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Effects of Mycorrhiza on Plant Nutrition, Enzyme Activities, and Lipid Peroxidation in Pepper Grown Under Salinity Stress

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ABSTRACT

This study was conducted to determine whether Arbuscular Mycorrhizal Fungi (AMF) [ROOTS-novozymes endo-mycorrhiza fungus (*Glomus* spp.)] increase salt stress tolerance. The effects of mycorrhiza inoculation and salt on root and stem development, mineral nutrition, enzyme activity and lipid peroxidation levels in pepper (*Capsicum annuum* L.) plant was investigated. These effects were explored in pepper plants grown under greenhouse conditions in a randomized block design. Four different doses of salt (0, 50, 100 and 150 mM NaCl) were applied to the soil-filled pots, in addition to two different doses of mycorrhiza (0 and 100 spore mycorrhiza plant^{-1}). It was found that the root and stem dry weights of pepper plants were greatly reduced in the non-mycorrhiza treatments, whereas the presence of mycorrhiza ameliorated these negative effects. N, P, K, Ca, Mg, S, Fe, Mn, Zn and Cu contents of AMF treated pepper were higher than non-mycorrhizal plants. Owing to the presence of AMF colonization, nutrient uptake was increased and, consequently, the nutrient contents of stem and root tissues of mycorrhizal inoculated plants were enhanced as well. On the other hand, the root and stem enzyme activity of plants increased with salinity. AMF inoculation decreased SOD, CAT, POD and AxPOD enzymes of plant and the MDA and H_2O_2 contents, indicating lower oxidative damage in the inoculated plants. Our results showed that AMF can contribute to protect plants against salinity by alleviating the salt induced oxidative stress and arranging the ion balance in plant via increasing nutrient uptake in saline soils.

Keywords: Arbuscular mycorrhizal fungi, Nutrient uptake, Saline soils, Salt stress tolerance.

INTRODUCTION

Salinity is one of the most destructive stress factors affecting soil fertility and crop yield. Soils that make up about 7% of the global land surface are affected by salinity (Sheng *et al*., 2011). Approximately 17% of the agricultural areas of the world have been irrigated and 20% of these are reported to have salinity problems (Tuteja, 2007).

Negative effects of salinity in plant growth include osmotic stress, which causes physiological drought and occurs as a result of nutritional imbalance; ion-specific phytotoxic effects; and a combination of these factors due to irregularities in the ion balance of plants' intake and transport of nutrients (Acosta-Motos *et al*., 2017). Soil salinity not only affects the uptake of some macronutrients but also prevents the intake of some micronutrients. Therefore, salinity is known to cause metabolic disorders and micronutrient deficiency in the plant (Munns and Tester, 2008).

Different plants can tolerate different doses of salt stress. This tolerance to the accumulation or excretion of toxic ions leads to molecular or biological activity. This activity is governed by physiological and biochemical events that accumulate ions in

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certain parts of the plant by limiting ion transmission from roots to shoots and increasing osmo-regulators and antioxidant enzymes or activating various genes at the molecular level.

Mycorrhiza, an important soil fungi that forms symbiotic association with the roots of plants, is effective in increasing the uptake of nutrients from the soil and enhancing tolerance to abiotic, biotic, and physiological stress conditions (Salam *et al*., 2017; Tedersoo *et al*., 2020). Improvement of plant growth due to mycorrhizal symbiosis might be explained by changes in both the photosynthesis and antioxidant enzyme activities of plants (Li *et al*., 2019). Mycorrhizal fungi increase the root surface area by forming many hyphae, thus, allowing the roots to absorb more water and nutrients (Barman *et al*., 2016).

AMF inoculation increases plant resistance to salinity stress by improving nutrient and water uptake in plants under saline conditions, maintaining ionic and osmotic balance, inducing antioxidant system to prevent damage caused by reactive oxygen species, increasing photosynthetic efficiency and modulating phytohormone profile (Evelin *et al*., 2012; Ruiz-Lozano *et al*., 2012; Augé *et al*., 2014; Mirzaei and Moradi, 2016). However, there have been still scientific gaps regarding the effects of AMF on the biochemical status of different parts of pepper plant. Therefore, the present study comprehensively covers biochemical and physiological changes that occur in plants that are inoculated with AMF fungi and exposed to salinity stress. The obtained data will contribute to a better understanding of the mechanisms by which AMF inoculation provides salinity stress alleviation.

