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Application of mycorrhizae and rhizobacteria inoculations in the cultivation of processing tomato under water shortage

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SUMMARY

The effect of mycorrhizal fungi and plant growth promoting rhizobacteria on some physiological properties, yield and soluble solid content (Brix) of 'Uno Rosso' F_1 processing tomato was studied under water scarcity. Inoculation was performed with mycorrhizal fungi (M) and rhizobacteria preparation (PH) at sowing (M1, PH1) and sowing + planting (M2, PH2). The treated and untreated plants were grown with regular irrigation (RI = ET100%), with deficit irrigation (DI = ET50%) and without irrigation (I0). In drought, the canopy temperature of plants inoculated with arbuscular mycorrhizal fungi (M1, M2) decreased significantly, however, the decrease was small in those treated with the bacterium (PH1, PH2), while the SPAD value of the leaves of plants treated only with Phylazonit increased significantly. On two occasions, inoculations (M2, PH2) significantly increased the total yield and marketable yield, however, under water deficiency, a higher rate of green yield was detected than untreated plants. In dry year using deficit irrigation, the one-time inoculation (M1, PH1) provided a more favorable Brix value, while the double treatments reduced the Brix. In moderate water scarcity, the use of mycorrhizal inoculation (M2) is preferable, while under weak water stress, the use of rhizobacteria inoculation (PH2) is more favorable.

Keywords: *bio-fertilizer; canopy temperature; chlorophyll content; Brix; drought*

INTRODUCTION

The productivity of open-field horticultural crops is exposed to the frequent occurrence of dry warm periods, which can be attributed to climate change. The yield of such conditions, especially vegetable varieties with high water requirement, is significantly limited. Although the decrease in productivity can be mitigated or avoided with the use of various irrigation models (Takács et al., 2020, 2021), the determination of the favorable irrigation water dose and irrigation time for different crops requires knowledge of several factors. Water-saving irrigation method so-called deficit irrigation for many plant species, taking into account the stress responses of the varieties, can provide a sustainable cultivation in particularly dry areas (Geerts and Raes, 2009).

The response of plants to water scarcity depends on the tolerance of the variety to water shortage, the intensity of stress, and the phenological stage at which water stress occurs. In water scarcity, plants respond to reduce water loss by closing stomata thereby the transpiration reduces and stomatal resistance increases in the leaves, which is closely related to water consumption (Nemeskéri et al., 2018). The reduction in transpiration leads to an increase in canopy temperature (Helyes, et al., 2010) which is accompanied by low stomatal conductance and an increase in soluble solid content in tomato fruit (Nemeskéri et al., 2019). At low soil moisture content, water and nutrient uptake of plants decreases which reduces photosynthesis impedes the plant growth and, if this occurs during flowering and fruit setting, the expected yield may be reduced. Tomatoes are most sensitive to water scarcity during fruit setting and intensive fruit development, when an increase in water stress intensity can decrease yields from 25% to even 50% (Helyes and Varga, 1994). Although the lack of water reduces the amount of fruit, the soluble solid content in the fruit, which is important for the processing of tomatoes, is higher in the fruit than that of well-irrigated plants (Pék et al., 2019).

Another option to reduce yield loss in water scarcity is to use bio-fertilizers containing mycorrhizal fungi and beneficial rhizobacteria. The arbuscular mycorrhizal fungi (AMF) in the soil, living in symbiosis with the root of the plant, improve nutrient and water uptake (Turk et al., 2006) photosynthetic activity and thereby productivity (Ebrahim and Saleem, 2017) and they impact crop quality (Bona et al., 2017). In this symbiotic relationship, AMF modifies the plant stomatal behaviour and improves plant water relations (Duc et al., 2018) by enhancing the synthesis of abscisic acid (ABA) in the root, which transported to the leaf induces closure of the stomata. In this process, during drought stress, AMF induces a change in the expression of the aquaporin gene in the root and up-regulated several genes in the ABA signalling pathway (Xu et al., 2018).

In addition to the fungi presented in the rhizosphere, a large number of bacteria occur, which together can affect the physiological processes of plants (Barriuso et al., 2008). Soil bacteria on the root surface alter the

