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RESPONSE OF PEPPER PLANTS TO INOCULATION WITH VESICULAR ARBUSCULAR MYCORRHIZAL (VAM) FUNGUS UNDER WATER STRESS

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ABSTRACT: Two pot experiments were carried out to illustrate the effect of vesicular arbuscular mycorrhiza (VAM) inoculation on growth, gas exchange, water relations endogenous phytohormones and minerals concentration as well as fruit yield of pepper plant (*Capsicum annum* L.) grown under four levels of water regime (100, 80, 60 and 40% of the field capacity). The obtained results indicated that, inoculation of pepper plants with VAM significantly increased shoot and root length, dry weight and leaf area under different levels of water regime. Moreover, mycorrhiza inoculation decreased stomatal conductance and transpiration rate under water regime. In addition, VAM-treated pepper plants recorded higher relative water content and water use efficiency with lower leaf water potential, osmotic potential and higher turgor potential under water regime. VAM inoculation under water regime recorded highly values of total chlorophyll, N, P and K, P-uptake, proline concentration and fruit yield as compared with non-inoculated plants. Moreover, VAM showed highly a significant effect on maintenance the concentration of cytokinine and reduced ABA concentration under water regime.

Key Words: Pepper plants, Mycorrhiza, Water stress, Growth, Water relation, Yield.

INTRODUCTION

More than any other single environmental factor, the shortage of water limits plant growth and crop productivity in many regions of the world.

Mycorrhizal infection can alleviate plant response to water stress. Some authors have suggested that mycorrhizal infection may be even more important to plant growth under drought conditions than when soil moisture can be plentiful (Allen and Allen, 1986; Nelsen, 1987; Sanchez-Diaz *et al.*, 1990 and Sanchez-Diaz and Honrubia, 1994). Mycorrhizal infection may increase drought resistance of plants by several mechanisms, including water uptake (Augé *et al.*, 1992), regulated stomatal conductance in response to hormonal signals (Drüge and Schönbeck, 1992) or by lower leaf osmotic potential for greater turgor maintenance (Augé *et al.*, 1986 and Davies *et al.*, 1993).

Water relation can partially be modified by the plant hormonal status, several authors have investigated the role of mycorrhizal infection in the phytohormone balance including abscisic acid, auxin, gibberellin and cytokinin level (Dunneberg *et al.*, 1992 and Drüge and Schönbeck, 1992) under well watered condition.

Several species of bacteria and non-pathogenic fungi are known to enhance the uptake of nutrients by the plant. Particularly VA mycorrhiza may increase the uptake of strongly absorbed compounds. In poor soil mycorrhizal roots generally improve the nutrients supply for the plant (Schüepp *et al.*, 1987).

This study was undertaken to evaluate the effect of VA mycorrhiza inoculation on pepper plants grown under drought stress conditions to study the growth, physiological aspects, minerals uptake and phytohormes in pepper plants.

MATERIALS AND METHODS

Pot experiments were carried out at the Experimental Farm of the Faculty of Agriculture, Minufiya University, to investigate the effect of VA mycorrhiza on growth, water relations, minerals uptake, endogenous phytohormones and productivity of pepper plants grown under drought stress.

Pepper seeds (*Capsicum annum*, L. cv. California wonder) were sown in seed beds on 18^{th} of Jan. 2000 and 2001 seasons. Thirty days later 2 uniforn seedlings were transplanted in black plastic pots (30 cm diameter), which were filled with 10 kg soil. Some physical and chemical properties of the soil are presented in Table (1), according to Chapman and Pratt (1961).

Table (1): Some physical and chemical properties of the used soil.

Property	Value	Property	Value
Physical analysis		Soluble anions	
Sand (%)	17	(meq. 100 g soil)	
Silt (%)	35	Cl	0.80
Clay (%)	48	$HCO^{=}_3$	0.95
Texture class	Clayey	$SO^{=}_4$	0.95
Chemical analysis		Total N %	0.12
OM (%)	1.98	Avail P (ppm)	10
pH (1 : 2.5)	7.90	Avail K (ppm)	390
EC, dS m^{-1}	0.67		
Soluble cations (meq/100 g soil)			
$Ca^{2+} + Mg^{2+}$	1.25		
Na^+	1.12		
K^+	0.33		

The soil was sieved through a 2- mm mesh screen and air dried. The soil was mixed (1 : 1, v / v) with fine sand and autoclaved for 90 min. at 120°C to destroy indigenous mycorrhizal fungi. Nutrients were added to soil at the rates of (weight per kg dry soil); 75 mg NH_4NO_3, 50 mg k_2SO_4, 100 mg kH_2PO_4, 5 mg Fe as Fe-EDTA, 5 mg $ZnCl_2$, 0.4 µg H_3MoO_4 (Bryla dn Duniway, 1997). Half of these pots were inoculated with VAM (*Glomus fasiculatum*). Five onion seedlings were transplanted in each pot as a host plant. At the end of the growth stage, onion plants were rooted. The soil of the used pots was mixed with VAM counted as described by Musandu and Giller (1994). The spore count was found to be 120 – 148 spores per g soil.