Pepper, which belongs to the genus *Capsicum*, has an economic importance in Turkey, as in many countries. According to Turkstat (2020) data, approximately 2.64 million tons (dry or green) pepper is produced in Turkey. Pepper was preferred as a plant material in the study because it is both widely grown and significantly affected by salinity.

In this study, the aim was to evaluate the nutritional elements, enzyme activity, and lipid peroxidation content of pepper (*Capsicum annuum* L. var. g*rossum*) plant under salinity conditions and to evaluate the effects of mycorrhizal infection on the plant.

MATERIALS AND METHODS

This study was carried out in a climate-controlled greenhouse at the Kırşehir Ahi Evran University, Faculty of Agriculture, in Turkey. In order to determine the effects of the different doses of salt on the development and nutrition of plants, a randomized block design was planned with 4 replications. The soil samples used in the experiment were taken from the region where the pepper genotype is widely grown, sterilized by autoclaving at 121°C for two hours, and passed through a 2 mm sieve as per the Bouyoucos hydrometer method (Bouyoucos, 1951). The soil reaction (pH) and Electrical Conductivity (EC) were measured with a glass electrode pH meter in the prepared 1: 2.5 soil-water mixture. Lime contents were determined by Scheibler calcimeter and the organic matter by the modified Walkley-Black method (Jackson, 1958). Total N was determined by Kjeldahl method (Bremner, 1965). Available K (extracted with ammonium acetate) was measured by flame photometry (Knudsen *et al*., 1983) and available P was extracted with sodium bicarbonate (Olsen *et al.,* 1954).

The soil sample characteristics are given in Table 1. Some micro elements (Fe, Zn, Cu, and Mn) were analyzed according to the DTPA method (Lindsay and Norvell, 1978) (Table 1). The soil texture was loamy. It was nitrogen poor, high in lime, non-saline, rich in available phosphorus, and rich in exchangeable potassium. The amounts of useful iron, zinc, manganese, and copper of the trial soil were above the sufficient level. In this study, the Cemele (*Capsicum annuum* cv.) local bell pepper genotype was used.

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Table 1. Some physical and chemical properties of the experimental soil.

Clay (%)	22.2	N (%)	0.071
Sand	35.8	Available P (mg kg^{-1})	55.0
Loam	42.0	Exchangeable K (mg kg^{-1})	600.0
Texture	Loamy	Available Fe (mg kg^{-1})	6.46
pH (1:2.5 water)	7.72	Available Zn (mg kg^{-1})	4.05
Electrical conductivity (dS.m^{-1})	0.209	Available Cu (mg kg^{-1})	1.71
Lime (%)	14.6	Available Mn (mg kg^{-1})	29.08
Total organic matter (%)	2.15		

The Cemele bell pepper, which is widely grown in Kırşehir Province, is mostly consumed as dried pepper. In this study, 1.5 kg of air dry soil was placed in pots with plastic bags at the bottom to prevent drainage.

In the current study, four different doses of salt (S_0, S_{50}, S_{100}, and S_{150} mM NaCI) were used and applied in both the control (M_0) and the 100 spore mycorrhizae (M_{100}) treated plants, with the initial electrical conductivities of, respectively, 0.21, 0.54, 3.23 and 5.61 dS.m^{-1}, in both M_0 and the M_{100} plants. The AMF inoculums (*Glomus intraradices, mosseae, aggregatum, clarum, monosporus, deserticola, brasilianum, etunicatum and Gigaspora margarita.*) consisted of spores named endo roots mycorrhiza inoculant (Novozymes Biologicals, Inc. 5400 Corporate Circle Salem, VA 24153) was applied to the root zone of the plants in the seedling stage during potting.

The experimental conditions in the greenhouse were 25-22°C ambient temperature and 65-70% relative humidity in day and night time, respectively. Throughout the experiment, the plants were irrigated with an average of 200 mL of distilled water every 3 days for 44 days, then, the plant samples were cut from the root collar and washed out of soil. In order to determine the root dry weights, the samples were dried in an oven at 65°C for 48 hours. In addition, some of the harvested and washed plant root and stem samples were stored at -20 ˚C for analysis of nutrient content, enzyme activity, and lipid peroxidation levels analyses.