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phytohormonal state of the root, thereby promoting plant growth and facilitating the uptake of nutrients by the plant. Tomato root secretes various biochemical compounds such as amino acids, organic acids sugars, which are also involved in root microbial colonization (Oku et al., 2012). PGP rhizobacteria, like mycorrhizal fungi, increase the biosynthesis of abscisic acid (ABA) in the plant and can stimulate elongation of the main roots in water shortage (Sharifi and Ryu, 2017). AMF treatments, together with rhizosphere bacteria, result in an intensive development of tomato seedlings and a significant increase in biomass of developed plants compared to non-inoculated plants (Candido et al., 2015). It has been found that the interaction of rhizosphere bacterial communities and fungi in the mycorrhizosphere promotes AMF germination and root colonization by causing spore-associated bacteria to adhere tightly to the spore wall or hyphae (Gopal et al., 2012). However, not all bacteria but some members of the genera *Bacillus* and *Pseudomonas* have been shown to be able to do so (Mansfeld-Giese et al., 2002) and even the compound secreted by the spores makes the environment favourable for bacterial growth (Bharadwaj et al., 2011). The use of AM fungi and PGPR in agricultural systems is still limited despite the fact that their beneficial effect has been proved in a greenhouse but this is not always achieved in the field (Singh et al., 2018). The differing response of inoculated plants in the field can be originated from the plant-microbe interactions which can be modified by natural system (Rouphael et al., 2015) or the relationship between the microorganisms in the soil under water shortage. Our knowledge of how a product consisting of a number of strains impacts the water shortage tolerance and productivity of various plant species is incomplete.

The studies aim to examine the effect of mycorrhizal fungi and a bio-fertilizer containing PGPR strains on some physiological properties of tomatoes. In addition the objective was to establish the application of mycorrhiza or bacterial treatments is more effective for improving processing tomato yields under water stress conditions.

MATERIALS AND METHODS

Experimental conditions

In 2015 and 2016, the effect of mycorrhizal fungi and rhizobacteria (PGPR) on some physiological properties and fertility of 'Uno Rosso' F_1 (United Genetics Seeds Co. CA, USA) tomatoes was investigated. 'Uno Rosso' F_1 is a processing tomato variety with strong growth, middle ripening (approx. 124 days), square/round berry shape and weight 60–65 g. The experiments were carried out at the horticultural experimental farm of Hungarian University of Agriculture and Life Sciences in Gödöllő. In 2015, the experimental soil type was sandy loam, which contained 69% sand, 22% silt, 9% clay, with a bulk density of 1.57 g cm^{-3}, and a field capacity of 19%. In 2016, the structure of the experimental soil was clayey (41% sand, 47.5% silt, 11.5% clay), with a bulk density 1.49 g cm^{-3} and field capacity 25%. Sowing was carried out every year in a greenhouse using special Klasmann TS3 medium (Klasmann-Deilmann GmbH, Geeste, Germany) and the four-week-old seedlings were transplanted to the field using a randomized complete block design. The water supply was the main factor in the two-factor experiments, within which the subplots represented the mycorrhiza treatments (M) and PGPR treatments (PH).

Mycorrhizal and rhizobacterial inoculation

Tomato seedlings were treated with arbuscular mycorrhizal fungi (AMF) and plant growth-promoting bacteria (PGPR) at sowing and planting. AMF treatment was provided by the product Symbivit (Symbiom Ltd. Lanskroun, Czech Republic www.symbiom.cz), which contains *Funneliformis mosseae, F. geosporum, Claroideoglomus etunicatum, C. claroideum, Rhizoglomus microaggregatum* and *Rhizophagus irregularis* spores, infected roots a mixture of mycelium. Inoculation with the 25 g per Litre substrate was carried out at the time of tomato sowing (M1) then the four-week-old M1 seedlings and non-inoculated (M0) seedlings were transplanted to the field on 4 May and 11 May, respectively. During transplantation, half of the M1 plants were re-inoculated (M2) as described by Bakr et al. (2017). The arrangement of inoculated and non-inoculated plants was performed in four repetitions according to a randomized block design. The plants were planted in 0.4 m + 1.2 m twin rows with row lengths of 10 m and a plant distance of 0.2 m.

The plant growth-promoting rhizobacteria (PGPR) were provided by the Phylazonit (PH) bacterial preparation (Phylazonit Ltd. Nyíregyháza, Hungary, www.phylazonit.hu). Phylazonit, containing strains of various bacteria (*Pseudomonas putida, Azotobacter chroococcum, Bacillus circulans, Bacillus megaterium*), is able to stimulate plant growth by breaking down nutrients in stubble residues, living in a symbiosis on the plant roots. Inoculation was performed with 1% Phylazonit solution at sowing (PH1), then the four-week-old treated (PH1) and untreated (PH0) seedlings were planted on 11 and 17 May, respectively. Half of the treated (PH1) seedlings were re-inoculated with Phylazonit solution (PH2) when planted using a drip irrigation system (10L solution m^{-3} water) as described in Le et al. (2018). The study was carried out in a randomized complete block design with four repetitions, where the seedlings were planted in 0.4 m + 1.6 m twin rows with a plant distance of 0.2 m.

