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Growth responses of barley and wheat seedlings to lead and cadmium

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Abstract

The responses of barley and wheat seedlings to lead and cadmium ions in relation to the concentration and duration of treatment were studied. Both metals inhibited seed germination and growth of roots and shoots, but the toxic effect of cadmium was observed at lower concentrations. Inhibition of seedling growth was already recorded already within a day after the beginning of the treatment, and then increased further. The sensitivity of the processes studied to both the metals decreased in the order: root growth, shoot growth and seed germination. The resistance of barley and wheat to lead was similar, whereas the resistance to cadmium was higher in barley.

Additional key words: germination, *Hordeum vulgare*, root growth, shoot growth, *Triticum aestivum*

Introduction

In recent years a sharp rise in accumulation of heavy metals in the environment has been observed. Increasing environmental pollution has serious consequences for plants, including crops (*e.g.* Foy *et al.* 1978). It has been common practice to assay the degree of metal tolerance in terms of the inhibition of growth. Such data were obtained, for example, on maize (Meuwly and Rauser 1992), wheat (Il'in *et al.* 1985), barley (Stiborová *et al.* 1986), cucumber (Burzynski 1987), *etc.* It is difficult to make comparisons because of great differences in experimental conditions (developmental stage of plants, concentrations of metals and duration of treatment, attendant conditions).

We have carried out a comparative investigation of the effects of lead and cadmium on germination and seedling growth of barley and wheat in relation to the degree of their tolerance.

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Materials and methods

The experiments were carried out on spring barley (*Hordeum vulgare* L. cv. Otra) and winter wheat (*Triticum aestivum* L. cv. Mironovskaya 808). Three experimental series were carried out, in which $Pb(NO_3)_2$ and $CdBr_2 . 4 H_2O$ were used. In the first experiment wheat seeds were germinated in darkness at 25 °C in Petri dishes on filter paper moistened with a solution containing lead and cadmium at concentrations from 0.2 to 2000 mg dm^{-3} or 0.11 to 1100 mg dm^{-3}, respectively, control - distilled water. Percentage germination was recorded 7 d after seed imbibition.

The second experiment was performed with wheat and barley seedlings grown during 3 d in rolls of filter paper in tap water in darkness at 22 - 25 °C. Lead (0.2 - 2000 mg dm^{-3}) or cadmium (0.11 - 1100 mg dm^{-3}) were introduced to the seedlings via roots (control - distilled water). After that the seedlings were grown for 7 d at a temperature of 22 - 25 °C, relative humidity of 60 - 70 %, irradiance of 220 μmol m^{-2} s^{-1} and photoperiod of 14 h. The response of seedlings to the effect of the metals was evaluated by measuring the length of roots (Wilkins 1957). The means of growth inhibition (I) were calculated using the formula (Ivanov *et al.* 1992): $I = (DC - DM)/DC$, where DC is the increase in control, DM is the increase on metal solution.

In the third experiment the kinetics of the growth processes in barley were studied in the presence of Pb^{2+} or Cd^{2+}. For this purpose 3-d-old seedlings were placed in solutions containing lead (600, 1200, 2400 and 4800 mg dm^{-3}) or cadmium (0.11, 1.1, 11 and 110 mg dm^{-3}) with the other conditions as in the second series. The lengths of roots and shoots of control and treated seedlings were measured 1, 2, 3, 4 and 7 d after the beginning of the experiment.

The replication within each variant for analysing germination of seeds - 50, and for growth indices - 20 - 25 seedlings. The experiments were performed three times. Data in the figures are the means of all experiments and their standard errors.

Results and discussion

Pb^{2+} and Cd^{2+} inhibited germination and caused stunting of wheat and barley seedlings in relation to concentrations used. In comparison with the effects on germination (Fig. 1), a decrease in seedling growth was observed at lower doses of heavy metals (Fig. 2). Pb^{2+} at concentration of 2 mg dm^{-3} caused a reduction in the growth of wheat and barley roots, at 20 mg dm^{-3} - its severe decrease, at 200 mg dm^{-3} - its cessation (Fig. 2). In comparison with Pb^{2+}, Cd^{2+} showed considerably more inhibition of seedling growth at concentrations ranging from 0.1 to 11 mg dm^{-3}.

The growth of wheat and barley shoots was more resistant to Pb^{2+} and Cd^{2+} than the growth of roots (Fig. 2). Even at a lead concentration of 2000 mg dm^{-3} it was not completely suppressed. Negative effects of cadmium showed up at lower (1.1 - 11 mg dm^{-3}) doses. Treatment with this metal at higher (110 - 1100 mg dm^{-3}) concentrations caused damage or death of seedlings.

