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Research Paper

The effect of magnesium nutrition on the antioxidant response of coffee seedlings under heat stress

Dayane Meireles da Silva*, Kamila Rezende Dázio de Souza, Lissa Vasconcellos Vilas Boas, Yara Santos Alves, José Donizeti Alves

Setor de Fisiologia Vegetal, Departamento de Biologia, Universidade Federal de Lavras, Campus Universitário, Caixa Postal 3037, CEP 37200-000, Lavras, Minas Gerais, Brazil

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ABSTRACT

High temperatures are already a current reality. If necessary attention is not given to plant nutrition, including magnesium nutrition, large losses in productivity can occur when plants are subjected to combinations of these heat and nutrient stresses. Thus, the goal of our work was to investigate the importance of adequate magnesium nutrition for an effective antioxidant response in coffee seedlings subjected to heat stress. As such, six-month-old *Coffea arabica* L. seedlings were transferred to plastic containers containing nutrient solutions with different concentrations of magnesium (Mg) and were cultivated at two different temperatures (25 or 35 °C). Fully expanded leaves and roots were evaluated at the beginning of the treatment and after 10, 20 and 30 days for the concentrations of magnesium, hydrogen peroxide, proline, ascorbate, malondialdehyde, protein and amino acids as well as the activities of the enzymes superoxide dismutase, catalase, ascorbate peroxidase, monodehydroascorbate reductase, dehydroascorbate reductase and glutathione reductase. The variables analyzed were mainly altered by the combination of stresses. Mg deficiency and heat stress caused an increase in hydrogen peroxide concentration that was accompanied by an increase in antioxidant metabolism and by greater production of proline and ascorbate. Nevertheless, antioxidant metabolism and osmoprotectants were insufficient at removing excess ROS, resulting in increased lipid peroxidation and protein degradation. When subjected to heat stress, coffee seedlings under adequate Mg nutrition showed lower production of hydrogen peroxide and, consequently, poor lipid peroxidation and protein denaturation compared with seedlings deficient in Mg. Therefore, adequate Mg nutrition is essential for minimizing oxidative damage caused by heat stress in coffee seedlings.

1. Introduction

Heat stress has become a growing concern due to damage caused to productivity of many crops (Luo et al., 2008). Increases in temperature trigger impacts to several physiological and metabolic processes, such as non-partitioning of carbohydrates to the roots and resultant damage to root growth (Du and Tachibana, 1994). Magnesium deficiency is another stress that also causes this reduction in carbohydrate translocation from source to sink (Cakmak and Yazici, 2010; Da Silva et al., 2014). In this condition, chloroplasts are exposed to excessive excitation energy triggering a high production of reactive oxygen species (ROS), such as superoxide radical (O_2^-), hydrogen peroxide (H_2O_2), hydroxyl radical (OH^-) and singlet oxygen (^1_2O) (Marutani et al., 2012).

Since ROS are unavoidable products of plant metabolism, under normal conditions ROS production and removal are well balanced (Mittler, 2002). However, under stress conditions, ROS production can overcome removal mechanisms, triggering oxidative stress (Gill and Tuteja, 2010; Marutani et al., 2012). This is due to the high toxicity of ROS, which are highly cytotoxic and can react with various biomolecules, such as lipids, proteins and nucleic acids, causing lipid peroxidation, protein denaturation and DNA mutations, respectively (Quiles and López, 2004).

Membranes are the main target of injury (Candan and Tarhan, 2003), since ROS can react with unsaturated fatty acids, triggering lipid peroxidation in plasma membranes and in organelle membranes (Karabal et al., 2003). Peroxidation of the plasma membrane causes extravasation of cellular contents, rapid desiccation and cell death,

Abbreviations: Mg, magnesium; ROS, reactive oxygen species; SOD, superoxide dismutase; CAT, catalase; APX, ascorbate peroxidase; MDHAR, monodehydroascorbate reductase; DHAR, dehydroascorbate reductase; GR, glutathione reductase; MDA, malondialdehyde

* Corresponding author.
E-mail addresses: dayanemeireles@yahoo.com.br (D.M.d. Silva), krdazio@hotmail.com (K.R.D.d. Souza), lissavilasboas92@outlook.com (L.V. Vilas Boas), yara.ufla@yahoo.com.br (Y.S. Alves), jdalves@dbi.ufla.br (J.D. Alves).

