Effects of the metal pollutants cadmium and nickel on soybean seed development

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Abstract
The chloride salts of Cd or Ni were added to the nutrient solution in which soybean (*Glycine max*) plants were grown and the response of the plants to these pollutants examined. Both metals markedly reduced plant biomass and seed production. Accumulation was mostly in the roots. Nickel was more mobile than Cd, reaching higher levels in all plant parts, especially seeds. Within the tissues of mature seeds, the highest concentrations of Ni were found in the axis and testa. The highest concentrations of Cd were in the testa and cotyledon, and the lowest in the axis. When expressed on a per seed basis, metal contents of these organs increased with developmental age. Nickel amounts were lower in the pods than the seeds for all growth stages, however there was no significant difference for Cd. Cadmium reduced mature seed mass. This effect was mostly due to decreased yields of lipids, protein and carbohydrates. Although the number of seeds per pod declined as a response to Ni, seed mass was unaffected and there was no apparent effect on storage reserves.

Keywords: metal pollutants, cadmium, nickel, heavy metal, *Glycine max*, soybean, seed

Introduction
There are several metal pollutants that are considered to be of potential threat to environmental systems. These include Cd, Cr, Cu, Hg, Ni, Zn and Pb (Marschner, 1982; Friedland, 1990). Due to their distinct chemistry and characteristics, each represents a rather different hazard to the environment. In this study, the effect of Cd and Ni on the development of soybean seeds was examined.

Cd is a non-essential element in plants (Verkleij and Schat, 1990). It is recognized as one of the most potentially hazardous of all metal pollutants since it is extremely toxic to humans and other animals (Rascio et al., 1993; Cieslinski et al., 1996) and is known to accumulate in mammalian kidneys (Quaife, 1981). Exposure is due mainly to high amounts in the diet, although tobacco smoking and occupational exposure to CdO fumes are also important sources (Alloway, 1990). The fact that this metal is fairly readily taken up by plants and translocated to aerial organs facilitates its entry into the food chain (Rauser and Meuwly, 1995; Salim et al., 1995).

Nickel, on the other hand, although a serious environmental pollutant (Seijwan et al., 1996) and phytotoxic at high concentrations (L’Huillier et al., 1996) is considerably less toxic to living organisms than Cd. It has been found by some researchers to be an essential micronutrient in certain plant species, especially when grown on urea-based media (Breckie, 1991; Gerendas and Sattelmacher, 1997). In comparison to Cd, Ni is even more mobile within plants (Marschner, 1982).

Natural amounts of Cd in the environment are generally low, however anthropogenic activities can drastically increase these levels (Woolhouse, 1982). Such activities include: zinc mining and smelting, use of sewage sludge for agricultural fertilization, motoring (car exhaust fumes), combustion of fossil fuels, application of phosphate fertilizers, industrial and manufacturing processes (Lund, 1981; Xian, 1989; Rascio et al., 1993; Marchiol et al., 1996).

Nickel is generally more naturally abundant than Cd. Some native soils, specifically mafic and ultramafic (serpentine) soils, have high indigenous amounts of this element (Mishra and Kar, 1974; Steyn et al., 1996). Specially adapted species and populations of plants have evolved to survive these conditions (Peterson, 1983). Localized high contents do occur as a result of mining, burning of fossil fuels, fertilizer application, automobiles (McIlveen and Negusanti, 1994) and industrial activities such as the manufacture of Ni-steel alloys (stainless steel), electronic components and batteries (McGrath and Smith, 1990).

Since the late 1960s extensive research has been carried out on the threat posed by metal pollutants to the environment (Marschner, 1982; Tjell and Christensen, 1992). However, very little research has

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been carried out on the effect of metal pollutants on seed development (Siegel and Siegel, 1985). A database survey on papers concerned with uptake, accumulation and translocation of heavy metals by vascular plants, revealed that fewer than 11% of the almost 25 000 listed papers studied the effect of metals on reproductive parts (Nellessen and Fletcher, 1993). Research that has been carried out has been limited almost exclusively to analyses of total metal content within seeds and whether this poses a potential risk to consumers. There are few reports concerning the effect metal pollutants may exert on metabolic and developmental processes occurring within the seed. Soybeans, because of their high nutritive value, are an important agricultural crop, grown increasingly in developing countries as a food source (Gupta, 1983; Odendaal et al., 1984). Thus it is important to assess the impact of metal pollution on seed production, and in this study we examined the effect of Ni and Cd on soybean seed development.

