



# Photosynthesis is induced in rice plants that associate with arbuscular mycorrhizal fungi and are grown under arsenate and arsenite stress



Sara Adrian Lopez de Andrade\*, Adilson Pereira Domingues Jr., Paulo Mazzafera

Departamento de Biologia Vegetal, Instituto de Biologia, Universidade Estadual de Campinas, Campinas, SP, Brazil

## HIGHLIGHTS

- AsV and AsIII were supplied to rice plants under AM symbiosis.
- AsV and AsIII decreased photosynthetic rates and PSII efficiency.
- AM promoted biomass accumulation, carbon assimilation and water use efficiency.
- Maximum and actual quantum yields of photosystem II increased due to AM under As.

## ARTICLE INFO

### Article history:

Received 3 June 2014

Received in revised form 8 April 2015

Accepted 10 April 2015

Handling Editor: X. Cao

### Keywords:

Arbuscular mycorrhiza

Arsenic

Chlorophyll fluorescence

Photochemical metabolism

*Rhizophagus irregularis*

## ABSTRACT

The metalloid arsenic (As) increases in agricultural soils because of anthropogenic activities and may have phytotoxic effects depending on the available concentrations. Plant performance can be improved by arbuscular mycorrhiza (AM) association under challenging conditions, such as those caused by excessive soil As levels. In this study, the influence of AM on CO<sub>2</sub> assimilation, chlorophyll *a* fluorescence, SPAD-chlorophyll contents and plant growth was investigated in rice plants exposed to arsenate (AsV) or arsenite (AsIII) and inoculated or not with *Rhizophagus irregularis*. Under AsV and AsIII exposure, AM rice plants had greater biomass accumulation and relative chlorophyll content, increased water-use efficiency, higher carbon assimilation rate and higher stomatal conductance and transpiration rates than non-AM rice plants did. Chlorophyll *a* fluorescence analysis revealed significant differences in the response of AM-associated and -non-associated plants to As. Mycorrhization increased the maximum and actual quantum yields of photosystem II and the electron transport rate, maintaining higher values even under As exposure. Apart from the negative effects of AsV and AsIII on the photosynthetic rates and PSII efficiency in rice leaves, taken together, these results indicate that AM is able to sustain higher rice photosynthesis efficiency even under elevated As concentrations, especially when As is present as AsV.

© 2015 Elsevier Ltd. All rights reserved.

## 1. Introduction

The metalloid arsenic (As) is not essential to living organisms and is considered as an important environmental toxin because it can enter the food chain through the consumption of contaminated edible plants by humans or animals (Zhao et al., 2010). Diverse anthropogenic activities, such those that are related to the use of contaminated irrigation waters and the misuse of agrotoxins containing arsenates, also contribute to the increase in As in agricultural soils. Indeed, As is a potent carcinogenic element; therefore, the control of its levels in soils and waters is of great

importance (Zhao et al., 2010). Plants preferentially take up As in the organic forms of arsenate (AsV) and arsenite (AsIII) but also may absorb methylated As, which is less toxic than the inorganic forms are (Abbas and Meharg, 2008). Root phosphate transporters are involved in AsV uptake by plants (Wu et al., 2011), as this anion is chemically analogous to inorganic phosphate. Conversely, a class of aquaporin channels are responsible for AsIII absorption (Ma et al., 2008). AsV exerts its toxicity by replacing phosphate in target molecules, such as DNA, RNA, proteins and other phosphorylated metabolites; inhibiting ATP synthesis; and targeting important phosphorylation reactions in primary metabolism (Finnegan and Chen, 2012). AsIII binds to sulfhydryl groups, disturbing protein/enzyme structure and functioning (Finnegan and Chen, 2012). Plants are in general sensitive to As toxicity, diminishing growth and impairing absorptive functions, and roots are in general the

\* Corresponding author. Tel.: +55 19 35216322; fax: +55 19 35216184.

