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Aluminum Accumulation Characteristics of Aluminum-Tolerant Plants

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Aluminum (Al) is one of the major growth-limiting factors in acid soils. Growth of some plants is hardly inhibited even by a high concentration of Al in the medium ; these plants are designated as Al-tolerant Plants.

The concentration of Al is considerably high in the roots, but is generally low in the tops. In Al-sensitive plants, Al is considerably deposited in the root tips, and the root elongation is retarded, and finally the top growth is inhibited.

Hydrangea is one of the typical calcifuge plants[2) ; hydrangea is tolerant to high-Al, and accumulates a considerable amount of Al, namely, more than 1%, in the tops.

In rabbiteye blueberry, a suitable pH of growth medium is in the range of 4.5 to 5.5[3), and rabbiteye blueberry is also the calcifuge plant. Cranberry plant, which belongs to the same family of Ericaceae and to the same genus of *Vaccinium* as rabbiteye blueberry, is extremely tolerant to high-Al[4) ; Al content of the tops is only 65 ppm in the growth medium containing the extremely high concentration of Al, i. e., 150 ppm ; the remakable tolerance to Al for cranberry plant is presumed to be attributable to the strong Al-excluding power of the roots.

The two mechanisms have conclusively been proposed on the Al tolerance : (i) resistance to a high concentration of Al in plant, namely, the detoxification mechanism, or (ii) resistance to a high concentration of Al in the medium, the Al-excluding power of roots.

The objective of the present study is (1) to investigate the Al accumulation characteristics of a variety of Al-tolerant plants, and (2) to clarify the mechanism of Al tolerance for a variety of Al-tolerant plants.

Materials and Methods

Roots of purchased seedlings of common hydrangea (*Hydrangea macrophylla* Ser. var. *macrophylla*) were washed carefully with tap water, and the developed shoots of these seedlings were thoroughly removed. Seedlings of hydrangea spp. (*Hydrangea macrophylla* Ser. subsp. yezoensis Kitamura) were collected early in May from Kushibiki-cho Hooya and Haguro-cho Konno, and prepared as common hydrangea. Roots of purchased seedlings of rabbiteye blueberry (*Vaccinium ashei* Reade var. homebell) were washed carefully with tap water. Seeds of oats (*Avena sativa* L. cv. Zenshin) and buckwheat (*Fagopyrum esculentum* Moench cv. Shinsyu-1) were germinated in tap water and grown for 7 days.

These prepared seedlings of common hydrangea, hydrangea spp. and rabbiteye blueberry were transferred to 54-liter containers filled with a third-strength complete nutrient solution and precultured for 40 days at a constant pH of 5.3. Culture medium was renewed weekly. Seedlings of oats and buckwheat were precultured with complete nutrient solution for 7 days.

Thereafter the precultured seedlings were introduced to each treatment solution, i. e., control treatment and high-Al treatment, and treated for 43 days in common hydrangea, hydrangea spp. and rabbiteye blueberry, and for 21 days in oats and buckwheat. The pH of control treatment was maintained at

5.3 ; the concentrations of Al and P in the filtrates with Toyo No. 6 filter paper were ca. 0 and 3 ppm, respectively. The pH of high-Al treatment was maintained at 4.2 ; the concentrations of added Al and P were 25 and 4 ppm, respectively, and those of Al and P in the filtrates were ca. 16 and 0.3 ppm, respectively.

In common hydrangea and hydrangea spp., the new shoots and the new roots developed during the period of preculturing and treatment were harvested. In rabbiteye blueberry, the harvesting method for tops was the same as hydrangea plants, but the roots were harvested the whole portion. In oats and buckwheat, the whole portions of tops and roots were harvested. After harvest, the plants were washed, dried, weighed, and digested with a HNO_3–$HClO_4$ mixture. The contents of Ca, Mg, K, Fe, and Mn were determined by the atomic absorption spectrophotometric method, and P and Al were determined colorimetrically by the molybdenum blue method and aluminon method, respectively. Total N was determined by the modified GUNNING method. In common hydragnea, rabbiteye blueberry, oats and buckwheat, culturing and analysis were carried out with 4 replications, but in hydrangea spp. with duplicates. The localization of Al in common hydrangea roots was investigated by the aluminon-staining method[1].