Materials and methods

Seeds were harvested from soybean plants (Glycine max (L.) Merr. cv. Crawford), grown in a modified Hoagland’s nutrient solution amended with either Ni or Cd. Details for the production of these seeds are given below.

Plant cultivation and seed production

Plants were grown in a controlled environment chamber at a 25°C day- and 20°C night temperature, 12-h photoperiod and PAR of 800 μmol m⁻² s⁻¹. Seven days after germination, seedlings were transferred to one litre plastic jars filled with nutrient solution. The concentration of macronutrients was as follows: 1 mM K₂HPO₄, 2 mM MgSO₄·7H₂O, 4 mM Ca(NO₃)₂, 4 mM KNO₃ and micronutrients: 89.9 μM FeNaEDTA, 46 μM H₂BO₃, 9.1 μM MnCl₂·4H₂O, 0.8 μM ZnSO₄·7H₂O, 0.3 μM CuSO₄·5H₂O, 0.1 μM H₂MoO₄·H₂O. After two weeks in the starting jars, seedlings were transferred to a circulating nutrient system, which consisted of a 25-litre growth tank, in which the roots were immersed. This was attached by tubing to a reserve tank. Four plants were allocated to each growth tank and the total volume of nutrient solution was 40 litres. The pH of each circulating system was adjusted to 6.0 every 1–2 days and deionized water added to bring the total volume back to 40 litres. Fresh nutrient solution was made up every 10 days and the growth tanks were constantly aerated. The same composition of nutrient solution was used as in the starting containers except that the chloride salts of either Cd or Ni were added to give resulting metal pollutant concentrations of 0 mg/litre (control) 0.05 mg/litre Cd or 1 mg/litre Ni. The Cd-stress experiments were first carried out utilizing one growth tank as the control treatment and another three tanks for the metal treatment. Subsequently the Ni-stress experiments were conducted using the same tanks as control and treatment tanks. Care was taken to ensure that the environmental and growth parameters were constant. In addition, the growth tanks were washed after the Cd-stress experiments and the rinse water analysed for this metal using the standard procedure (see below). Cadmium contamination of the growth tanks was minimal and is therefore not discussed further.

Seeds were harvested at four distinct stages in development which were determined by the size and morphology of the pod and seed. Pods were measured with regard to length, depth and thickness, as well as the extent to which the depth of the locule was filled by the developing ovule. This was based on the method of Miles et al. (1988). Approximate DAF (days after flowering) for each stage are also given.

Immature pods (IP) – pods dark green in colour, at least 50 mm in length and 10 mm in depth. Ovules 4–6 mm in depth, i.e. filling half the depth of the locule. Seeds in rapid growth stage. DAF approximately = 16–17.

Expanded pods (EP) – pods light green in colour, fully expanded (> 7 mm in thickness) and turgid. Ovules filling the entire locule depth, green and showing no yellowing. Seeds at mid-seed fill period. DAF approximately = 30.


Seeds were harvested at each growth stage, freeze-dried for 48 h and stored at −80°C until further processing.

Uptake of metal pollutants

Plants were grown in nutrient solution amended with either 0.05 mg/litre Cd or 1 mg/litre Ni and the visual toxicity symptoms noted. At senescence (when all remaining pods were at the BP stage), plants were separated into roots, leaves and pods. These were washed under running deionized water for 20 s and oven-dried at 70°C for 48 h. Material was finely ground, and 0.5-g samples ashed in a muffle furnace for 5 h at 500°C. Freeze-dried seed samples were processed in a similar manner, except that the oven drying step was omitted and 2-g samples were used. All samples were then digested for 24 h in concentrated HNO₃ at a temperature of 150°C and made up to a final volume of 25 ml in 0.1 M HNO₃.
Samples were analysed for Cd or Ni using a Jobin Yvon JY138 ultratrace ICP-AES (inductively coupled plasma - atomic emission spectrophotometer).

**The effect of metal pollutants on seed development**

Seeds, harvested from metal-treated plants at various stages of development, were compared with those from control plants. The following parameters were examined: total seed yield, mass, moisture content, germination and storage reserve accumulation. Lipid determination was carried out on freshly harvested seeds according to a modified method of Christie (1973). Total extractable carbohydrates were determined on freeze-dried tissue according to the method of Adams et al. (1980). Total N (nitrogen) was assayed using the standard micro-Kjeldahl method (Stock and Lewis, 1986) and the crude protein content estimated by multiplying the nitrogen content by a factor of 5.49 which is appropriate for soybean seeds (Mossé and Pernollet, 1983).

