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The use of biological tests for establishing the influence of flue dust from lead and zinc works on plant development *

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Abstract

The biological activity of water extracts of flue dust from lead and zinc works was assayed by means of biological tests. As test species served: *Pinus silvestris, P. nigra, Trifolium pratense, Cucumis sativus* variety Delikates, *Raphanus sativus, Pisum arvense* and *Allium cepa*. The extracts tested with a containing as low as 26.0 mg/ml Zn and 1.02 mg/ml Pb, caused a shortening of the roots of the tested plants. Most sensitive proved to be *Cucumis sativus, Trifolium pratense* and *Pinus silvestris*. Cytological analysis of the growth apex of *Allium cepa* roots demonstrated that the solutions used caused disturbances in cell division in the form of c-mitosis and lowered the value of the mitotic index.

INTRODUCTION

Biological tests are more and more frequently used in investigations on the effect of air pollution on the vegetation. These tests are, as compared with chemical analyses, more convenient, and they allow to follow the reaction of plants to the presence of noxious substances.

The biological test developed by S. Prát (Sládeček, 1961) consists in evaluation of the germination capacity of seeds and the development of seedlings. At first this test was applied for estimation of the toxicity of industrial wastes and later also in other studies. For instance Paluch (1966, 1968) undertook a trial of establishing the degree of air pollution in highly industrialized towns by examining the influence of rain water on the development of seedlings and Mašek (1971, 1973) after introducing certain modifications, applied the same test in the assay of the toxicity of coke dust.

* The investigations were performed as part of the work on "The influence of industrial air pollution on Scots pine (*Pinus silvestris* L.)".

The present paper reports the results of investigations on the effect of flue dust from lead and zinc works on the germination and development of seedlings of several plant species. A modification of M a š e k' s (l. c.) biological test was applied, adapted to the character of the observations peformed.

MATERIAL AND METHODS

For studying the effect of flue dust from lead and zinc work on the germination and development of seedlings the following plant species were used: *Pinus silvestris* L., *P. nigra* Arnold, *Trifolium pratense* L., *Cucumis sativus* L. variety Delikates, *Raphanus sativus* L. and *Pisum arvense* L.

The seeds germinated on Petri dishes as follows: double pieces of cheesecloth were placed on the bottom of well washed and dried dishes 9 cm in diameter and on these 25 healthy intact seeds were placed at regular intervals (in the case of *Pisum* 20 seeds). Seeding was done in 4 replications of 4 variants. In the control sample denoted O the cheesecloth was soaked in 5 ml of boiled tap water, and in variants A, B and C the same amount of water extract from flue dust was introduced. These extracts were prepared from 2, 4 and 8 per cent suspensions of furnace dust from the lead and zinc works, shaken for 3 h. at 20° C. The filtrates were clear, straw-coloured, becoming darker with higher concentration. The zinc and lead content in the extracts was determined colorimetrically.

The seeds germinated under daylight at room temperature. Observations concerning germination and development were continued up to the full expansion of the cotyledones in the controls. At this developmental phase the total number of germinated seeds and developed seedlings was counted. Then the main root and hypocotyl lengths were measured in all the specimens of the given experimental variant. From these measurements the arithmetic mean and the hypocotyl length to root length ratio are calculated.

Moreover, on preparations of the onion (*Allium cepa* L.) root cap cytological analysis was performed. The seedlings of the latter plant were cultured in the same conditions as those of the above named species. Smears were prepared by the method of M u r i n (1961) with the use of gentian blue staining. The mitotic indexes were calculated expressing the number of cells in division stages per 1000 meristematic cells.

RESULTS

1. Zinc and lead content in water extracts from flue dust

The water extracts from flue dust of the lead and zinc works had a slightly acidic pH passing to neutral (variant C). The zinc and lead concentration was lowest in variant A. In the other variants the content

of both metals was almost doubled, the maximum reaching 109 mg/ml for Zn and 5.3 mg/ml for Pb (Table 1).

Table 1

pH and zinc and lead content in water extracts from flue dust

Experimental variant	pH	Content mg/ml	
		Zn	Pb
0	Control samples		
A	6.1	26.0	1.02
B	6.3	50.0	2.30
C	6.6	109.0	5.30

2. Germination and growth of test plant seedlings

The results obtained for investigated plants are shown in Table 2.

(a) *Pinus silvestris* L.

Seeds of *P. silvestris* began to germinate 4 days after sowing. At first no noticeable difference appeared in the course of germination in any of the variants, and thus at all concentrations of the solution.

The germination capacity was calculated as the mean from 4 replications, and it amounted to 68—87 per cent. In the control experiment and in variant A nearly all the germinating seeds developed into seedlings, while in variants B and C the number of seedlings was as low as 66 and 55, respectively (Table 2).

