Influences of the arbuscular mycorrhizal fungus *Glomus mosseae* on morphophysiological traits and biochemical compounds of common bean (*Phaseolus vulgaris*) under drought stress

Ali Ganjeali*, Etham Ashiani, Maryam Zare and Elahe Tabasi

Department of Biology, Faculty of Sciences, Ferdowsi University of Mashhad, Mashhad, Iran

*Corresponding author, email: ganjeali@um.ac.ir

The symbiosis of arbuscular mycorrhizal fungi (AM) with plant roots can enhance plant responses, especially to drought stress. An experiment was conducted in a growth chamber to examine the impacts of arbuscular mycorrhizae on improving the drought tolerance of common bean (*Phaseolus vulgaris* L.) subject to different drought level conditions (25%, 50% and 75% field capacity) and control (field capacity). The seeds were inoculated with *Glomus mosseae* and 10-day-old seedlings were subjected to the drought treatments. After nine weeks, the plants were harvested. The results indicated that root and shoot dry weight increased, whereas the root:shoot ratio decreased, in drought-treated AM plants. Furthermore, maximum root colonisation was observed at 75% field capacity. In the drought-treated AM plants, the phosphorus content of the root and shoot significantly increased, whereas the potassium content of the root declined compared with that of non-AM plants. Mycorrhizal plants showed higher CO₂ assimilation, water relative content, transpiration rate, superoxide dismutase, polyphenol oxidase and peroxidase activities, proline content, and leaf soluble proteins, as well as lower stomatal resistance, compared with the non-AM plants, especially in drought-stress conditions. In conclusion, common bean can benefit from the AM symbiosis.

**Keywords:** antioxidant enzymes, drought stress, mycorrhizae, *Phaseolus vulgaris*

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**Introduction**

Drought is one of the most severe environmental stresses, which influences agricultural productivity by reducing yield and adversely affects almost all plant growth processes (Boyer 1985), such as photosynthesis, chlorophyll content, Calvin cycle activities and, consequently, the productivity of crop plants (Monakhova and Chernyad 2002; Youpensuk et al. 2009). However, plant response to stress depends on the intensity and duration of exposure and the growth stage. A number of reactive oxygen species (ROS) produced in plants under drought stress may cause destructive oxidative processes (Lin and Kao 1998). However, some antioxidant compounds play a key role in scavenging ROS (Yooyongwech et al. 2013), such as superoxide dismutase (SOD), glutathione reductase, se and peroxidase as enzymatic antioxidants, and ascorbic acid, glutathione, α-tocopherol, flavonoids, carotenoids and proline as non-enzymatic antioxidants (Wu and Zou 2009; Rapparini and Peñuelas 2014). Drought stress causes restricted transpiration rate, impaired active transport and altered membrane permeability, and consequently reduced nutrient transport from roots to shoots (Sardans et al. 2008).

Arbuscular mycorrhizal (AM) symbiosis improves plant functionality through helping plants to cope with the detrimental effects of water deficit of soil. AM plants withstand drought-induced oxidative stress by increasing the production of antioxidant compounds and enhancing the activities of antioxidant enzymes. AM root colonisation can enhance root growth and form an organised root system for nutrient/water uptake (reviewed by Augé 2001). Increased phosphorus (P) uptake has been observed in several legumes infected by *Glomus mosseae* and *Glomus intraradices* (Cozzolino et al. 2013; Williams et al. 2013).

Common bean (*Phaseolus vulgaris* L.) is a valuable food resource, particularly in tropical and subtropical regions. In these regions, environmental stresses such as drought can limit the growth and yield of bean plants (Fageria and Santos 2008). The symbiosis of AM fungi enhances the drought tolerance of legume host plants (Alroca et al. 2007).

Accordingly, the objective of the present study was to investigate the possibility of improving the performance of bean plants through a symbiotic relationship with arbuscular mycorrhizae under drought stress conditions.

**Materials and methods**

This study was undertaken at the Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran. The experimental station is located at 36°18′44.0892″ N, 59°31′54.9156″ E.

**Plant materials**

The seeds of common bean (*Phaseolus vulgaris* 'Brilliant Red') were surfaced-sterilised with sodium hypochlorite (10% v/v, 10 min) and sown in pots filled with clay and sand (2:1). The soil in the pots was sterilised by autoclaving (90 °C, 1 h). Soil was inoculated with inoculum.
of the mycorrhizal fungus *Glomus mosseae* at the rate of 100 g inoculum per 1 kg soil and added to the pots (12 000–15 000 spores kg⁻¹ soil). The AM plants were grown in the mycorrhiza-inoculated soil and control plants were grown in sterilised soil. Maize (*Zea mays* L.) was used as a host plant for multiplication of mycorrhizal inoculum.