Comparison of the data obtained shows that wheat and barley seedlings practically do not differ in their resistance to Pb^{2+}, but barley is characterized by a higher resistance to Cd^{2+}.

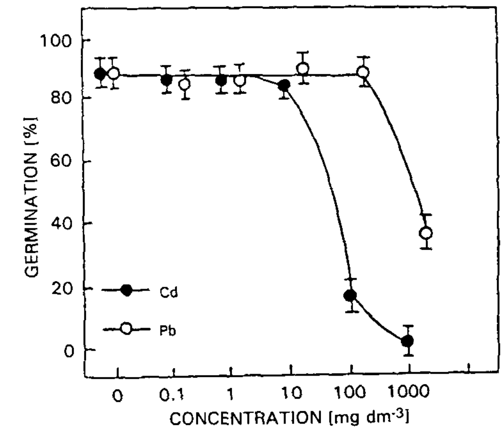

Fig. 1 Effect of Cd^{2+} (*closed circles*) and Pb^{2+} (*open circles*) at different concentrations on wheat seed germination. *Bars* are standard errors.

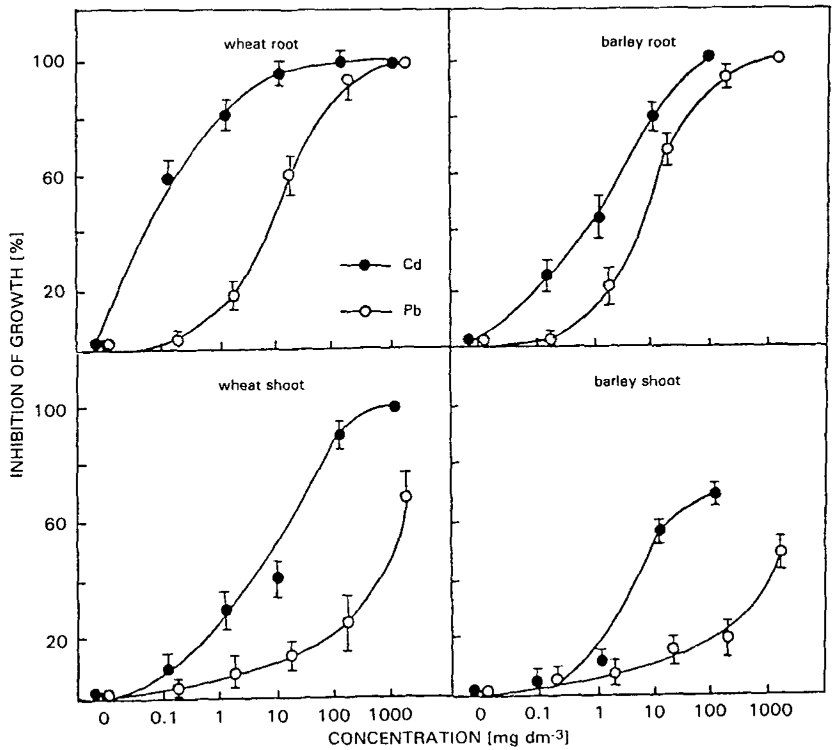

Fig. 2. Effect of Cd^{2+} (*closed circles*) and Pb^{2+} (*open circles*) at different concentrations on growth of roots and shoots of wheat and barley seedlings. *Bars* are standard errors.

Cadmium at a concentration of 110 mg dm^{-3} had already caused a reduction in root growth of barley after 1 d (Fig. 3). At lower concentrations only a small decrease in root growth was registered within 1 d after the beginning of treatment, but after 4 d inhibition increased. The prolongation of Cd^{2+} treatment to 7 d did not cause an increase in inhibiting effect.