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Table 1
Concentrations of hydrogen peroxide and proline in leaves and roots of *Coffea arabica* L. seedlings subjected to different concentrations of magnesium and temperature. Capital letters compare the effects of magnesium deficiency at each temperature and sampling time, and lowercase letters compare the effects of temperature elevation in each Mg condition and at each sampling time. Different letters indicate significant differences with 0.05 probability according to the Scott-Knott test.

			H_2O_2 Leaves	H_2O_2 Roots	Proline Leaves	Proline Roots
T. (°C)	Days	Treat.	(μmol g^{-1} FW)		(μg g^{-1} DW)	
25	0	Control Mg	12.7 ± 0.4 Aa	2.9 ± 0.1 Aa	1.1 ± 0.1 Aa	0.4 ± 0.0 Aa
	10		16.8 ± 0.3 Ab	2.8 ± 0.1 Aa	1.0 ± 0.1 Bb	0.5 ± 0.0 Ab
	20		16,3 ± 0.3 Bb	2.8 ± 0.1 Bb	1.2 ± 0.1 Bb	0.6 ± 0.0 Bb
	30		16.3 ± 0.3 Bb	3.1 ± 0.1 Bb	1.2 ± 0.1 Bb	0.7 ± 0.0 Bb
	0	Mg-deficient	12.7 ± 0.4 Aa	2.9 ± 0.1 Aa	1.1 ± 0.1 Aa	0.4 ± 0.0 Aa
	10		17.4 ± 0,7 Ab	3.5 ± 0.3 Aa	1.5 ± 0.1 Ab	0.6 ± 0.0 Ab
	20		21.6 ± 0.1 Ab	4.2 ± 0.1 Ab	1.7 ± 0.2 Ab	0.9 ± 0.0 Ab
	30		30.6 ± 2.0 Ab	4.6 ± 0.1 Ab	1.6 ± 0.1 Ab	0.9 ± 0.0 Ab
35	0	Control Mg	12.7 ± 0.4 Aa	2.9 ± 0.1 Aa	1.1 ± 0.1 Aa	0.4 ± 0.0 Aa
	10		19.3 ± 0.3 Ba	3.2 ± 0.1 Ba	4.3 ± 0.2 Ba	1.2 ± 0.0 Ba
	20		24.3 ± 0.6 Ba	3.9 ± 0.1 Ba	3.5 ± 0.2 Ba	1.4 ± 0.0 Ba
	30		28.9 ± 1.3 Ba	3.9 ± 0.1 Ba	4.9 ± 0.2 Ba	3.4 ± 0.0 Ba
	0	Mg-deficient	12.7 ± 0.4 Aa	2.9 ± 0.1 Aa	1.1 ± 0.1 Aa	0.4 ± 0.0 Aa
	10		30.4 ± 1.5 Aa	4.1 ± 0.6 Aa	5.5 ± 0.5 Aa	1.4 ± 0.0 Aa
	20		31.6 ± 1.7 Aa	5.2 ± 0.1 Aa	4.7 ± 0.2 Aa	2.2 ± 0.1 Aa
	30		36.6 ± 1.5 Aa	5.8 ± 0.2 Aa	6.6 ± 0.3 Aa	4.1 ± 0.3 Aa

T.: temperature; Treat: treatment; DW: dry weight; FW: fresh weight.