The pots were irrigated with Nile water to the field capacity before planting and after transplanting, the soil surface was then covered with aluminum foil to prevent the evaporation. The moisture content of all pots was kept at 100% F.C. by 2 days weighing and Nile water was added to compensate the lost by evaporation for two weeks before the commencement of water regimes. Four water regimes, i.e. 100, 80, 60 and 40% of the water field capacity of the soil (F.C.) were applied as a main factor. The moisture was then adjusted to each level of F.C. by 2 days weighing pots. Two control pots with and identical amount of soil but without plants were watered and weighed to monitor evaporative losses.

The treatments of this experiment under each level of water regime were:

1. Control (non-inoculated plants)
2. Inoculation with VAM

The experimental design was a split plot with five replications, in which the main plots represented the watering regimes and the sub-plots represented the VAM treatments.

After 55 days from transplanting, the pepper plants were harvested, collected carefully with roots and the following data were recorded.

1. Growth analysis: Shoot and root lengths were measured and then oven dried at 70°C for 72 hrs and weighed, besides leaf area was calculated.

The percentage response of plants to mycorrhizal colonization in term of total plant dry weight (mycorrhizal growth response, % MGR) under each level of water stress was calculated using the following equation as described by Dickson *et al.* (1999).

$$\% \text{ MGR} = \frac{\text{Mean D.W. (treat.)} - \text{Mean D. W. (control)}}{\text{Mean D. W. (control)}} \times 100$$

Water *use efficiency (WUE)* was calculated as described by Raeini-Sarjaz *et al.* (1998) following the relation: WUE = total dry matter per plant (g)/total amount of water consumed by plant (kg).

2. Gas exchange: Stomatal conductance (g_s) and Transpiration Rate were measured using steady state porometer (Li-1600, Li-Cor) at 1200 hr.
3. Water relations: Relative water content (RWC) was calculated by the equation of Hsiao (1990),

$$RWC = [(W_t - W_d) / (W_f - W_d)] \times 100$$

Where, W_t : turgid weight, W_f : Fresh weight and W_d : dry weight.

Leaf water potential (Ψ_L) using the modified dye method of Marathe (1989). Values of the total soluble solids of the cell sap were obtained for the pressed sap using the Abbe Reflectometer and osmotic potential values ($\Psi\pi$) were calculated according to the method described by Goseve (1960) leaf turgor potential (Ψ_T) was calculated as described by (Nobel, 1991).

4. Chemical analysis:

Total chlorophyll concentration was estimated in fresh leaves as described by the method of Witham *et al.* (1971). Proline concentration was estimated according to the methods described by Bates *et al.* (1973), total phosphorus in shoots was measured using the molybdo-phosphate method according to Wild *et al.* (1979). Nitrogen was measured in shoots using micro-Kjeldahl method (Chapman and Pratt, 1961). Potassium was determined by using flamephotometer. Endogenous cytokinin, and abscisic acid concentration were determined using the gas liquid chromatography method as described by Kirally *et al.* (1967) and Creelman *et al.* (1990).

5. Total yield:

At the harvest time, the number of fruits/pot, average fruit weight and fruit yield/pot were determined. Total fruit yield was determined by weighing fruits at each pick and the sum of all picks were recorded.

The obtained data were statistically analyzed according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

1. Growth analysis

Data presented in Table (2) clearly show that, with decreasing soil moisture, there was a highly significant decrease in shoot and root length, shoot and root dry matter and leaf area. Meanwhile, inoculation with VAM significantly increased the previous growth parameters under different levels of soil moisture. Root length and dry weight either in the first or the second season draw our attention herein, particularly in the plants received less water regime. Wherever, it augmented by about twofold as affected by VAM inoculation. This may be ascribed either to the fungal biomass of VAM exist inside the root, consequently enhanced the root dry weight and length, or to the roll of VAM in promoting the nutrients uptake by plant, sequentially

Table (2): Effect of water stress and mycorrhizal inoculation on some growth parameters of pepper plant during the seasons of 2000 and 2001.

