Plant Physiology and Biochemistry 74 (2014) 205–211

Contents lists available at ScienceDirect

Plant Physiology and Biochemistry

journal homepage: www.elsevier.com/locate/plaphy

Research article

Contrasting effect of silicon on iron, zinc and manganese status and accumulation of metal-mobilizing compounds in micronutrient-deficient cucumber

Nikolai Bityutskii [a,1], Jelena Pavlovic [b,1], Kirill Yakkonen [a], Vuk Maksimović [b], Miroslav Nikolic [b,*]

[a] Department of Agricultural Chemistry, Saint Petersburg State University, 16th linia 29, V.O. Saint Petersburg 199178, Russia
[b] Institute for Multidisciplinary Research (IMSI), University of Belgrade, Kneza Višeslava 1, 11030 Belgrade, Serbia

ARTICLE INFO

Article history:
Received 26 September 2013
Accepted 13 November 2013
Available online 21 November 2013

Keywords:
Cucumber
Micronutrient deficiency
Organic acids
Phenolics
Silicon

ABSTRACT

Although the beneficial role of silicon (Si) in alleviation of abiotic stress is well established, little is known of the relevance of Si nutrition under microelement deficiency. The aim of our work was to investigate the physiological role of Si in relation to micronutrient (Fe, Zn and Mn) deficiencies in cucumber (*Cucumis sativus* L.). Cucumber (cv. Semkross) plants were grown hydroponically in a complete nutrient solution (control) and in nutrient solutions free from Fe, Zn or Mn, with or without Si supply. Plant tissue concentrations of microelements, organic acids and phenolics were measured. Si supply effectively mitigated the symptoms of Fe deficiency, but only in part, the symptoms of Zn- or Mn deficiency. Leaf Fe concentration significantly increased in plants deprived of Fe but treated with Si, whereas the concentrations of other microelements were not affected by Si supply. The effects of Si supply in increasing accumulation of both organic acids and phenolic compounds in cucumber tissues were exclusively related to Fe nutrition. Enhancement of Fe distribution towards apical shoot parts, along with the tissue accumulation of Fe-mobilizing compounds such as citrate (in leaves and roots) or cathechin (in roots) appears to be the major alleviating effect of Si. Si nutrition, however, was without effect on the mobility and tissue distribution of either Zn or Mn.

1. Introduction

Iron (Fe), zinc (Zn) and manganese (Mn) are essential microelements for all living organisms including plants, and are responsible for numerous important physiological functions. The biological importance of Fe is a result of its reversible changes of oxidation state over a wide range of redox potentials. Fe is a component of a number of enzymes involved in various biological processes, including respiration and photosynthesis (Römheld and Nikolic, 2006). Zn is an important component of many enzymes, and a structural stabilizer of proteins and plant membranes (Aravind and Prassad, 2004). Mn is the active constituent of the water-splitting system of photosystem II, which provides the necessary electrons for photosynthesis (Goussias et al., 2002). In addition, Mn plays an important role in biosynthesis of secondary metabolites, such as flavonoids and lignin (Millaleo et al., 2010).

Despite the abundance of Fe, Zn and Mn in most agricultural soils, their bioavailability is often limited. The deficiency of these microelements is a consequence of various factors, which modify their availability, acquisition or utilization by plants. Most commonly, the symptoms of micronutrient deficiency occur due to their low bioavailability, particularly in calcareous soils, which make up one third of the world's agriculture soils (Guerinot and Yi, 1994; Lindsay, 1995; Vose, 1982). The deficiency of the micronutrients is one of the major limiting factors for crop production causing considerable yield losses of economically important crops throughout the world (Alloway, 2008). As a consequence of these crop deficiencies in micronutrients, the diets of a large proportion of the world's population are also deficient. This is especially the case for Fe and Zn deficiencies, which have a strong negative impact on human health and longevity leading to the recommendation of crop biofortification of these nutrients (White and Broadley, 2009).

Although the second most abundant element in the earth's crust, silicon (Si) is not yet listed among the essential elements for higher plants (Epstein, 1999), and consequently it has been omitted from the formulations of nutrient solutions widely used in plant biology research. However, beneficial effects of Si mainly in

* Corresponding author. Tel.: +381 113058956; fax: +381 113055289.
E-mail address: mnikolic@imsi.bg.ac.rs (M. Nikolic).
[1] Both authors contributed equally to this work.

0981-9428/$ – see front matter © 2013 Elsevier Masson SAS. All rights reserved.
http://dx.doi.org/10.1016/j.plaphy.2013.11.015

alleviating various biotic (diseases and pests) and abiotic (e.g. metal toxicities, nutrient imbalances, salinity, drought, freezing, high temperature, and UV radiation) stresses in many plant species are well documented in the literature [for reviews, see Refs. (Epstein, 1999; Ma, 2004; Hattori et al., 2005; Linag et al., 2007)]. Over the past five years rapid progress has been made predominantly in elucidation of the mechanisms of how Si mediates metal excess (Li et al., 2008; Song et al., 2009; Prabagar et al., 2011; Song et al., 2011; Führs et al., 2009; Dragisic Maksimovic et al., 2012), whereas limited information is available on how Si affects nutrient deficiency in crops. It has been reported that the addition of Si to the nutrient solution is able to mitigate Fe deficiency chlorosis in Strategy 1 plants such as cucumber, pumpkin and soybean (Bityutskii et al., 2010; Gonzalo et al., 2013). Very recently, Pavlovic et al. (2013) were the first to demonstrate Si-induced increase of the apoplastic Fe pool, together with the enhanced expression of genes involved in biosynthesis of Fe-mobilizing compounds in roots of Fe-deficient cucumber.