Three moisture regimes (25%, 50% and 75% field capacity [FC]) and 100% FC (as the control) were used. The seedlings were subjected to drought stress 10 d after emergence. The factorial experiment was performed based on a complete randomised design with three replicates. The plants were grown at 25 °C in a growth chamber with photosynthetic photon flux density (PPFD) of 1 200 µmol m⁻² s⁻¹ and 16 h/8 h (light/dark) photoperiod. Moisture levels were kept constant at the prescribed levels during the experiment.

**Measurement of morphological traits**

The plants were harvested 60 d after emergence at the flowering stage. After harvest, the shoots and roots were separated, and the leaf area, root length, shoot dry weight (SDW) and root dry weight (RDW) were determined. The leaf area was measured using a leaf area meter (ADC BioScientific Ltd, Hoddesdon, UK). The roots in each plant were recovered from the soil by washing, divided into 4–6 sections and placed on a scanner connected to a computer for analysis. Root length was calculated using ROOTEDGE 2.3 software (Iowa State University Research Foundation Inc., Ames, IA, USA, 1999). Finally, the root:shoot ratio (R/S) was determined.

**Determination of root colonisation percentage**

In accordance with Kormanik and McGraw’s (1982) method, fresh root segments (1 cm long) were stored in formalin, cleared in 10% KOH at room temperature for 24–72 h), boiled for 20–25 min, placed in H₂O₂ for 10–30 min, acidified in 1% HCl for 3–5 min and stained with 1% fuchsine-lactic acid. The stained root segments were placed on microscope slides and then the colonisation components were determined.

**Determination of nutrient uptake**

The nutrient content of the shoots and roots were analysed using flame-photometry (for postassium [K]) and colourimetric spectroscopy (molybdenum blue) (for P). In accordance with Chapman and Pratt’s (1982) method, the segments were digested in concentrated nitric acid. The solution turned blue after incubation of the sample in molybdic acid phosphate solution. The dye intensity was measured at 730 nm. The values were expressed as grams per 100 grams dry weight.

**Determination of water relations and physiological traits**

Leaf relative water content (RWC) was measured in accordance with Bian and Jiang (2008):

\[
\text{RWC} = \left( \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \right)
\]

where RWC = relative water content, FW = fresh weight, DW = dry weight and TW = leaf weight in the fully turgid state.

Stomatal conductance was measured using a steady-state porometer (LI-1600, LICOR, Lincoln, NE, USA). Carbon dioxide assimilation, transpiration (E), and intracellular CO₂ concentration (C) were measured using a portable infrared gas analyser (LCA4, ADC BioScientific Ltd) under PPFD of 1 200 µmol m⁻² s⁻¹ between 09:00 and 13:00 at 25 °C. All measurements were carried out on the healthy youngest fully expanded leaf. Water use efficiency (WUE) was calculated by dividing the CO₂ assimilation value by the transpiration level (Ahmad and Sakuratsui 2002).

Chlorophyll and carotenoid contents were measured by Lichtenthaler’s (1987) method. Briefly, 0.1 g leaf tissue was ground in a mortar in 4 mL of 80% acetone and then centrifuged at 700 ×g for 5 min. The absorbance of the supernatant was measured at 470, 647 and 664 nm. The contents of the photosynthetic pigments were calculated using the following equations:

\[
\text{Chl}_a (\text{mg g}^{-1} \text{FW}) = (12.25 A_{664} - 2.79 A_{647}) \quad (1)
\]

\[
\text{Chl}_b (\text{mg g}^{-1} \text{FW}) = (21.21 A_{647} - 5.1 A_{664}) \quad (2)
\]

\[
\text{Chl}_t (\text{mg g}^{-1} \text{FW}) = \text{Chl}_a + \text{Chl}_b \quad (3)
\]

\[
\text{Carotenoids (mg g}^{-1} \text{FW}) = \left( \frac{1000A_{470} - 1.8Chl_b - 85.02Chl_a}{198} \right) \times 1000 \quad (4)
\]

where Chlₐ = chlorophyll a, Chl₇ = chlorophyll b, Chlₜ = total chlorophyll, and A = absorbance at 470, 647 and 664 nm.