Water supply

The plants were irrigated using a drip irrigation system in both years. The following irrigation treatments were applied: regular irrigation (RI) where the total evapotranspiration (100% ETc) amount was replenished, DI means deficit irrigation where 50% of ETc was replenished and I0 where ETc was not replenished. In the I0 treatment, the plants received a natural rainfall supply during their development. The

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dose of regular irrigation (RI) and deficit (DI) irrigation i.e. the value of plant evapotranspiration (ETc) was calculated using CROPWAT 8.0 software (FAO Rome, Italy). Based on the amount of precipitation and temperature of the years, 2015 is very dry while 2016 can be said to be wetter (*Table 1*). In 2015, during the development of the tomato, there was little rainfall (101 mm) but significantly more rainfall (359 mm) and lower temperatures characterized the 2016. However, there was a significant difference in precipitation distribution; in 2015, during flowering and fruit setting (ST2) a medium amount of precipitation (29 mm) fell and the average temperature was relatively high (29.73 ºC), while during this period there was a similarly high temperature and shortage of precipitation in 2016 (*Table 2*). During early fruit development (ST3) and ripening (ST4), the temperature and precipitation relationship of 2015 was favorable for yield ripening and the accumulation of soluble solids content (ºBrix) compared to 2016, when the amount of significant precipitation affected both yield and quality distribution.

Table 1. **Meteorological data and irrigation during the growth of tomatoes**

Year	T_{max} average ºC	T_{min} average ºC	Precipitation (mm)	Irrigation	(mm)	Total water	(mm)
			I0	DI	RI	DI	RI
2015	25.7	14.1	101.1	140.6	262.5	241.7	363.6
2016	24.7	13.5	359.4	112.6	211.5	472	570.9

DI = deficit irrigation, RI = regular irrigation

Table 2. **Temperature and precipitation during the growth of 'Uno Rosso' F_1 tomato**

Periods	2015			2016		
	T_{max} average ºC	T_{min} average ºC	Precipitation (mm)	T_{max} average ºC	T_{min} average ºC	Precipitation (mm)
ST0	21.86	11.04	0.0	20.48	10.45	127.7
ST1	25.38	14.17	42.0	24.28	13.17	13.5
ST2	29.73	16.93	29.1	29.75	17.00	0.0
ST3	27.93	16.29	30.0	26.30	15.37	152.7
ST4	29.41	16.19	0.0	25.00	13.40	65.5
Total			**101.1**			**359.4**

ST0 = from plantation to flowering, ST1 = flowering, ST2 = flowering and fruit setting, ST3 = early fruit development, ST4 = fruit ripening

Soil microbial activity and root colonization

The determination of the total microbial activity of the soil sample was based on the hydrolysis of fluorescein diacetate (3′, 6′-diacetylfluorescein (FDA)). Through the hydrolysis of FDA, the free enzymes and the enzymes bound to membranes in the soil release coloured fluorescein that can be measured with a spectrophotometer, making it the optimal method to determine the general microbial activity of clay, silt loam, and sandy loam soil types (Green et al., 2006). The degree of root colonization was determined from four plants taken randomly selected in the subplots. Then, in the different treatments, the root samples were cut and dyed with Trypan Blue solution. The internal fungal structure and percentage of colonized root length were determined as described by Giovannetti and Mosse (1980).

Field measurements

Five plants were selected in each plot to measure physiological properties. The chlorophyll content of the leaves and the canopy temperature were measured four occasions between 10:00 am and 1:00 pm on the selected plants at the beginning of flowering (ST1) during flowering and fruit setting (ST2), during early fruit development (ST3) and fruit ripening (ST4). The chlorophyll content of the leaves was measured with a portable chlorophyll meter (SPAD 502 Konica Minolta, Warington, UK). The instrument measures the photosynthetic light absorption of the leaves without damage and the calculated SPAD value is proportional to the chlorophyll content of the leaves. Canopy temperature was measured with a Raytek MX4 (Raytek Corporation, Santa Cruz, CA, USA) hand-held infrared thermometer simultaneously with SPAD measurements.

Yield analysis

The harvested yield of the selected plants was classified: the first group contained red, healthy marketable fruits, group 2 contained healthy but green, unripe fruits and group 3 was for diseased, damaged, or otherwise unmarketable crop. The soluble solid content of the mature marketable crop was measured annually with a Krüss DR201-95 hand-held refractometer (A. Krüss Optronic GmbH, Hamburg, Germany) and specified in degrees Brix.

Statistical analysis

Data were evaluated by two-way analysis of variance with SPSS 20 Windows software (IBM Hungary Ltd, Budapest, Hungary) in each year. A