Measurements of root length of the pine seedlings demonstrated marked differences, particularly between the specimens from the extreme combinations (Fig. 1). In the controls and in variant A the difference between the maximal and minimal root length was wide, whereas when higher concentrations of zinc and lead were used (variants B and C) the variations were slight (Table 2).

The above-ground parts, the hypocotyl, did not show as wide differences as did the roots. The hypocotyl length reached its maximum in variant A in which the extract of flue dust contained 26.0 mg/ml Zn and 1.02 mg/ml Pb.

Table 2

Number of germinated seeds and dimensions of test plant seedlings in particular variants of the experiment

Experimental variant	Number of:		Dimensions of seedlings, cm					
	germinated seeds	developed seedlings	root			hypocotyl		
			min.	max.	mean	min.	max.	mean
			I *Pinus silvestris*					
O	87	85	0.2	4.5	2.59±0.11	0.5	4.0	2.53±0.10
A	86	85	0.3	4.0	1.47±0.09	0.6	4.5	3.13±0.10
B	86	66	0.2	1.1	0.45±0.08	0.4	3.8	2.09±0.10
C	87	55	0.2	0.7	0.35±0.06	0.6	3.4	1.77±0.10
			II *Pinus nigra*					
O	85	82	0.3	7.1	3.91±0.13	1.3	5.8	3.69±0.09
A	79	71	0,2	5.7	2.89±0.15	0.5	4.9	3.39±0.12
B	74	64	0.2	2.9	1.31±0.08	0.8	4.7	2.97±0.13
C	70	65	0.2	1,2	0.58±0.03	0.7	3.7	2.16±0.08
			III *Trifoljum pratense*					
O	79	66	0.3	6.1	1.75±0.13	0.3	1.7	1.06±0.03
A	67	51	0.2	1.6	0.65±0.05	0.3	1.2	0.71±0.03
B	63	47	0.2	0.9	0.43±0.04	0.2	1.0	0.51±0.03
C	38	21	0.2	0.6	0.29±0.02	0.2	0.6	0.37±0.03
			IV *Cucumis sativus* var. Delikates					
O	90	88	5.8	10.5	8.21±0.22	0.4	1.3	0.72±0.04
A	98	97	0.9	7,2	3.01±0.28	0.4	2.0	1.32±0.08
B	90	89	0,5	4.2	1.31±0.14	0.5	1.5	0.99±0.05
C	90	85	0.3	1.6	0.65±0.05	0.6	1.9	1.22±0.07
			V *Raphanus sativus*					
O	92	85	0.7	5.3	2,52±0.13	0,2	2.5	1.02±0.05
A	83	52	0.6	4.4	1.92±0.14	0.3	1.8	0.77±0.05
B	95	77	0.5	3.4	1.52±0.09	0.4	2.2	1.07±0.06
C	95	78	0.2	4.1	1.25±0.09	0.3	2.5	1.10±0.06
			VI *Pisum arvense*					
O	75	68	4.0	13.4	8.59±0,28	0.4	5.2	2.39±0.15
A	72	60	1.7	8.7	4.21±0.18	0.5	4.7	1.91±0.14
B	78	70	0.8	4,2	2.74±0.10	0.3	5.0	1.68±0.14
C	73	55	0.7	3.1	1.61±0.06	0.2	4.0	1.13±0.14

The experiment with *Pinus silvestris* seeds was repeated twice and each time the results were closely similar. Most numerous seedlings were obtained in variant A. The hypocotyls of these seedlings were longest and their maximal and mean dimensions were larger than the control values.

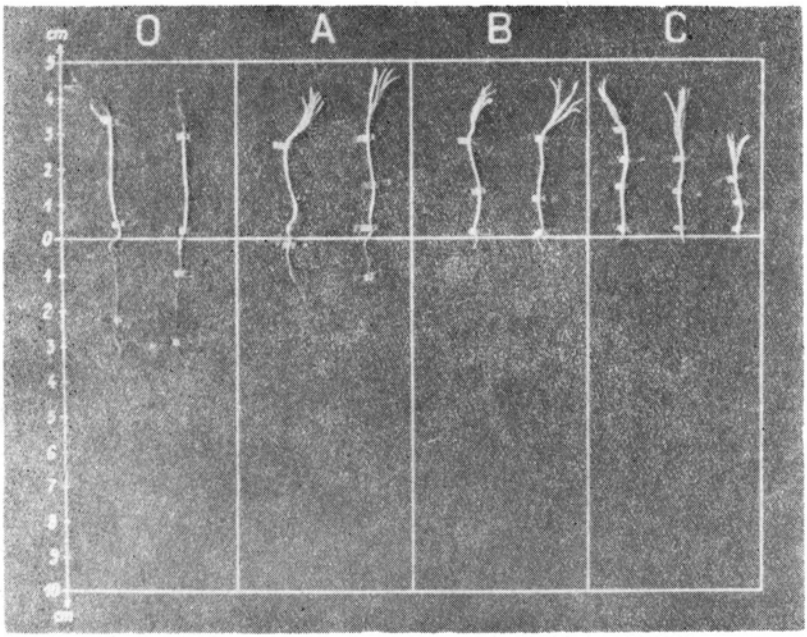

Fig. 1. *Pinus silvestris* L. seedlings

O — control, A, B and C — experimental variants with increasing Zn and Pb content in the solution applied. Photo. by A. Kalemba