Water supply % FC	First season			Second season		
	VAM inoculated					
	–	+	Mean	–	+	Mean
	Plant height (cm) / plant					
100	45.8^{b}	50.8^{a}	48.3^{A}	46.1^{b}	51.2^{a}	48.7^{A}
80	37.5^{e}	43.6^{c}	40.6^{B}	37.9^{e}	43.1^{c}	40.5^{B}
60	31.2^{g}	39.2^{d}	35.2^{C}	31.8^{f}	39.8^{d}	35.8^{C}
40	23.1^{h}	35.1^{f}	29.1^{D}	23.5^{g}	35.6^{f}	29.6^{D}
Mean	34.4^{B}	42.2^{A}		34.8^{B}	42.4^{A}	
	Root length (cm) / plant					
100	7.5^{e}	9.3^{a}	8.4^{A}	7.7^{d}	9.5^{a}	8.1^{A}
80	5.9^{f}	10.2^{b}	8.5^{A}	6.1^{d}	10.8^{b}	7.9^{A}
60	4.3^{g}	11.1^{c}	7.2^{A}	4.5^{e}	11.5^{b}	7.5^{A}
40	3.5^{h}	12.5^{d}	7.0^{A}	3.7^{f}	12.8^{c}	7.3^{A}
Mean	5.3^{B}	9.5^{A}		5.5^{B}	10.2^{A}	
	Shoot dry weight (gm) / pot					
100	6.7^{b}	8.1^{a}	7.4^{A}	6.9^{b}	8.4^{a}	7.6^{A}
80	5.2^{c}	6.2^{b}	6.1^{B}	5.3^{c}	6.3^{b}	6.2^{B}
60	4.1^{e}	5.4^{c}	4.8^{C}	4.5^{d}	5.5^{c}	5.6^{C}
40	3.2^{f}	4.9^{d}	3.7^{C}	3.4^{e}	4.9^{d}	3.9^{C}
Mean	4.98^{B}	5.9A	–	5.2B	6.1A	
	Root dry weight (gm) / pot					
100	2.1^{f}	3.0^{d}	2.6^{C}	2.4^{e}	3.1^{d}	2.8^{A}
80	2.0^{f}	3.9^{c}	2.9^{B}	2.2^{f}	3.8^{c}	3.1^{A}
60	1.8^{e}	4.5^{b}	3.2^{B}	2.0^{f}	4.3^{b}	3.4^{A}
40	1.5^{g}	5.8^{a}	3.3^{A}	1.8^{g}	4.5^{a}	3.5^{A}
Mean	1.9^{B}	4.3^{A}		2.2^{B}	3.9^{A}	
	Leaf area (cm^2 / pot)					
100	862^{c}	1042^{a}	952^{A}	870^{c}	1051^{a}	961^{A}
80	824^{d}	926^{b}	875^{B}	831^{d}	930^{b}	881^{B}
60	602^{f}	822^{d}	712^{C}	612^{f}	831^{d}	722^{C}
40	570^{g}	714^{e}	642^{D}	575^{g}	721^{e}	648^{D}
Mean	715^{B}	876^{A}		722^{B}	883^{A}	

– = non-inoculation + = inoculation

Values within the same horizontal and vertical rows area with the same letter are not significantly different at 5% probability level by Duncan's Multiple Range Test.

increased its growth and dry matter yield. In this respect Nadian *et al.* (1992), reported that mycorrhizal fungi is able to synthesize indole acetic acid (IAA) where it is able to metabolize endogenous treptophan to IAA.

Regarding the mycorrhizal growth response (MGR %) as shown in Table (3 a) significantly increased with decreasing soil moisture level. The results are in accordance with those reported by Dickson *et al.* (1999).

Root/shoot ratio increased significantly with decreasing soil moisture and more increase in this ratio was observed when pepper plants inoculated with mycorrhiza. Similar results were obtained by Nadian *et al.* (1997).

2. Gas exchange

Data recorded in Table (3 b) show that stomatal conductance (g_s) of pepper leaves was decreased linearly with decreasing soil-moisture content to reach its lower value at 40% FC, however it showed a negative correlation with Ψ_L (Fig. 1), while inoculation with VAM mycorrhiza fungi, significantly decreased the inhibition effect of drought stress (increased g_s decreased resistance under drought) stress on g_s. This is commonly found in many species and may indicate a control of g_s through a hydraulic feed-back mechanism (Giorio *et al.*, 1999).

The transpiration rate in non-inoculated plants recorded highly significant reduction with decreasing soil moisture in non-inoculated plants. Inoculation with VAM, showed also a significant increase in transpiration rate with decreasing soil moisture. In this concern, Zhongjin and Neumann (1998) reported that, drought stress led to an inhibition in leaf growth which could be considered to be an adaptive response. Thus, it limited leaf area production and eventually for plant, rates of transpiration. Reduced transpiration may then prolong plant survival by extending the period of availability of soil water reserves in root zone (Passioura *et al.*, 1993). Drought resistance of pepper plant may increased by mycorrhizal infection by regulating stomatal conductance in response to hormonal signal (Drüge and Schonbeck, 1992 and Taiz and Seiger, 1998).

3. Water relations

As shown in Table (4), drought stress significantly decreased RWC of water-stressed pepper plants. Meanwhile VAM inoculation seemed has a beneficial effect for increasing the RWC under drought stress compared to non inoculated treatments which were of limited benefit. It seems that if pepper plants are exposed to severe water stress (as in 40% F.C.), then inoculated with VAM, this may be benefit in increasing RWC %.

Concerning turgor (Ψ_t) and the results in Fig. (1), showed highly significant reduction with decreasing soil moisture. However, VAM inoculation significantly increased Ψ_L and Ψ_{π} values with decreasing soil moisture, consencountly, higher Ψ_T values compared with non-inoculated

Table (3): Effect of water stress and mycorrhizal inoculation on total dry matter, mycorrhiza growth rate (MGR %), root / shoot ratio and gas exchange of pepper plant during the seasons of 2000 and 2001.