**Antioxidant assays**

For proline determination in accordance with Bates et al. (1973), 0.2 g fresh samples were extracted with 4 mL of 3% hydrated sulfoasalicylic acid. A portion (2 mL) of the extract was added to the reaction mixture (2 mL ninhydrin solution and 2 mL acetic acid) for 1 h at 100 °C. The coloured product was extracted with 4 mL toluene by shaking. The absorbance of the supernatant was measured at 366 nm.

The protein content was determined using the revised method of Lowry et al. (1951). Briefly, 1 mL of the diluted extracts (1:10) was added to 15 mL reagent A (100 g Na₂CO₃ in 1 L of 0.5 N NaOH), 0.75 mL reagent B (1 g hydrated CuSO₄·5H₂O in 100 mL distilled water), and 0.75 mL reagent C (4.91 g KNaC₆H₄O₆·4H₂O in 100 mL distilled water). Next, 1 mL of this solution and 3 mL Folin-Ciocalteau reagent (1:10) were added to 1 mL of the extract. After 45 min, the absorption was measured at 520 nm. Bovine serum albumin was used as a protein standard (Bradford 1976).

To assay superoxide dismutase (SOD) activity, Giannopolitis and Rice’s (1977) method was applied. Briefly, 0.5 g samples were homogenised in 5 mL cold 50 mM phosphate buffer (pH 7.0) containing 1 mM EDTA. An aliquot (3 mL) of the reaction mixture (50 mM phosphate buffer [pH 7.8], 0.1 mM EDTA, 75 µM NBT, 13 mM methionine and 4 µM riboflavin) was added to 200 µL of the extract and the tubes were placed under white fluorescent light (40 W). After 15 min, the reaction product was measured at 560 nm.

Following the method of Hoyle (1972), peroxidase (POX) activity was analysed in a reaction mixture (2 mL of 0.2 M acetate buffer [pH 5], 0.2 mL of 0.3% H₂O₂, and 0.1 mL of 0.02 M benzidine in 50% methanol) using 100 µM extract. The absorbance was measured at 530 nm.
Polyphenol oxidase (PPO) activity was analysed in accordance with the method of Raymond et al. (1993). In this assay, 2.5 mL of 0.2 M potassium phosphate buffer, 0.2 mL of 0.02 M pyrogallol and 0.2 mL enzymatic extract were mixed in tubes and incubated in a water bath at 40 °C. The absorbance was recorded at 430 nm.

**Statistical analyses**

The data obtained were statistically analysed using one-way analysis of variance (ANOVA) and Duncan’s multiple range test \((P < 0.05)\) as implemented in MSTAT-C version 2.1 software (Michigan State University, East Lansing, MI, USA).

**Results and discussion**

**Morphological traits**

Leaf area, root traits (including area, length and dry weight) and shoot weight (stem and leaves) were significantly affected by drought stress \((P < 0.05)\). At all moisture levels, leaf area in AM plants was significantly higher than that of non-AM plants. Conversely, no significant differences between AM and non-AM plants were observed for root traits. Results for shoot weight were similar to those of leaf area, except at 25% FC (Table 1).

Thakur and Panwar (1997) reported that mycorrhizae increased leaf area by 9.1% in bean. In mung bean, mycorrhizal plants had relatively higher root area than non-mycorrhizal plants under drought stress (Habibzadeh 2014). Increased RDW and SDW in AM plants under drought stress (Habibzadeh et al. 2014). Increased RDW and SDW in AM plants under drought stress (Habibzadeh et al. 2014). However, no significant differences between AM and non-AM plants for root traits. Results for shoot weight were similar to those of leaf area, except at 25% FC (Table 1).

**Root colonisation percentage**

In AM plants, the majority of colonisation was observed at 75% FC (Table 2). Examination of infection types revealed that roots had only mycelia at 25% FC, and spores, vesicles and seldom arbuscules at 75% FC. The control and 50% FC treatment showed a mixture of mycelia, spores and vesicles (Figure 1). These results were in agreement with those of previous research. Borowicz et al. (2010) stated that drought stress damaged the roots and decreased the number of arbuscules and vesicles in mycorrhizal strawberries. Ibijiben et al. (1996) reported that production of dry matter significantly increased by 8–23% in AM beans.