Results and Discussion

Common hydrangea and hydrangea spp. grew excellently in high-Al treatment, but a large number of white lateral roots were developed ; the root tips were made round and the color of the root tips turned brown (Fig. 1A). However, the growth of oats was inhibited in high-Al treatment ; the characteristic symptoms were the interveinal chlorosis in the lower leaves and the coralloidal roots.

The growth inhibition (high-Al/control) was in the order of oats (60%)>hydrangea spp. (78%)> buckwheat (95%) >common hydrangea (99%)>rabbiteye blueberry (125%), and the growth inhibition was considerable in oats (Table 1).

Al content of tops was in the order of buckwheat >hydrangea spp., common hydrangea>rabbiteye blueberry>oats.

These results indicate as follows : (i) all the plant species examined, namely, common hydrangea, hydrangea spp., rabbiteye blueberry, osts and buckwheat, were tolerant to high-Al ; (ii) Al accumulation in tops was most considerable in buckwheat, and considerable in common hydrangea and hydran-

Table 1. Dry weights and mineral status of plant samples. (Tops)

Species	Treatment	D. W.* g/plant	Al ppm	N %	P %	K %	Ca %	Mg %	Fe ppm	Mn ppm
Common hydrangea	Control	28.9	55	1.71	0.202	3.77	0.737	0.216	45	125
	High-Al	28.5	391	1.55	0.107	3.83	0.582	0.224	78	88
Hydrangea spp.	Control	8.85	186	2.74	0.365	3.75	1.00	0.369	56	153
	High-Al	6.93	393	2.05	0.126	3.58	0.862	0.398	84	157
Rabbiteye blueberry	Control	3.33	47	0.876	0.129	1.09	0.251	0.111	52	138
	High-Al	4.17	105	0.965	0.085	1.18	0.218	0.109	60	84
Oats	Control	0.88	12	3.57	0.718	7.40	0.442	0.275	79	178
	High-Al	0.53	30	2.94	0.143	4.86	0.198	0.125	54	33
Buckwheat	Control	0.87	16	2.36	0.159	4.31	1.26	0.574	97	198
	High-Al	0.83	479	3.18	0.114	4.13	0.797	0.466	83	136

* Dry weights of common hydrangea, hydrangea spp. and rabbiteye blueberry were those of the new shoots grown during the periods of preculturing and treatment.

gea spp. (Al content of tops, however, was less than 10^3 ppm in any plant species) ; (iii) Al accumulation in tops was remarkably low in rabbiteye blueberry and oats.

Phosphorus content of oats tops in high-Al treatment was extremely low, and therefore the considerable inhibition of growth in oats may be attributable in part to P deficiency.

The results of the nutrients composition of tops in high-Al treatment are summarized as follows (Table 1) : (i) in all plant species except oats, the contents of N, K, Mg, Fe and Mn were almost similar to those in control treatment ; (ii) in all plant species, the contents of P and Ca were lower than those in control treatment, and the decrease was considerable in oats.

The results of the nutrients composition of roots in high-Al treatment are summarized as follows (Table 2) : (i) in all plant species, N content was almost similar to that in control treatment ; (ii) in all plant species, Ca content was lower than that in control treatment ; (iii) the contents of P, Mg, Fe and Mn were generally lower than those in control treatment, and the decrease was considerable in oats ; (iv) in hydrangea plants K content was similar to that in control treatment, but in rabbiteye blueberry and buckwheat higher in high-Al treatment ; in oats K content was considerably lower in high-Al treatment.

All the root cells of common hydrangea grown in the medium containing the negligible amount of ionic Al were intact ; Al was hardly absorbed in the root cells (Fig. 1B). The cells of the epidermis and the endodermis in high-Al treatment were deformated ; Al was highly accumulated in these cells (Fig. 1C) ; however, no Al was detected in the cortex cells.