(b) *Pinus nigra* Arnold

The highest per cent of germinated seeds and most numerous seedlings were obtained in the control group. In the remaining variants germination was defective and the number of seedlings decreased (Table 2).

The dimensions of *Pinus nigra* roots, although smaller in the particular variants (Fig. 2) were not so much reduced as in the case of *Pinus silvestris*. The hypocotyl also developed differently. Its length gradually diminished with the increase of Zn and Pb content in the extracts. Thus, no stimulating action of these extracts on the hypocotyl of *Pinus nigra* seedlings was noted in variant A, as had been noted in the case of *P. silvestris*.

(c) *Trifolium pratense* L.

The appearance of the first germs was noted before the end of 48 h. After 72 h the germinating seeds were counted in each variant, and again

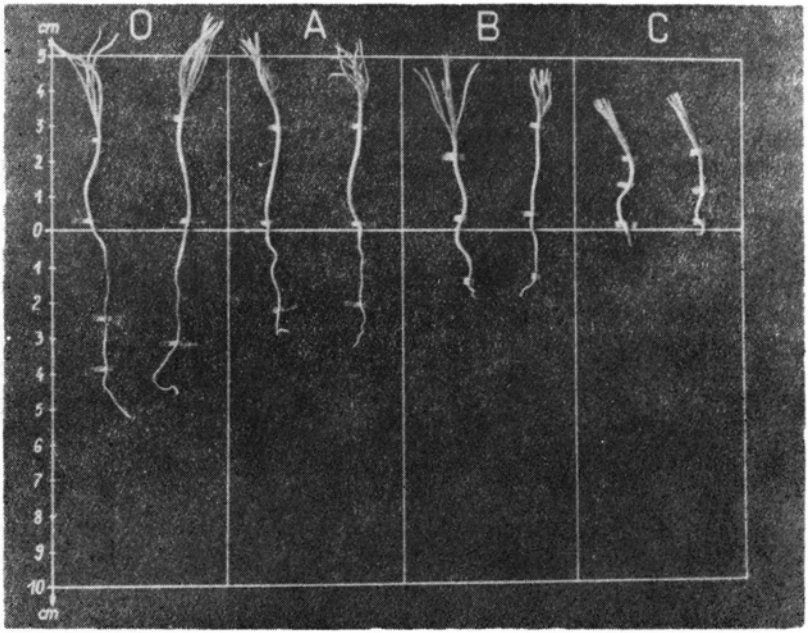

Fig. 2. *Pinus nigra* Arnold seedling
Notations as in Fig. 1. Photo. by A. Kalemba

at the moment when the experiment was ended. The number of germinating *Trifolium pratense* seeds was as follows:

Variant	O	A	B	C
Number of germinating seeds				
a. after 72 h.	71	46	52	26
b. after 10 days	79	67	63	38

It results from these data that in the control experiment the majority of seeds developed germs between the second and third 24 h. after seeding (only few seeds germinated later), whereas in the variants A—C almost 1/3 of the seeds germinated much later. The highest germination capacity (79%) was noted in variant O, in the remaining ones it decreased gradually till in variant C it was almost 1/2 lower than in the control. In general, seedlings did not develop from the seeds germinating at a delayed period.

It results from measurements of root and hypocotyl length that both these parts of the plants became shorter with increasing concentration of zinc and lead in the solutions (Table 2).

(d) *Cucumis sativus* L. var. Delikates

Germination started 30 h after seeding. The germinating seeds were most numerous in variants A and B, and least in the control experiment (Table 3). The next inspection after 48 h of the experiment demonstrated that in variants O, A and B the course of germination was more or less

Table 3

Course of germination of *Cucumis sativus* var. Delikates seeds

Hours	Experimental variant			
	O	A	B	C
	No. of germinated seed			
30	38	46	42	40
48	86	87	85	60
72	90	95	89	87
135	90	98	90	90

regular, whereas in variant C the process showed a tendency to decline, and the number of germinated seeds reached the same level as in the control only at the last moment. It is noteworthy that germination not only occurred fastest in variant A, but the highest per cent (98%) of germinated seeds and developed seedlings was also obtained in this combination (Table 2).