**Statistical treatment of the data**

Significant differences between means were examined using Student’s t test at the 95% confidence limit. In cases where sample size was small, Wilcoxon’s rank sum test was employed.

**Results**

**Visual toxicity symptoms**

Visual toxicity symptoms exhibited by the leaves on exposure to the two metals were similar to those previously described for white beans by Rauser (1978). The pods and seeds produced by metal-treated plants were for the most part indistinguishable in appearance from those of the controls. However, plants treated with Ni occasionally produced deformed terminal racemes, composed of pods greatly reduced in size (approximately 10 mm compared to 50 mm). These abnormal pods remained green and contained either no seeds or those that were rudimentary and non-viable.

**Effect on plant biomass**

Table 1 shows the effects of Cd and Ni on plant growth parameters as represented by pod yields as well as by the root dry mass per plant. Both metals markedly decreased pod production and root biomass relative to the controls. Cadmium appears to be more toxic than Ni since a lower concentration of the former was required to elicit the same degree of pod and root biomass depression.

**Distribution of metal within the plant**

Table 2 shows the Cd and Ni content of roots, leaves, pods and mature (BP) seeds taken from metal-treated and control plants. Metal content in all parts was higher than in the equivalent organ of controls. Considerable Cd enrichment occurred in the roots, accumulating to a concentration of 130 μg/g dm from the 0.05 mg/litre present in the nutrient solution. Cadmium values for the aerial portions of the plant were low in comparison to the roots, the concentration in the leaves being 30-fold lower than the roots. Cadmium contents were lowest in the reproductive tissues. Nickel was also concentrated in the roots with lower levels in the shoots and seeds. Nickel values for the leaves were 20-fold less than for the roots. In general the amounts in all parts were much higher than for Cd. Leaves and seeds accumulated similar Ni concentrations but pod contents were considerably lower.

The distribution of Cd and Ni within mature soybean seeds is shown in Table 3. Cadmium enrichment occurred in the testa and cotyledons with very little accumulating in the axis. Nickel concentrations on the other hand were highest in the axis, intermediate in the testa and lowest in the cotyledons.

**The effect of seed growth stage on metal accumulation**

The concentration of the two metals in seeds and pods at each developmental growth stage was examined (Table 4). Concentrations were always significantly higher in treated, relative to control, seeds and pods. For all developmental stages Ni contents were higher in the seed than in the pod. However, there appeared to be little difference between pods and seeds of Cd-treated plants whatever the stage of development. Metal concentrations (calculated per gram dry mass) were higher in young (IP) seeds but declined significantly by the EP stage. However if the results are expressed on a per seed basis, metal content of treated seeds generally positively correlated with seed age.

**The effect of metal pollutants on seed growth parameters**

Table 5 summarizes the effect of Cd and Ni on seed mass and the average number of seeds per pod for mature seeds. The seed number did not change during development and so results for earlier developmental stages are not given. Cadmium had a significant effect on the average size of BP seeds, resulting in decreased seed mass relative to the controls ($P \geq 0.001$). However this metal did not affect the average number of seeds per pod. On the other hand, although Ni did not exert
Table 1. Effect of Cd and Ni on seed yield and root dry mass for plants grown in 0.05 mg/litre Cd or 1 mg/litre Ni. SD given in parenthesis. n = 3 for metal treatments, n = 4 for control

<table>
<thead>
<tr>
<th>Growth parameter</th>
<th>Cd-treated plants</th>
<th>Ni-treated plants</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. pods/plant</td>
<td>67.5 ± 13.3</td>
<td>68.7 ± 9.1</td>
<td>93.5 ± 7.20</td>
</tr>
<tr>
<td>Root dry mass (g)</td>
<td>6.8 ± 3.3</td>
<td>6.9 ± 0.12</td>
<td>10.6 ± 2.1</td>
</tr>
</tbody>
</table>

Table 2. Distribution of Cd and Ni in various parts of plants grown in 0.05 mg/litre Cd or 1 mg/litre Ni. SD given in parenthesis. Minimum sample size = 3

