UPTAKE, TRANSLOCATION AND EFFICIENCY OF NUTRIENTS IN *PHASEOLUS VULGARIS* L. cv CONTENDER EXPOSED TO ALUMINUM

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RESUMEN

ABSORCION, TRANSLOCACION Y EFICIENCIA DE NUTRIENTES EN PLANTAS DE *PHASEOLUS VULGARIS* L. cv CONTENDER EXPUESTAS A ALUMINIO

Plantas de judía, ***Phaseolus vulgaris*** L. cv Contender, cultivadas en solución nutritiva (10% Hoagland, pH inicial 4.0) fueron expuestas a diferentes tratamientos con Al (0, 37, 93, 185, 370 y 740 μM). La especiación del Al en la solución se realizó mediante el programa GEOCHEM. Tras 15 días de exposición se analizó el contenido de Al y de nutrientes esenciales (K, Ca, P, Fe, Mg y Mn) en diferentes órganos. Se han calculado los valores de inhibición de absorción y translocación de nutrientes, así como la eficiencia de utilización para cada elemento y tratamiento. Se discute la importancia de los cambios de pH inducidos por las plantas y de las alteraciones de los niveles de nutrientes esenciales en el fenómeno de tolerancia al Al.

Palabras clave: Aluminio. Especiación. ***Phaseolus vulgaris*** L. pH. Nutrientes esenciales. Tolerancia.

SUMMARY

Bean plants, ***Phaseolus vulgaris*** L. cv Contender were grown in nutrient solutions (10% Hoagland, initial pH 4.0) with different Al concentrations (0, 37, 93, 185, 370, 740 μM). Aluminum speciation in solution was performed with the GEOCHEM programme. After 15 days plants were analysed for concentrations of Al and of essential nutrients (K, Ca, P, Fe, Mg and Mn) in different organs. Inhibition of nutrient uptake and translocation, as well as nutrient efficiency was calculated. The significance for Al-tolerance of both plant-induced pH changes and alterations of mineral nutrient is discussed.

Key words: Aluminum. Speciation. ***Phaseolus vulgaris*** L. pH. Essential nutrients. Tolerance.

INTRODUCTION

Aluminum toxicity is one of the most important agricultural problems on acid soils which principally occur in the tropics (Clark, 1982).

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In these regions, unexpensive lime sources are usually not available, so that the best way to improve crop productivity seems to be breeding for tolerance to Al toxicity and to other chemical factors related to soil acidity (Mn toxicity, P-deficiency, etc.).

Varietal differences in the response to high Al activity has been reported for different crops (Foy *et al.*, 1972; Horst and Klotz, 1990; Massot *et al.*, 1991). Nevertheless, the mechanisms of Al tolerance are not clearly established (Taylor, 1988).

The ability to increase the pH in the rhizosphere has been related with tolerance to Al, among others, in *Hordeum vulgare, Pisum sativum, Secale cereale,* and *Triticum aestivum.* But there are also cultivars of several species, *Glycine max, Hordeum vulgare, Phaseolus vulgaris,* in which Al-tolerance could not be related to plant-induced pH increase in the rhizosphere or the nutrient solution (Taylor, 1988).

In former nutrient solution studies we found that *Phaseolus vulgaris* L. cv Contender is moderately Al-tolerant (Massot *et al.*, 1991) and that effect of Al on the growth of this cultivar was unrelated to plant-induced pH changes in the nutrient solution (Massot *et al.*, 1990). In the present study, using the same cultivar, we analysed the effect of different Al concentrations on both the inhibition of uptake and translocation of certain essential nutrients and the nutrient use efficiency. The GEOCHEM programe (Parker *et al.*, was used for ion-speciation in the nutrient solution in order to reveal possible correlations between metal complexes, pH and growth response.

MATERIALS AND METHODS

Seeds from *Phaseolus vulgaris* L. cv Contender (Rocalba, SA) were germinated on perlite with distilled water. At day eight from sowing, seedlings were transplanted to continuously aerated 10 % Hoagland nutrient solution containing 0, 37, 93, 185, 370 and 740 μM Al as $Al_2(SO_4)_3 . 6H_2O$. Plants were grown for further 15 days in a growth chamber under the following conditions: photoperiod 12 h light, 12 h darkness; photon fluence rate 150 $\mu E\ s^{-1}\ m^{-2}$ day/night temperature 26 °C/18 °C; day/night relative humidity 70 % / 85 %.

