The characteristics of aluminum uptake in roots of Melastoma malabathricum, an aluminum accumulating plant

Toshihiro Watanabe[1)], Seiji Misawa[1)], Syuntaro Hiradate[2)], Steven Jansen[3)], and Mitsuru Osaki[1)]
[1)] Graduate School of Agriculture, Hokkaido University, Kita 9, Nishi 9, Kitaku, Sapporo 060-8589, Japan, nabe@chem.agr.hokudai.ac.jp
[2)] National Institute for Agro-Environmental Sciences, 3-1-3 Kan-nondai, Tsukuba, Ibaraki 305-8604, Japan
[3)] Jodrell Laboratory, Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3DS, U.K.

Key words: acid soils, aluminum accumulators, aluminum uptake, citrate, Melastoma malabathricum L., mucilage

Abstract

In general, plants that have Al levels of at least 1000 mg kg^{-1} in their leaves can be defined as Al accumulators. These plants are often found in tropical, strongly acid soils. Mechanisms of Al uptake in strong Al accumulators are still unclear. In this study, the characteristics of Al uptake in Melastoma malabathricum, an Al accumulating plant which grows in tropical acid soils, were investigated. M. malabathricum roots hardly absorb La, indicating that the roots have a specific Al uptake/transport system. Whereas application of La did not affect the concentration of citrate in roots, Al application increased the citrate level considerably, corresponding to the Al accumulation in the symplast. Although mucilage is generally considered to be effective in excluding Al from roots, large quantities of mucilage are exuded by roots of M. malabathricum. The mucilage exuded from M. malabathricum roots showed a high affinity to adsorb Al compared with Ba and La. The removal of the mucilage from roots decreased Al uptake in the seedlings of M. malabathricum, indicating that M. malabathricum roots solubilize the Al concentrated in the mucilage possibly by exuding H^+ or organic acids, and absorb it.

Introduction

Melastoma malabathricum L. is an aluminum (Al) accumulating woody plant that grows in tropical Southeast Asia in acid soils with high Al concentrations. This species accumulates more than 10000 mg Al kg^{-1} in leaves in the form of monomeric Al and Al-oxalate complexes (Watanabe et al., 1998). It was also demonstrated that the Al-form for translocation from the roots to the shoots is an Al-citrate complex (Watanabe and Osaki, 2001). However, the exact mechanisms of Al uptake in M. malabathricum roots remain to be elucidated. In the present study, La uptake in M. malabathricum was compared with Al uptake (Experiment 1), and the role of the mucilage exuded by M. malabathricum roots in Al uptake was examined (Experiments 2 and 3).

Materials and methods

Experiment 1: Responses of M. malabathricum roots to aluminum and lanthanum

The preparation of M. malabathricum seedlings was conducted as described in a previous paper (Watanabe and Osaki, 2001). M. malabathricum seedlings were transferred to containers containing the standard nutrient solutions (pH4.2) with 0.5 mM Al (as $AlCl_3$; +Al), with 0.5 mM La (as $LaCl_3$; +La), or without either (Control). Seedlings were sampled at 0.5, 3, 24 and 72 h after treatment started and were separated into shoots and roots. Al in roots was fractionated to symplastic, apoplastic and residual fractions. The analytical procedure of fractionation was done according to the method of Watanabe et al. (2001), whereas 5 mM EDTA with 5 mM $CaCl_2$ was used as desorbing solution (pH4.2).

Concentrations of minerals and organic acids were determined by ICPS (ICPS-7000, SHIMADZU, Japan) and capillary electrophoresis (Quanta 4000CE, Waters, USA), respectively, as described in a previous study (Watanabe and Osaki, 2001). Citrate concentration in symplastic fraction was also determined.

Experiment 2: Selective absorption of cations in the mucilage exuded from M. malabathricum roots

In general, the mucilage is considered to be effective in excluding Al (Horst et al., 1982). Although M. malabathricum is an Al accumulating plant, it exuded large quantities of mucilage from its roots (Fig. 1). The mucilage exuded from roots of M. malabathricum grown in a nutrient solution was manually collected, filtered on a gauze and centrifuged at 12000 g to remove excess water. One mL of mucilage was added to 4 mL of the cation mix solution (0.1 mM $AlCl_3$, 0.1 mM $BaCl_2$, 0.1 mM $LaCl_3$; pH4.2), shaken for 2 h and centrifuged at 12000 g. The supernatant was filtered on a membrane filter (pore size = 0.45 µm). Al, Ba and La concentrations in the filtrate were determined with ICPS.

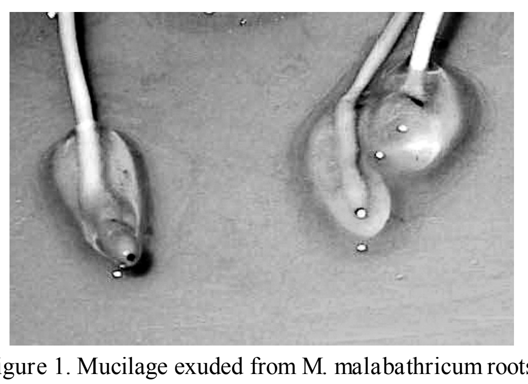

Figure 1. Mucilage exuded from M. malabathricum roots.

