the intermediate stage at 20 and 40 ppm $CdCl_2$ concentrations, where the accumulation of the heavy metal was reduced by almost 60% and 36% , respectively, as compared with the respective controls at zero GA_3. A reduction in the level of Cd induced by the combined treatment of Cd and GA_3 was reported by Rubio *et al.* [12] in rice, *Oryza sativa* L., plants, who indicated that GA_3 strongly inhibited heavy metal (Cd, Ni) incorporation into plants. Hence, the decrease in Cd content by GA_3 treatment observed in the present study may be attributed to the hormone action in reducing the uptake of the heavy metal. In addition, GA_3 application seems to affect Cd uptake within the plant by affecting membrane transport processes, possibly by altering membrane permeability [22].

Table 4. The effect of various concentrations of $CdCl_2$ in the presence or absence of GA_3 on magnesium content of *Vigna unguiculata* L. shoots and roots at the three studied developmental stages

Treatment (ppm)		Magnesium (mg/g) (Mean ± SD)					
		Early vegetative		Intermediate		Late vegetative	
Cd	GA_3	Shoot	Root	Shoot	Root	Shoot	Root
0	0	0.584 ± 0.028	0.813 ± 0.0473	0.764 ± 0.046	1.110 ± 0.079	0.906 ± 0.038	1.320 ± 0.017
20	0	0.529 ± 0.037	$0.904 \pm 0.046^{*}$	0.714 ± 0.904	$1.300 \pm 0.125^{*}$	0.885 ± 0.038	1.390 ± 0.089
20	100	$0.637 \pm 00.037^{++}$	0.815 ± 0.108	$0.904 \pm 0.037^{++}$	$1.130 \pm 0.005^{++}$	$1.040 \pm 0.074^{++}$	1.340 ± 0.010
40	0	$0.502 \pm 0.038^{*}$	$0.976 \pm 0.054^{**}$	0.682 ± 0.048	$1.330 \pm 0.076^{*}$	0.868 ± 0.039	1.420 ± 0.062
40	100	$0.592 \pm 0.047^{++}$	0.926 ± 0.058	$0.845 \pm 0.038^{++}$	$1.200 \pm 0.004^{+}$	$0.988 \pm 0.067^{*}$	1.390 ± 0.010
80	0	$0.383 \pm 0.027^{**}$	$1.070 \pm 0.010^{**}$	$0.636 \pm 0.761^{**}$	$1.360 \pm 0.090^{**}$	0.837 ± 0.043	$1.470 \pm 0.105^{*}$
80	100	0.425 ± 0.039	0.995 ± 0.078	$0.761 \pm 0.039^{++}$	1.260 ± 0.003	0.907 ± 0.067	1.450 ± 0.010
160	0	$0.307 \pm 0.030^{**}$	$1.240 \pm 0.027^{**}$	$0.590 \pm 0.049^{**}$	$1.440 \pm 0.072^{**}$	$0.809 \pm 0.037^{*}$	$1.510 \pm 0.102^{*}$
160	100	0.323 ± 0.019	1.161 ± 0.098	$0.674 \pm 0.031^{+}$	1.350 ± 0.000	0.836 ± 0.072	1.500 ± 0.010
Cd	LSD at 5%	0.059	0.073	0.085	0.165	0.071	0.149
	LSD at 1%	0.084	0.103	0.121	0.234	0.100	0.212
Cd + GA_3	LSD at 5%	0.064	0.123	0.077	0.120	0.103	0.118
	LSD at 1%	0.091	0.175	0.109	0.170	0.147	0.168

** and * denote significant differences between Cd-treated plants and controls at the 0.01 and 0.05% levels, respectively.
$^{++}$ and $^{+}$ denote significant differences between plants treated with GA_3 + Cd and plants treated with Cd alone at the 0.01 and 0.05% levels, respectively.

In addition, an increase in the concentration of Ca, Fe, K and Mn was observed in *Vigna unguiculata* roots and shoots when GA_3 was applied simultaneously with various concentrations of $CdCl_2$. However, the Mg level decreased in roots, but increased in shoots. This effect was most significant at 20 and 40 ppm $CdCl_2$ concentrations and during the intermediate growth stage followed by the early stage, and shoots were more affected by GA_3 treatment compared to roots. An enhancement of *Vigna unguiculata* root growth induced by GA_3 treatment was reported by Al-Rumaih [21], and this possibly explains the present increase in the uptake of mineral nutrients. In this regard Khan *et al*. [23] also indicated that GA_3-sprayed mustard, *Brassica juncea* L., plants showed more nutrient (N, P, K) uptake due to increase in growth rate.