At day 15 from transplantation, plants were harvested. Dry weight of roots, stems, primary and first trifoliolate leaves was determined after 48 h at 80 °C. Oven dried material was dry ashed at 450 °C and Al was determined according to Jayman and Sivasubraniam (1974). Concentrations of K, Ca, Fe, Mg and Mn were determined by atomic absorption spectrophotometry (Perkin Elmer, 703). Phosphorous concentration was determined according to Allen *et al.* (1974). Given results are the mean of three replicates per organ and treatment.

With these data inhibition of uptake was calculated as:

$$PI = [\ (U_0 - U_1)\ /\ U_0]\cdot 100$$

where U_0 is the amount of a given nutrient in the control and U_1 in the Al-treated plant (Rengel and Robinson, 1989). Inhibition of translocation was estimated by the shoot/root ratio of nutrient content and nutrient use efficiency was calculated as the coefficient between total plant dry weight and the total amount of a nutrient.

For ion speciation in the nutrient solution, the PC version 2.0 of the GEOCHEM programme (Parker *et al.*, in press) was used.

RESULTS

Table 1 shows the activity of free Al and the per cent distribution of complexed Al in the nutrient solutions with different total Al concentrations and an initial pH of 4.0. The activity of free Al was significantly lower than the total Al concentration supplied and did not linearily increase with the Al supply. Aluminum formed soluble complexes mainly with sulphate, phosphate and EDTA. The percent of phosphorous and sulphur complexed with Al increased with Al supply. In controls

TABLE 1

Total concentracíón (µM), activity of free Al (µM) and per cent distribution of soluble Al-complexes in the nutrient solutions with an initial pH of 4.0.

Total Al concentration . . .	Control	37.0µM	93 µM	185.0 µM	370.0 µM	740 µM
Activity free Al.	–	4.7µM	15.6 µM	64.1 µM	72.2 µM	132 µM
% distr. of Al conc.:						
Free Al	–	21.2 %	28.5 %	60.7 %	36.2 %	36.3 %
Complexed with SO_4	–	5.3 %	10.0 %	29.2 %	27.2 %	40.3 %
Complexed with PO_4	–	45.0 %	48.6 %	0.0 %	31.3 %	19.4 %
Complexed with EDTA . .	–	26.7 %	10.7 %	5.4 %	2.7 %	1.3 %
Complexed with OH^-. . . .	–	1.7 %	2.3 %	4.7 %	2.7 %	2.6 %
% distr. of PO_4:						
Complexed with H.	99.0 %	90.5 %	76.4 %	44.7 %	41.7 %	27.9 %
Complexed with Al	–	8.3 %	22.6 %	54.7 %	57.7 %	71.8 %
% distr. of SO_4:						
Free SO_4	93.2 %	92.1 %	89.8 %	80.3 %	79.3 %	70.3 %
Complexed with Ca	4.7 %	4.7 %	4.4 %	3.7 %	3.4 %	2.7 %
Complexed with Al	–	1.2 %	3.8 %	14.2 %	15.6 %	25.6 %
% distr. of EDTA:						
Complexed with Fe	87.9 %	0.2 %	0.1 %	0.01 %	0.01 %	0.00 %
Complexed with Al	–	98.9 %	99.3 %	99.5 %	99.6 %	99.7 %

