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Vanadium bioaccumulation in *Pisum sativum* seedlings

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Abstract

Vanadium bioaccumulation calculated as the ratio of its content in plant biomass to that in the substrate (Vbi-index) was studied in pea. Vbi was on average 11.275, 11.770 and 13.153 in the roots, and 0.809, 0.467 and 0.749 in the shoots of the cultivars Opal, Laser and Ramir, respectively. This indicates cultivar differences in vanadium uptake, and low translocation rates from roots to shoots. Vanadium (3 to 30 mg l^{-1}) decreased shoot and root fresh and dry masses of the three cultivars. Seedlings of the cv. Opal were the most susceptible to higher concentrations of vanadium (20 to 30 mg l^{-1}), whereas seedlings of cv. Laser were the most resistant.

Introduction

Among the numerous heavy metals coming from fuel combustion and present in the natural environment, vanadium and its effect on vegetation is still little recognised. Plants contain usually about 1 (between 0.2 and 4) μg V g^{-1}(fresh matter) (Bertrand 1941), but in regions with high vanadium concentration in the environment, they may contain between 7 and 144 g V g^{-1}(fresh matter) (Cannen 1963).

The content of vanadium and other heavy metals in plants is proportional to its concentration in the environment, and depends on species, cultivar and plant organ. In general, dicotyledonous plants contain higher amounts of heavy metals than monocotyledonous plants, fruits and seeds exhibiting the lowest content (Kabata-Pendias and Pendias 1979, Nowakowski 1982, 1983, Nowakowski and Podgórski 1987).

Some authors reported that low concentrations of vanadium (*e.g.* 0.1 μg g^{-1}, Arnon and Wessel 1953) affected favourably growth of *Scenedesmus obliquus*. Similar effect was observed in *Chlorella*. Many authors, however, found a toxic effect of vanadium on crop plants: Wallace *et al.* (1977) reported that vanadium in concentrations 0.05 and 5 μg g^{-1} decreased the yield of beans by 12 and 50 %, respectively. Harra *et al.* (1976) found similar depression of yield in cabbage.

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In concentration up to 10 μg g^{-1}, vanadium has a distinctly toxic effect on the growth of higher plants. This effect may be associated with the vanadium-induced depression of nitrate reductase and ATPase activities (Bowman *et al.* 1978, Buczek 1973, Ramadoss 1979).

In algae, vanadium in concentration up to 20 μg g^{-1} stimulated synthesis of δ-aminolevulinic acid indispensable in porphyrin and chlorophyll syntheses (Meisch and Bauer 1978), and increased the contents of *P*700, cytochrome *f* and carotenoids (Wilhelm and Wild 1980).

According to Niebeer and Richardson (1980), vanadium, as many other heavy metals (*e.g.* lead, chromium, cadmium), belongs to the intermediate class as regards the ion index, *i.e.* Z^2/r, and the covalence index, X^2m^r, called the 'borderline class'. Hence, it can form ligand complexes in biological systems with all the known ligand groups described by Woolhouse (1983). This is the cause of the long retention of vanadium in organism and thus its long-term influence on metabolic processes.

The aim of this investigation was to determine the response of pea cultivars to different vanadium concentrations.

Material and methods

Plants of three pea cultivars (*Pisum sativum* L. cvs. Laser, Ramir and Opal) were grown in laboratory (20 °C, 70 % r. h., daylight). Seeds were obtained from the Experimental Department of the Institute of Plant Breeding and Acclimatization (IHAR) in Radzików. Seedlings were grown in Petri dishes in distilled water and in NH_4VO_3 solutions (0, 5, 10, 20, 30 mg l^{-1}).

In 14-d-old seedlings fresh and dry masses of shoots and roots and their vanadium content were determined. Vanadium was mineralized by HNO_3 and $HClO_4$ (2:1) and determined spectrophotometrically using gallic acid for the range 0.2 - 8 mg l^{-1} (Qiang 1983), or using pyrogallol red for the range 0.02 - 1.8 mg l^{-1} (Escriche *et al.* 1983). Absorbance was measured at λ=415 nm for gallic acid and λ=510 nm for pyrogallol red with spectrophotometer *VSU2-P* (Orzechowska 1987).

The vanadium bioaccumulation index, Vbi, was calculated as the ratio between the vanadium content in plant biomass and its content in the substrate (Célardin and Landary 1988).

Results and discussion

Vanadium depressed the dry and fresh masses of shoots and roots in seedlings of the three pea cultivars tested, the cv. Opal being the most susceptible and the cv. Laser the most resistant. The water content in shoots and roots of the three cultivars decreased with increasing vanadium concentration as well (Table 1).

There were found distinct differences in Vbi between the organs of the three cultivars tested. In cvs. Opal, Laser and Ramir, the mean Vbi's of the roots were

Table 1. Fresh and dry masses and water contents in 14-d-old seedlings of three pea cultivars grown under different vanadium concentration. Means ± S.E. * - average Vbi.