The *Cucumis sativus* seedlings in combination O had a well developed root system with an elongated main root which in variant A was reduced to one half, so that in some seedlings the lateral roots were longer (Fig. 3). A further inhibition of development of the underground part of the seedlings was observed in variant B where the solution contained 50 mg/ /ml Zn and 2.3 mg/ml Pb. The seedlings growing in these conditions had a shortened and thickened main root, frequently curved at the end with few lateral roots. Most noxious for the development of *Cucumis sativus* proved the extract applied in variant C. In this case only few seedlings had a very short root, whereas in most specimens its development was inhibited in the initial phase of seed germination.

The course of growth of the above ground parts of the *Cucumis* seedlings differed from that of the root, in variants A—C they reached larger maximal and mean dimensions as compared with the control plants (Table 2).

Measurement of the cotyledons of *Cucumis* seedlings demonstrated that, as regards length, they were almost equal in all the experimental combinations, only slightly shorter than in the controls, but their width decreased with the increase in the concentration of the tested solutions.

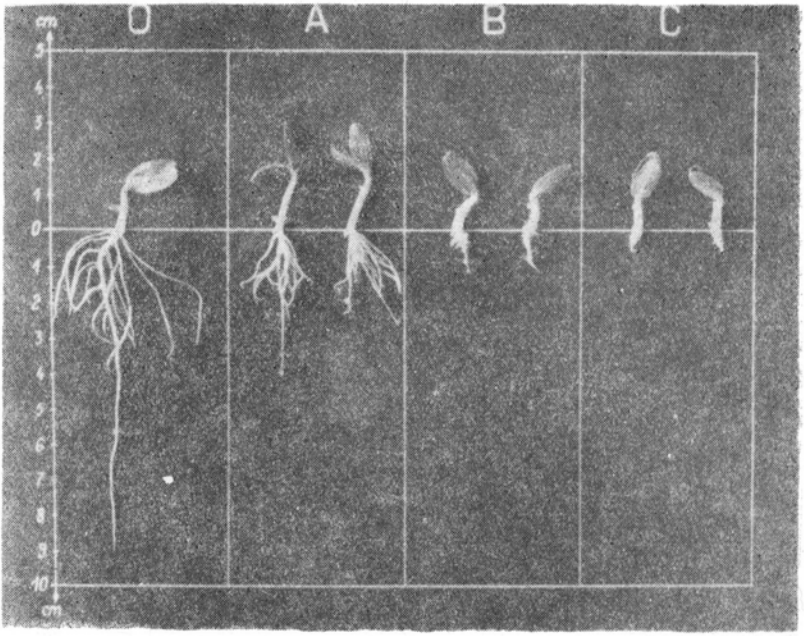

Fig. 3. *Cucumis sativus* L. var. Delikates seedlings
Notations as in Fig. 1. Photo. by A. Kalemba

(e) *Raphanus sativus* L.

The heginning of germination was noted 24 h. after seeding. The germination capacity was highest in variants B and C, but seedlings developed most numerously in the control combination (Table 2).

The mean root length decreased gradually in the successive variants, but the difference as compared with the control plants and those of variant C, was not as wide as in the case of the above discussed species (Fig. 4). On the other hand, the mean hypocotyl length in Raphanus sativus seedlings was almost equal, only slightly shorter in variant A.

(f) *Pisum arvense* L.

The germination capacity was rather high in all experimental variants (90—97%), but only few seedlings developed in variant C (Table 2). A wide disproportion was observed in root length between the control specimens and those of the remaining variants (Fig. 4). Moreover, in variants B and C the root cap was thickened and necrotic, only few plants had lateral roots. The mean hypocotyl dimensions decreased successively and were smallest in variant C.