A:

Water supply % FC	First season				Second season			
	VAM inoculated							
	–	+	Mean	MGR%	–	+	Mean	MGR%
	Total dry matter (g / pot) and MGR %							
100	8.8^{d}	11.1^{a}	9.9^{A}	26.5	9.3^{c}	11.5^{a}	10.4^{A}	23.7
80	7.2^{e}	10.1^{b}	8.7^{B}	40.3	7.5^{d}	10.1^{b}	8.8^{B}	34.7
60	5.9^{f}	9.9^{c}	7.9^{BC}	67.8	6.5^{d}	9.8^{c}	8.2^{BC}	50.8
40	4.7^{g}	9.7^{c}	7.2^{C}	106.4	5.2^{f}	9.4^{c}	7.3^{C}	80.8
Mean	6.7^{B}	10.2^{A}			7.1^{B}	10.2^{A}		

B:

Water supply % FC	First season			Second season		
	VAM inoculated					
	–	+	Mean	–	+	Mean
	Root / shoot ratio					
100	0.31^{f}	0.37^{e}	0.31^{C}	0.35^{f}	0.37^{f}	0.34^{C}
80	0.38^{e}	0.63^{c}	0.42^{BC}	0.41^{e}	0.60^{c}	0.46^{B}
60	0.44^{d}	0.83^{b}	0.51^{B}	0.44^{e}	0.78^{b}	0.54^{B}
40	0.47^{d}	0.97^{a}	0.66^{A}	0.53^{d}	0.92^{a}	0.72^{A}
Mean	0.40^{B}	0.55^{A}		0.41^{B}	0.59^{A}	
	Stomatal conductance (g_s) m mol . m^{-2} . S^{-1}					
100	84.1^{b}	99.5	91.8^{A}	84.2^{b}	99.6^{a}	94.9^{A}
80	69.3^{d}	75.4	72.4^{B}	70.1^{d}	75.5^{c}	72.8^{B}
60	52.0^{g}	61.4	56.6^{C}	52.2^{g}	61.6^{e}	56.9^{C}
40	48.3^{h}	57.2	52.8^{D}	48.5^{h}	57.5^{f}	53.0^{D}
Mean	63.4^{B}	73.3^{A}		63.8^{B}	73.6^{A}	
	Transpiration rate (A) μ mol . m^{-2} . S^{-1}					
100	4.8^{d}	4.6^{e}	4.7^{A}	4.9^{d}	4.5^{e}	4.7^{A}
80	3.9^{f}	5.1^{c}	4.5^{B}	3.8^{f}	5.2^{c}	4.5^{B}
60	3.4^{g}	5.6^{b}	4.5^{B}	3.3^{g}	5.8^{b}	4.5^{B}
40	2.8^{h}	5.9^{a}	4.4^{B}	2.7^{h}	6.0^{a}	4.4^{B}
Mean	3.7^{B}	5.3^{A}		3.7^{B}	5.4^{A}	

– = non-inoculation + = inoculation

Values within the same horizontal and vertical rows area with the same letter are not significantly different at 5% probability level by Duncan's Multiple Range Test.

Table (4): Effect of water stress and mycorrhizal inoculation on some parameters of water relations, total chlorophyll and proline concentration of pepper leaves during the seasons of 2000 and 2001.

Water supply % FC	First season			Second season		
	VAM inoculated					
	–	+	Mean	–	+	Mean
	Water use efficiency (WUE) g Dr. wt / kg H_2O					
100	4.8^{a}	4.9^{a}	4.9^{A}	4.7^{a}	4.9^{a}	4.8^{A}
80	3.1^{c}	3.7^{b}	3.4^{B}	3.3^{b}	3.7^{b}	3.5^{B}
60	2.4^{d}	3.5^{c}	2.9^{BC}	2.7^{c}	3.3^{b}	3.0^{BC}
40	1.5^{e}	2.1^{d}	1.8^{C}	1.7^{e}	2.1^{d}	1.9^{C}
Mean	2.9^{B}	3.6^{A}		3.1^{B}	3.5^{A}	
	Relative water content (RWC %)					
100	90^{b}	92^{a}	91.0^{A}	91^{b}	93^{a}	92.0^{A}
80	70^{d}	83^{c}	76.5^{B}	71^{d}	83^{c}	77.0^{B}
60	62^{f}	77^{e}	69.5^{C}	61^{f}	75^{e}	67.0^{C}
40	54^{h}	69^{g}	61.5^{D}	53^{h}	68^{g}	60.5^{D}
Mean	69^{B}	80.3^{A}		69.0^{B}	79.8^{A}	
	Total chlorophyll (mg / g Dr. wt)					
100	6.4^{d}	6.6^{d}	6.5^{D}	6.5^{d}	6.8^{d}	6.7^{D}
80	7.4^{c}	8.9^{b}	8.2^{C}	7.6^{c}	8.9^{b}	8.3^{C}
60	8.6^{b}	10.4^{a}	9.5^{B}	8.7^{b}	10.5^{a}	9.6^{B}
40	5.8^{e}	6.5^{d}	6.2^{A}	5.9^{f}	6.1^{e}	6.0^{A}
Mean	7.1^{B}	8.2^{A}		7.2^{B}	8.1^{A}	
	Proline concentration (µg / g Dr. wt)					
100	129^{g}	152^{f}	140.5^{D}	131^{f}	155^{e}	143.0^{D}
80	510^{e}	640^{d}	575.0^{C}	511^{e}	645^{d}	578.0^{C}
60	804^{c}	930^{b}	867.0^{B}	812^{c}	942^{b}	877.0^{B}
40	960^{b}	995^{a}	977.5^{A}	965^{b}	998^{a}	981.5^{A}
Mean	600.8^{B}	679.3^{A}		604.8^{B}	685.0^{A}	

– = non-inoculation + = inoculation

Values within the same horizontal and vertical rows area with the same letter are not significantly different at 5% probability level by Duncan's Multiple Range Test.

