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The Uptake of Platinum Group Metals by Tomato, Bean and Corn

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The uptake of platinum, palladium and rhodium by tomato, corn and bean plants grown hydroponically, has been investigated. Platinum, and to a lesser extent, palladium, is transported to the tops of the plants, and extensively taken up by the roots. Growth of the plants and calcium translocation is affected. Rhodium appears to have little effect on the growth of tomato and corn plants.

Introduction

Hamner [1] investigated the effects of platinum-(IV) chloride on bean and tomato plants. He found that plants grown in sand culture with added $[PtCl_6]^{2-}$ have smaller leaves, are inhibited in growth and resist wilting longer than controls. However, the uptake of platinum by the plants was not investigated. The object of this present investigation is two-fold, firstly to ascertain if plants are able to extract platinum metals from solution at low levels and secondly to find species which might grow and colonise tips from mining areas. In this paper we present the results of preliminary investigations into the uptake of platinum, palladium and rhodium.

Experimental

The experiments were carried out in a Prestcold controlled environment growth room. The conditions were: illumination, 10^3 ft candles; temperature, 20 ∓ 1 °C (14 hour day), 15 ∓ 1 °C (night); relative humidity, 65%.

Uptake of Platinum Applied as $(NH_4)_2[PtCl_6]$

Seeds were placed in rows in a 355 X 217 mm seed tray of acid washed Loch Aline sand for germination. The sand was moistened with demineralised water and the tray was transferred to the growth room. During the germination period the tray was covered with polyethylene film. When the first leaves had become established, the individual seedlings, selected for uniformity of growth, were transferred to 2 dm^3 black plastic boxes. Half strength nutrient solutions [2] were added to six boxes each containing four plants. When the plants were well established the boxes were treated with full strength nutrient solutions containing the following concentrations of platinum: 0.05, 0.5, 2.5, 5.0, 10.0, 30.0 ppm.

After 14 days the plants were harvested. Wet weights of the plant tops and roots were taken. The samples were then dried and reweighed. After wet ashing with concentrated nitric acid, the mixtures were taken to dryness. 2 cm^3 concentrated HCl and 5 cm^3 lanthanum chloride solution (200 mg dm^{-3}) were added and the samples were made up to 50 cm^3 for atomic absorption analysis. Standards were made up similarly. Results at the low end of the sensitivity scale were diluted and re-analysed using the carbon furnace. Calcium was assayed similarly in the presence of strontium chloride (5 mg dm^{-3}).

Uptake of Palladium Applied as $Na_2[PdCl_4]$

The methods described above were used. When the plants were well established full nutrient solutions containing the following contractions of palladium were added: 0.05, 0.5, 2.5, 5.0 ppm. The samples were analysed as before by atomic absorption techniques [3].

Uptake of rhodium applied as $Na_3[RhCl_6]$

The method was identical to that used for palladium.

Results

The results of the growth and uptake experiments are shown in Tables I–VII.

Plants fed with platinum solutions showed normal healthy growth with 0.05 ppm platinum. At 0.5 and 2.5 ppm levels there was evidence of chlorosis and a slowing of growth. Little growth was apparent at

TABLE I. Yields and Analysis of Tomato Plants Treated with $(NH_4)_2[PtCl_6]$.

Tops	A1	B1	C1	D1	E1	F1
Applied Pt/ppm	0.05	0.50	2.50	5.00	10.00	30.00
Wet weight/g	63.15	58.91	21.44	7.27	3.53	2.80
Dry weight/g	4.060	3.630	1.473	0.752	0.433	0.353
Water present/%	93.6	93.8	91.9	89.2	87.7	87.4
Total Pt/μg	6.0	23	32	10	19	40
Pt (dry wt)/ppm	1.4	6.3	21.7	13.3	43.8	113
Total Ca/mg	105	92	43.5	12.4	7.8	4.3
Ca (dry wt)/%	2.58	2.53	2.40	1.65	1.80	1.22
Roots Box	**A1**	**B1**	**C1**	**D1**	**E1**	**F1**
Applied Pt/ppm	0.05	0.50	2.50	5.00	10.00	3.00
Wet weight/g	11.60	11.23	7.00	3.47	1.11	0.32
Dry weight/g	0.720	0.764	0.560	0.318	0.170	0.066
Water present/%	93.8	93.2	92.3	90.8	84.7	79.2
Total Pt/μg	12	480	950	1425	1625	850
Pt (dry wt)/ppm	17	630	1760	4480	9560	12880
Total Ca/mg	6.5	5.9	4.6	2.1	1.3	0.43
Ca (dry wt)/%	0.90	0.77	0.85	0.660	0.76	0.65