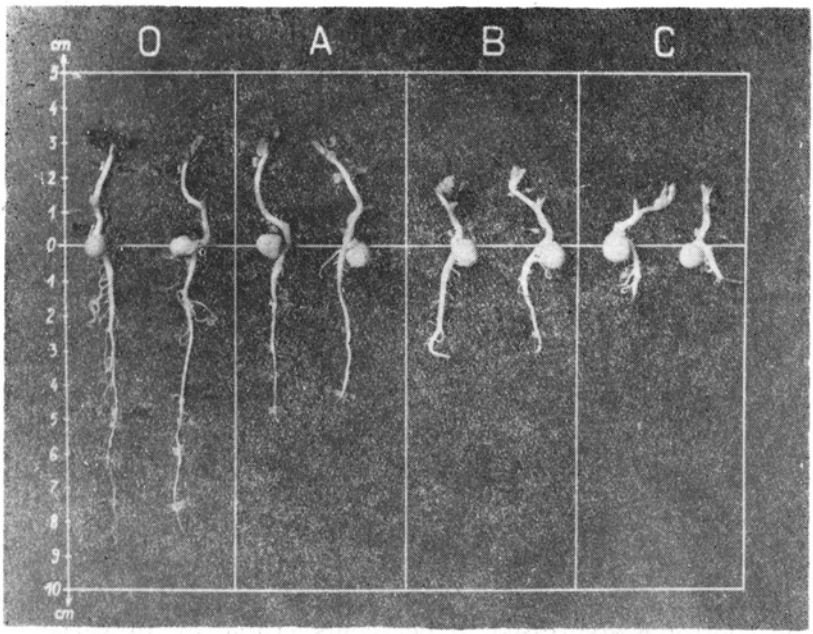

Fig. 4. *Pisum arvense* L. seedlings.
Notations as in Fig. 1. Photo. by A. Kalemba

3. Assay of toxicity of water extracts from flue dust of the zinc and lead works

The toxicity of water extracts of this flue dust was assayed on the basis of: (a) the ratio of the hypocotyl length to root length, (b) the percentual decrease in root growth and (c) cytological analysis.

(a) Hypocothyl-length to root-length ratio

These values for the seedlings of the species tested and for the particular experimental variants are shown in Table 4. It results from these data that in *Pinus silvestris, P. nigra* and *Trifolium pratense* the hypocotyl-length to root-length ratio is higher than 1 in all cases except the experimental combination. This ratio is particularly high in the pines. In the tested species even in the control combination, it is close to 1. As regards the cucumber, the hypocotyl increases in length faster than does the root only in combination C, whereas in radish and field pea in all variants the hypocotyl-to-root ratio shows low values.

Table 4

Hypocotyl-length to root-length ratio in control plants

Experimental variant	Plant species					
	Pinus silvestris	*Pinus nigra*	*Trifolium pratense*	*Cucumis sativus* var. Delikates	*Raphanus sativus*	*Pisum arvense*
0	0.98	0.94	0.58	0.09	0.40	0.28
A	2.13	1.20	1.09	0.53	0.40	0.48
B	4.98	2.32	1.19	0.76	0.70	0.61
C	5.06	3.79	1.28	1.86	0.88	0.70

(b) Percentual decrease in root growth

The decrease in root length of seedlings in variants A—C as compared with the control is expressed in per cents (Table 5). In variant A the smallest reduction of root growth (average up to 25%) was noted in *Pinus nigra* and *Raphanus*. It was much more pronounced (up to 50%) in *Pisum* and *Pinus silvestris*, whereas in *Cucumis* and *Trifolium* the roots were shortened by one half already in combination A as compared with the control specimens.

Table 5

Reduction of root length as compared with control expressed in percents

Experimental variant	A			B			C		
	< 25%	25—50 %	> 50 %	do 50%	50—80 %	> 80 %	< 50%	50—90 %	> 90 %
Cucumis sativus var. Delikates			× × ×			× × ×			× × ×
Trifolium pratense			× × ×		× × ×			× × ×	
Pisum arvense		× × ×			× × ×			× × ×	
Pinus silvestris		× × ×				× × ×		× × ×	
Pinus nigra	× × ×				× × ×			× × ×	
Raphanus sativus	× × ×			× × ×			× × ×		

In variant B *Raphanus* was the only species in which root reduction did not reach 50 per cent, and in *Trifolium*, *Pisum* and *P. nigra* it attained more than 80 per cent; in *Cucumis* and *P. silvestris* root shortening even exceeded this value.

In variant C *Raphanus* also exhibited the smallest reduction of root growth as compared with the control, and *Cucumis* the highest values.