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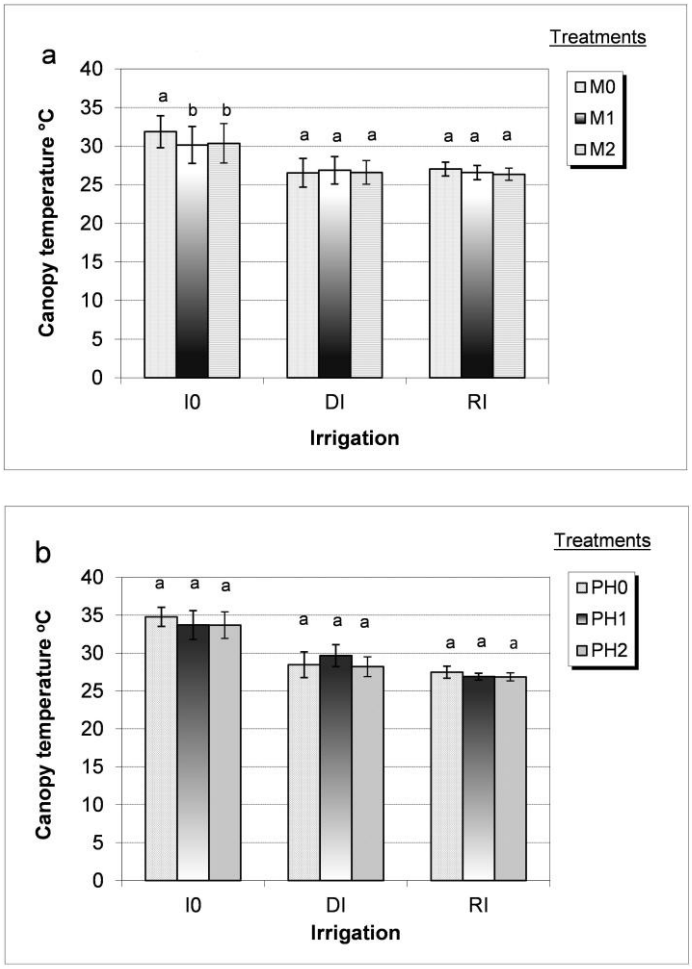
significant difference between treatment means was detected at the $P < 0.05$ level using Duncan's multi-range test. In each year soil microbial activity and root colonization were also assessed by two-way ANOVA and significant differences were performed at $P < 0.05$ level using Tukey's HSD test.

RESULTS AND DISCUSSION

Root colonization was determined at harvest for both AMF and PGPR treatments. In the dry year (2015), fluorescent diacetate hydrolysis (FDA) indicated higher soil microbial activity in the rhizosphere of inoculated plants without irrigation (I0) but no significant difference could be identified under regular and deficit irrigation (RI, DI). Greater microbial activity in the mycorrhizosphere in dry soil was also manifested in root colonization (I0) (Bakr 2018). In a dry (2015) year, the soil microbial activity (FDA) and the degree of PH2 root colonization did not substantially differ from the control in dry soil. In wet year (2016), there was a significant difference between the degree of PH2 treated and untreated root colonization under irrigated (DI, RI) conditions (*data not shown*).

Tomatoes are sensitive to water shortage during flowering and fruit development. In a dry year, without irrigation and deficit irrigation, M-treated plants showed a lower canopy temperature from flowering to early fruit development, than the PH-treated plants (*Figure 1*). This indicates that the mycorrhizal plants kept their canopy temperature lower with more intensive water uptake and transpiration than the plants treated with bacteria. The effect of mycorrhizal fungi (M) and bacterial (PH) treatments was particularly varied among unirrigated plants (I0); the canopy temperature was significantly lower in mycorrhizal-inoculated (M1, M2) plants compared to untreated plants, while it was slightly reduced in the plants treated with bacteria (PH1, PH2). Nevertheless, the effect of the treatments was not detectable in the irrigated plants (DI, RI) (*Figure 1*).

Figure 1. **Change in canopy temperature in tomato plants treated by mycorrhiza (M) treatment (a) and Phylazonit (b) under different water supplies in dry 2015 year**



Means ± SE presented the average of the measurements from flowering to early fruit development. The average following different letter is significant different at $P < 0.05$ level using Duncan's test. I0 = non-irrigation DI = deficit irrigation, RI = regular irrigation M0, PH0 = non-inoculation, M1, PH1 = once inoculation, M2, PH2 = twice inoculation