E-mail address: [sara.adrian@gmail.com](mailto:sara.adrian@gmail.com) (S.A.L. de Andrade).

first barrier to As translocation to the aerial parts, limiting the toxicity of photosynthetic tissues (Macnair and Cumbes, 1987). As stress interferes with important metabolic processes, such as those that are related to photosynthesis and respiration, and, depending on the severity, it can ultimately lead plant to death (Abedin and Meharg, 2002). Regarding the impact of As on photosynthesis, As is able to inhibit this process by lowering chlorophyll synthesis and the activity of the photosystem II (Rahman et al., 2007; Finnegan and Chen, 2012), although its specific effects on the photochemical and gas exchange capacities are still largely unexplored.

Arbuscular mycorrhizal fungi (AMF) are plant symbionts with a profound influence on plant physiology by affecting their nutritional status (Smith and Read, 2008). The role of arbuscular mycorrhizal (AM) symbiosis in sustaining plant development under harsh environmental conditions has been widely recognized (Smith and Smith, 2011), and AM associated plants usually perform better under different biotic and abiotic stressors, such as drought, nutrient deficiencies or imbalances, excessive levels of toxic elements or salinity (Pozo and Azcón-Aguilar, 2007; Auge et al., 2008; Andrade et al., 2009). In the context of nutrients/element acquisition, extraradical mycelia may increase the root absorption surface and, by modifying root absorption properties, may improve plant nutrition, growth and general fitness (Smith and Read, 2008). AM association confers As tolerance and attenuation of toxicity in diverse plant species (Gonzalez-Chavez et al., 2002; Chen et al., 2007, 2013). Several high-affinity phosphate transporters may be down-regulated, diminishing AsV uptake (Gonzalez-Chavez et al., 2002; Christophersen et al., 2009). In addition to transporter modulation, AM can improve P nutrition, promoting plant growth, increasing the P/As ratios, diluting As contents and reducing toxicity (Christophersen et al., 2009; Li et al., 2011). AMF are obligate biotrophs and depend on the plant carbon (C) supply to maintain their intra and extraradical fungal growth and to complete their life cycle (Johnson et al., 2002). Estimates suggest that AMF may compromise 4–17% of the C photosynthates, constituting a strong sink and stimulating photosynthesis (Wright et al., 1998) independently of their influence on nutrient acquisition (Kaschuk et al., 2009). In this regard, AM may enhance photosynthesis in crop plants, such as maize or rice, especially under stress conditions, such as drought or salinity (Sheng et al., 2008; Ruiz-Sánchez et al., 2010).

AM presence in roots changes the nutrient balance and element uptake properties as hyphal pathway operate in associated plants (Christophersen et al., 2009). However, and in spite of the existing reports on As effects on plant physiology, the role of AM symbiosis has been relatively neglected in relation to AsV and AsIII accumulation and their effects on photosynthetic performance. Rice has been used as a model plant among cereals and its genome was fully sequenced (Project, 2005). Under aerobic conditions, rice is able to form mycorrhizae, as is the case for upland rice cultivated in many regions of the world. In addition, rice is a species with a high As uptake and accumulation capacity compared to that of other cereal plants mainly due to the high efficiency of silicon uptake in this plant (Zhao et al., 2010). On the other hand very recently the *Rhizophagus irregularis* genome was sequenced and showed 28% of the annotated genes are representatives of kinase-domain proteins, suggesting important signaling interactions with host plants (Tisserant et al., 2013; Lin et al., 2014). Thus, from both sides there is a great perspective to understand physiological processes underlying rice/AM interactions at molecular levels.

Here, as part of a comprehensive study involving physiology, proteomic and transcriptomic approaches, we report on the alterations in the gas exchange capacities, chlorophyll *a* fluorescence, SPAD-chlorophyll contents and plant growth in rice plants inoculated with *R. irregularis* and exposed to AsV or AsIII.