<table>
<thead>
<tr>
<th>Plant part</th>
<th>Cadmium (µg/g dm)</th>
<th>Nickel (µg/g dm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treatment</td>
<td>Control</td>
</tr>
<tr>
<td>Roots</td>
<td>130.09 ± 34.2</td>
<td>1.31 ± 0.19</td>
</tr>
<tr>
<td>Leaves</td>
<td>3.80 ± 0.08</td>
<td>0.43 ± 0.17</td>
</tr>
<tr>
<td>Pods</td>
<td>0.78 ± 0.24</td>
<td>0.48 ± 0.01</td>
</tr>
<tr>
<td>Mature seeds</td>
<td>0.96 ± 0.15</td>
<td>0.12 ± 0.04</td>
</tr>
<tr>
<td>ND = Not detectable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Distribution of Cd and Ni within the tissues of mature (BP) soybean seeds harvested from plants grown in 0.05 mg/litre Cd or 1 mg/litre Ni. Because of the low amounts of metal present in the seed, the dry mass of tissue required per sample was high and thus sample size was small (n = 2 for axes, n = 3 for other tissues). The approximate number of seeds required per sample is given for each treatment. The same mass for treatment and the equivalent control was used. SD given in parenthesis

<table>
<thead>
<tr>
<th>Seed tissue</th>
<th>Cadmium (µg/g dm)</th>
<th>Nickel (µg/g dm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treatment</td>
<td>Control</td>
</tr>
<tr>
<td>Testa</td>
<td>1.52 ± 0.51</td>
<td>0.04 ± 0.01</td>
</tr>
<tr>
<td>Cotyledon</td>
<td>1.53 ± 0.19</td>
<td>0.05 ± 0.01</td>
</tr>
<tr>
<td>Axis</td>
<td>0.04 ± 0.06</td>
<td>0.01 ± 0.00</td>
</tr>
<tr>
<td>ND = Not detectable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Effect of seed development stage on metal concentration in seeds and pods harvested from plants grown in 0.05 mg/litre Cd or 1 mg/litre Ni. Seed concentrations given both on a µg/g dm and per seed basis. IP = immature pod, EP = expanded pod, YP = yellow pod; BP = brown pod. Complete descriptions of developmental stages given under Materials and methods. Ni control values omitted for clarity as all were below detection limit. SD given in parenthesis. Minimum sample size = 3

<table>
<thead>
<tr>
<th>Seed development stage</th>
<th>Cadmium (µg/g dm)</th>
<th>Nickel (µg/g dm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treatment</td>
<td>Control</td>
</tr>
<tr>
<td>IP</td>
<td>0.46 ± 0.01</td>
<td>0.37 ± 0.03</td>
</tr>
<tr>
<td></td>
<td>(± 0.01)</td>
<td>(± 0.02)</td>
</tr>
<tr>
<td>EP</td>
<td>0.47 ± 0.01</td>
<td>0.34 ± 0.06</td>
</tr>
<tr>
<td></td>
<td>(± 0.01)</td>
<td>(± 0.29)</td>
</tr>
<tr>
<td>YP</td>
<td>0.52 ± 0.02</td>
<td>0.33 ± 0.04</td>
</tr>
<tr>
<td></td>
<td>(± 0.02)</td>
<td>(± 0.15)</td>
</tr>
<tr>
<td>BP</td>
<td>0.48 ± 0.01</td>
<td>0.15 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>(± 0.01)</td>
<td>(± 0.24)</td>
</tr>
<tr>
<td></td>
<td>µg Cd/seed</td>
<td>µg Ni/seed</td>
</tr>
<tr>
<td>31.03 ± 5.8</td>
<td>71.2 ± 5.5</td>
<td>0.926 ± 0.01</td>
</tr>
</tbody>
</table>
Table 5. Effect of Cd and Ni on dry mass and seeds per pod for mature (BP) seeds harvested from plants grown in 0.05 mg/litre Cd or 1 mg/litre Ni. SD and sample size given in parenthesis

<table>
<thead>
<tr>
<th>Growth parameter</th>
<th>Cd-treated plants</th>
<th>Ni-treated plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treatment</td>
<td>Control</td>
</tr>
<tr>
<td>No. seeds/pod</td>
<td>1.94 (± 0.4, n = 14)</td>
<td>2.12 (± 0.19, n = 11)</td>
</tr>
<tr>
<td>Seed mass (g/seed)</td>
<td>0.192* (± 0.04, n = 84)</td>
<td>0.229 (± 0.02, n = 53)</td>
</tr>
</tbody>
</table>

* Indicates significance at P ≥ 0.001

A significant effect on seed mass, the presence of this element in the growth medium did decrease the mean number of seeds per pod (p ≥ 0.001).