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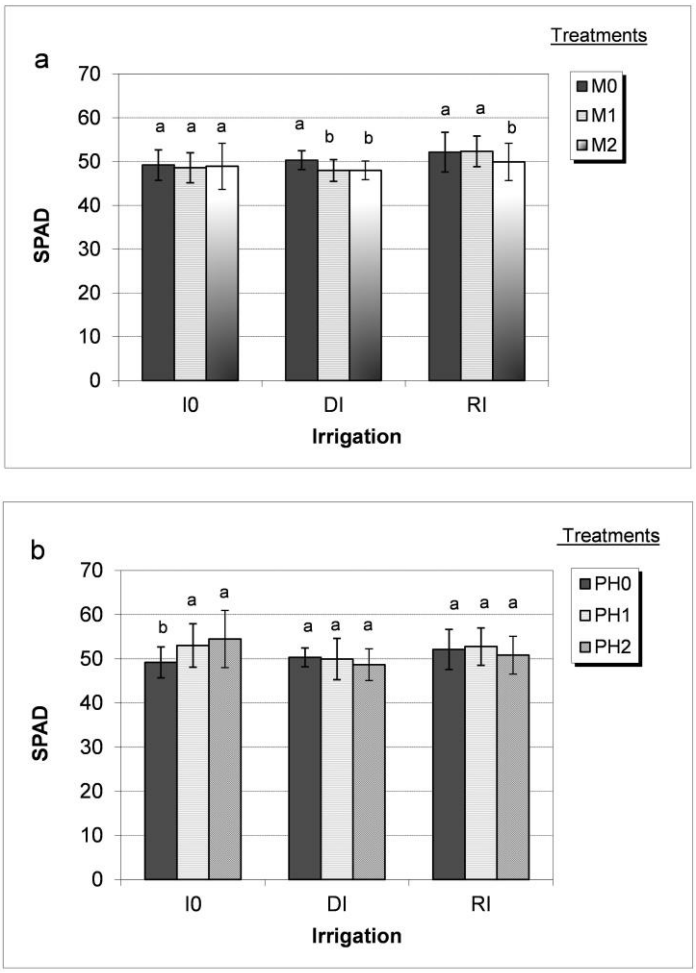
Calvo-Polanco et al. (2016) found that in drought, the relative chlorophyll content (SPAD) increased in AMF and PGPR treated tomato plants compared to good water supply, but the difference between the varieties can only be detected in AMF treatments. In contrast, our results showed that, the effect of mycorrhizal fungi and bacterial treatments on SPAD value differed depending on the degree of water scarcity. Under non-irrigated condition (I0) no significant change in SPAD was detected in mycorrhizal (M) plants (*Figure 2a*), however, in the plants treated with rhizobacteria (PH1, PH2) the SPAD value increased significantly compared to untreated plants (*Figure 2b*). Under this condition, the highest SPAD value (54.48) was shown by the plants treated on two occasions (PH2). Under deficit irrigation, the SPAD value decreased slightly in mycorrhizal (M1, M2) plants compared to untreated plants, but it did not change in the plant treated with bacteria (PH1, PH2) (*Figure 2*).

Figure 2. **Change in SPAD values in tomato plants treated by mycorrhiza (M) (a) and Phylazonit (b) under different water supplies in dry 2015 year**



Means ± SD presented the average of the measurements from flowering to early fruit development. The average following different letter is significant different at $P < 0.05$ level using Duncan's test. I0 = non-irrigation. DI = deficit irrigation, RI = regular irrigation, M0, PH0 = non-inoculation, M1, PH1 = once inoculation, M2, PH2 = twice inoculation

In severe water shortage (dry year + without irrigation), changes in canopy temperature (CT) and SPAD during the generative phase of mycorrhizal plants seem to have a more favourable effect on the yield than in the plants treated with rhizobacteria (*Figures 1 and 2*, *Table 3*), although the quality distribution of the fruit was influenced similarly. The double inoculations M2 and PH2 significantly increased the total yield and marketable yield regardless of the distribution of rainfall over the years, however, they resulted in a greater quantity of green fruits in the dry year with a water shortage (I0, DI) than in the untreated plants. In the dry (2015) year, under deficit irrigation, plants inoculated twice with mycorrhiza (M2) produced 34% more marketable crops but the same amount of green crops as the plants inoculated twice with rhizobacteria (PH2) (*Table 3*). According to the others (Andryei et al., 2021) a bio-fertilizer containing *Bacillus* species causes a prolonged photosynthesis, greater green mass,

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prolonged ripening, and a slow-down in the biosynthesis of colour substances in berries resulting in an increase in the amount of green tomatoes fruits. This may be related to the mineral acquisition ability of rhizobacteria, as some members of *Bacillus* and *Pseudomonas* have been shown to increase mineral uptake of plants (Ghoghari et al., 2022) which affects crop formation. In the wetter (2016) year, both mycorrhiza (M1, M2) treatments significantly increased the total and marketable yield, especially in water shortage (I0, DI). Under deficit irrigation PH2 treatment results in higher marketable yields, less green yields than using M2 treatment in wetter year (*Table 3*).

Table 3. **Effect of water supply and AMF (M) and PGPR (PH) on the yield and Brix of 'Uno Rosso' F_1 tomato in dry (2015) and wet (2016) year**