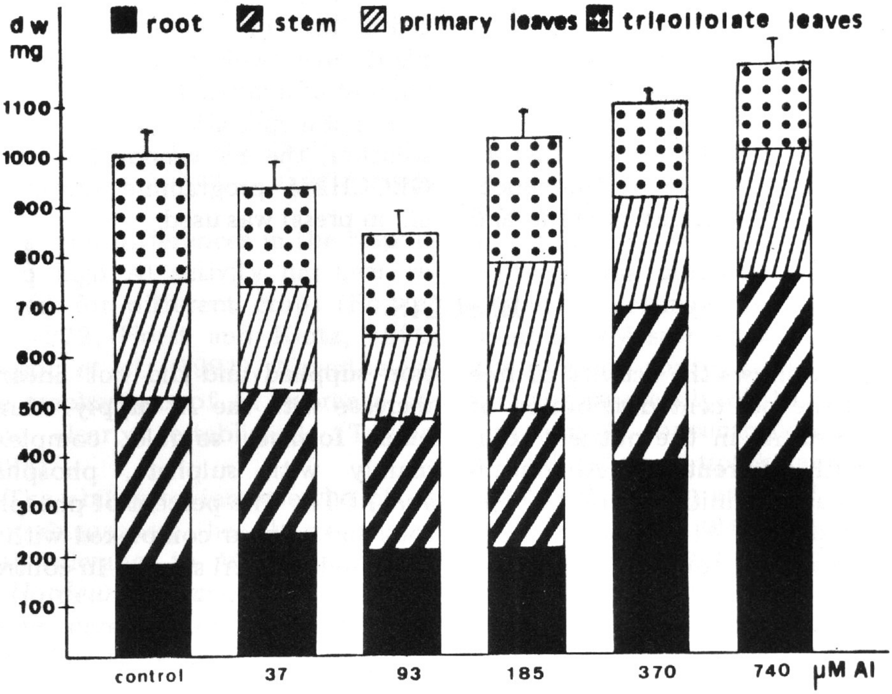

FIG. 1.–*Dry weight of different organs of bean plants exposed to different Al concentrations.*

more than 90% of EDTA was complexed with Fe, while in presence of Al almost all EDTA was complexed with Al (Table 1).

The bean plants substantially increased the pH of nutrient solution (Table 2). But the pH change was not correlated to the Al-treatment, which may result in lower free Al activities in solutions with higher total Al concentrations as illustrated by the theoretical calculation of free Al activity using the initial total Al concentrations (Table 2).

The growth response of plants exposed to different Al concentrations is shown in figure 1. The total plant dry weignt significantly decreased with 93 μM Al in solution, but higher concentrations increased dry matter accumulation. Aluminium supply significantly increased the Al concentration in all plant organs (Fig. 2). But plant dry weight was not correlated to Al accumulation in the different organs. Aluminum uptake significantly increased with Al supply (Table 3), exhibiting significantly higher Al concentrations in roots than in upper plants parts (Table 4). The supply of Al significantly affected the uptake of essential nutrients. Generally, the percent inhibition of uptake was highest for the 93 μM treatment (Table 3). Manganese was mostly affected, followed by K, Ca, Mg and P. No clear response pattern

TABLE 2

Final pH of nutrient solutions and activity of free Al calculated with total initial concentrations.

Treatments	Control	37 µM	93 µM	185 µM	370 µM	740 µM
Final pH	5.3	5.4	4.4	5.6	5.4	4.0
Free Al activity	–	0.3 µM	9.1 µM	2.3 µM	14.9 µM	132 µM

TABLE 3

Percent inhibition of nutrient uptake in bean plants exposed to different Al concentrations.

Al conc. supplied	Percent inhibition of uptake						
	K	Ca	P	Fe	Mg	Mn	Al
37 µM	21.6	23.7	17.1	44.5	11.6	23.3	–46.4
93 µM	36.0	32.4	30.2	30.3	20.7	50.6	–308.3
185 µM	11.5	4.1	17.9	13.3	–12.2	34.0	–765.9
370 µM	7.7	17.6	4.3	6.1	12.9	27.7	–2793.3
740 µM	6.7	17.2	21.4	21.7	17.5	27.2	–3063.7

TABLE 4

Shoot/root ratio of mineral nutrient contents in bean plants exposed to different Al concentrations.

Al conc. supplied	K	Ca	P	Fe	Mg	Mn	Al
Control	9.8	4.6	3.3	1.9	5.8	2.3	1.5
37 μM	6.2	4.4	2.2	4.8	3.5	2.4	0.6
93 μM	10.8	5.1	2.8	1.4	6.2	3.0	1.1
185 μM	6.8	5.4	3.8	2.1	5.1	–	0.5
370 μM	13.5	3.9	2.3	1.5	6.0	1.9	0.1
740 μM	5.8	3.9	1.5	1.7	6.0	2.7	0.2

TABLE 5

Nutrient use efficiency (mg dry weight/mg nutrient) in bean plants exposed to different Al concentrations.