All the results (Tables 1 and 2, and Fig. 1) are are summarized as follows : (i) common hydrangea, hydrangea spp., rabbiteye blueberry and buckwheat are extremely tolerant and oats is tolerant to high-Al ; (ii) Al accumulation in tops is greater in buckwheat, common hydrangea and hydrangea spp., and fewer in rabbiteye blueberry and oats ; (iii) in any plant species but oats, the contents of N, P, K, Ca, Mg, Fe and Mn in high-Al treatment are not so low as the respective deficient levels ; (iv) in common hydrangea, Al toxicity is restricted to the epidermis and the endodermis.

The mechanism of Al tolerance for rice and oats

Table 2. Dry weights and mineral status of plant samples. (Roots)

Species	Treatment	D. W.[*1] g/plant	Al ppm	N %	P %	K %	Ca %	Mg %	Fe ppm	Mn ppm
Common hydrangea	Control	0.58	470	3.54	0.582	2.48	0.485	0.111	12,245	1,140
	High-Al	1.22	14,822	2.59	0.469	2.41	0.181	0.074	4,028	868
Hydrangea spp.	Control	0.687	512	4.69	0.880	2.21	0.391	0.193	7,504	1,564
	High-Al	0.271	17,340	3.04	0.720	2.17	0.376	0.081	2,726	674
Rabbiteye blueberry	Control	0.278	3,666	1.73	0.359	0.509	0.455	0.150	3,551	119
	High-Al	0.526	13,619	1.65	0.377	1.37	0.134	0.073	1,682	43
Oats	Control	0.19	340	—[*2]	0.579	7.14	0.267	0.564	5,667	195
	High-Al	0.11	2,424	—	0.282	4.00	0.155	0.112	1,248	15
Buckwheat	Control	0.25	225	2.75	0.311	2.36	0.364	0.442	2,431	88
	High-Al	0.21	5,265	2.65	0.335	2.62	0.259	0.465	1,276	83

[*1] Dry weights of common hydrangea and hydrangea spp. were those of the new roots grown during the periods of preculturing and treatment.

[*2] Nitrogen contents of oats roots were not determined.

was presumed as follows[5]: (i) the destruction of root cells by Al is restricted to the tip and the epidermal portions; (ii) little Al are absorbed by the root cells, and therefore the Al-excluding power of the plasmalemma of root cells may be strong.

From the results both of the aluminon-staining test for common hydrangea and of the good growth for hydrangea plants, rabbiteye blueberry and buckwheat in high-Al treatment, the strong Al tolerance for all plant species is presumed to be attributable to the strong Al-excluding power of their root cells.

Al accumulation in tops was most considerable in buckwheat, and considerable in hydrangea spp. and common hydrangea. Al content of tops, however, was less than 500 ppm in high-Al medium containing 16 ppm of ionic Al; Al content was less than 10^3 ppm which was the lower limit for Al accumulator defined by WEBB[6]. Therefore, common hydrangea and hydrangea spp. are not regarded as Al accumulator; Al tolerance for these plant species may not be attributable to the tolerance to high-Al in plants.

Higher content of Al in the tops of common hydrangea, hydrangea spp. and buckwheat may be ascribed to the abundance of passage cell in the endodermis.

Summary

Oats, buckwheat, common hydrangea, hydrangea spp. and rabbiteye blueberry were grown in water culture containing a high concentration of ionic Al, i. e., 16 ppm, and finally all plant species were proved to be the Al-tolerant plants.

Al accumulation in the tops of common hydrangea and hydrangea spp. (<500 ppm) was too low to be regarded as Al accumulator.

Al tolerance for all plant species may be attributable to the Al-excluding power of the plasmalemma of root cells.