Subramanian and Santhanakrishnan (2006) reported that the colonisation levels of mycorrhizal tomato were 45% in AM plants. However, no significant differences were observed between AM and non-AM plants at 75% FC. The control and 50% FC treatment showed a mixture of mycelia, spores and vesicles (Figure 1). These results were in agreement with those of previous research. Borowicz et al. (2010) stated that drought stress damaged the roots and decreased the number of arbuscules and vesicles in mycorrhizal strawberries. Ibijiben et al. (1996) reported that production of dry matter significantly increased by 8–23% in AM beans.

**Table 1:** Effects of mycorrhiza and drought stress on morphological traits of *Phaseolus vulgaris* seedlings. Different letters within a column indicate a significant difference at \(P < 0.05\) according to Duncan’s multiple range test. AM = arbuscular mycorrhizal plants, NM = non-arbuscular mycorrhizal plants, FC = field capacity

<table>
<thead>
<tr>
<th>Mycorrhizal inoculation</th>
<th>FC (%)</th>
<th>Leaf area (cm² plant⁻¹)</th>
<th>Root area (cm² plant⁻¹)</th>
<th>Root length (cm plant⁻¹)</th>
<th>Root dry weight (g plant⁻¹)</th>
<th>Shoot dry weight (g plant⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Control</td>
<td></td>
<td>519.4±</td>
<td>305.2±</td>
<td>4.375±</td>
<td>1.2±</td>
<td>3.4±</td>
</tr>
<tr>
<td>AM 75</td>
<td></td>
<td>463.0±</td>
<td>379.2±</td>
<td>5.436±</td>
<td>1.3±</td>
<td>3.8±</td>
</tr>
<tr>
<td>AM 50</td>
<td></td>
<td>358.8±</td>
<td>279.8±</td>
<td>3.900±</td>
<td>1.0±</td>
<td>2.6±</td>
</tr>
<tr>
<td>AM 25</td>
<td></td>
<td>245.5±</td>
<td>206.5±</td>
<td>3.067±</td>
<td>0.8±</td>
<td>1.3±</td>
</tr>
<tr>
<td>NM Control</td>
<td></td>
<td>317.5±</td>
<td>330.9±</td>
<td>4.732±</td>
<td>1.2±</td>
<td>2.7±</td>
</tr>
<tr>
<td>NM 75</td>
<td></td>
<td>255.4±</td>
<td>326.1±</td>
<td>4.497±</td>
<td>1.4±</td>
<td>2.7±</td>
</tr>
<tr>
<td>NM 50</td>
<td></td>
<td>212.7±</td>
<td>298.9±</td>
<td>4.002±</td>
<td>1.0±</td>
<td>2.1±</td>
</tr>
<tr>
<td>NM 25</td>
<td></td>
<td>161.3±</td>
<td>187.8±</td>
<td>2.838±</td>
<td>0.7±</td>
<td>1.1±</td>
</tr>
</tbody>
</table>

**Table 2:** Effects of mycorrhiza and drought stress on the extent of root colonisation and nutrient contents in *Phaseolus vulgaris* seedlings. Different letters within a column indicate a significant difference at \(P < 0.05\) according to Duncan’s multiple range test. AM = arbuscular mycorrhizal plants, NM = non-arbuscular mycorrhizal plants, FC = field capacity, K = potassium, P = phosphorus