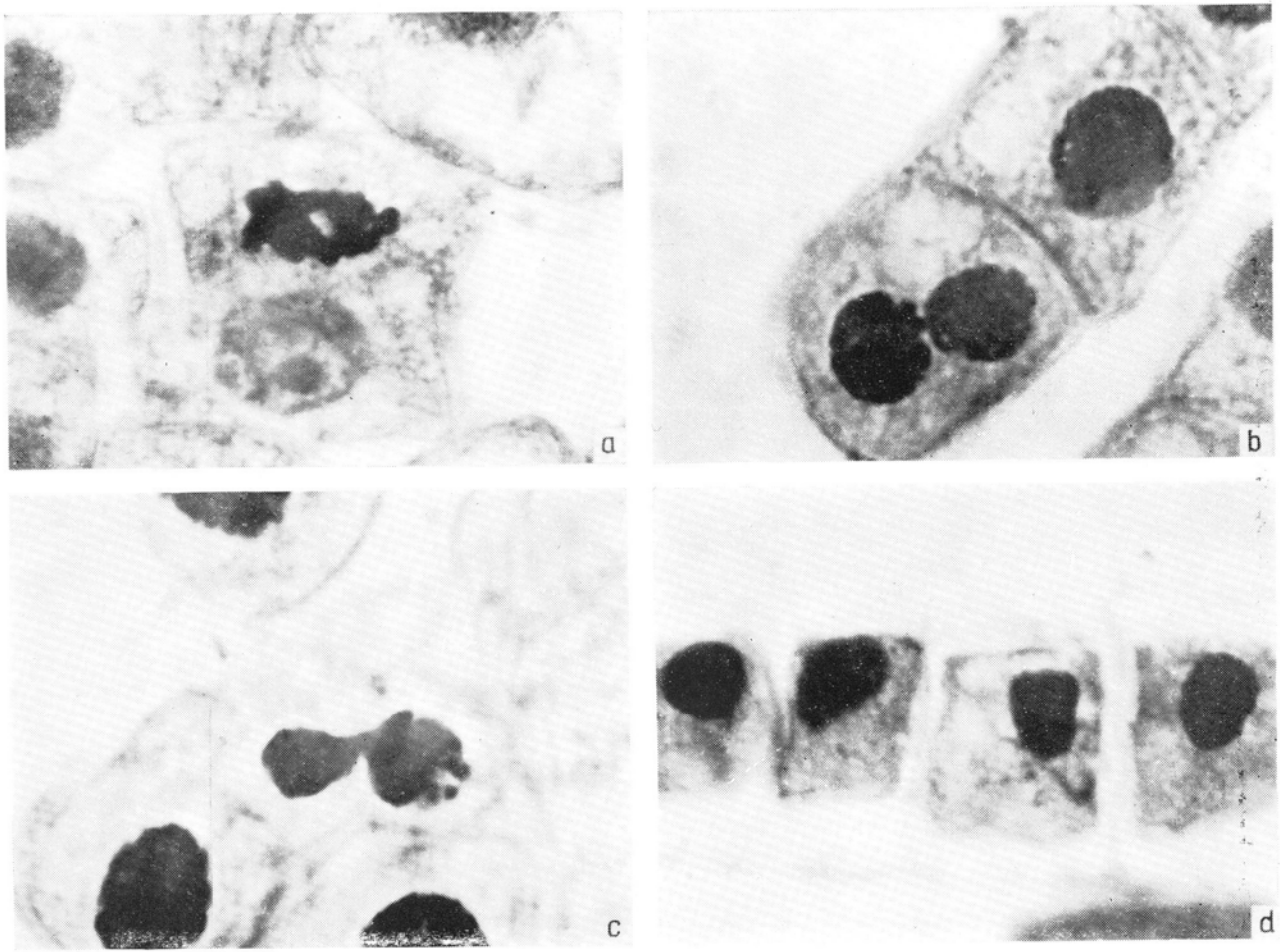

Fig. 5. Disturbances in the course of mitotic division of meristematic cells of *Allium cepa* L. roots

a — shortening and thickening of chromosomes in metaphase, *b* — binuclear cells with unmerged nuclei, *c* — binuclear cells with merged nuclei, *d* — pycnosis. Photo. by A. Grzybek

(c) Cytological analysis

In the course of mitotic division of meristematic cells in the roots of *Allium cepa* the following disturbances were observed: the shortening and thickening of chromosomes in metaphase, the appearance of binuclear cells with merged or unmerged nuclei and pycnosis (Fig. 5). The latter phenomenon consisting in accumulation of chromatin substance into a homogeneous, strongly staining compact mass with enhanced viscosity is a transitional stage leading to disintegration of the cell nucleous.

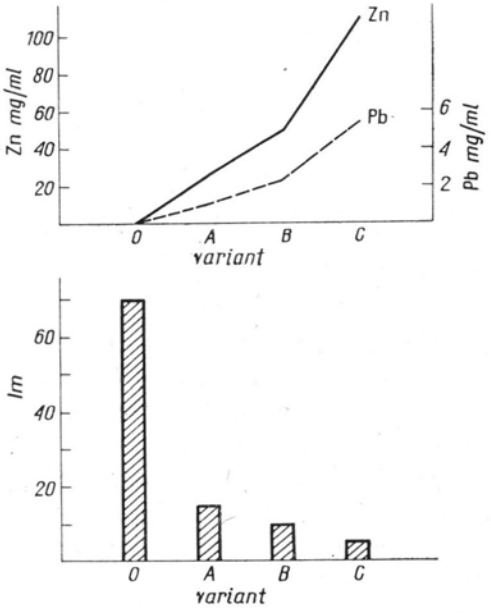

Fig. 6. Relation between amount of Zn and Pb in the water extracts from industrial dust and the mitotic index value in the particular variants of the experiment
Im — mitotic index, O, A, B and C — experimental variants

The inhibitory influence of the tested extracts on the development of roots in onion seedlings was also noticeable in the values of the mitotic index (Im). These values were inversely proportional to the zinc and lead concentration in the extracts of flue dust (Fig. 6).

