Response of Plant Growth to Low Calcium Concentration in the Nutrient Solution

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Abstract

Many studies have indicated the importance of calcium in fruit disorders. This nutrient is often applied in the nutrient solution in relatively high amounts throughout the crop season, usually without taking into account the physiological stage of the plant. Our study aimed to determine the effect of calcium supply on growth of young, vegetative tomato plants. The experiment was carried out in a growth chamber under fully controlled climate conditions. Treatments consisted of four periods of 1, 3, 7 or 14 days of low calcium (0.5 meq l^{-1}) compared with the control (9 me l^{-1}). Plant dry matter content, total leaf area, leaf dry matter and specific leaf area were not affected after 14 days of low Ca supply. Ca concentrations in young leaves, stem, and roots were quickly reduced after only 1 day of low-Ca. After 14 days, Ca concentration in all plant organs (leaves, stems and roots) was reduced by approximately 70% compared to control plants. Stomatal regulation was not affected by this level of calcium stress as leaf transpiration in treated plants was similar to control plants with the same leaf area. Our data show that calcium supply and consequently Ca concentration in the plant can be reduced drastically without any adverse effect on growth.

INTRODUCTION

Nowadays horticultural practices usually involve application of water and fertilizers in excess to ensure that there is no nutrient shortage in the nutrient solution. Theses practices allow maximum yields but increase contamination. Currently, technological developments, agricultural policy alterations, and environmental regulation revisions are changing the agricultural production and processing environment (Attwood et al., 2000). Greater nutrient efficiencies constitute a major improvement to increase profit margins while maintaining crop yield and reducing pollution (Sampat, 2001). To increase nutrient efficiencies it is necessary to know the nutrient concentrations required by the plant, at each phenological stage, in relation to growth. Calcium is a major nutrient necessary for membrane stability and maintenance of cell integrity and also essential for cell division and expansion (Hepler and Wayne, 1985). Usually, a high Ca concentration is applied to horticultural crops, such as tomato or sweet pepper, to avoid blossom end rot during fruit development. Although high Ca could reduce important physiological disorders in fruit, the aim of the present research was to study the response of vegetative tomato plants to low Ca concentration in the nutrient solution.

MATERIALS AND METHODS

Seeds of tomato (*Lycopersicon esculentum* Mill.) cv. Capita (De Ruiter Seeds) were sown in a growth chamber in moist vermiculite. At 24 DAS (days after sowing) each plant was transferred to a 12-L bucket. Buckets contained 10 ± 0.01 L of nutrient solution, were oxygenated continuously with compressed air, and were refilled to avoid increase in electrical conductivity. The temperature was 22°C, RH was 70 %, and a photosynthetic photon flux of 300 μmol m^{-2} s^{-1} was supplied for 16 hours, followed by 30 minutes of incandescent light. All lateral shoots were removed during the experiment. Treatments consisted of a control treatment and four low-Ca periods of 1, 3, 7, and 14 d. Solution with low Ca had the following composition in meq l^{-1}: Ca^{2+}: 0.5, K^{+}: 11.7, Mg^{2+}: 6.7, NO_3^{-}: 10.9, $H_2PO_4^{-}$: 0.9, SO_4^{2-}: 6.4,. The control solution had the following composition in meq l^{-1}: Ca^{2+}: 9.0; K^{+}: 7.0;

Mg^{2+}: 4.0; NO_3^-: 12.0; $H_2PO_4^-$: 1.0; SO_4^{2-}: 7.0 Low calcium treatments started at 28 DAS. Roots of these plants were carefully rinsed in a low-calcium solution before being transferred to a new bucket to avoid Ca^{2+} contamination. Treated and control plants were harvested at 29, 31, 35 DAS and 42 DAS. Six plants were harvested in each treatment.

At each harvest time, the area and fresh and dry weights of each leaf, individually, and of roots and stem (including petioles) were measured. Leaves were separated into young (1st to 4th) and old (total number of leaves per plant varied from 7 at start to 13 at end of treatment period). Dry weight was determined after at least 72 h at 80°C. Water uptake was measured by weighing buckets with nutrient solution. Transpiration was calculated as the water uptake minus the increase in plant fresh weight. The transpiration per unit leaf area of each plant was calculated by dividing the transpiration of the whole plant by the average leaf area at the start and end of each period between consecutive measurements. For Ca^{2+} determination, HCl and trichloracetic acid were added to the dry matter and boiled for 30 min after addition of $BaCl_2$ and $SrCl_2$. Ca^{2+} was determined by atomic absorption spectrometry (Varian AA10).