Leaf macro (%) and micro (mg kg^{-1}) nutrient contents were determined on a dry weight basis. Nitrogen content was determined via Kjeldahl method (Bremner, 1965). Phosphorus (P) was quantified via the vanadomolybdophosphoric acid colorimetric method (Kacar and İnal, 2008). K, Mg, Ca, Fe, Zn, Cu and Mn contents were determined by using AAS (Atomic Absorption Spectrophotometer) (Kacar and İnal, 2008). Lipid peroxidation was determined by measuring Malondialdehyde (MDA) by the methods of Heath and Packer (1968). The Hydrogen peroxide (H_2O_2) content was determined by the method of Velikova *et al*. (2000). Enzyme activities [Superoxide Dismutase (SOD), Catalase (CAT), Peroxidase (POD) and Ascorbate Peroxidase (AxPOD)] were measured using spectrophotometric method (Sairam and Srivastava, 2002).

Experiment was conducted according to randomized block design. The obtained data were statistically analyzed by GLM procedure of SPSS (Windows version of SPSS, release 20.00). The means were compared by Duncan Multiple Range Test in the same software. Significant differences were accepted at the level $P < 0.05$ and analysis of variance was performed to determine the differences between groups.

RESULTS AND DISCUSSION

Salt stress significantly reduced root and stem dry weights compared to the control (Table 2). As can be seen from this data, there were statistically significant ($P < 0.01$)

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Table 2. The effects of mycorrhiza and salt applications on root and stem dry weights of pepper plants (g plant^{-1}). [a]

Applications		N	Root dry weights	Stem dry weights	Stem:Root ratio
M_0	S0	4	2.53a	27.75b	10.96
	S50	4	0.87bc	19.93c	22.91
	S100	4	0.42d	9.25de	22.02
	S150	4	0.26d	2.74f	10.54
M_{100}	S0	4	2.73a	33.05a	12.11
	S50	4	1.11b	21.40c	19.27
	S100	4	0.56cd	10.71d	19.13
	S150	4	0.35d	5.85ef	16.71
	SEM		0.237	2.512	-
	P		0.000**	0.000**	-
M_0		16	1.03B	14.92B	16.61
M_{100}		16	1.19A	17.75A	16.81
P			0.011**	0.000**	-

[a] (a-b) and (a-f) The differences between mean values indicated by different letters are significant (P< 0.05). The different letters in the same column show the statistical difference between applications according to Duncan Multiple Range Test. Std. Error Mean (SEM), M0: 0 spore Mycorrhiza plant^{-1}, M100: 100 spore Mycorrhiza plant^{-1}. * and **: Significant at P< 0.05 and P< 0.01 levels.

linear decreases in the root and stem dry weights of the pepper plant due to the increased salt content in both mycorrhiza and non-mycorrhiza trials (Table 2). Control plants were affected more by salt stress compared to mycorrihiza treated ones. Both the mycorrhizal plants and the non-mycorrhizal plants experienced a reduction in dry weight in stems and roots, but the reduction in weight was lower in the mycorrhizal plants. This result indicates that AMF colonization increased dry matter content in plants under salt stress. Supporting our findings, Souza *et al.* (2020) reported that *Hyptis suaveolens* plant inoculated with AMF increased dry matter compared to plants without mycorrhiza inoculation, and plants colonized with AMF on 35 mM NaCl treatment increased biochemical and physiological responses. The effect of AMF on dry matter content was more pronounced in the stem and leaf biomass than root biomass.

In addition, the stem to root ratio of plants increased by the S_{50} dose and decreased by the S_{100} and S_{150} doses, medium and high salinity, respectively (Table 2). In other words, although the plant roots were directly exposed to salinity, the growth of stem was more negatively affected than root due to the salt stress. Daei et al. (2009) reported that the reduced water uptake in plants due to the effect of salt stress increased with mycorrhizal inoculation, and thus the negative effect of salt stress could be partially or fully alleviated.