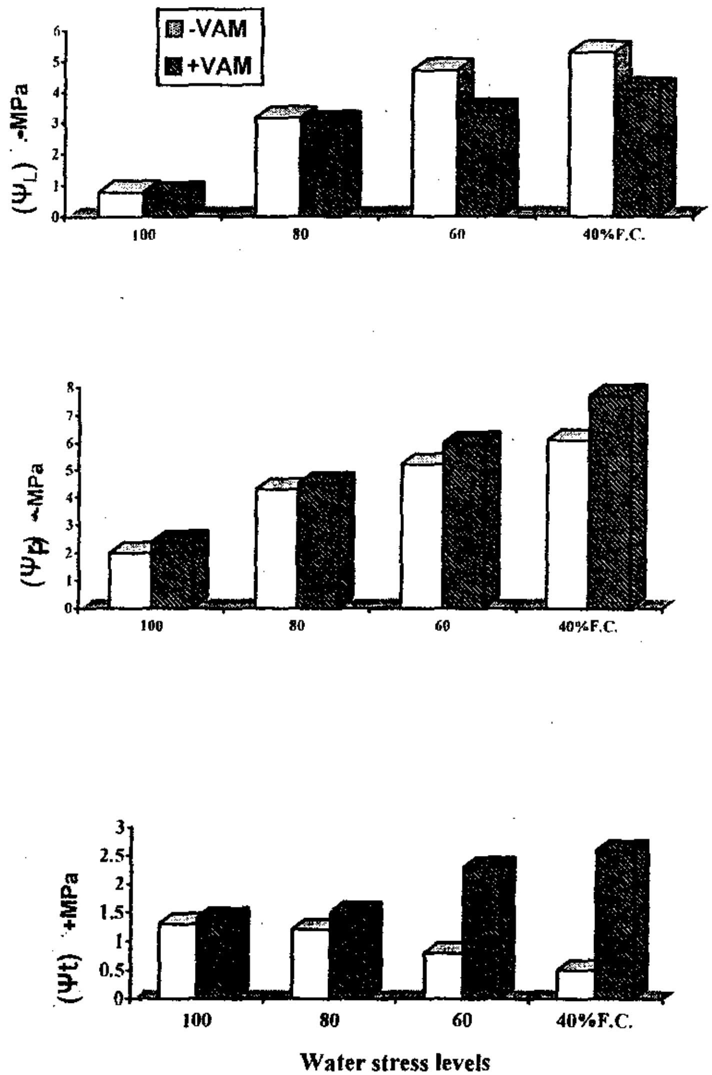

Fig. (1): Effect of water stress and VAM inoculation on leaf water potential (Ψ_L), osmotic potential (Ψ_P) and turgor potential (Ψt) in pepper leaves (second season).

plants. Water use efficiency values recorded higher values for plant grown under low soil water content when inoculated with VAM compared with non-inoculated plants. Mycorrhizal infection may increase drought resistance of plants by several mechanisms, including, increased water uptake due to the hyphal extraction of soil water (Augé *et al.*, 1992 and Davies *et al.*, 1993) or by lower leaf osmotic potential for greater turgor maintenance (Davis *et al.*, 1993; Zhongjin and Neumann, 1998 and Giorio *et al.*, 1999).

Several investigators concluded that mycorrhizal infection can alter plant water relations as compared to non-mycorrhizal controls. They attribute this effect to improve osmotic adjustment (Augé *et al.*, 1986 and Augé and Stodola, 1990), improved stomatal control (Augé *et al.*, 1986) and higher water uptake rates per unit root length (Kothari *et al.*, 1991 and Bryla and Duniway, 1997).

4. Chemical analysis

4.1. Chlorophyll concentration

Data presented in Table (4) elucidate clearly that total chlorophyll, increased with decreasing soil moisture content, except at 40% FC chlorophyll dramatically reduced. VAM inoculation significantly increased total chlorophyll under drought stress compared with non-inoculated plants. In this connection, Hayman (1974) reported that the VAM inoculated plants showed better light absorption and more efficient plant nutrition and growth. Ezz and Nawar (1994) concluded that mycorrhizal infection induced chlorophyll concentration in orange seedlings.

4.2. Proline concentration

Data presented in Table (4) clearly showed that, with decreasing soil moisture content, there was a highly significant increase in proline. Moreover, VAM inoculation showed a highly significant effect on increasing in proline concentration. This mainly its effect on enhancing the availability of phosphorus, consequently growth characteristics. Similar results were obtained by Smith *et al.* (1992) and Sorial and Ali (1998).