## 2. Materials and methods

### 2.1. Experimental design

A greenhouse experiment was set up using a  $3 \times 2$  factorial scheme and completely randomized design with 10 replications. The treatments that were used were the absence or presence of  $50 \mu\text{mol L}^{-1}$  of AsV or AsIII in the nutrient solution and the inoculation or not with the AMF *R. irregularis*. The six treatments were denominated as follows: NM-C (grown in the absence of As and *R. irregularis*), M-C (grown in the absence of As and inoculated with *R. irregularis*), NM-AsV (grown in the presence of AsV and not inoculated), M-AsV (grown in the presence of AsV and inoculated), NM-AsIII (grown in the presence of AsIII and not inoculated) and M-AsIII (grown in the presence of AsIII and inoculated).

### 2.2. Biological material and inoculation

The AMF that were used as inocula included *R. irregularis* DAOM 197198 from Premier Tech Biotechnologies (Rivière-du-Loup, QC, Canada) as an aseptic spore solution. The plant that was used was *Oryza sativa* var. IAC202, an upland rice variety from the Agronomic Institute (Campinas, SP, Brazil). Manually dehusked seeds were surface sterilized (2 min at 70% ethanol and 10 min at 2.5% NaClO, followed by sterile water washing). The seeds were previously germinated in sterilized vermiculite, and after emergence, 3 to 4 seedlings were transplanted to 1-L plastic pots in which sterilized ground quartz silica (2–3 mm) was used as ground support. Each pot received approximately 400 spores of *R. irregularis* DAOM 197198 at transplanting. The rice plants were irrigated with nutrient solution ( $\text{mg L}^{-1}$  concentrations: N-NO<sub>3</sub> 154.6; N-NH<sub>4</sub> 19.5; P 10; S-SO<sub>4</sub> 18.7; Ca 151.2; K 70.9; Mg 18.8; B 0.53; Fe 1.99; Mn 0.97; Cu 0.076; Zn 0.3; and Mo 0.15) (Furlani and Furlani, 1988) or supplied with distilled water on alternate days. After 25 d, As was applied with the irrigation water or nutrient solution to As-treatment pots twice a week. As ( $50 \mu\text{mol L}^{-1}$ ) was applied as Na<sub>2</sub>HAsO<sub>4</sub> or NaAsO<sub>2</sub> for the AsV and AsIII treatments, respectively. The plants were allowed to grow for 8 weeks, after which they were harvested. The volume of nutrient solution or water amended with As and used to irrigate the plants was recorded, and at the end of the experiment it was calculated that each pot received 1.91 mg of As. The day and night temperatures ranged between 28 and 17 °C, respectively, with a photoperiod of 12 h and an irradiance of approximately  $1200 \mu\text{mol quanta m}^{-2} \text{s}^{-1}$ .

### 2.3. Plant growth analysis and mycorrhizal colonization evaluation

The shoots and roots were separated at harvest. The shoots were washed in tap water, dried (at 60 °C for 72 h), weighed and ground for chemical analysis. The root subsamples (2–3 g fresh weight) were stored in 50% ethanol for mycorrhizal colonization determination. Four replicates per treatment were used to evaluate the percentage of the root length that was colonized by AMF, which was estimated using the slide method (Giovannetti and Mosse, 1980) after they were cleared with KOH and stained with 0.05% trypan blue (Phillips and Hayman, 1970). For each replicate, 30 root segments of approximately 1 cm were observed using an Olympus BX 40 light microscope (Olympus Optical Co., Tokyo, Japan).

### 2.4. As, P and S content determination

Shoots and roots of four plants per treatment were washed in tap water, dried at 60 °C, weighed and ground in mortar with a pestle. The As P and S contents in shoots and roots were determined by ICP-OES (JobinYvon, JY50P Longjumeau, France) after

Download English Version:

<https://daneshyari.com/en/article/6307634>

Download Persian Version:

<https://daneshyari.com/article/6307634>

[Daneshyari.com](https://daneshyari.com)