As shown in Tables 3, 4, and 5, N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn concentrations of stem were significantly decreased by increased salinity. The concentration of Na increased with increasing salinity levels in non-mycorrhizal plants. However, N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn concentrations of AMF treated plant were higher than untreated plants. On the other hand, the N, P, Ca, Mg, S, Fe and Zn contents of the roots increased significantly by increased salinity in mycorrhiza treated and untreated plants. A similar situation was reported by Taban and Katkat (2000), who applied increasing doses of NaCl (0, 15, 30, 45, and 60 mM) to the corn plant. It was observed that AMF inoculation increased nutrient uptake in control plants untreated salt stress.

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Table 3. The effects of mycorrhiza and salt applications on root N, P, K and Na contents of pepper plants (mg kg^{-1}).[a]

Applications		N	N		P		K		Na	
			Root	Stem	Root	Stem	Root	Stem	Root	Stem
M_0	S_0	4	50.99cd	313.7ab	7.73b	35.28b	137.8a	279.8ab	2.18a	4.11g
	S_{50}	4	59.01bcd	273.7bc	8.67b	26.63d	147.9a	202.9c	1.87ab	7.84d
	S_{100}	4	61.91bc	197.9d	14.03a	20.82e	91.2bc	123.5e	1.58bc	15.55b
	S_{150}	4	81.31a	131.5e	12.64a	17.92f	100.9b	77.5f	1.15cd	28.04a
M_{100}	S_0	4	45.11d	342.8a	8.22b	38.51a	147.7a	302.7a	2.14a	4.31fg
	S_{50}	4	49.01cd	301.8ab	13.24a	30.31c	78.8c	254.5b	1.51bcd	4.92ef
	S_{100}	4	68.89ab	251.9bcd	12.37a	27.89cd	78.3bc	171.5d	1.16cd	5.41e
	S_{150}	4	79.16a	235.4cd	11.96a	21.91e	71.5c	127.9e	0.99d	8.85c
	SEM		2.474	12.218	0.468	1.213	5.768	13.796	0.082	1.386
	P		0.000**	0.000**	0.002**	0.000**	0.000**	0.000**	0.000**	0.000**
M_0	Mean	16	63.30	229.2B	11.76	25.16	119.5A	170.9	1.70	13.89A
M_{100}	Mean	16	60.54	282.9A	11.44	29.66	94.1B	214.2	1.45	5.87B
	P		0.586	0.025*	0.470	0.063	0.025*	0.119	0.207	0.002**

[a] (a-b) and (a-f) The differences between mean values indicated by different letters are significant (P< 0.05). Std. Error Mean (SEM).

* and **: Significant at P< 0.05 and P< 0.01 levels.

Table 4. The effects of mycorrhiza and salt applications on root and stem Ca, Mg and S contents of pepper plants (mg kg^{-1}).

Applications		N	Ca		Mg		S	
			Root	Stem	Root	Stem	Root	Stem
M_0	S_0	4	48.3c	169.2bc	5.29c	14.04ab	2.11bcd	11.52b
	S_{50}	4	56.5bc	153.2cd	5.38c	12.73b	2.03cd	9.59cd
	S_{100}	4	89.4ab	87.5ef	7.14b	8.72c	2.65a	8.23ef
	S_{150}	4	96.5a	61.2f	8.48a	8.54c	2.57ab	7.75f
M_{100}	S_0	4	55.5bc	239.3a	5.53c	15.08a	1.78d	13.86a
	S_{50}	4	72.9abc	197.9b	6.12bc	13.97ab	2.63a	11.47b
	S_{100}	4	76.3abc	123.7de	6.41bc	12.79b	2.45abc	10.46bc
	S_{150}	4	69.7abc	86.8ef	5.89bc	10.35c	2.38abc	9.13de
	SEM		3.756	10.587	0.201	0.446	0.062	0.348
	P		0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
M_0	Mean	16	72.7	117.8B	6.57	11.01B	2,35	9.27B
M_{100}	Mean	16	68.6	161.9A	5.99	13.05A	2.31	11.23A
	P		0.597	0.035*	0.147	0.020*	0.790	0.003*

[a] (a-b) and (a-f) The differences between mean values indicated by different letters are significant (P< 0.05). Std. Error Mean (SEM).

* and **: Significant at P< 0.05 and P< 0.01 levels.

Sallaku *et al.* (2019) reported that inoculation with

AMF enhanced the nutrient uptake of cucumber seedlings, through extending their root system and enhancing the photosynthetic rate.