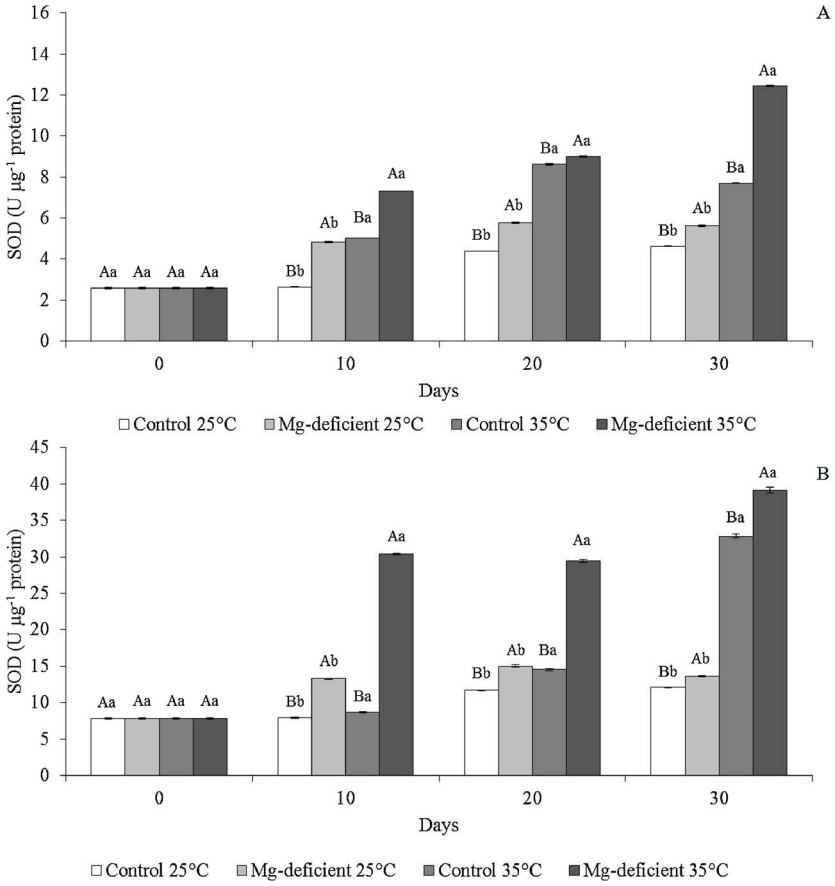

Fig. 1. Superoxide dismutase (SOD) activity in leaves (A) and roots (B) of *Coffea arabica* L. seedlings subjected to different concentrations of magnesium and different temperatures. Capital letters compare the effects of magnesium deficiency at each temperature and sampling time, and lowercase letters compare the effects of temperature elevation in each Mg condition and at each sampling time. Different letters indicate significant differences with 0.05 probability according to the Scott-Knott test. Bars show the standard error of five replicates.

whereas peroxidation of the intracellular membrane can affect mitochondrial respiratory activity, pigment deterioration and loss of carbon fixation capability in chloroplasts (Foyer and Noctor, 2000).

To counteract the effects of heat on cellular metabolism, plants respond by synthesizing and accumulating osmoprotectants. Osmoprotectants are small, electrically neutral molecules that stabilize proteins and membranes against the denaturing effects of heat (Rivero et al., 2014). Proline is an osmoprotectant that is responsible by stabilization of proteins, membranes and subcellular structures and is involved in the removal of reactive oxygen species (Kumar et al., 2012).

In addition to osmoprotectants, to protect cells from oxidative damage plants have developed different antioxidant defense systems to minimize cellular damage from ROS. The enzymatic antioxidant system includes superoxide dismutase (SOD), which catalyzes the dismutation of O_2^- to H_2O_2 and O_2. H_2O_2 is converted to H_2O and O_2 by the action of catalase (CAT), various peroxidases and enzymes of the ascorbate-glutathione cycle. This cycle is characterized by a series of coupled redox reactions involving ascorbate peroxidase (APX),