		2015					2016				
Water supply (WS)	**Treatment**	**TY**	**MY**	**GY**	**DY**	**BRIX**	**TY**	**MY**	**GY**	**DY**	**BRIX**
I0	Ø	19.83 b	14.69 a	4.06 c	1.08 a	8.03 a	111.08 b	61.22 b	9.41 c	40.45 a	3.65 c
	M1	19.40 b	15.16 a	4.57 b	0.47 a	7.80 a	121.68 a	69.75 a	9.63 c	42.30 a	4.05 b
	M2	21.18 a	14.92 a	5.45 b	0.80 a	8.20 a	121.13 a	71.09 a	11.05 c	38.95 a	4.10 b
	PH1	20.96 b	14.91 a	4.83 b	1.22 a	7.83 a	113.00 b	62.80 b	18.63 a	31.58 a	4.65 a
	PH2	21.61a	13.62 a	6.27 a	1.46 a	7.60 a	120.25 a	67.81 a	15.31 b	34.27 a	4.10 b
		20.54 C	***14.66 C***	***5.04 B***	***1.01 C***	***7.89 A***	***117.43 B***	***66.53 B***	***12.80 A***	***37.51 A***	***4.11 A***
DI	Ø	68.12 c	56.45 c	3.37 c	7.94 a	5.03 b	117.89 c	67.61 c	12.97 a	40.17 a	4.45 a
	M1	78.15 b	63.50 b	5.83 b	8.38 a	5.10 b	137.65 b	83.06 b	12.22 a	42.36 a	4.00 b
	M2	110.82 a	96.47 a	8.98 a	5.37 a	3.88 d	143.93 b	96.09 a	9.77 b	38.06 a	4.13 b
	PH1	66.10 c	51.30 c	8.32 a	7.23 a	5.13 b	139.58 b	88.25 b	9.47 b	41.86 a	4.13 b
	PH2	88.48 a	71.86 a	8.55 a	8.07 a	4.13 c	200.07 a	107.50 a	7.95 c	45.33 a	3.65 c
		82.33 B	***67.99 B***	***7.08 A***	***7.40 B***	***4.65 B***	***147.82 A***	***88.50 A***	***10.48 AB***	***41.56 A***	***4.07 A***
RI	Ø	87.02 b	68.41 c	2.89 b	15.71 a	3.73 d	125.39 b	79.30 b	6.83 c	39.17 a	3.55 c
	M1	68.58 c	57.64 d	1.51 b	9.43 a	3.80 d	137.66 a	81.84 a	6.64 c	46.17 a	3.25 c
	M2	89.74 b	75.38 b	2.84 b	11.52 a	3.45 d	131.84 a	74.48 b	12.81 a	43.03 a	3.05 c
	PH1	87.11 b	66.54 c	3.41 a	17.16 a	3.95 d	133.59 a	80.86 a	10.28 a	42.44 a	3.28 c
	PH2	113.32 a	93.77 a	3.90 a	15.65 a	4.38 c	132.21 a	86.28 a	8.14 b	37.78 a	3.38 c
		89.15 A	***72.35 A***	***2.91 C***	***13.89 A***	***3.86 C***	***132.13 B***	***80.57 A***	***9.54 B***	***41.72 A***	***3.30 B***
	WS	***	***	***	***	***	***	***	*	ns	***
	Tr	***	***	*	ns	**	*	*	ns	ns	ns
	WS x Tr	***	***	ns	ns	***	ns	ns	*	ns	ns

***P < 0.001 **P < 0.01 *P ≤ 0.05 ns = non-significant Ø = no treatments M0, PH0 = non-inoculation, M1, PH1 = once inoculation, M2, PH2 = twice inoculation. TY=total yield t ha^{-1}; MY = marketable yield t ha^{-1}; GY = green yield t ha^{-1}; DY = diseased yield t ha^{-1} I0 = non-irrigation, DI = deficit irrigation, RI = regular irrigation. The average following different letter are significant different at P < 0.05 level using Duncan's test. Capital letters represent significant difference of water supplies smaller letters represent significant difference of treatments.

The amount of diseased crop was less in the dry year than in the rainy year, and their quantity was not significantly impacted by the treatments. Nevertheless, in a dry year (2015) with deficit irrigation, M2-treated plants produced fewer diseased crops than untreated plants (*Table 3*). It is well known that the soluble solid content (ºBrix) of the crop is high under dry conditions and it decreases under good water supply. We expected a high Brix values from microbial treatments however, their effect on tomato fruit quality was significantly influenced by years and water supply. Both double treatments (M2, PH2) significantly increased the yield of 'Uno Rosso' F_1 variety, though the soluble solid content of the fruit, i.e. the Brix value, decreased. However in a moderate water shortage (dry year + deficit irrigation), the effect of once-inoculated (M1) mycorrhiza and rhizobacteria (PH1) treatments was manifest primarily in preserving crop quality, as they provided a Brix value similar to that of untreated plants (*Table 3*).