RESULT AND DISCUSSION

The primary functions of calcium within plants are enzyme activation and stabilization (metabolism) and maintenance of membrane form and activity and cell wall structure (Christiansen and Foy, 1979). Recently, it has been established that calcium acts as an intracellular messenger in coupling a wide range of extracellular signals to specific responses such as cell division, cell elongation or cell differentiation (Reddy, 2001). In our experiment, when young vegetative tomato plants were grown in low-Ca solution, total plant dry matter was not significantly affected after 14 days, compared to the control plants (Fig. 1). In the same way, total plant leaf area, leaf dry matter percentage, and specific leaf area were not affected after this period of low calcium supply.

Ca concentration in young leaves, stem, and roots decreased by 30% after only 1 day of low Ca supply compared with the control plants (Fig. 2), but this effect was less strong when we compared old leaves. As the low calcium period increased, Ca concentrations in all plant organs were reduced to a similar extent. Despite this important reduction in Ca concentration (almost 70 %), plant growth was not affected. Most of the water-soluble calcium in plant tissues is located in the vacuoles, accompanied by organic (e.g. malate) or inorganic anions (e.g. nitrate, chloride). In contrast to the cell wall or vacuoles, the concentration of calcium in the cytosol is very low (0.1-0.2 µM of free Ca) (Marschner, 2002). Our data showed that, although calcium concentrations in tissues were drastically reduced, the cytosolic calcium concentration in the cell was enough to allow cell division and expansion. Contrary to complete calcium depletion, where root growth stops almost immediately (del Amor and Marcelis, 2003), vegetative tomato plants were able to grow at a very low concentration without any symptom of deficiency. Early studies also reported general disintegration of membrane structure with Ca deficiency (Marinos, 1962). Contrary to Ca, deficiencies of other nutrients such as N or K, result in a shift in dry-matter allocation in favour of root growth (del Amor et al., 2003; del Amor and Marcelis, 2004), thus this response enables the plant to optimize its allocation of resources and therefore growth.

Plant dry matter increase and Ca uptake showed a strong linear relationship (Fig. 3). Control plants absorbed almost four times more than treated plants but had a similar increase in DM. Leaf transpiration per unit leaf area was reduced as plant size increased, due to an over-shading effect (Fig. 4). Calcium regulates guard-cell turgor and stomatal aperture (MacRobbie, 1997). Cytosolic calcium concentration has been shown to be a key component of the signal transduction pathways by which guard cells respond to stimuli that induce both stomatal opening and closure (Blatt, 2000). Calcium stress did not reduce leaf transpiration, which indicates no stomatal closure, as all climate conditions were constant and the data were compared to plants with the same leaf area.