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アルミニウム耐性植物のアルミニウム集積性

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摘　要

エンバク，ソバ，セイヨウアジサイ，エゾアジサイおよびブルーベリーを16 ppmの溶存アルミニウムを含有する培養液で水耕栽培した結果，これらいずれの植物もアルミニウム耐性植物であった．

セイヨウアジサイ，エゾアジサイの地上部のアルミニウム含有率（500 ppm以下）は高くないので，これらの植物はアルミニウム集積性植物とはみなされない．

供試全植物の強いアルミニウム耐性の原因は根細胞の原形質膜のアルミニウム排除能に由来するものと推察される．

C B A

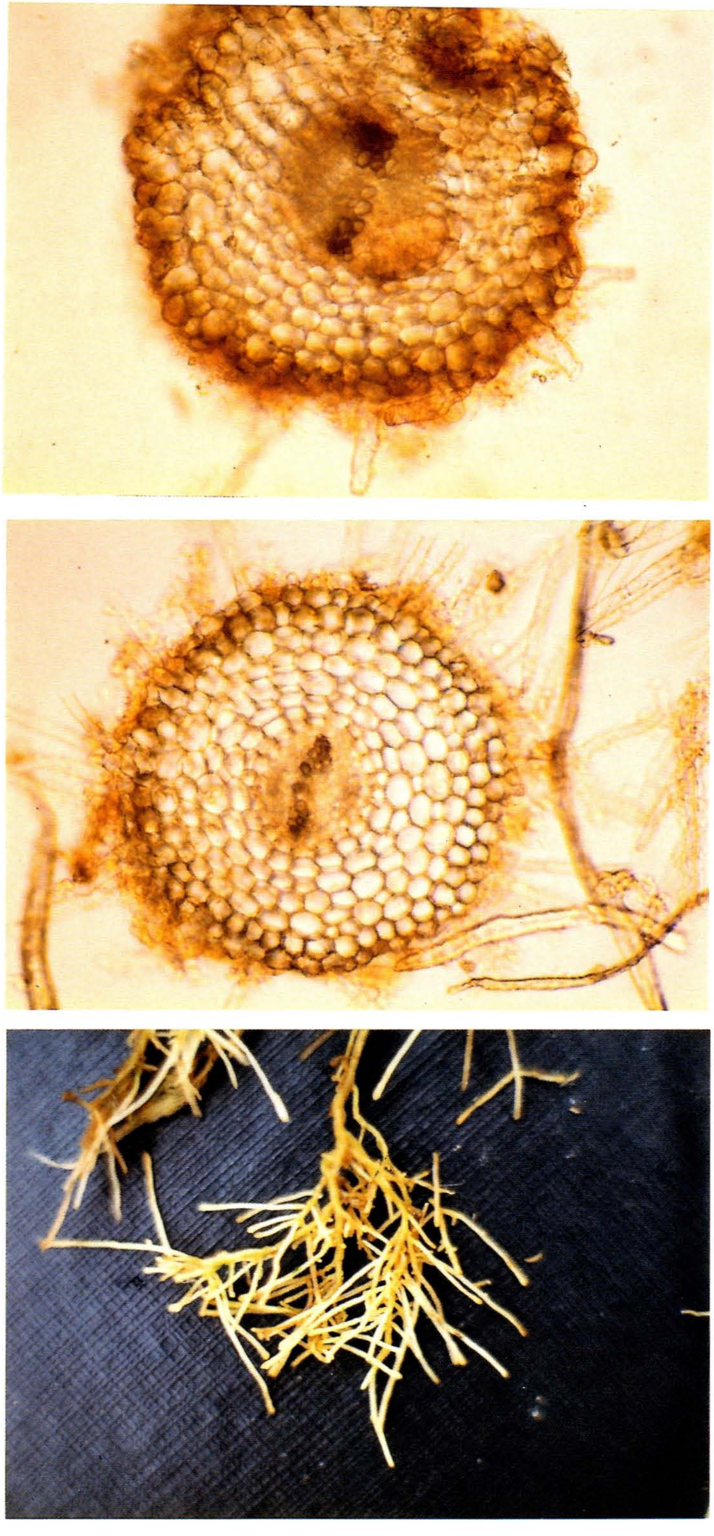

Fig. 1. Root symptoms and aluminon-staining test (common hydrangea)

A : root symptoms in high-Al treatment (pH 4.2, ionic Al=16 ppm)

B : aluminon-staining test in high-pH treatment (pH 7.0, ionic Al=0)

C : aluminon-staining test in high-Al treatment (pH 4.2, ionic Al=16 ppm)