The composition of inoculations and the interaction between microbes may be a condition for the effectiveness of bio-fertilizers under field conditions. Several rhizobacteria with plant growth promoting activity have been discovered, such as *Bacillus, Pseudomonas, Azotobacter*, which impact both yield and the development of plant (Kloepper et al., 1989). Of these, *Pseudomonas* species have been shown to have a positive effect of on the flowering and fruit setting of tomato plants (Bona et al., 2017) and in the rhizosphere of tomatoes *Bacillus* bacterium successfully colonizes and contributes to better growth and fruiting (Zhou et al., 2016). Our results confirm that Phylazonit, which contains *Pseudomonas* and *Bacillus* strains, is effective in increasing the marketable yield of 'Uno Rosso' F_1 tomatoes when used in a doubled treatment (PH2) with deficit irrigation. A double dose of the Symbivit product (M2) containing mycorrhizal fungi has similar efficacy. However, their effectiveness is also affected by the rainfall conditions of the years;

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in moderate water shortage, the use of Symbivit is more favorable in processing tomato cultivation, while under a slight shortage of water, Pylazonit biofertilizer is more effective. The use of microbial consortia can be a promising method in sustainable agriculture (Ghoghari et al., 2022), but in the absence of water, the effective use of multi-component vaccines and bio-fertilizers can also be influenced by the genetic background of the plant species and variety, which must be taken into account in their selection.

CONCLUSIONS

Under drought, both mycorrhizae (M1, M2) and rhizobacterium (PH1, PH2) inoculations reduced the canopy temperatures, while SPAD value of the leaves in rhizobacteria-treated plants increased but did not change in mycorrhizal plants. The double mycorrhizae (M2) and rhizobacteria (PH2) inoculations significantly increased the marketable yield of tomatoes experiencing water shortages but did not provide the high Brix value of the crop. In moderate water scarcity, the use of double mycorrhizal inoculation (M2) is more favorable for marketable yield but under mild water stress the double rhizobacteria inoculation (PH2) can achieve a larger marketable yield and less green crop than with use of M2 treatment.

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REFERENCES

Andryei, B.–Horváth, K.Zs.–Agyemang, Duah. S.–Takács, S.–Égei, M.–Szuvandzsiev, P.–Neményi, A. (2021): Use of plant growth promoting rhizobacteria (PGPRs) in the mitigation of water deficiency of tomato plants (*Solanum lycopersicum* L.). *J Cent Eur Agric 22* (1), 167–177. https://doi.org/10.5513/JCEA01/22.1.3036

Bakr, J.A. (2018): Arbuscular Mycorrhizae fungi role in tomato (*L. esculentum* Mill.) production under water scarcity conditions. *PhD Diss.*, Szent Istvan University, Gödöllő, Hungary

Bakr, J.–Daood, H.G.–Pék, Z.–Helyes, L.–Posta, K. (2017): Yield and quality of mycorrhized processing tomato under water scarcity. *Appl Ecol Environ Res 15*, 401–413. http://dx.doi.org/10.15666/aeer/1501_401413

Barriuso, J.–Solano, B.R.–Mañero, F.J.G. (2008): Protection against pathogen and salt stress by four plant growth-promoting rhizobacteria isolated from *Pinus* sp. on *Arabidopsis thaliana*. *Phytopathology 98*, 666–672.

Bharadwaj, D.P.–Alström, S.–Lundquist, P.O. (2011): Interactions among *Glomus irregulare*, arbuscular mycorrhizal spore-associated bacteria, and plant pathogens under in vitro conditions. *Mycorrhiza 22*, 437–447.

Bona, E.–Cantamessa, S.–Massa, N.–Manassero, P.–Marsano, F.–Copetta, A.–Lingua, G.–D'Agostino, G.–Gamalero, E.–Berta, G. (2017): Arbuscular mycorrhizal fungi and plant growth-promoting pseudomonads improve yield, quality and nutritional value of tomato: a field study. *Mycorrhiza 27*, 1–11. https://doi.org/10.1007/s00572-016-0727-y

Calvo-Polanco, M.–Sánchez-Romera, B.–Aroca, R.–Asins, M.J.–Declerck, S.–Dodd, I.C.–Martínez-Andújar, C.–Albacete, A.–Ruiz-Lozano, J.M. (2016): Exploring the use of recombinant inbred lines in combination with beneficial microbial inoculants (AM fungus and PGPR) to improve drought stress tolerance in tomato. *Environ Exp Bot 131*, 47–57.

Candido, V.–Campanelli, G.–D'Addabbo, T.–Castronuovo, D.–Perniola, M.–Camele, I. (2015): Growth and yield promoting effect of artificial mycorrhization on field tomato at different irrigation regimes. *Sci Hortic (Amsterdam) 187*, 35–43. http://dx.doi.org/10.1016/j.scienta.2015.02.033

Duc, N.H.–Csintalan, Zs.–Posta, K. (2018): Arbuscular mycorrhizal fungi mitigate negative effects of combined drought and heat stress on tomato plants. *Plant Physiol Biochem 132*, 297–307. https://doi.org/10.1016/j.plaphy.2018.09.011

Ebrahim, M.K.H.–Saleem, A.R. (2017): Alleviating salt stress in tomato inoculated with mycorrhizae: photosynthetic performance and enzymatic antioxidants. *J Taibah Univ Sci 11* (6), 850–860.