These results show that the negative effects of salt stress in the plants were significantly reduced in all mycorrhizal treatments, but this effect decreased at high salinity levels. While plants can tolerate salinity up to 100 mM with AMF application under salt stress conditions, damage occurs above this salinity level. However, when these losses are compared to the control, it is seen that AMF applications prevent 30-70% product decrease under salt stress conditions. Since mycorrhiza has vesicles resembling fungal vacuoles and accumulates large amounts of heavy metals in them, it

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Table 5. The effects of mycorrhiza and salt applications on root and stem Fe, Cu, Mn and Zn contents of pepper plants (mg kg^{-1}).

Applications		N	Fe		Cu		Mn		Zn	
			Root	Stem	Root	Stem	Root	Stem	Root	Stem
	S_0	4	10.66c	124.7bc	2.53a	8.75a	3.34bc	28.00ab	22.45c	14.00ab
	S_{50}	4	29.17a	113.8c	1.36b	6.87ab	2.85cd	22.93abc	48.74a	12.09b
M_0	S_{100}	4	25.08a	75.7d	1.31b	3.53c	2.40d	14.57de	44.27a	6.66c
	S_{150}	4	24.18ab	62.5d	1.20b	3.13c	2.59cd	8.33e	39.99ab	5.41c
	S_0	4	11.94c	166.9a	2.56a	8.99a	4.04ab	29.47a	24.54bc	16.59a
	S_{50}	4	14.76bc	143.1b	2.95a	7.09a	4.22a	21.83bc	20.03c	13.45ab
M_{100}	S_{100}	4	32.88a	119.8c	1.41b	4.62bc	2.77cd	17.23cd	49.84a	8.59c
	S_{150}	4	26.76a	78.0d	1.46b	3.63c	3.02cd	13.54de	46.09a	7.88c
			1.538	6.240	0.134	0.432	0.123	1.325	2.370	0.709
	P		0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
M_0	Mean	16	22.27	94.2B	1.61	5.57	2.80B	18.46	38.87	9.54
M_{100}	Mean	16	21.59	126.9A	2.10	6.09	3.52A	20.52	35.13	11.63
	P		0.829	0.006**	0.066	0.561	0.002**	0.446	0.440	0.144

[a] (a-b) and (a-f) The differences between mean values indicated by different letters are significant (P< 0.05). Std. Error Mean (SEM).

**: Significant at P< 0.01 level.

provides toxic tolerance to the host plant (Dhalaria *et al*., 2020). The decrease of leaf Na content from 13.89 mg kg^{-1} in mycorrhiza untreated plants to 5.87 mg kg^{-1} in mycorrhizal plants was significant in terms of mycorrhiza's reducing effect on Na toxicity (Table 3).

Hydrogen peroxide and MDA contents were used to determine the effects of salt stress on plants, while enzyme analyses were done to determine the efficacy of mycorrhiza application on the elimination of salinity stress.

In this study, it was determined that the application of mycorrhiza induced the activity of antioxidant defense enzymes to a great extent (Table 6). Despite the symbiotic nature of AMF associations, the induction of antioxidant enzymes observed during appressoria formation was attributed to the defense responses of plants during the early stage of symbiosis development (Blilou *et al*., 2000; Hajiboland *et al.*, 2010).

While the highest enzyme activity was determined at 50 mM Salt dose (S_{50}) in plants treated with mycorrhiza, the difference between the enzyme activities detected at the 100 mM and 150 mM salt doses was not statistically significant. This situation was determined to be due to the mycorrhiza inoculation in the pepper plant activating the enzymatic antioxidant defense system at the 50 mM (moderate) salt dose ($M_{100}S_{50}$). In other words, the supportive effect of mycorrhiza decreased with excessive salt doses ($M_{100}S_{100}$; $M_{100}S_{150}$). Similarly, arbuscular mycorrhizal fungal symbiosis at 0 mM and 50 mM salt doses was reported to increase the antioxidant enzyme activities of plants and alleviate the negative impact of salt stress (Alguacil *et al*., 2003) (Table 6).

In this study, SOD, CAT, POD and AxPOD enzyme activities determined in the mycorrhizal plants at 100 mM and 150 mM salt concentrations ($M_{100}S_{100}$; $M_{100}S_{150}$) were at a lower level than the plants without mycorrhiza inoculation. AMF inoculation is known to alleviate salt stress by enhancing the rhizospheric soil characteristics (Ahanger *et al*., 2014), but it is known that the formation of mycorrhizal symbiosis is negatively affected by high salt doses (Wang *et al*., 2021).