DISCUSSION

The result obtained indicate that zinc and lead compounds from flue dust pass into the water extracts and are subsequently taken up by plant roots. These extracts variously affect the course of seed germination in dependence on the zinc and lead concentration in them and on the plant species.

The number of *Pinus silvestris* germinating seeds is almost equal in all the experimental combinations, whereas in *Cucumis* a stimulating effect of the extract containing 26.0 mg/ml Zn and 1.02 mg/ml Pb is observed. The germination capacity of the seeds is in this case highest in variant A.

In *P. nigra* and *Trifolium* germination deteriorates with the rise of concentration of the extract, this is most spectacular in the case of *Trifolium* (variant C).

The course of germination is different in *Raphanus* and *Pisum* than in the previously discussed species. In both these plants a lowered germination capacity is observed in variant A, whereas in variants B and C, in spite of the higher zinc and lead concentration, the number of germs is higher.

The noxious influence of extracts containing zinc and lead on seedling development is manifested above all in the inhibition of elongation growth of the roots. In extreme cases the root length is reduced by more than 90 per cent as compared with the control plants. On the other hand, the above-ground part of the plants, the hypocotyl, develops under the same conditions normally or even shows enhanced development.

The different behaviour of both thse plant organs may be explained by the fact that roots come into immediate contact with the substrate containing the toxic components, therefore they are the first to react to this unfavourable influence. The hypocotyl, on the other hand, is less exposed to the action of the toxic compounds. In roots of many plants, as shown by the investigations of other authors (Joseph et al., 1971; Jones et al., 1973a, b) there exists a mechanism restricting the transfer of zinc and lead to the above ground parts.

In all the species included in the experiment inhibition of root elongation growth appeared even in variant A, this indicating the toxicity of the extract containing 26 mg/ml Zn and 1.02 mg/ml. Pb. *Cucumis* seedlings from variant A when transferred to pure water, continued to develop normally, since the fuctions of the main root showing necrosis of the root cap were taken over by the numerously developed lateral roots. In the case of higher concentrations of zinc and lead (variants B and C), however, the changes in development involved the lateral roots as well and were irreversible.

The method of assay of the toxicity of water extracts from industrial dust, developed by Prát and applied by other authors (Paluch 1966; 1968; Mašek, 1971, 1973; Spálény, 1970; Supuka, 1974) is based on the assumption that the tested solution is not poisonous if the plant roots grow faster than the hypocotyl, whereas if the situation is reversed, the extract has a toxic effect on the developing seedlings. Thus, the ratio of hypocotyl length to root-length, which in normal conditions is lower

than 1 is an index of the toxic influence of the components of the extract.

The data obtained in the present study indicate that the hypocotyl-to--root ratio is different in particular plants and largely depends of specific characters. For instance in *Cucumis* a very short hypocotyl develops with large cotyledons, whereas the root is elongated. Hence the ratio of hypocotyl-length to root length is even in variants A and B lower than 1, although it would result from the extent of root reduction that the solution applied has a toxic effect on their development. On the other hand in *Pinus silvestris* and *P. nigra* the hypocotyl is almost as long as the root and even in the control plants the length-ratio is close to 1.

Assay of the toxicity of the flue dust extract on the basis of the hypocotyl-length to root-length ratio seems, therefore, appropriate only in cases when the concentrations of the toxic substances are high. Then, in all species the hypocotyl is longer than the root. On the other hand, when the concentration of the solution is low, in some plants the hypocotyl-to-root ratio may be below 1, thus suggesting that there is no toxic influence.

Of high importance in investigations of this kind is a suitable choice of seeds as regards their size and germination capacity. Seeds of *Cucumis sativus* for instance exhibit such properties. They germinate as early as after 24 h., develop rapidly a long root and a hypocotyl with large cotyledons so that observations and measurements are easy. Spruce (*Picea*) and pea (*Pisum sativum* L.) seeds, on the other hand, were unsuitable for such experiments. Particularly the pea seeds required a higher imbibition of the cheesecloth with the extracts and this in turn caused rotting of the seeds.

Evaluation of the toxic effect of water extracts from industrial dust on the basis of the percentual reduction of seedling growth in the case of application of these extracts to the roots of seedlings seems more reliable. According to the adopted criterion (W o o l s o n, 1973), the given solution has a toxic influence on development when it causes a reduction of root length by 50 per cent as compared with the control plants.

In the case of the species included in the experiment, 3 groups may be distinguished on the basis of the above mentioned criterion, differing by their sensitivity. Most susceptible to the extracts from dust of the lead and zinc works proved the cucumber and trefoil. In these species the reduction of root growth by more than 50 per cent was already noted in variant A at a concentration of 26 mg/ml Zn and 1.02 mg/ml Pb. To the intermediate more tolerant group belong the field pea and *Pinus silvestris*, and to the most resistant *P. nigra* and radish. In the latter plants the reduction of root length, as compared to the control plants was smallest.