<table>
<thead>
<tr>
<th>Mycorrhizal inoculation</th>
<th>FC (%)</th>
<th>Shoot K content (g per 100 g FW)</th>
<th>Root K content (g per 100 g FW)</th>
<th>Shoot P content (g 100 g FW)</th>
<th>Root P content (g 100 g FW)</th>
<th>Root colonisation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Control</td>
<td></td>
<td>18.2±</td>
<td>12.7±</td>
<td>0.51±</td>
<td>0.58±</td>
<td>40.18±</td>
</tr>
<tr>
<td>AM 75</td>
<td></td>
<td>15.8abc</td>
<td>8.3bc</td>
<td>0.31b</td>
<td>0.63b</td>
<td>87.19b</td>
</tr>
<tr>
<td>AM 50</td>
<td></td>
<td>12.2c</td>
<td>7.4c</td>
<td>0.46c</td>
<td>0.67c</td>
<td>43.79c</td>
</tr>
<tr>
<td>AM 25</td>
<td></td>
<td>12.5c</td>
<td>9.1c</td>
<td>0.48c</td>
<td>0.83c</td>
<td>7.01c</td>
</tr>
<tr>
<td>NM Control</td>
<td></td>
<td>17.4±</td>
<td>16.2±</td>
<td>0.31±</td>
<td>0.41±</td>
<td>–</td>
</tr>
<tr>
<td>NM 75</td>
<td></td>
<td>16.6abc</td>
<td>14.8abc</td>
<td>0.28b</td>
<td>0.46b</td>
<td>–</td>
</tr>
<tr>
<td>NM 50</td>
<td></td>
<td>15.9abc</td>
<td>12.6abc</td>
<td>0.29b</td>
<td>0.48b</td>
<td>–</td>
</tr>
<tr>
<td>NM 25</td>
<td></td>
<td>12.6abc</td>
<td>6.4c</td>
<td>0.44±</td>
<td>0.51±</td>
<td>–</td>
</tr>
</tbody>
</table>
50% and 47% in the well-watered control, light moderate and severe drought stress, respectively. Root colonisation level under drought stress differs between plant species depending on the soil conditions, the intensity of drought stress, and physiological factors such as leaf water potential and accumulation of osmotic regulators.

**Nutrient uptake**
Mycorrhizae affected host photosynthesis, water relations and drought tolerance by improving P uptake. In the present study, the interaction of mycorrhizal and drought stress had considerable impacts on P content of the root and shoot (Table 2). In AM plants, the P content of roots increased notably at all drought levels (Table 2), except for 75% FC, compared with the non-AM plants. The highest and lowest root P contents were observed in AM plants at 25% FC and non-AM plants in the control, respectively. Augé et al. (2004) indicated that the P content of leaves in AM beans (inoculated with *G. intraradices*) was higher than that of non-AM plants. Ibibijen et al. (1996) reported that P content in AM beans significantly increased by 160–335% because of improved P acquisition by mycorrhizal roots.

Drought stress significantly decreased the K content of the shoot under severe drought stress (25% FC), but mycorrhizae improved K nutrition. Neumann and George (2009) reported that the K and P contents of mycorrhizal cowpea under drought stress were significantly higher than that of non-mycorrhizal plants.

**Water relations**
Relative water content is a good indicator of drought stress tolerance. The majority of previous studies have reported a reduction in RWC in response to drought stress (Shaw et al. 2002). In the present study, AM plants at all moisture levels exhibited lower stomatal resistance compared with the non-AM counterparts, regardless of water regime. However, the difference was not significant at 25% FC. Water uptake in AM plants was 2–3 times higher than that of the non-AM plants (Pawlowska and Taylor 2004). The main reason for this is probably the high hydraulic conductivity in mycorrhizal roots. Salim and El-Yazied (2015) stated that mycorrhizal snap bean plants at 75% water-holding capacity showed the highest values for all growth parameters, yield traits and biochemical constituents except for proline concentration.

Subramanian and Santhanakrishnan (2006) showed that RWC in mycorrhizal tomato under drought stress was significantly higher than that of non-AM plants. The authors concluded that high RWC improved P and N uptake from the soil. Augé et al. (2004) observed higher stomatal conductance in mycorrhizal beans in comparison with non-mycorrhizal plants. Enhanced stomatal resistance is a mechanism to avoid drought stress. Tezara et al. (2002) observed that low soil moisture reduced leaf water content and guard-cell turgidity and led to stomatal closure. The authors observed that low soil moisture decreased water transport to leaves and stomatal conductance, resulting in low transpiration rate and restricted photosynthesis. Lee and Muner (2012) showed that stomatal resistance, transpiration and photosynthesis in AM plants were higher than those of non-AM plants under drought stress.

In the present study, the transpiration rate was significantly higher in AM plants compared with that of non-AM plants in all drought treatments and the control. In all plants, WUE was enhanced with increasing drought severity (Table 3). The highest and the lowest WUE were observed in non-AM plants at 25% FC and AM plants in the control, respectively. However, Neumann and George (2009) observed that WUE in AM cowpea plants was higher than that of non-AM cowpea plants under drought stress.

**CO₂ assimilation and photosynthetic pigments**
At all drought levels, the photosynthetic rate in AM plants was significantly higher than that of non-AM plants (Table 3).