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Figures

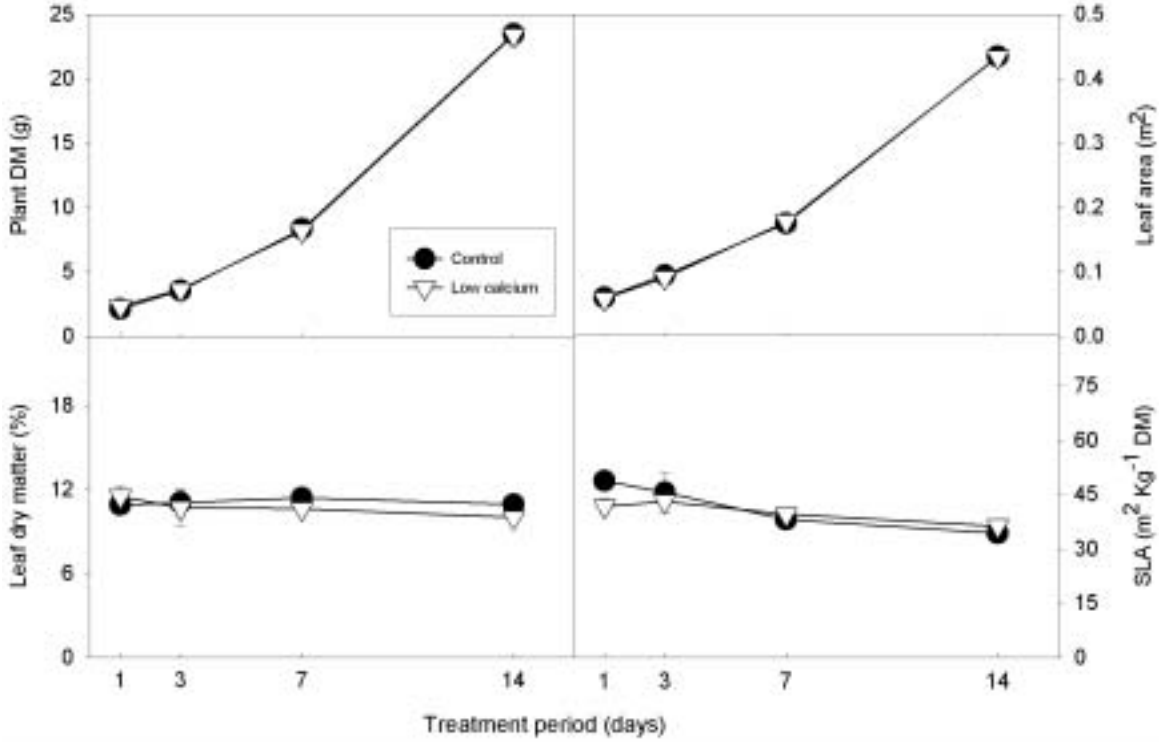

Fig. 1. Total plant dry matter, total leaf area, leaf dry matter, and specific leaf area of control and low-calcium plants after 1, 3, 7 or 14 days. Vertical bars represent the standard errors of the means.

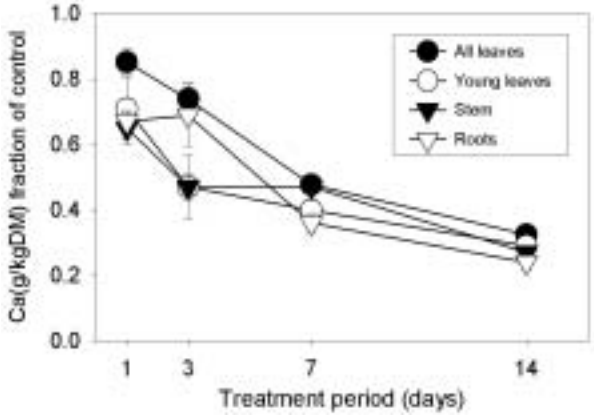

Fig. 2. Ca concentration in leaves (old and young), stem, and roots expressed as a fraction of control plants after 1, 3, 7 or 14 days. Vertical bars represent the standard errors of the means. Control treatment (mg Ca/g DM±SE): Young leaves: 22.5±0.8; All leaves: 40.1±1.8; Stem: 10.2±1.2; roots: 17.7±0.8.

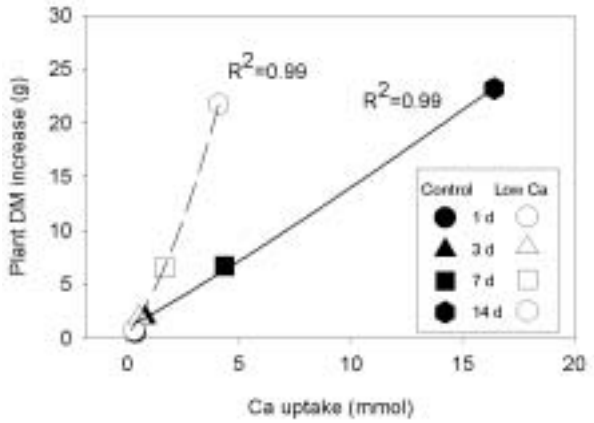

Fig. 3. Relationship between plant dry matter increase and Ca uptake during 1, 3, 7 or 14 days of high and low Ca concentration in the nutrient solution. Standard errors of the means were smaller than the symbol size.

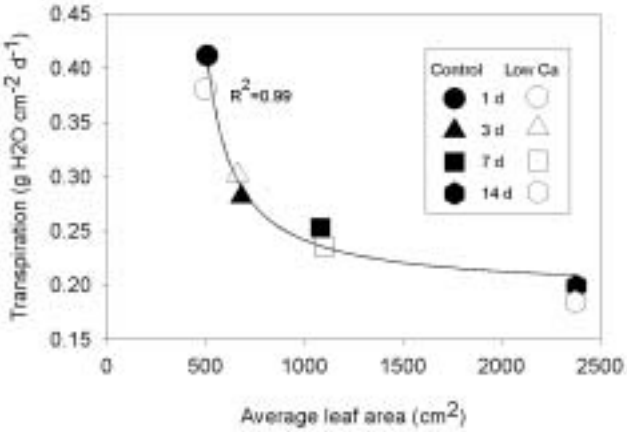

Fig. 4. Relationship between transpiration and the average leaf area during 1, 3, 7 or 14 days of high and low Ca concentration in the nutrient solution. Standard errors of the means were smaller than the symbol size.