V conc. [mg l^{-1}]	Cultivar	Water content [%]		Fresh mass [mg per seedling]		Dry mass [mg per seedling]		V content [μg g^{-1}(dry m.)]		Vbi	
		Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
0	Laser	91.57	91.75	391.1 ± 14.1	217.2 ± 18.4	31.1 ± 0.7	17.9 ± 1.1	0.19 ± 0.01	0.91 ± 0.05	-	-
5		92.18	92.19	395.6 ± 30.3	227.8 ± 19.6	30.9 ± 2.1	17.8 ± 1.0	1.57 ± 0.11	43.54 ± 1.02	0.314	8.708
10		91.65	90.29	342.8 ± 18.4	147.4 ± 10.9	28.6 ± 1.3	14.3 ± 0.8	4.34 ± 0.06	107.39 ± 18.20	0.434	10.739
20		90.41	89.96	262.8 ± 30.5	104.6 ± 8.2	25.2 ± 3.3	10.5 ± 1.0	9.87 ± 0.59	272.41 ± 16.70	0.493	13.620
30		89.89	88.95	212.8 ± 27.4	79.7 ± 3.8	21.5 ± 2.1	8.8 ± 0.7	18.84 ± 0.98	420.46 ± 17.90	0.628	14.015
										(0.467)*	(11.770)*
0	Ramir	90.49	90.12	340.8 ± 29.7	189.4 ± 18.1	32.4 ± 2.6	18.7 ± 1.7	0.88 ± 0.03	0.95 ± 0.03	-	-
5		90.06	89.26	295.8 ± 15.9	154.6 ± 25.3	29.4 ± 2.6	16.6 ± 1.5	3.14 ± 0.02	59.59 ± 4.47	0.628	11.918
10		90.01	89.48	281.3 ± 28.6	158.8 ± 17.0	27.1 ± 3.1	16.7 ± 1.8	5.15 ± 0.06	99.40 ± 4.83	0.515	9.940
20		89.45	88.17	229.6 ± 24.1	98.1 ± 10.1	24.2 ± 3.3	11.6 ± 1.0	12.87 ± 1.32	293.23 ± 10.38	0.643	14.662
30		88.63	87.50	149.6 ± 12.6	63.2 ± 9.9	17.0 ± 2.1	7.9 ± 0.7	36.10 ± 0.91	482.72 ± 47.06	1.203	16.091
										(0.749)*	(13.153)*
0	Opal	90.87	89.89	372.8 ± 35.2	215.7 ± 23.2	34.0 ± 2.0	21.8 ± 2.0	0.41 ± 0.01	0.60 ± 0.03	-	-
5		91.02	90.39	349.7 ± 30.6	222.7 ± 23.5	31.4 ± 2.7	21.4 ± 1.9	2.77 ± 0.38	47.35 ± 1.39	0.554	9.470
10		91.08	89.36	356.7 ± 35.7	163.5 ± 19.4	31.8 ± 3.2	17.4 ± 1.4	6.02 ± 0.04	95.62 ± 14.95	0.602	9.562
20		90.35	85.79	232.2 ± 26.6	93.6 ± 10.1	22.4 ± 2.4	13.3 ± 1.2	12.02 ± 0.15	258.56 ± 14.45	0.601	12.928
30		89.58	86.63	162.2 ± 11.5	59.1 ± 7.5	16.9 ± 1.3	7.9 ± 0.6	44.43 ± 7.90	394.14 ± 14.50	1.481	13.138
										(0.809)*	(11.275)*

Correlation coefficients: for shoot dry mass × vanadium content for cv. Laser = -0.992, for cv. Ramir = -0.967, and for cv. Opal = -0.909,
for root dry mass × vanadium content for cv. Laser = -0.992, for cv. Ramir = -0.995, and for cv. Opal = -0.989.

11.275, 11.770 and 13.153, respectively, whereas Vbi's in the shoots were 0.809, 0.467 and 0.749, respectively (Table 1).

Among the three pea cultivars studied, Opal exhibits the greatest inhibition of shoot and root dry mass under high vanadium concentration in the substrate. So, 14-d-old seedlings of cv. Opal seem most susceptible and cv. Laser most resistant to vanadium.

In conclusion, (*1*) vanadium concentration applied (5 to 30 $\mu g\ g^{-1}$) depressed the fresh and dry masses of both shoot and root in pea seedling. (*2*) The calculated vanadium bioaccumulation indexes in pea cultivars indicated differences in vanadium uptake and its low translocation from root to shoot. (*3*) The cultivar Opal was most susceptible and cv. Laser most resistant to vanadium in concentrations 20 - 30 $\mu g\ g^{-1}$.

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