Title
Possible Reasons Why Aluminum is a Beneficial Element for *Melastoma malabathricum*, an Aluminum Accumulator

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Introduction

Although it has been well known that aluminum (Al) toxicity restricts plant productivity in acid soils, there are several reports indicating the beneficial effect of Al on plant growth, especially in Al accumulators (Watanabe and Osaki, 2002). *Melastoma malabathricum* L. (Melastomataceae) is an Al accumulator and dominant species in acid sulfate soils in tropical Southeast Asia. This species accumulates more than 10 mg Al kg^{-1} in leaves and roots. The growth of *M. malabathricum* is remarkably enhanced by Al application in hydroponics. Additionally, when *M. malabathricum* was grown without Al for long periods, abnormal visual symptoms, such as rolling of the leaves and spotty chlorosis, are often observed. Here we propose two possible mechanisms accounting for the Al-induced growth enhancement in *M. malabathricum*. In acid sulfate soils, relatively high concentration of iron (Fe) ion, derived from the oxidation of pyrite, can occur in soil solution. Thus, plants are exposed to not only high concentration of Al but also of Fe in such soils. In the present study, Al-Fe interactions in *M. malabathricum* were examined. Moreover, we also examined the effect of Al on nutrient cation availability in plant.

Materials and Methods

Al-Fe interactions in *Melastoma malabathricum* and *Melaleuca cajuputi*

Both *M. malabathricum* and *Melaleuca cajuputi* L. (Myrtaceae, Al non-accumulator) are members of order Myrtales, and are dominant woody species in acid sulfate soils in tropical Southeast Asia. Seedlings of *M. malabathricum* and *M. cajuputi* were grown in a nutrient solution (pH4.0) with different levels of Al (0, 500 µM) and Fe (10, 100 µM (40 µM for the determination of lipid peroxidation)) for 30 d (7 d for the determination of lipid peroxidation). Dry weight, Al and Fe accumulations, lipid peroxidation and lignin accumulation were determined after the treatment.

Effect of Al on nutrient cation availability in *Melastoma malabathricum*

Seedlings of *M. malabathricum* were grown for 30 d in a nutrient solution with or without 500 µM Al at pH 4.0. After the treatment, the roots of seedlings were washed with deionized water, and then the seedlings were separated into roots and shoots, lyophilized, and ground. Water soluble K, Ca, Mg and oxalate concentrations were determined after extracting with deionized water (lyophilized sample : water = 1 : 10). Total K, Ca and Mg concentrations were determined by ICP-OES after wet-digestion. Total oxalate concentrations were determined by capillary electrophoresis after extracting with 0.2 M HCl.

Results and Discussion

Al-Fe interactions in *Melastoma malabathricum* and *Melaleuca cajuputi*

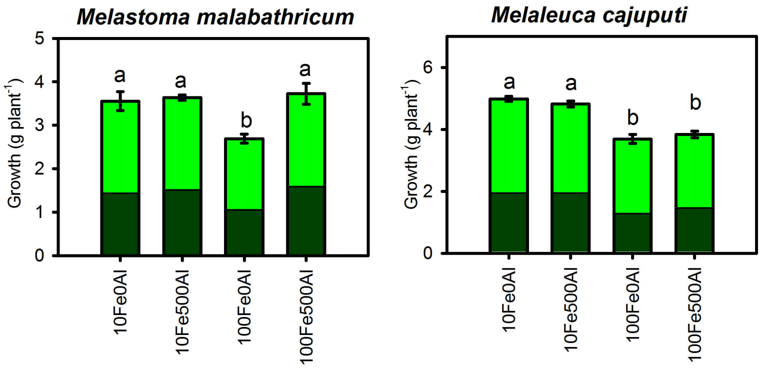

Fig. 1. Dry matter accumulation by *M. malabathricum* and *M. cajuputi* grown with different levels of Fe (10 and 100 μM) and Al (0 and 500 μM). Bars indicate ±SE for total dry matter accumulation. Different letters indicate significant differences (*P*<0.05, Tukey's multiple comparison test) in total dry matter accumulation.

Although excess Fe induces impairment in plant, 100 μM Fe is considered to be far lower than toxic level for the most plant species. Growth of both *M. malabathricum* and *M. cajuputi* significantly decreased by 100 μM Fe (Fig. 1), indicating that these species are very sensitive to Fe. Visual Fe toxicity symptoms were observed in leaves of *M. malabathricum* and in roots of both species (blackish color). These symptoms were canceled by the Al application in *M. malabathricum* but not in *M. cajuputi*. Likewise, Fe accumulation in shoots was drastically decreased by the Al application in *M. malabathricum* but not in *M. cajuputi* (Fig. 2). Oxidative stress is one of the primary factors of Fe toxicity (Fang et al., 2001). The Fe-induced accumulation of lignin and lipid peroxide (MDA), indicators of oxidative stress, was reduced by the Al application in *M. malabathricum* roots (data not shown). These results strongly suggest that *M. malabathricum* evolved mechanisms of internal Al tolerance and uses Al to avoid Fe toxicity.