Al conc. supplied	K	Ca	P	Fe	Mg	Mn	Al
Control	24.5	167.2	243.2	4900	326.4	3300	24.9
37 μM	29.3	205.7	275.2	8300	346.9	5800	15.9
93 μM	32.2	207.9	292.8	5900	346.1	7500	5.1
185 μM	28.6	180.1	305.9	5800	300.7	5200	2.9
370 μM	29.2	223.8	280.1	5700	413.3	7700	0.9
740 μM	30.6	235.3	360.7	7300	461.3	7300	0.9

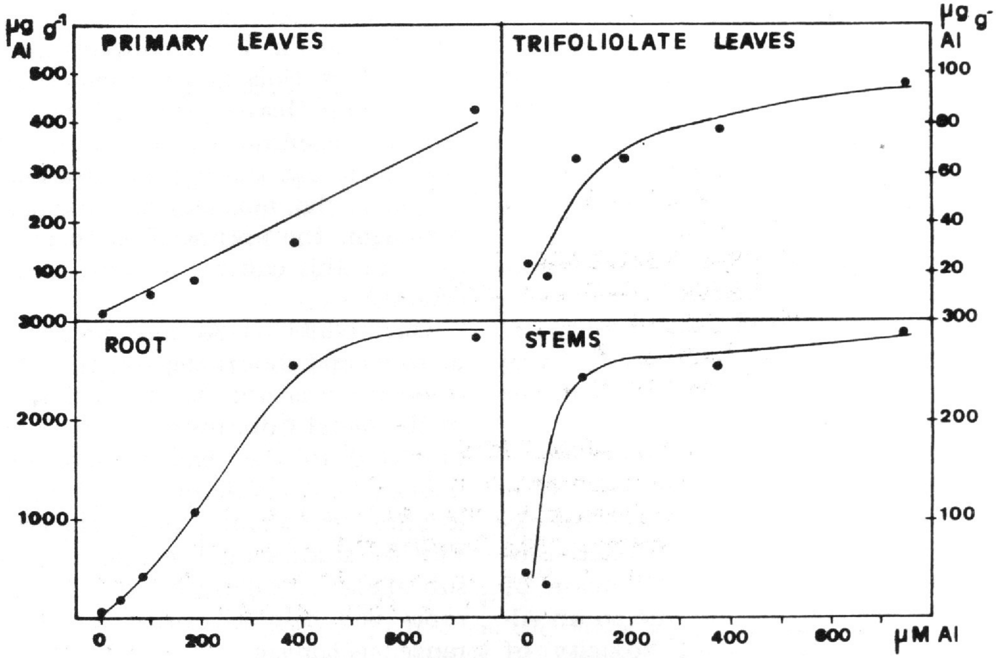

FIG. 2.–*Aluminum concentration in different organs of bean plants exposed to different Al concentrations.*

was observed for higher Al supply (Table 3). The inhibitory effect of the 93 µM treatment was not exclusively due to the Al-induced growth inhibition, yet relatively high nutrient utilization index (total dry weight/total amount of nutrient) (Table 5) were found for the 93 µM Al-Treatment.

DISCUSSION

Our results confirm earlier findings (Massot *et al.*, 1991), which indicated that, under our experimental conditions, the bean cultivar Contender shows Al-tolerance. Plants exposed to Al concentrations up to 370 µM Al, increased the solution pH. This effect has been related to preference for NO_3^- uptake in mixed, NH_4-NO_3, solutions, which may affect the relative uptake of cations and anions, leading to pH increase (Taylor and Foy, 1985). The failure of plants exponsed to 740 µM Al to increase the pH of the nutrient solution may be due to both the buffer effect of Al in solution (Driscoll and Schecher, 1988) and the excess of cations taken up by plants exposed to this high Al concentration. The increase of solution pH causes precipitation of $Al(OH)_3$ and drastically reduces the activity of free Al in solution. Nevertheless, plant-induced pH increase may not explain the tolerance of Contender, yet plants did not show growth reduction but growth stimulation when grown in a solution containing 740 μM Al, in which pH remained low.

In contrast, growth inhibition was observed in the 93 μM Al treatment with a final pH of 4.4. This suggests, that the increase of solution pH was a consequence of tolerance rather than its cause.

The Al-induced increase of dry matter accumulation observed in our experiment remains difficult to explain. Heiriah *et al.* (1990) have proposed that Al-induced increase of plant growth may be due to an Al-induced reduction of toxicity of other elements occurring in supra-optimal concentrations in solution, e.a. P, N or Ca. The P concentration in the 10% Hoagland nutrient solution used in this experiment is higher than P concentrations in solutions of acid soils, but the P concentrations in plants did not indicate toxicity. Although, the optimal P concentration for this cultivar remains to be established.