4.3. N, P and K concentration and uptake

Data presented in Tables (5 and 6) revealed that VAM inoculation significantly enhanced N and K concentration of pepper plants under well irrigated plants (100% FC). Drought stress gradually decreased N and K concentrations and uptake meanwhile inoculated pepper shoots maintained highly N concentration under water stress condition. The positive stimulatory effect of VAM can be attributed to that the mycorrhiza promote the absorption of nutrients by plants (Fitter,1991). Maintenance highly nutrient concentration under drought stress with VAM inoculation may be improve the osmotic adjustment (Augé and Stodola, 1990). Sequentially enhancing the capability of plant for preserving the nutrient inside and does not lose it to the soil

Table (5): Effect of water stress and mycorrhizal inoculation on nitrogen, phosphorus and potassium concentrations of pepper shoots during the seasons of 2000 and 2001.

Water supply % FC	First season			Second season		
	VAM inoculated					
	–	+	Mean	–	+	Mean
	Nitrogen concentration (%)					
100	3.81^{c}	4.35^{a}	4.08^{A}	3.83^{c}	4.36^{a}	4.09^{A}
80	3.46^{e}	4.00^{b}	3.73^{B}	3.47^{e}	4.06^{b}	3.76^{B}
60	3.01^{f}	3.61^{d}	3.31^{C}	3.02^{f}	3.63^{d}	3.33^{C}
40	2.61^{g}	3.41^{e}	3.01^{D}	2.62^{g}	3.42^{e}	3.02^{D}
Mean	3.22^{B}	3.84^{A}		3.24^{B}	3.87^{A}	
	Phosphorus concentration (%)					
100	0.18^{a}	0.20^{a}	0.19^{A}	0.19^{a}	0.21^{a}	0.20^{A}
80	0.12^{d}	0.19^{a}	0.16^{B}	0.13^{d}	0.20^{a}	0.17^{A}
60	0.10^{e}	0.16^{b}	0.13^{C}	0.10^{e}	0.17^{b}	0.14^{B}
40	0.07^{f}	0.14^{c}	0.11^{D}	0.09^{f}	0.15^{c}	0.12^{C}
Mean	0.118^{B}	0.173^{A}		0.153^{A}	0.183^{A}	
	Potassium concentration (%)					
100	1.42^{d}	1.71^{c}	1.57^{A}	1.46^{d}	1.80^{c}	1.63^{A}
80	1.20^{e}	2.01^{b}	1.61^{A}	1.21^{e}	2.08^{b}	1.65^{A}
60	1.00^{e}	2.24^{a}	1.62^{A}	1.01^{e}	2.31^{a}	1.66^{A}
40	0.81^{f}	1.69^{c}	1.25^{C}	0.80^{f}	1.70^{c}	1.25^{B}
Mean	1.11^{B}	1.91^{A}		1.12^{B}	1.97^{A}	

– = non-inoculation + = inoculation

Values within the same horizontal and vertical rows area with the same letter are not significantly different at 5% probability level by Duncan's Multiple Range Test.

Table (6): Effect of water stress and mycorrhizal inoculation on N, P and K uptake (mg / pot) of pepper shoot during the seasons of 2000 and 2001.

Water supply % FC	First season			Second season		
	VAM inoculated					
	–	+	Mean	–	+	Mean
	N uptake (mg / pot)					
100	255^{c}	352^{a}	304^{A}	264^{c}	366^{a}	315^{A}
80	180^{e}	248^{b}	214^{B}	184^{e}	256^{b}	220^{B}
60	123^{f}	195^{d}	159^{C}	136^{f}	200^{d}	168^{C}
40	84^{g}	167^{e}	126^{D}	123^{g}	168^{e}	146^{D}
Mean	161^{B}	241^{A}		177^{B}	248^{A}	
	P uptake (mg / pot)					
100	12.1^{a}	16.2^{a}	14.2^{A}	13.1^{a}	17.6^{a}	15.4^{A}
80	6.2^{d}	11.8^{b}	9.0^{B}	6.9^{b}	12.6^{b}	9.8^{B}
60	4.1^{e}	8.6^{c}	6.4^{C}	4.5^{c}	9.4^{c}	7.0^{C}
40	2.2^{f}	6.9^{d}	4.6^{D}	3.1^{d}	7.4^{d}	5.3^{D}
Mean	6.2^{B}	10.9^{A}		6.9^{B}	11.8^{A}	
	K uptake (mg / pot)					
100	95.1^{a}	138.5^{a}	116.8^{A}	100.7^{d}	151.2^{a}	126.0^{A}
80	62.4^{b}	124.6^{b}	93.5^{B}	64.1^{e}	131.0^{b}	97.6^{B}
60	41.0^{c}	121.0^{c}	81.0^{C}	45.5^{f}	127.1^{c}	86.3^{C}
40	25.9^{d}	82.8^{d}	54.4^{D}	27.2^{g}	83.3^{d}	55.3^{D}
Mean	56.1^{B}	116.7^{A}		59.4^{B}	123.2^{A}	

– = non-inoculation + = inoculation

Values within the same horizontal and vertical rows area with the same letter are not significantly different at 5% probability level by Duncan's Multiple Range Test.

solution.