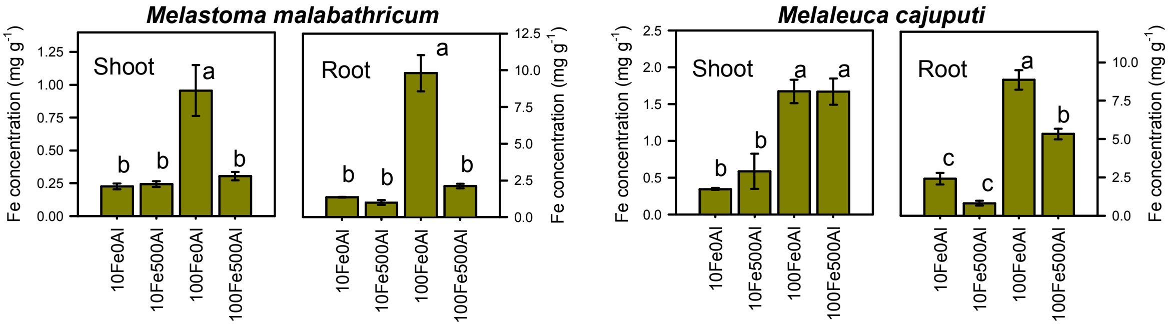

Fig. 2. Fe concentrations in shoots and roots of *M. malabathricum* and *M. cajuputi* after the Al-Fe treatments. Bars indicate ±SE. Different letters indicate significant differences (*P*<0.05, Tukey's multiple comparison test).

Effect of Al on nutrient cation availability in *Melastoma malabathricum*

It may be possible in some Al accumulator species, which have completely adapted to acid soils with very high levels of Al ion, that the internal mechanisms to inactivate Al negatively affected their growth in the absence of Al. We focused on oxalate in *M. malabathricum*. Oxalate and citrate are ligands for Al accumulation and translocation in *M. malabathricum*, respectively (Watanabe and Osaki, 2002). Whereas citrate synthesis is upregulated by Al application, oxalate concentrations are constitutively very high in this species (Watanabe et al., 2005). Since oxalate forms very stable complexes with alkaline earth metals, such as Ca and Mg, we expected the decrease in availability of these nutrient elements. As expected, water-soluble Ca, Mg, and oxalate concentrations in both shoots and roots of *M. malabathricum* grown hydroponically in the absence of Al were significantly lower than that in the presence of Al (Fig. 3). Thus, in some cases, Ca and Mg deficiencies can be involved in growth impairment of *M. malabathricum* when grown in the absence of Al.

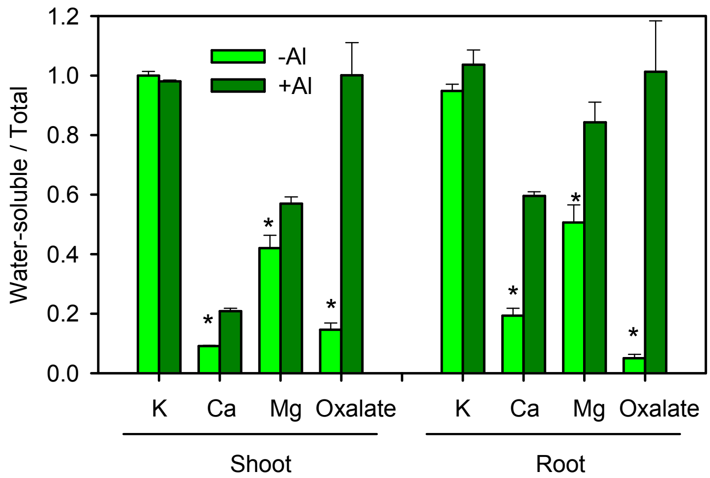

Fig. 2. Ratio of water-soluble K, Ca, Mg and oxalate to total concentration in *M. malabathricum* grown in a nutrient solution with or without 0.5 mM Al for 30 d. There was no significant difference in total concentrations between the treatments. Bars indicate ±SE. *; significantly different from the +Al treatment (P<0.05, Student's *t*-test).

References

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