While CAT, SOD, and POD enzyme activities in stem tissues were

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Table 6. The effects of mycorrhiza and salt applications on root and stem enzyme activities and lipid peroxidation of pepper plants.

Applications		N	SOD (EU g leaf^{-1})		CAT (EU g leaf^{-1})		POD (EU g leaf^{-1})	
			Root	Stem	Root	Stem	Root	Stem
M_0	S_0	4	56.19c	189.4c	148.48c	479.8c	21.07c	72.3c
	S_{50}	4	62.44bc	208.9bc	159.91c	563.9bc	26.48bc	89.2bc
	S_{100}	4	103.92a	265.7a	279.23a	714.0ab	57.90a	147.8a
	S_{150}	4	77.31b	257.9a	255.06ab	848.3a	41.13b	136.4a
M_{100}	S_0	4	64.91bc	193.5c	197.44bc	553.0bc	29.72bc	87.2bc
	S_{50}	4	79.23b	263.7a	184.12c	612.4bc	39.85b	132.2a
	S_{100}	4	63.97bc	240.3ab	177.71c	641.5bc	32.39bc	118.7ab
	S_{150}	4	67.40bc	230.8abc	172.29c	589.5bc	34.14bc	109.9abc
			2.877	5.890	9.077	21.999	2.164	5.300
	P		0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
M_0	Mean	16	74.97	230.5	210.67	651.5	36.65	111.4
M_{100}	Mean	16	68.88	232.1	182.89	599.1	34.03	112.1
	P		0.298	0.894	0.128	0.240	0.554	0.954
Applications		N	AxPOD (EU g leaf^{-1})		MDA (EU g leaf^{-1})		H_2O_2 (EU g leaf^{-1})	
			Root	Stem	Root	Stem	Root	Stem
M_0	S_0	4	22.01e	10.6b	49.91b	26.5b	19.13e	12.9c
	S_{50}	4	28.98e	18.9b	107.48a	53.7a	36.02d	24.2b
	S_{100}	4	86.89bc	49.8a	98.54a	44.3a	60.77b	30.1a
	S_{150}	4	120.60a	53.9a	99.98a	54.9a	75.29a	28.4ab
M_{100}	S_0	4	25.39e	13.4b	46.59b	24.5b	13.44e	11.9c
	S_{50}	4	73.90cd	47.7a	40.06b	20.1b	18.09e	15.5c
	S_{100}	4	69.40d	42.6a	99.69a	47.3a	29.66d	25.4ab
	S_{150}	4	101.11b	42.7a	97.19a	51.1a	44.61c	26.8ab
			6.352	3.201	5.378	2.553	3.725	1.280
	P		0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
M_0	Mean	16	64.62	33.3	88.98	44.9	47.81A	23.9
M_{100}	Mean	16	67.46	36.6	70.89	35.8	26.45B	19.9
	P		0.828	0.615	0.093	0.074	0.003**	0.120

[a] (a-b) and (a-f) The differences between mean values indicated by different letters are significant (P< 0.05). Std. Error Mean (SEM).

**: Significant at P< 0.01 level.

approximately 3 times higher than the values in the root tissues, the AxPOD, MDA, and H_2O_2 levels were determined approximately 2 times higher than the values determined in stem tissues. Root H_2O_2 level of plants inoculated with mycorrhiza decreased by 44.7% compared to those without mycorrhiza, while there was only 16.7% decrease in the stem tissues. This decrease may be due to the increased AxPOD activity in root by mycorrhiza inoculation (Table 6). In addition to CAT, peroxidases (POD and AxPOD) also serve a function in the detoxification of H_2O_2, which increases under stress conditions. Because AxPOD has a higher substrate affinity than catalase due to the presence of ascorbic acid, it is known to be more effective in the degradation of H_2O_2 (Willekens *et al*., 1994).

