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RESEARCH ARTICLE

Exogenously applied nitrate improves the photosynthetic performance and nitrogen metabolism in tomato (*Solanum lycopersicum* L. cv Pusa Rohini) under arsenic (V) toxicity

Ashish Agnihotri[1] · Chandra Shekhar Seth[1]

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Abstract Tomato (*Solanum lycopersicum* L.) being a widespread and most commonly consumed vegetable all over the world has an important economic value for its producers and related food industries. It is a serious matter of concern as its production is affected by arsenic present in soil. So, the present study, investigated the toxicity of As(V) on photosynthetic performance along with nitrogen metabolism and its alleviation by exogenous application of nitrate. Plants were grown under natural conditions using soil spiked with 25 mg and 20 mM, As(V) and nitrate, respectively. Our results revealed that plant growth indices, photosynthetic pigments, and other major photosynthetic parameters like net photosynthetic rate and maximum quantum efficiency (F_v/F_m) of photosystem II (PSII) were significantly ($P \leq 0.05$) reduced under As(V) stress. However, nitrate application significantly ($P \leq 0.05$) alleviated As(V) toxicity by improving the aforesaid plant responses and also restored the abnormal shape of guard cells. Nitrogen metabolism was assessed by studying the key nitrogen-metabolic enzymes. Exogenous nitrate revamped nitrogen metabolism through a major impact on activities of NR, NiR, GS and GOGAT enzymes and also enhanced the total nitrogen and NO content while malondialdehyde content, and membrane electrolytic leakage were remarkably reduced. Our study suggested that exogenous nitrate application could be considered as a cost effective approach in ameliorating As(V) toxicity.

Keywords Nitrate reductase · Nitrite reductase · Photosynthetic quantum yield · *Solanum lycopersicum* L. · Scanning electron microscope · Nitric oxide

Abbreviations

As(V)	Arsenic
MDA	Malondialdehyde
A	Net photosynthetic rate
AAS	Atomic absorption Spectroscopy
SEM	Scanning electron microscopy
NO	Nitric oxide

Introduction

A wide variety of heavy metals are released into the environment by unprecedented anthropogenic activities like agricultural practices, industrialization, urbanization and mining activities. In the recent decades, there has been a massive As(V) accumulation in the environment through series of consequences such as burning of coal, industrial metal smelting, mining, semiconductor manufacturing, fertilizers, pesticides and sewage (Rubinos et al. 2010; Marmiroli et al. 2014).

Arsenic, a metalloid is a lethal poison as its toxicity has been already proven on plants and animals and its low level exposure can cause cancer (Mandal and Suzuki 2002). In the environment, arsenic is found in both organic and inorganic forms where later forms are more toxic. Inorganic forms include arsenate [As(V)] and arsenite [As(III)] where As(V) taken up by plants *via* phosphate transporter is first reduced into As(III) that got chelated or effluxed out of the cell (Kumar et al. 2015) and/or poses toxicity to several metabolic processes by generating reactive oxygen species (ROS) like superoxide ($O_2^{\cdot -}$) radicals, hydroxyl

✉ Chandra Shekhar Seth
seth_bhu@yahoo.co.in

[1] Department of Botany, University of Delhi, Delhi 110007, India

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