Effects of Organic Acids on Alleviation of Aluminum Toxicity in Alfalfa

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Introduction

On a global scale, acidic soils cover an estimated 37.8 million km^2 of the earth's surface, and up to 50% of the world's potentially arable soils are acidic. Aluminum (Al) is highly abundant in acid soil conditions. At low (<5.5) pH, a toxic form of aluminum, Al^{3+}, is solubilized from aluminosilicate clay minerals into soil solutions. High concentrations of Al^{3+} in soil solutions caused seriously damage to plants by enhancing lipid per-oxidation, limiting root elongation and nutrient uptake, as well as decreasing plant growth (Kochian *et al.* 2005). Al toxicity represents one of the most important constraints for agricultural production in areas with acidic soils. Organic acid exudation or accumulation in roots could alleviate plant Al toxicity in acidic soils. Alfalfa (*Medicago sativa* L.) is an important legume used as a forage crop worldwide. Al toxicity is a major factor limiting alfalfa production in soils with low pH. However, limited information is available on the effects of different organic acids on Al tolerance in alfalfa. The purpose of this study was to confirm that different organic acids may assume different function in Al tolerance of alfalfa via Al exclusion or internal detoxification.

Methods

We investigated the effects of exogenous foliar application of organic acids (succinic acid ($C_4H_6O_4$), citric acid ($C_6H_8O_7$), malic acid ($C_4H_6O_5$) and oxalic acid ($H_2C_2O_4$) to alfalfa under Al stress. Seedlings were grown in pH 4.5 nutrient solution containing Al at 0 or 100 µmol/L, and were sprayed with water or 100 µmol/L of oxalic acid, malic acid, citric acid or succinic acid every 3 d during a 10-d experiment. The measurements taken included: root length, root weight and above-ground biomass. Mineral nutrient concentration were assayed in both roots and shoots, root viability assessed by triphenyltetrazolium chloride (TTC) reduction and leaf membrane lipid peroxidation by malondialdehyde (MDA) content. Organic acid content in roots and expression of six genes related to regulate organic acid synthesis through TCA cycle were measured.

Results

Aluminum stress caused significant reduction in root length (Fig. 1a), above-ground biomass (Fig. 1b), root weight (Fig. 1c), root viability, mineral nutrient concentrations (Ca, K, Mg, Mn and Zn) in shoots and roots, and a significant increase in leaf membrane lipid peroxidation (MDA).

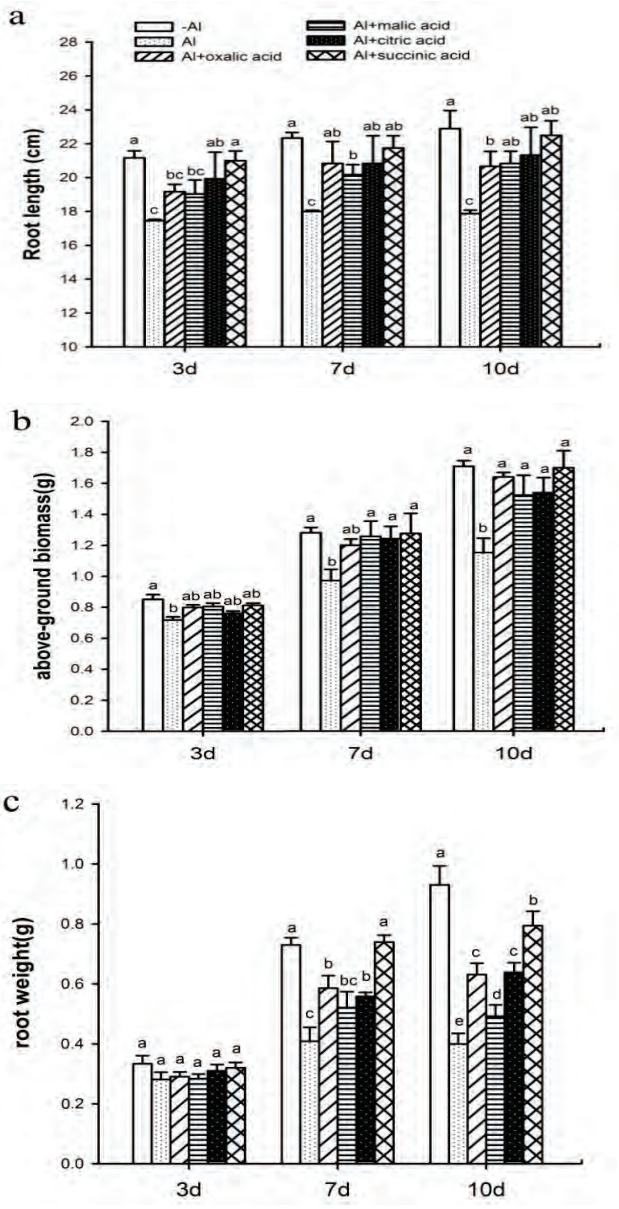

Figure 1. Effects of foliar sprays of the four organic acids on root length (a), above ground biomass (b) and root weight (c) after alfalfa exposed to Al stress.

Foliar application of the four organic acids, especially succinic acid, alleviated Al toxicity, as demonstrated by the increase in plant growth (Figure 1) and root viability, as well as reduction in lipid peroxidation. Oxalic acid and malic acid treatments significantly increased oxalate exudation and decreased Al concentration in roots exposed to Al stress. Succinic acid treatment significantly increased accumulation of all four organic acids in roots, accumulation of Ca, K, Mg, Mn and Zn, and up-regulated the gene transcription level of malate dehydrogenase (MDH) and phosphoenolpyruvate carboxylase (PEPC) in roots.

Conclusions

Our results suggested that the promotion of oxalate exudation from roots through exogenous application of oxalic acid and malic acid could contribute to the improvement in Al tolerance in alfalfa, and the positive effects of exogenous application of succinic acid on Al tolerance could be associated with the increased endogenous accumulation of all four organic acids in roots, which may constitute an internal organic-acid detoxification system for Al tolerance in alfalfa. It may be an effective way to breed Al tolerance alfalfa by increasing internal succinic acid synthesis under Al-stressed condition.

References

Kochian LV, Piñeros MA, Hoekenga OA (2005). The physiology, genetics and molecular biology of plant aluminum resistance and toxicity. *Plant Soil* **274**, 175–195.