Our results on Al concentrations in roots and shoots suggest, that Al-tolerance was not due to exclusion of the metal from roots and may be unrelated to the plant-induced pH increase, but restriction of Al-translocation to shoots was achieved. Further studies on the cellular and subcellular localization of Al in roots will help to clarify the tolerance mechanism.

CONCLUSIONS

We may conclude from our study, that the growth response of the bean cultivar Contender to Al was neither in good correlation with the activity of free Al in solution and the Al concentration in tissues nor to the plant-induced increase of solution pH. Therefore, the Al-tolerance of Contender does not seem due to exclusion from roots, but to internal tolerance mechanisms.

REFERENCES

ALLEN, S. E., GRIMSHAW, H. M. and PARKINSON, J. A., 1974. Chemical analysis of ecological materials. Brackwell, Oxford.

CLARK, R. B., 1982. Plant responses to mineral element toxicity and deficiency. In: Breeding Plants for Less Favorable Environments. M. N. Christiansen and C. F. Lewis, (Eds.). 71-142. John Wiley & Sons, New York.

DRISCOLL, C. T. and SCHECHER, W. D., 1988. Aluminum in the environment. In: Metal Ions in Biological Systems. vol..24. Aluminum and its Role in Biology. H. Sigel and A. Sigel, (Eds.) 59-122. Marcel Dekker, Inc., New York.

FOY, C. D., FLEMING, A. L. and GERLOFF, G. C., 1972. Differential aluminum tolerance in two snapbean varieties. Agron. J., 64: 815-818.

HAIRIAH, K., STULEN, I. and KUIPER, P. J. C., 1990. Aluminium tolerance of the velvet beans ***Mucuna pruriens*** var. utilis and ***Mucuna deeringiana***. I. Effects of aluminium on growth and mineral composition. In: Plant Nutrition - Physiology and Applications. M. L. van Beusichem, (Ed.). 365-374. Kluwer Academic Publ., Dordrecht.

HORST, W. J. and KLOTZ, F., 1990. Screening soybean for aluminium tolerance and adaption to acid soils. In: Genetic Aspects of Plant Mineral Nutrition. N. El Bassam, M. Dambroth and B. C. Lougham, (Eds.). 355-360. Kluwer Academic Publ., Dordrecht.

JAYMAN, T. C. Z. and SIVASUBRANIAM, S., 1974. The use of ascorbic acid to eliminate interference from iron in the aluminon method for determining Al in plant and soil extracts. Analyst, 296-301.

MASSOT, N., POSCHENRIEDER, CH. and BARCELO, J., 1990. Effects of aluminum on mineral nutrition of ***Phaseolus vulgaris*** L. cv Contender grown in hydroponics. In: Nutrición Mineral Bajo Condiciones de Estrés. Proc. III Simp. Nac. Nutrición Mineral de las Plantas. 199-204. Servei de Publicacions i Intercanvi Cientific de la Universidad de las Islas Baleares, Palma de Mallorca.

MASSOT, N., POSCHENRIEDER, CH. and BARCELO, J., 1991. Aluminum tolerance assessment in bush bean cultivars by root growth analysis and hematoxylin staining. Suelo y Planta, 1: 25-32.

PARKER, D. R., NORVELL, W. A. and CHANEY, R. L., (in press). GEOCHEM-PC: a chemical speciation program for IBM and compatible personal computers. In: Chemical Equilibrium and Reaction Models. Soil Science Society of America, special publication. R. H. Loeppert (Ed.), American Society Agronomy, Madison.

RENGEL, Z. and ROBINSON, D. L., 1989. Aluminum effects on growth and macronutrient uptake by annual ryegrass. Agron. J., 81: 208-215.

TAYLOR, G. J., 1988. The physiology of aluminum tolerance. In: Metal Ions in Biological Systems. vol. 24. Aluminum and its Role in Biology. H. Sigel and A. Sigel, (Eds.). 165-198. Marcel Dekker, Inc., New York.

TAYLOR, G. J., and FOY, C. D., 1985. Mechanisms of aluminium tolerance in *Triticum aestivum* (wheat). IV. the role of ammonium and nitrate nutrition. Can J. Bot., 63: 2181-2186.

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