Supporting the findings obtained in this study, Rai *et al*. (2004) reported that AxPOD enzyme protected plants from oxidative damage by eliminating toxic H_2O_2 from plant cells. Ghorbanli *et al*. (2004) stated that mycorrhizal plants removed higher amounts of H_2O_2 when compared to non-mycorrhizal, due to their higher AxPOD activities. On the other

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hand, the adverse effect of free oxygen radicals on cell membrane occurs via lipid peroxidation. Due to the increased salt concentrations, the increased electrolyte leakage in stem and root tissues enhanced H_2O_2 and MDA, signs of lipid peroxidation. However, these parameters showed higher values in root tissues. The H_2O_2 content of mycorrhizal plants was at lower level than those of non-mycorrhizal for all salt doses, including the control.

MDA content is an important parameter in determining the extent of stress damage in salt stress studies (Gossett *et al*., 1994). In this study, the MDA content increased significantly as the salt concentration increased in both the mycorrhizal and the non-mycorrhizal plants. While the stem and root SOD, CAT and POD enzyme activities of mycorrhizal plants increased up to 50 mM NaCl dose, they decreased at higher salt doses. However, root and stem H_2O_2 and MDA levels of mycorrhizal inoculated plants did not show any significant change at 50 mM NaCl compared to the control plants, but increased statistically significantly with the effect of increasing salt doses. This situation implies that the enzymatic antioxidant defense system's inhibitory effect on lipid peroxidation is insufficient for a dose of salt exceeding 50 mM.

CONCLUSIONS

In this study, activity of antioxidant enzymes in AMF colonization of pepper plants compared with non-mycorrhizal plants was associated with lower activity of antioxidant enzyme such as SOD, CAT, POD and AxPOD. This indicated lower oxidative damage in the colonized plants and stimulate plant nutrient uptake. According to our results, AMF can contribute to protect plants against salinity by alleviating the salt induced oxidative stress and arranging the ion balance in plant via stimulating the nutrient in saline soil.

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اثرهای قارچ میکوریزا بر تغذیه گیاه، فعالیت آنزیمی و پراکسیداسیون لیپیدی در فلفل کشت شده در تنش شوری

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چکیده

این پژوهش برای تعیین اینکه آیا قارچ‌های میکوریزا آربوسکولار (AMF) (ROOTS-novozymes endo-mycorrhiza fungus (Glomus spp.)) تحمل به تنش شوری را افزایش می‌دهند انجام شد. بنا بر این، اثرهای تلقیح میکوریزا و نمک بر رشد ریشه و ساقه، تغذیه معدنی، فعالیت آنزیمی و سطوح پراکسیداسیون لیپیدی در گیاه فلفل (Capsicum annuum L.) بررسی شد.این اثرها در گیاهان فلفل رشد کرده در شرایط

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گلخانه در یک طرح بلوک‌های تصادفی بررسی شد. به این منظور، به گلدان‌های پر از خاک، چهار تیمار مختلف نمک (۰، ۵۰، ۱۰۰ و ۱۵۰ میلی مولار NaCl) افزون بر دو تیمار مختلف میکوریزا (۰ و ۱۰۰ اسپور میکوریزا در هرگیاه) اعمال شد. مشخص شد که وزن خشک ریشه و ساقه گیاهان فلفل در تیمارهای غیر میکوریزا به میزان زیادی کاهش یافت، در حالی که حضور قارچ این اثرات منفی را بهبود بخشید. محتوای N، P، K، Ca، Mg، S، Fe ونیزMn ، Zn و Cu فلفل تیمار شده با AMF بیشتر از گیاهان غیرمیکوریزی بود. به خاطر وجود کلونیزاسیون AMF، جذب عناصر غذایی افزایش یافته و در نتیجه محتوای مواد مغذی بافت های ساقه و ریشه گیاهان تلقیح شده با میکوریز نیز افزایش یافت. از سوی دیگر، فعالیت آنزیم ریشه و ساقه گیاهان با شوری افزایش یافت. تلقیح AMF باعث کاهش آنزیم های SOD، CAT، POD و AxPOD گیاه و محتوای MDA و H2O2 شد که نشان دهنده آسیب کمتر اکسیداتیو در گیاهان تلقیح شده است. نتایج ما نشان داد که AMF می‌تواند با کاهش تنش اکسیداتیو ناشی از نمک و تنظیم تراز یونی در گیاه از طریق افزایش جذب مواد مغذی در خاک‌های شور، به محافظت از گیاهان در برابر شوری کمک کند.

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