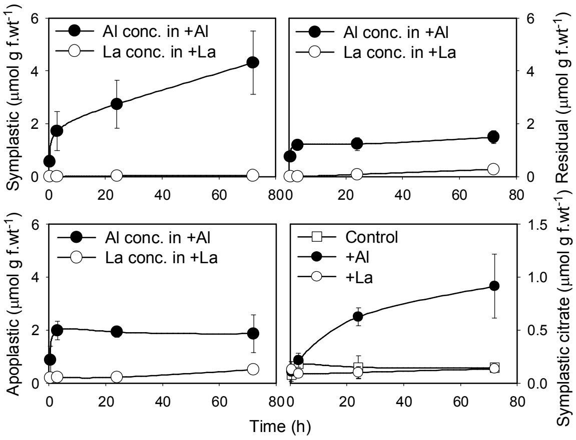

Figure 2. Concentrations of Al and La in each fraction, and citrate concentration in symplastic fraction (Experiment 1). Concentrations of Al and La were shown only in +Al treatment and +La treatment, respectively. Data are means of four replicates ± SE.

Experiment 3: Effect of the removal of mucilage from M. malabathricum roots on cation uptake

M. malabathricum seedlings from which mucilage was removed were transferred to containers containing the standard nutrient solution with 0.5 mM $AlCl_3$ at pH4.2 (–Muci). As a control, the seedlings with mucilage were also treated (+Muci). At the end of the 10-day treatment period, the seedlings were sampled to determine their mineral concentrations in shoots.

Results and discussion

Al concentration in the symplastic fraction increased with time of treatment (Fig. 2). Al concentration in the apoplastic fraction increased up to 3 h, and this level was constant until the end of the treatment. Its level was higher after 72 h in the symplastic fraction than in the apoplastic fraction, and exceeded 4 µmol g.fw^{-1}. In contrast, La did not penetrate into the root cells after 72 h, and very small quantities of La were found in apoplastic and residual fractions (Fig. 2). These results suggest that M. malabathricum roots have a specific Al uptake/transport system. The concentration of citrate, a ligand for Al translocation in M. malabathricum, increased in the symplastic fraction by application of Al, but not by applying La, which indicates that induction of citrate synthase is an Al specific response. The increase of citrate in its symplastic fraction was observed after 3 h, and this corresponds with the penetration of Al into the symplast (Fig. 2).

The mucilage exuded from M. malabathricum roots adsorbed more Al than Ba (Fig. 3). This can be explained by the general phenomenon that the amount of the cation absorbed by the cation exchangers increases with the number of charges on the cation. Interestingly, the mucilage adsorbed more Al than La (Fig. 3). As both Al and La are trivalent cations, it was suggested that the cation exchange sites in mucilage have a specific configuration for absorption of Al. In order to elucidate

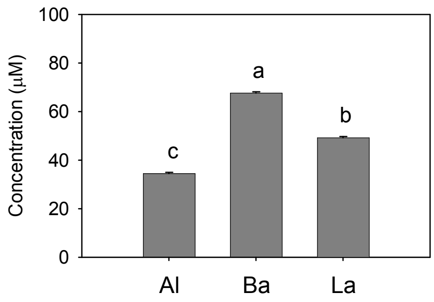

Figure 3. Concentrations of Al, Ba and La in the supernatant (Experiment 2). Data are means of five replicates ± SE. Different letters indicate significant differences at P < 0.05.

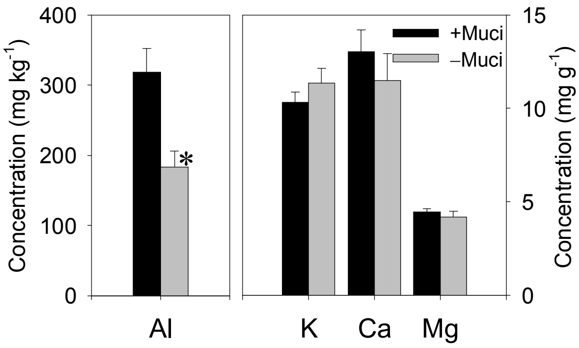

Figure 4. Concentrations of Al, K, Ca and Mg in shoots of M. malabathricum after the treatment (Experiment 3). Data are means of three replicates ± SE. *, significantly different from +Muci treatment at P < 0.05.

the contribution of the mucilage on Al uptake in M. malabathricum, the effect of the removal of mucilage from roots on Al uptake was examined. Whereas K, Ca and Mg uptakes were not affected by mucilage removal, Al uptake significantly decreased (Fig. 4). It is considered that M. malabathricum roots solubilize Al concentrated in the mucilage possibly by exuding H^+ or organic acids, and absorb it.

Acknowledgments

We thank Dr. O. Nakahara for valuable comments. Part of this study was financially supported by a Grand-in-Aid for Scientific Research (No. 16208008) from the Japan Society for the Promotion of Science.

References

Horst WJ, Wagner A and Marschner H 1982 Z. Pflanzenphysiol. 109, 95-103.
Watanabe T and Osaki M 2001 Plant Soil 237, 63-70.
Watanabe T, Osaki M and Tadano T 2001 Plant Soil 231, 283-291.
Watanabe T, Osaki M, Yoshihara T and Tadano T 1998 Plant Soil 201, 165- 173.