The objective of this study was to investigate the physiological role of Si in hypothesized alleviation of micronutrient deficiencies in cucumber, with special emphasis on the distribution of Fe, Zn and Mn in relation to tissue accumulation of metal-mobilizing compounds such as carboxylates and phenolics.

2. Results

2.1. Effect of Si on plant growth and visual symptoms of micronutrient deficiencies

Cucumber plants grown in the absence of Fe, Zn or Mn, respectively showed characteristic deficiency symptoms, such as chlorosis or necrotic spots on the young expanded leaves, and inhibited plant growth (Figs. 1 and 2). The visual symptoms of Fe deficiency were especially dramatic (Fig. 1A). In comparison to the control plants, plants deprived of Fe (−Fe) showed 12-times lower total chlorophyll concentration (severe chlorosis), whereas the leaf chlorophyll concentration of Mn deprived plants (−Mn) was only 1.5-fold lower in comparison to the control. Cucumber plants grown in Zn-free nutrient solution (−Zn) developed necrotic spots on young expanded leaves, with no significant changes in the chlorophyll concentration (Fig. 1).

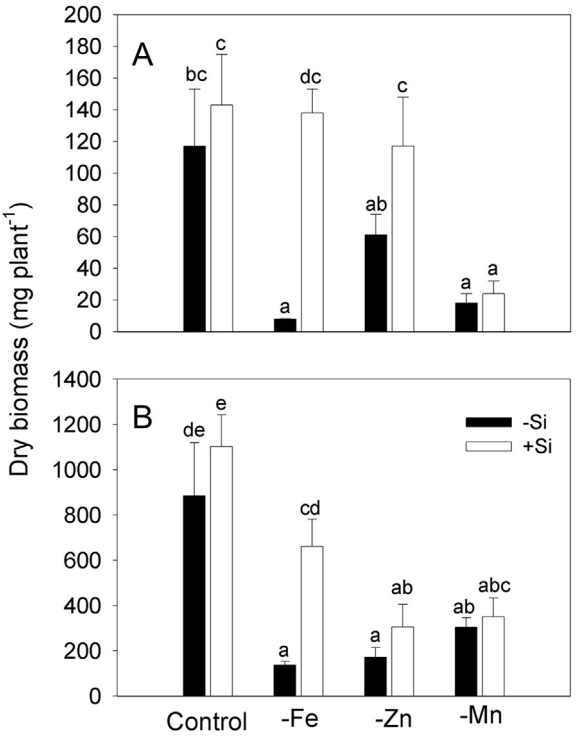

Fig. 2. Effect of Si supply on the dry root (A) and shoot (B) biomass of cucumber plants subjected to micronutrient deficiency. Data are expressed as mean ($n = 4$) ± SD. Significant differences between treatments ($p < 0.05$) are indicated by different letters.

Silicon supply successfully ameliorated the leaf symptoms of Fe deficiency (preventing or delaying chlorosis), and to some extent the leaf symptoms of Zn deficiency (preventing necrotic spots; Fig. 1A). However, the Mn deprived plants treated with Si did show

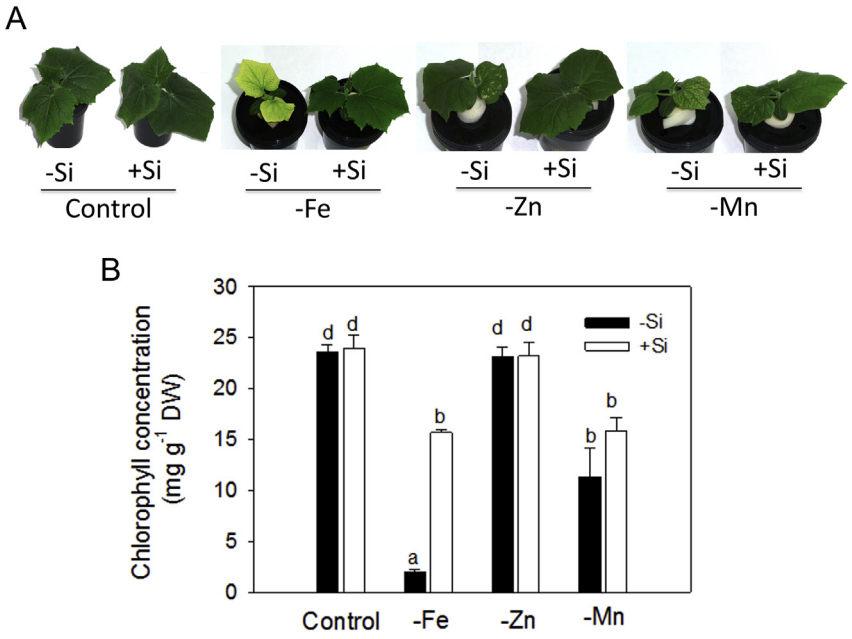

Fig. 1. Effect of Si supply on the development of visual symptoms of micronutrient deficiency (A) and leaf chlorophyll concentration (B) in cucumber plants subjected to micronutrient deficiency. Data are expressed as mean ($n = 4$) ± SD. Significant differences between treatments ($p < 0.05$) are indicated by different letters.