Concerning P uptake by pepper plants, data presented in Tables (5 and 6) illustrate that mycorrhizal inoculated pepper plants recorded higher P% and uptake than non-inoculated plants. This may be due to the reduction of nutrient different distance to plant roots under non-inoculation condition (Pearson and Jakobsen, 1993 and Edathil *et al.*, 1996).

Moreover, roots infected with mycorrliza had higher rate of nutrient absorption than uninoculated roots (Thomson *et al.*, 1991). Likewise, mycorrhizal hyphae may chemically improve the availability of nutrients for uptake by plant roots (Pearson and Jakobsen, 1993). On the other hand, Hayman (1983), showed that, mycorrhizal plants are more efficient in P-uptake beyond the zone of P depletion in the rhizosphere by the hyphal which translocate P directly into the roots, and enhance P-percentage and P-uptake (Kothari *et al.*, 1991; Edathil *et al.*, 1996). Therefore, the role of VAM in mineral nutrition of plants arises from the simultaneous changes in growth and particularly root morphology and physiology, brought about by mycorrhizal colonization (Marschner, 1998).

4.4. Endogenous phytohormones

Generally water stress highly significant reduced the production of cytokinin, especially under the highest stress (40% FC) (Fig. 2). VAM inoculation showed an interested results by maintaining cytokinin level under drought stress. Meanwhile, there was an increase in leaf ABA concentration with the decrease in soil-moisture content, but VAM inoculation decreased the ABA concentration, particularly in water-stressed plants as compared to well-watered ones (100% FC).

The root system is considered an important site of cytokinin production and a source of cytokinin for shoots (Itai and Birnbaum, 1991). Moreover, VAM inoculation maintained highly RWC and Ψ_T , g_s values, which reflected lower ABA concentration under drought stress. These results are in agreement with the findings of Kraigher *et al.* (1991), Danneberg *et al.* (1992) and Plant (1995).

5. The yield

Data presented in Table (7) show that pepper plants grown under water stress significantly depressed fruit number / pot, fruit weight as well as fruit yield. The reduction in fruit yield under low water supply may be attributed to several factors such as reducing vegetative growth and plant water status. The negative effect of water stress on the fruit yield of pepper and tomato was also reported by Bres and Weston (1993) and Sorial and El-Adgham (1995). However, VAM significantly increased pepper yield compared with non-inoculated plants grown under water stress condition. The percentage of

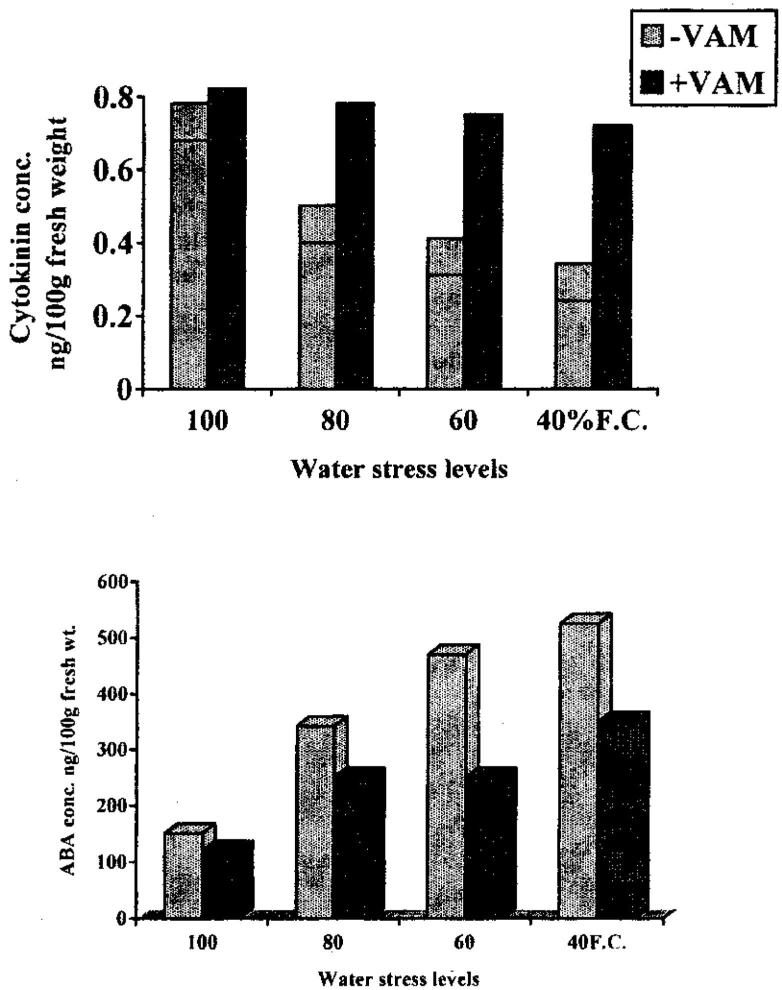

Fig. (2): Effect of water stress and VAM inoculation on cytokinin and ABA conc. of pepper leaves (second season).

Table (7): Effect of water stress and mycorrhizal inoculation on yield and its components of pepper plants during the seasons of 2000 and 2001.