Table 5. The effect of various concentrations of $CdCl_2$ in the presence or absence of GA_3 on iron content of *Vigna unguiculata* L. shoots and roots at the three studied developmental stages

Treatment (ppm)		Iron (µg/g) (Mean ± SD)					
		Early vegetative		Intermediate		Late vegetative	
Cd	GA_3	Shoot	Root	Shoot	Root	Shoot	Root
0	0	49.38 ± 4.38	88.15 ± 4.45	58.96 ± 4.14	104.72 ± 4.251	65.79 ± 4.25	116.53 ± 5.45
20	0	45.80 ± 5.06	81.11 ± 4.67	56.08 ± 4.61	97.69 ± 6.29	64.00 ± 5.02	111.53 ± 4.60
20	100	$58.70 \pm 2.34^{++}$	$99.05 \pm 10.17^{+}$	$74.84 \pm 0.94^{++}$	$125.09 \pm 6.46^{++}$	$75.93 \pm 70.41^{+}$	$127.41 \pm 5.97^{+}$
40	0	$40.43 \pm 5.26^{*}$	$70.17 \pm 4.31^{**}$	53.87 ± 5.29	$94.79 \pm 5.28^{*}$	62.37 ± 4.82	108.89 ± 4.16
40	100	$49.40 \pm 2.20^{+}$	$83.87 \pm 10.20^{+}$	$66.97 \pm 2.76^{++}$	$115.10 \pm 6.30^{++}$	$71.98 \pm 3.64^{+}$	120.70 ± 8.2
80	0	$34.25 \pm 5.17^{**}$	$50.30 \pm 4.43^{**}$	$49.56 \pm 4.74^{*}$	$82.28 \pm 4.26^{**}$	60.61 ± 5.29	$105.05 \pm 4.57^{*}$
80	100	40.13 ± 3.45	56.67 ± 9.40	$58.54 \pm 1.17^{+}$	95.95 ± 4.09	66.72 ± 5.26	111.15 ± 8.42
160	0	$27.68 \pm 4.16^{**}$	$35.21 \pm 5.09^{**}$	$47.19 \pm 5.19^{*}$	$73.24 \pm 4.65^{**}$	58.81 ± 3.97	$101.87 \pm 4.3^{**}$
160	100	30.57 ± 2.66	37.21 ± 8.24	53.03 ± 0.97	79.67 ± 5.25	61.89 ± 4.69	102.04 ± 9.15
Cd	LSD at 5%	8.78	8.35	8.74	9.11	8.53	8.43
	LSD at 1%	12.48	11.88	12.43	12.96	12.13	11.99
Cd + GA_3	LSD at 5%	7.24	13.63	6.72	9.81	9.20	11.77
	LSD at 1%	10.29	19.39	9.56	13.96	13.06	16.74

** and * denote significant differences between Cd-treated plants and controls at the 0.01 and 0.05% levels, respectively.
++ and + denote significant differences between plants treated with GA_3 + Cd and plants treated with Cd alone at the 0.01 and 0.05% levels, respectively.

In conclusion, the results of this study have shown clearly that Cd content in plant tissues is directly related to Cd content of the soil. As Cd level increases, the uptake and distribution of other minerals in plant tissues is severely deranged. This effect is overcome by the plant growth regulator GA_3, particularly at the lower Cd concentrations.

Table 6. The effect of various concentrations of $CdCl_2$ in the presence or absence of GA_3 on manganese content of *Vigna unguiculata* L. shoots and roots at the three studied developmental stages