TABLE II. Yields and Analysis of Corn Plants Treated with $(NH_4)_2[PtCl_6]$.

Tops Box	A2	B2	C2	D2
Applied Pt/ppm	0.05	0.50	2.50	5.00
Wet wt/g	7.76	10.486	4.446	4.557
Dry wt/g	0.473	0.762	0.344	0.346
Water present/%	93.9	93.6	92.3	92.4
Total Pt/μg	2.5	3.0	4.5	8.5
Pt (dry wt)/ppm	140	343	1496	3575
Roots Box	**A2**	**B2**	**C2**	**D2**
Applied Pt/ppm	0.05	0.50	2.50	5.00
Wet wt/g	3.137	3.716	2.003	3.056
Dry wt/g	0.178	0.219	0.201	0.308
Water present/%	94.3	92.2	90.0	89.9
Total Pt/μg	25	100	300	1100
Pt (dry wt)/ppm	140	343	1496	3575

5.0 ppm, roots were yellow and stunted; at 30 ppm there was no growth, severe yellowing and stunting of roots, and necrotic spots on the lower leaves.

For palladium treated plants, drop-off in yield occurs between the 0.5 and 2.5 ppm levels, the effect is similar to that found with platinum treated plants but less drastic.

At the concentrations investigated, rhodium had little effect on the growth of the plants.

Discussion

The effects of platinum are largely the same as those previously described for bean and tomato [1], where it was reported that the percentage of water in the plant, the yield and the calcium content decreased with increasing concentrations of platinum applied. Tables I–III show that this behaviour is observed for tomato, bean and corn plants treated

TABLE III. Yields and Analysis of Bean Plants Treated with $(NH_4)_2[PtCl_6]$.

Tops Box	A3	B3	C3	D3	E3	F3
Applied Pt/ppm	0.05	0.50	2.50	5.00	10.00	30.00
Wet wt/g	24.16	15.08	12.03	13.22	7.72	3.61
Dry wt/g	2.214	1.279	1.386	1.578	0.986	0.511
Water present/%	90.8	91.5	88.5	88.1	87.2	85.9
Total Pt/μg	1	5	9	40	28	65
Pt (dry wt)/ppm	0.4	3.9	6.5	25.3	28.4	127
Total Ca/mg	55	23.5	21.8	20.5	11.8	4.6
Ca (dry wt)/%	2.48	1.84	1.57	1.30	1.19	0.90

(continued on facing page)

TABLE III. *(continued)*

Roots	Box	A3	B3	C3	D3	E3	F3
Applied Pt/ppm		0.05	0.50	2.50	5.00	10.00	30.00
Wet wt/g		8.53	5.40	2.71	2.38	1.63	1.21
Dry wt/g		0.527	0.301	0.336	0.303	0.221	0.121
Water present/%		93.8	94.4	87.6	87.3	86.4	89.9
Total Pt/μg		40	340	880	1650	1400	3100
Pt (dry wt)/ppm		76	1130	2620	5440	6330	25560
Total Ca/mg		2.4	1.7	1.6	1.5	0.9	1.0
Ca (dry wt)/%		0.456	0.550	0.48	0.48	0.41	0.82

TABLE IV. Yields and Analysis of Tomato Plants Treated with $Na_2[PdCl_4]$.