The effect of metal pollutants on storage reserves

Figures 1, 2 and 3 show the effect of Cd and Ni on storage reserves of treated seeds. Protein contents, as determined from total nitrogen, increased with seed development in all treatments (Fig. 1). Cadmium significantly reduced the total protein content of mature seeds, a reflection of reduced seed mass. Nickel on the other hand did not result in any significant changes in protein content.

Lipid content increased with seed age until the YP stage, thereafter it levelled off (Fig. 2). In the case of the Cd treated seeds and control seeds, lipid levels were slightly lower than at the YP growth stage due to the fact that the BP seeds were slightly smaller in size (data not shown). Cadmium significantly reduced the lipid content of the mature seeds relative to the controls, again a reflection of reduced seed size. A similar effect was evident in Ni-treated mature seeds. However the effect of this metal was not statistically significant.

Soluble carbohydrate (sugars) and insoluble carbohydrate (starch) levels are given in Figure 3. Soluble carbohydrates increased with seed development, reaching a peak at maturity. Starch, on the other hand, increased during the early growth stages (IP and EP) and then declined in mature seeds. Cadmium decreased carbohydrate levels in treated compared to control seeds, although only the effect on starch was significant. Nickel decreased the levels of soluble sugars compared to the controls.

Discussion

The major effect exerted by Cd and Ni in this study was a general reduction in plant biomass. This was observed in the form of decreased root mass and decline in pod yield and was the response to both...
metal pollutants. Reduction in plant biomass as a result of heavy metal stress appears to be an almost universal finding (MacNicol and Beckett, 1985; Leita et al., 1993; Dudka et al., 1996; Ouzounidou et al., 1997). A few cases of yield enhancement due to metal pollutants have been reported in the literature, but these were from experiments utilizing extremely low concentrations of metals (Mishra and Kar, 1974; Breckle, 1991). Root growth appears to be especially susceptible to metal toxins compared to the shoots and has been used extensively as a convenient criterion of metal tolerance (Ouzounidou et al., 1997). A reduction in the yield of reproductive tissues has also been reported for several species (Huang et al., 1974; Cimino and Toscano, 1993; Singal et al., 1995).

Nickel concentrations in seeds were consistently higher than those in pods for all growth stages, whilst there was little difference in the Cd content of the two. This suggests that the pods pose only a minimal barrier, and exert little screening effect on metal pollutants. Other reports in the literature however do not support these findings. Cimino and Toscano (1993) examined uptake of Cd, Pb and Cu from sludge- or metal-amended soils into pea and bean seeds. Cadmium contents of the pods were significantly higher than of the seeds for both species. Haghiri (1973), experimenting with radioactive Cd in soybean plants, also found that Cd was higher in pods than seeds. It is possible that the pod to seed ratio may be dependent on the concentration of Cd supplied to the plant.

The low Cd content of seeds found in this study is similar to other values found in the literature, and is consistent with the general view that plant reproductive organs tend to be protected from toxic metals (Marschner, 1982). On the other hand, high seed concentrations of Ni have also been reported by other authors (Halstead et al., 1969; Cataldo et al., 1978) and support the contention that Ni appears to be an exception to this rule of minimal seed accumulation (Welch, 1995; Sajwan et al., 1996). Thus Ni appears to be more mobile within plants than Cd, as shown by the elevated Ni concentrations of this element in all plant parts. Whilst the concentration of Ni used in the nutrient solution was twenty times higher than that of Cd, calculation of the concentration factor (i.e. the ratio of the concentration of metal accumulated to that available for uptake) for seeds in this study, yields values of 20 for Cd and 50 for Ni. Thus the magnitude of accumulation in soybean seeds was greater for Ni than for Cd, and was not simply a result of a higher supplied concentration.