Treatment (ppm)		Manganese (µg/g) (Mean ± SD)					
		Early vegetative		Intermediate		Late vegetative	
Cd	GA_3	Shoot	Root	Shoot	Root	Shoot	Root
0	0	36.85 ± 2.94	22.44 ± 1.14	50.90 ± 3.64	31.77 ± 2.68	58.66 ± 3.69	36.18 ± 2.76
20	0	34.84 ± 1.81	20.30 ± 0.67*	48.76 ± 2.66	29.07 ± 2.81	57.08 ± 3.60	34.76 ± 1.75
20	100	42.65 ± 2.06++	24.38 ± 2.35+	63.10 ± 0.24++	35.52 ± 2.58++	67.27 ± 3.85++	40.27 ± 3.25+
40	0	32.56 ± 2.34*	18.61 ± 1.28**	47.34 ± 2.61	27.70 ± 1.74	55.22 ± 3.74	33.49 ± 1.70
40	100	38.88 ± 1.91++	21.95 ± 2.12+	59.22 ± 0.65++	33.16 ± 1.84+	62.83 ± 4.03+	37.60 ± 3.18
80	0	26.93 ± 1.89**	14.88 ± 0.79**	44.20 ± 1.90*	25.08 ± 1.95**	54.11 ± 2.90	32.35 ± 1.32*
80	100	31.76 ± 2.96+	17.26 ± 1.92	52.94 ± 0.21++	29.39 ± 1.90+	59.70 ± 3.55	35.33 ± 2.66
160	0	21.41 ± 2.12**	8.85 ± 1.36**	39.72 ± 1.91**	21.39 ± 2.71**	51.81 ± 3.73*	29.85 ± 1.90**
160	100	24.03 ± 2.88	9.70 ± 1.99	45.81 ± 0.47++	24.25 ± 2.60	55.15 ± 4.74	31.49 ± 3.37
Cd	LSD at 5%	4.11	1.97	4.77	4.40	6.45	3.53
	LSD at 1%	5.84	2.80	6.79	6.26	9.18	5.02
Cd + GA_3	LSD at 5%	4.15	3.03	3.01	4.19	6.90	4.56
	LSD at 1%	5.91	4.31	4.28	5.96	9.82	6.50

** and * denote significant differences between Cd-treated plants and controls at the 0.01 and 0.05% levels, respectively.
++ and + denote significant differences between plants treated with GA_3 + Cd and plants treated with Cd alone at the 0.01 and 0.05% levels, respectively.

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تأثير هرمون حمض الجبريليك على التغذية المعدنية في نباتات اللوبيا (*Vigna unguiculata*) المعرضة للإجهاد بالكادميوم أثناء مراحل النمو

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ملخص البحث. تضمن هذا البحث دراسة تأثير التركيزات المختلفة (صفر،١٦٠،٨٠،٤٠،٢٠ جزء في المليون) من كلوريد الكادميوم ($CdCl_2$) في وجود وغياب حمض الجبريليك (١٠٠ جزء في المليون) على محتوى الكادميوم وبعض العناصر المعدنية الغذائية الكبرى(Ca ,K ,Mg) والصغرى (Fe ,Mn) في المجموع الخضري والمجموع الجذري لنبات اللوبيا *Vigna unguiculata* ، وذلك في ثلاث مراحل من النمو الخضري (مبكرة ، متوسطة ، متأخرة). أظهرت النتائج تراكم كميات كبيرة من الكادميوم في كل من المجموع الخضري والمجموع الجذري لنبات اللوبيا، خاصة عند أضافته بتركيزات عالية ، وقد كان الجزء الأكبر منه متراكماً في الجذور. وبصفة عامة ، سجلت أعلى قيم لتراكم الكادميوم أثناء المرحلة المبكرة وتلتها المرحلة المتوسطة للنمو.

كما أظهرت النتائج أن التركيزات المختلفة من كلوريد الكادميوم أحدثت نقصاً واضحاً وتدريجياً لمعظم العناصر المعدنية تحت الدراسة في كل من المجموع الخضري والمجموع الجذري لنبات اللوبيا ، ويقل هذا التأثير تدريجياً باستمرار نمو النبات لتصبح المرحلة المتأخرة من النمو أقل المراحل تأثراً . كما أوضحت النتائج أن إضافة حمض الجبريليك في وجود التركيزات المختلفة من كلوريد الكادميوم أدت إلى خفض محتوى الكادميوم في المجموع الخضري والمجموع الجذري. ومن جهة أخرى ، فإن معظم العناصر المعدنية قد تزايدت محتوياتها في كل من المجموع الخضري والمجموع الجذري لنبات اللوبيا عند إضافة حمض الجبريليك ، مما يؤكد دوره في تخفيف التأثير الضار الناتج عن الكادميوم عند التركيزات المنخفضة (٢٠ ، ٤٠ جزء من المليون). وقد كانت المرحلة المتوسطة للنمو أكثر المراحل تأثراً بالهرمون وتلتها المرحلة المبكرة .