Tops	Box	G1	H1	J1	K1
Applied Pd/ppm		0.05	0.50	2.50	5.00
Wet wt/g		36.88	38.50	8.037	7.340
Dry wt/g		2.325	2.317	0.624	0.572
Water present/%		93.7	94.0	92.2	92.2
Total Pd/μg		1.5	2.3	2.4	3.2
Pd (dry wt)/ppm		0.64	0.99	3.8	5.5
Roots	**Box**	**G1**	**H1**	**J1**	**K1**
Applied Pd/ppm		0.05	0.50	2.50	5.00
Wet wt/g		8.515	9.897	1.765	2.142
Dry wt/g		0.607	0.670	0.210	0.184
Water present/%		92.9	93.2	88.2	91.5
Total Pd/μg		40.0	149	525	3170
Pd (dry wt)/ppm		65.9	222	2504	17230

TABLE V. Yields and Analysis of Corn Plants Treated with $Na_2[PdCl_4]$.

	Tops	G2	H2	Roots	G2	H2
Applied Pd/ppm		2.5	5.0		2.5	5.0
Wet wt/g		4.187	5.439		2.029	3.056
Dry wt/g		0.306	0.404		0.190	0.297
Water present/%		92.7	92.6		90.7	90.3
Total Pd/μg		1.5	4.5		410	2150
Pd (dry wt)/ppm		4.9	11.1		2160	7237

TABLE VI. Yields and Analysis of Tomato Plants Treated with $Na_3[RhCl_6]$.

Tops	Box	L1	M1	N1	P1
Applied Rh/ppm		0.05	0.50	2.50	5.00
Wet wt/g		12.80	34.08	36.85	37.19
Dry wt/g		0.857	2.025	2.309	2.149
Water present/%		93.0	94.0	93.7	94.2
Total Rh/μg		0.75	10.5	46.0	65.0
Rh (dry wt)/ppm		0.87	5.2	19.9	30.3
Roots	**Box**	**L1**	**M1**	**N1**	**P1**
Applied Rh/ppm		0.05	0.50	2.50	5.00
Wet wt/g		4.944	6.554	8.651	7.676
Dry wt/g		0.259	0.418	0.532	0.500
Water present/%		94.8	93.6	93.9	93.5
Total Rh/μg		10.0	142	450	385
Rh (dry wt)/ppm		38.7	339	847	771

TABLE VII. Yields and Analysis of Corn Plants Treated with $Na_3[RhCl_6]$.

	Top	L2	M2	Roots	L2	M2
Applied Rh/ppm		10.0	30.0		10.0	30.0
Wet wt/g		13.44	8.134		4.406	3.632
Dry wt/g		0.783	0.540		0.261	0.247
Water present/%		94.2	93.4		94.1	93.2
Total Rh/μg		22.3	45		45	108
Rh (dry wt)/ppm		28.4	83.3		173	438

with $(NH_4)_2[PtCl_6]$, in addition the platinum taken up by the plants increases as the contraction of applied platinum is increased. In all three plants platinum is translocated to the leaves. The roots appear to extract platinum from solution, and the high levels shown by tomato and bean roots at 5.0, 10.0, and 30.0 ppm Pt, when little of no root growth takes place, could be explained by the precipitation of platinum species in the free spaces of the roots. This precipitation would cause their yellow colour. This point is being further investigated. In the course of the experiments the percentages of the total platinum removed by the tomato plants was: A, 14%; B, 29%; C, 14%; D, 5%; E, 3%; F, 1%. They are thus reasonably efficient at the removal of platinum from dilute solution.

Tables IV and V show the results from the treatment of tomato and corn plants with $Na_2[PdCl_4]$.

The limited results indicate that there is some transfer to the leaves, and that like platinum, palladium is deposited in the roots.

Preliminary results for rhodium, applied as Na_3RhCl_6 are shown in Tables VI and VII. Tomato plants are not affected by rhodium at the concentrations studied, and the possible toxicity at higher concentrations is being investigated. There is some transfer of metal to the leaves, but much less metal is deposited in the roots than with either platinum or palladium.

References

1 C. L. Hamner, *Bot. Gazette, 104,* 161 (1942).
2 E. Epstein, 'Mineral Nutrition in Plants: Principles and Perspectives', Wiley, New York (1972).
3 W. T. Elwell and J. A. F. Gidly, 'Atomic Absorption Spectroscopy', Pergamon, Oxford (1966).