Many variables such as soil composition, temperature, pH, chemical form and concentration have been shown to affect plant uptake of metal pollutants in the field (Ernst, 1996). In this study, plants were grown in nutrient solution and the root environment strictly controlled. Extrapolation of results from plants grown in such an artificial system to those in the field can be difficult. In the soil, due to binding of metal cations by soil components not all the metal is available for plant uptake (Chaney, 1991). In nutrient solution systems, on the other hand, the proportion of bioavailable metal ions is often higher because of the absence of this binding and thus plant uptake is often greater from nutrient solution than from a soil containing the equivalent concentration of a given metal ion. Reports of Cd values slightly higher than 1 μg/g dm have been reported in the literature for seeds harvested from plants grown in polluted areas (Yoshida, 1986; Stefanov et al., 1995). Therefore it is felt that the levels of metal pollutants used in this study and the effects exerted by them are comparable to those that may be found at contaminated sites in the field. It is of interest that the limit for Cd in legume crops as recommended by the World Health Organization in 1992 (Pettersson and Harris, 1995) is 0.1 μg/g dm.
Both metal treatments resulted in declined pod numbers, which in turn affected total seed yield. Thus the primary effect of these metals was on early events such as flower production or fruit set. Once committed to pod formation however, the pollutants had differing effects on seed development. Nickel treatment resulted in reduced numbers of seeds per pod, but seed mass was equivalent to control seeds. Cadmium treatment resulted in the same number of seeds per pod as the control, but individual seeds were smaller. This could be explained in terms of photosynthate available from the parent for reserve accumulation. Because Ni treatment reduced the number of seeds during early development, there was more photosynthate available per seed for reserve accumulation. With greater numbers of seeds reaching the stage of nutrient deposition, Cd treatment resulted in reduced storage reserve accumulation and this affected seed mass. Although the total concentration of Cd in the seeds was low, 83% was located in the cotyledon, the principal site of storage reserve deposition. On the other hand, only 43% of the Ni taken up into the seeds was located in the cotyledons. This may be the reason that reserves are lowered in seeds exposed to Cd, but reserve accumulation and hence seed size were not affected by Ni. Cieslinski et al. (1996) concluded that yield reduction in strawberry fruit when grown in Cd-amended soil resulted mainly from decreases in fruit number rather than average weight per berry. Moraghan (1993) in investigating the effect of the same metal pollutant found similar effects on yield parameters of flaxseed. On the other hand, Singal et al. (1995), examined the effect of Cd on seed mass of fenugreek, and found that at all developmental stages there was a general decrease in seed size with increasing Cd concentration.

The differing metal distribution patterns found in the seeds is interesting. When expressed as percentage of total metal uptake, 42% of the total Ni was localized in the maternal tissue of the testa and is unlikely to affect subsequent germination. Fifteen percent was found in the axis. However, despite this relatively high value, it was found (data not reported) that seed germination was not profoundly affected, vigour was slightly decreased relative to the controls but viability was the same. In the case of Cd, although the total concentration of the metal in the seed was low, 83% was located in the cotyledon and comparatively little in the testa (17%) or axis (0.1%). Even though the amount in the axis was extremely low, vigour was also slightly decreased in these seeds, but there was no effect on viability. Thus, the results indicate that Cd is more toxic than Ni and exerts a more pronounced effect on seed development.

It is possible that the quality of the storage reserves within the seed are altered as a response to the presence of either metal pollutant, since only the quantities of storage reserves were investigated in the present study. Stefanov et al. (1995) found that lead altered the lipid content in seeds of green pepper, shifting the balance between saturated and unsaturated fatty acids in a complex manner. Cadmium was found to generally increase lipid phosphorus (P) and decrease protein P in the seeds of fenugreek (Singal et al., 1995). Further studies on the effect of toxic metals on the chemical composition of soybean seeds may be rewarding, especially if the nutritional value is affected. Although it is well documented that soybean seeds contain very little starch at maturity (Adams et al., 1980) results from these experiments consistently showed starch contents up to 20 mg/seed in the oldest growth stage. This may be due to the cultivar, but is most likely due to inefficient separation of soluble sugars from starch during the extraction process.

In conclusion, it can be seen that the presence of metal pollutants in the nutrient solution greatly affected the parent plant. At levels of Cd or Ni where adult plants could survive, seed production was greatly diminished. Significant amounts of metal did enter the seeds, especially in the case of Ni due to its enhanced mobility. This did not markedly reduce the quality of the seed with respect to the quantity of nutrients in the case of Ni, however yields of storage reserves from Cd-treated plants were reduced. Cadmium appears to have a more profound effect on seed development than Ni.

Acknowledgements

This work was supported by the FRD (Foundation for Research Development), South Africa.

References


Received 22 January 1998, accepted after revision 10 July 1998 © CAB INTERNATIONAL, 1998