Water supply % FC	First season			Second season		
	VAM inoculated					
	–	+	Mean	–	+	Mean
	Fruit numbers / pot					
100	26.5^{c}	36.3^{a}	31.4^{A}	25.1^{c}	35.5^{a}	30.3^{A}
80	21.4^{e}	31.8^{b}	26.6^{B}	20.4^{e}	31.0^{b}	25.7^{B}
60	15.8^{g}	23.8^{d}	19.8^{C}	14.8^{g}	23.1^{d}	18.9^{C}
40	11.1^{h}	19.2^{f}	15.2^{D}	12.1^{h}	17.5^{f}	14.8^{D}
Mean	18.7^{B}	27.8^{A}		18.1^{B}	26.8^{A}	
	Fruit weight (g)					
100	27.7^{b}	31.1^{a}	29.4^{A}	27.5^{b}	31.2^{a}	29.4^{A}
80	22.8^{c}	27.4^{b}	25.1^{B}	22.7^{c}	27.1^{b}	24.9^{B}
60	14.4^{e}	23.7^{c}	19.1^{C}	14.5^{e}	23.5^{c}	19.0^{C}
40	10.8^{f}	18.2^{d}	14.5^{D}	10.5^{f}	17.9^{d}	14.2^{D}
Mean	18.9^{B}	25.1^{A}		18.8^{B}	24.9^{A}	
	Fruit yield (g / pot)					
100	734.1^{c}	1128.9^{a}	931.5^{A}	690.3^{c}	1107.6^{a}	898.9^{A}
80	487.9^{e}	871.3^{b}	679.6^{B}	463.1^{e}	848.1^{b}	655.6^{B}
60	227.5^{g}	564.1^{d}	395.8^{C}	214.6^{g}	542.9^{d}	398.8^{C}
40	119.9^{h}	349.4^{f}	234.7^{D}	127.1^{h}	313.3^{f}	220.2^{D}
Mean	392.4^{B}	728.4^{A}		373.8^{B}	7029.9^{A}	

– = non-inoculation + = inoculation

Values within the same horizontal and vertical rows area with the same letter are not significantly different at 5% probability level by Duncan's Multiple Range Test.

increased fruit yield due to VAM inoculation were 79, 148 and 191% under 80, 60 and 40% FC, respectively as compared with non-inoculated plants. This may be due to the ability of VAM fungi to supply the growing plant not only with phosphorus but also with other nutrients as reported by Teulat *et al.* (1997). Also, the positive correlation between grain yield and RWC was observed in wheat under drought stress (Al-Hakimi *et al.*, 1995).

In conclusion, the present study provided the importance of mycorrhiza fungi inoculation might have drought tolerance or avoidance, which played an important role in plant water status during droughtness. This may be associated also with both improving plant nutrition, particularly, phosphorus and plant performance under drought stress condition. The data revealed that, stomatal control, plant water relations, growth especially root system, nutrients uptake and yield obviously improved in mycorrhizal-treated pepper plants when subjected to water stress conditions.

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إستجابة نباتات الفلفل للمعاملة بفطــر الميكروهيزا تحت ظــروف الإجهاد المائى

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الملخص العربى :

أجــرى هــذا البحــث بمزرعة كلية الزراعة جامعة المنوفية لدراسة تأثير العدوى بفطر الميكورهــيزا علــى كــل مــن النمو وتبادل الغازات والعلاقات المائية والمحتوى الداخلى من الهــرمونات والعناصــر والبرولين وصبغات الكلوروفيل وكذلك المحصول لنباتات الفلفل النامية تحت أربع مستويات من الرى متمثلة فى ١٠٠ و ٨٠ و ٦٠ و ٤٠% من السعة الحقلية . وقد أوضحت النتائج المتحصل عليها أن العدوى بالميكورهيزا أعطت زيادة واضحة فى كلٍ من طول الجذر والساق والوزن الجاف والمساحة الورقية وخاصةً تحت المستويات المختلفة من الرى . كذلك أدى الحقن بالميكروهيزا إلى نقص فى مقاومة الثغور ومعدل النتح تحت ظروف الجفاف. كذلــك ســجلت نــباتات الفلفــل المعاملة بالميكورهيزا نسب عالية من المحتوى النسبى للماء بــالأوراق وكفاءة الإستهلاك المائى إلى جانب إنخفاض الجهد المائى والأسموزى للأوراق مع الإحتفاظ بجهد الإمتلاء للأوراق وخاصةً تحت ظروف الجفاف . أثبتت النتائج أيضاً أن المعاملة بالميكورهــيزا خاصــةً تحت ظروف الجفاف أعطت معدلات عالية من الكلوروفيل والنيتروجين والفوســفور والبوتاسيوم ومعدل إمتصاصها وتركيز البرولين والذى ينعكس فى محصول الثمار وهــذا بالمقارنــة بالنباتات الغير معاملة بالميكروهيزا . سجلت النباتات المعاملة بالميكورهيزا محتوى عالى من السيتوكينين مع إنخفاض فى مستوى حمض الأبسيسيك وخاصةً تحت ظروف الجفاف .