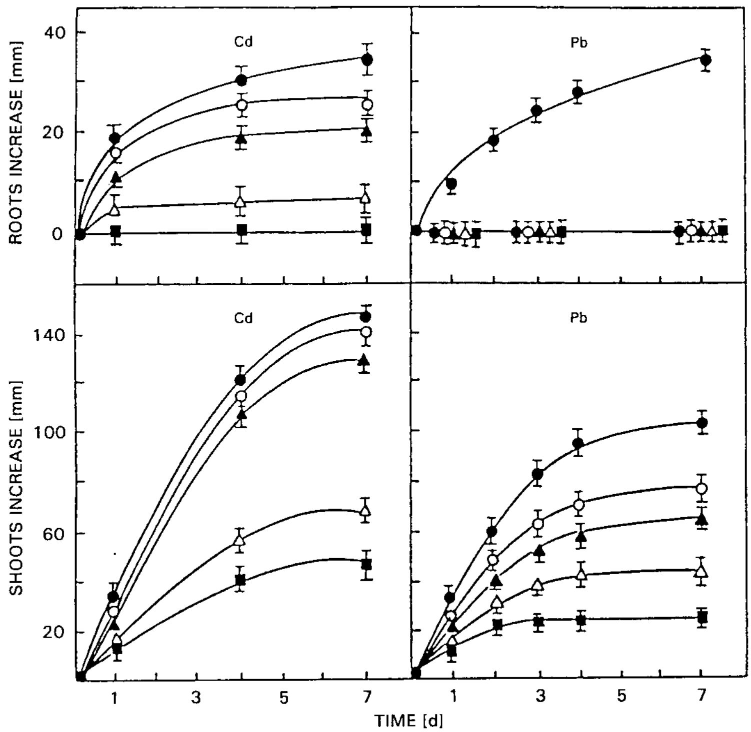

Fig. 3. Effect of Cd^{2+} and Pb^{2+} on growth of roots and shoots of barley seedlings in relation to the duration of treatment. Concentrations [mg dm^{-3}] of cadmium: 0 (control) - *closed circles*, 0.11 - *open circles*, 1.1 - *closed triangles*, 11 - *open triangles*, 110 - *closed squares*; of lead: 0 (control) - *closed circles*, 600 - *open circles*, 1200 - *closed triangles*, 2400 - *open triangles*, 4800 - *closed squares*. *Bars* are standard errors.

Presence of Cd^{2+} affected the growth of barley shoots to a lesser extent. For instance, within 1 d after the beginning of the experiment it did not differ in treated and control seedlings (Fig. 3). Prolongation of treatment to 4 d led to its decrease only at high concentrations (11 and 110 mg dm^{-3}) and after 7 d - at low (1.1 mg dm^{-3}) concentration as well.

In the similar experiment with Pb^{2+} high concentrations were used, and root growth had already completely stopped within 1 d after the beginning of the treatment (Fig. 3). However, the growth of shoots was markedly reduced only after 2 d and on the 3 - 4th d the inhibition became maximal. Consequently, Pb^{2+} as well as Cd^{2+} have a strong and quickly manifested effect on seedlings, which shows up as a decrease in growth processes.

From the results of these experiments, higher toxicity of Cd^{2+} compared to Pb^{2+} is evident. This is in good agreement with the data of other investigations. A considerable decrease of wheat and barley growth was induced only by a relatively high level (1 - 2 mM) of Pb^{2+} (Il'in *et al.* 1985, Stiborová *et al.* 1986, Kobbia and Ibrahim 1988). Cd^{2+} inhibited the wheat and barley growth at much lower concentrations (0.01 - 0.1 mM) than Pb^{2+} (Il'in *et al.* 1985, Stiborová *et al.* 1986).

The difference between the values of growth inhibition found in our investigation and reported in the literature may be partially due to the different plant cultivars employed and differences in experimental conditions. For example, the effects of Pb^{2+} and Cd^{2+} on barley and wheat were dependent of not only on the concentrations employed but also on time. The effects of metal shows up very quickly - already after a day of treatment. Rapid inhibitory effects of cadmium were also reported on bean by Poschenrieder *et al.* (1990).

The resistance of growth processes studied in presence of cadmium and lead increased in the following order: growth of roots, growth of shoots, germination. This inhibitory effect is in agreement with the high sensitivity of roots to heavy metals, frequently mentioned earlier (*e.g.* Wilkins 1957, Foy *et al.* 1978). Reduction of growth induced by heavy metals may be connected with changes in metabolic processes, especially inhibition of protein synthesis and photosynthesis (Stiborová *et al.* 1986).

Plants have various mechanisms by which they can tolerate high concentrations of cadmium and lead. These include prevention of extracellular uptake and accumulation of metal (Malone *et al.* 1974, Nishizono *et al.* 1989), their removal from the cell (Foy *et al.* 1978) and detoxification inside the plant (Meuwly and Rauser 1992). In particular, tolerance of plants to toxic amounts of Cd^{2+} is related to their ability to produce metallothioneins (Steffens 1990) and phytochelatins (Rauser 1987) and then to form metal-binding complexes. Detailed explanation of the mechanism of metal resistance requires further studies.

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