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**Figure 1:** Root colonisation at different levels of drought stress. (a) 25% Field capacity (FC), (b) 50% FC, (c) 75% FC, (d) 100% FC
Guard cells lose their turgidity under drought stress, resulting in stomatal closure. This limits the rate of CO₂ diffusion through the stomata and reduces photosynthesis (Sikuku et al. 2010). AM plants supply symbiont requirements by regulating the photosynthesis rate in different ways (Sánchez-Bianco et al. 2004; Valentine et al. 2006).

Increasing severity of drought stress significantly decreased the chlorophyll a, chlorophyll b and total chlorophyll concentrations in leaves of both AM and non-AM plants (Table 3). These characteristics were not affected by AM inoculation. Under drought stress, leaf area was reduced to prevent water loss, resulting in increased chlorophyll concentrations per unit leaf area (Estill et al. 1991; Salehi and Kouchaki 2002). Conversely, Panwar (1992) and Mathura and Vyas (1995) reported that chlorophyll concentration often is higher in leaves of AM plants compared with that of non-AM plants.

Carotenoids, as light-harvesting molecules, enable efficient utilisation of the light spectrum (Porra et al. 1997) and protect pigment–protein complexes and chloroplasts against photo-oxidation (Demmig-Adams 1990). In the present study, carotenoid content was significantly increased by mycorrhizae, but was decreased under drought stress ($p < 0.05$; Table 4). Therefore, AM plants show higher photosynthetic efficiency, indicating that the photosynthetic apparatus shows limited damage under drought stress (Ibrahim et al. 1990). Enhanced CO₂ fixation during and after drought stress may account for the enhanced growth of AM plants (Ruiz-Sánchez et al. 2010).

Antioxidant compounds and enzymes

Under drought stress, plants accumulate organic osmolytes, such as sugars and amino acids (e.g. proline), to regulate osmotic potential (Yang and Miao 2010). These compounds play primary roles in plant tolerance under water-deficit conditions (Schellenbaum et al. 1998; Trottel-Aziz et al. 2000). In the present study, drought stress and mycorrhizal inoculation had significant effects on leaf proline and protein contents (Table 4). Accumulation of proline increased considerably in leaves of AM plants during drought stress compared with that of non-AM plants. AM plants efficiently create an osmotic balance to improve drought tolerance. These results are in accordance with those of Ruiz-Lozano et al. (1995) and Ruiz-Sánchez et al. (2010).

Moucheshi et al. (2012) observed that inoculation with G. intraradices alleviated the deleterious effects of water-deficit stress on wheat cultivars via proline accumulation and high antioxidant activities. This and other experiments suggest that AM symbiosis enhances the tolerance of host plants under water stress (Asrar et al. 2012).

Protein content was significantly different in AM and non-AM plants in the 25% FC and 50% FC treatments, and was lower in AM plants compared with that of the control (Table 4). Several studies have reported low protein content in AM plants under drought stress (Subramanian and Charest 1997; Thakur and Panwar 1997; Sannazaro et al. 2006).

The enzymes SOD, PPO and POX perform protective roles in scavenging ROS (Lin and Kao 1998). We observed that POX activity increased with elevation in drought stress.
both in AM and non-AM plants. The findings also showed that PPO and POX activities of AM plants at 50% FC and 25% FC (moderate and severe drought stress, respectively) were higher than those of non-AM plants, although the difference was significant only under severe stress. At all drought levels, SOD activity in AM plants was higher than that of non-AM plants except at 75% FC. These findings indicate that AM plants increase the activities of antioxidant enzymes to reduce ROS concentration and enhance drought tolerance of the host plants. These results are in agreement with those obtained by Porcel and Ruiz-Lozano (2004) and Younesi and Moradi (2013). In addition, Gillham and Dodge (1987) stated that higher POX activity shows a positive correlation with drought tolerance in crop plants. Peroxidase scavenges the products of oxidative stress such as H₂O₂, and, thus, can ameliorate the adverse effects of oxidative damage (Sairam et al. 1997; Pandey et al. 2010).

The relationship between PPO activity and salt and drought stresses has been demonstrated previously (Agarwal and Pandey 2003). PPO catalyses phenolic compounds (Jang and Song 2004). In the present study, mycorrhiza had no significant effect on PPO activity.

**Conclusion**

The results obtained in this study showed that *Phaseolus vulgaris* could benefit from AM symbiosis and attained a good level of AM root colonisation. The AM symbiosis improved plant photosynthetic efficiency under drought stress and enhanced antioxidant enzyme activities. Thus, these combined effects enhanced the performance of bean plants under drought stress conditions.

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