In variant B this order is somewhat changed. *Cucumis* continues to exhibit the greatest reduction of root length, and from among the species

included in the preceding variant into the tolerant group *Pinus silvestris* shows the widest difference. Seedlings of these plants show a root reduction by more than 80 per cent as compared with the controls. Only in *Raphanus* the reduction of root growth continues to be below 50 per cent.

Most of the tested species show in variant C inhibition of root growth reaching 90 per cent. The only exception is the cucumber, because its root is more than 90 per cent shorter than that of controls, and radish in which only a concentration as high as 109 mg/ml Zn and 5.30 mg/ml Pb reduced the root length by 50 per cent. Thus, this plant may be considered as exceptionally resistant to zinc and lead solutions.

Cytological investigations demonstrated that the water extract of flue dust from the lead and zinc works produced disturbances in mitotic divisions. The most frequent was the formation of binuclear cells and pycnosis. These disturbances occurred already in variant A, but became more pronounced in the remaining ones with higher zinc and lead concentrations. The values of the mitotic index in the particular variants were also much lower as compared with those for the control combination.

Heavy metal (mercury and lead) compounds, as affirmed by Ahlberg et al. (1972), cause disturbances in cell division, producing the phenomenon of c-mitosis. In thecase of the tested extracts containing zinc and lead it could not be established which of these metals had the strongest cytostatic effect. The inhibition of root growth in the seedlings was probably the result of the synergistic action of both components.

CONCLUSIONS

1. The test based on Prát's method may be considered as useful in the assay of the toxic influence of industrial dust on plants. It allows a rapid evaluation of the biological activity of flue dust emitted by a given industrial establishment and gives an answer to the question what concentration of noxious substances inhibits root elongation growth.

2. Of high importance in such tests is, as shown by preliminary investigations, a suitable choice of seeds as regards their size and germination capacity in experimental conditions and the reaction of seedlings to the components of the extract applied.

3. Determination of the toxicity of the solution on the basis of root length reduced by 50 per cent as compared with the control plants demonstrates not only the toxic action of the substances contained in the solution, but makes possible the establishment of the concentration of agents toxic to the particular plant species with different susceptibility.

4. Cytological analysis allows to establish whether the given solution has an effect on the meristematic cells and what are the results of this

influence. This is particularly important when extracts with a higher content of toxic substances are used, since then the symptoms of damage to the plants, as for instance inhibition of linear growth of the root, may be the result of general poisoning of the cells and not of an antimitotic effect.

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Zastosowanie testów biologicznych do określania wpływu pyłów kominowych huty ołowiu i cynku na rozwój roślin

Streszczenie

Określenie toksyczności pyłów kominowych huty ołowiu i cynku przeprowadzono przy pomocy testu biologicznego Práta (Sládeček 1961). Zawartość Zn i Pb w użytych do badań roztworach przedstawiono w tabeli I. Gatunkami testowymi były: *Pinus silvestis, P. nigra, Trifolium pratense, Cucumis sativus* odm. Delikates, *Raphanus sativus, Pisum arvense* i *Allium cepa.*

W czasie trwania doświadczenia poczyniono obserwacje dotyczące kiełkowania nasion i rozwoju siewek. Uzyskane wyniki przedstawiono na ryc. 1—4 oraz w tabelach 2 i 3.

Toksyczność wodnych wyciągów oceniano na podstawie stosunku długości hypokotylu do długości korzenia (tab. 4), procentowego obniżenia wzrostu korzenia siewek z poszczególnych wariantów doświadczenia w stosunku do okazów kontrolnych (tab. 5) oraz analizy cytologicznej (ryc. 5 i 6).

Na podstawie przeprowadzonych badań stwierdzono, że wodne wyciągi z pyłów huty ołowiu i cynku wpływają szkodliwie na rozwój siewek analizowanych roślin już w stężeniu 26 mg/ml Zn i 1,02 mg/ml Pb. Ujemny wpływ tych wyciągów wyraża się skróceniem długości korzenia, zaburzeniami w przebiegu procesu mitozy oraz obniżeniem wartości indeksu mitotycznego.

Spośród analizowanych roślin najbardziej wrażliwymi okazały się: ogórek gruntowy, koniczyna łąkowa oraz sosna zwyczajna. Dużą odpornością cechowała się rzodkiew zwyczajna. Stopień uszkodzenia siewek zależał więc nie tylko od stężenia roztworu, ale również od cech gatunkowych danej rośliny. Stąd też duże znaczenie przy określaniu biologicznej aktywności pyłów hutniczych ma odpowiedni dobór roślin testowych.