Geerts, S.–Raes, D. (2009): Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agric Water Manag 96 (9)*, 1275–1284.

Ghoghari, N.–Bharwad, K.–Champaneria, A.–Rajkumar, S. (2022): Microbial consortia for augmentation of plant growth–revisiting the promising approach towards sustainable agriculture. In: *New and Future Development in Microbial Biotechnology and Bioengineering. Sustainable Agriculture: Microorganisms as Biostimulants* Singh, H.B., Vaishnav, A. Eds., Elsevier, Netherlands pp. 231–256.

Giovannetti, M.–Mosse, M. (1980): Evaluation of the techniques for measuring vesicular arbuscular mycorrhizal infections in roots. *New Phytol 84*, 489–500.

Gopal, S.–Chandrasekaran, M.–Shagol, C.–Kim, K.–Sa, T. (2012): Spore associated bacteria (SAB) of arbuscular mycorrhizal fungi (AMF) and plant growth promoting rhizobacteria (PGPR) increase nutrient uptake and plant growth under stress conditions. *Korean J Soil Sci 45* (4), 582–592. https://doi.org/10.7745/KJSSF.2012.45.4.582

Green, V.S.-Stott, D.E.-Diack, M. (2006): Assay for fluorescein diacetate hydrolytic activity: optimization for soil samples. *Soil Biol Biochem 38* (4), 693–701.

Helyes, L.–Varga, G. (1994): Irrigation demand of tomato according to the results of three decades. *Acta Hortic 376*, 323–328.

Helyes, L.–Bőcs, A.–Pék, Z. (2010): Effect of water supply on canopy temperature, stomatal conductance and yield quantity of processing tomato (*Lycopersicon esculentum* Mill.). *Int J Hortic Sci 16*, 13–15. (Hungary).

Kloepper, J.W.–Lifshitz, R.–Zablotowich, R.K. (1989): Free-living bacterial inocula for enhancing crop productivity. *Trends Biotechnol 7*, 39–43.

DOI: 10.34101/ACTAAGRAR/2/13340

Le, A.T.–Pék, Z.–Takács, S.–Neményi, A.–Helyes, L. (2018): The effect of plant growth-promoting rhizobacteria on yield, water use efficiency and Brix degree of processing tomato. *Plant Soil Environ 64* (11), 523–529.

Nemeskéri, E.–Molnár, K.–Pék, Z.–Helyes, L. (2018): Effect of water supply on water use related physiological traits and yield of snap beans in dry seasons. *Irrig Sci 36 (3)*, 143–158.

Nemeskéri, E.–Neményi, A.–Bőcs, A.–Pék, Z.–Helyes, L. (2019): Physiological factors and their relationship with the productivity of processing tomato under different water supplies. *Water 11* (3), 586. https://doi.org/10.3390/w11030586

Mansfeld-Giese, K.–Larsen, J.–Bodker, L. (2002): Bacterial populations associated with mycelium of the arbuscular mycorrhizal fungus *Glomus intraradices*. *FEMS Microb Ecol 41*, 133–140.

Oku, S.–Komatsu, A.–Tajima, T.–Nakashimada, Y.–Kato, K. (2012): Identification of chemotaxis sensory proteins for amino acids in Pseudomonas fluorescens Pf0-1 and their involvement in chemotaxis to tomato root exudate and root colonization. *Microb Environ 27*, 462–469.

Pék, Z.–Szuvandzsiev, P.–Neményi, A.–Tuan, L.A.–Bakr, J.–Nemeskéri, E.–Helyes, L. (2019): Comparison of a water supply model with six seasons of cherry type processing tomato. *Acta Hortic 1233* (1), 41–46. https://doi.org/10.17660/ActaHortic.2019.1233.7

Rouphael, Y.–Franken, P.–Schneider, C.–Schwarz, D.–Giovannetti, M.–Agnolucci, M.–De Pascale, S.–Bonini, P.–Colla, G. (2015): Arbuscular mycorrhizal fungi act as biostimulants in horticultural crops. *Sci Hortic 196*, 91–108.

Sharifi, R.–Ryu, C.M. (2017): Chatting with a tiny belowground member of holobiome: communication between plants and growth-promoting rhizobacteria. *Adv Bot Res 82*, 135–160.

Singh, V.K.–Singh, A.K.–Singh, P.P.–Kumar, A. (2018): Interaction of plant growth promoting bacteria with tomato under abiotic stress: A review. *Agric Ecosyst Environ 267*, 129–140.

Takács, S.–Pék, Z.–Csányi, D.–Daood, H.G.–Szuvandzsiev, P.-Palotás, G.-Helyes, L. (2020): Influence of water stress levels on the yield and lycopene content of tomato. *Water 12* (8), 2165. https://doi.org/10.3390/w12082165

Takács, S.–Csengeri, E.–Pék, Z.–Bíró, T.–Szuvandzisev, P.–Palotás, G.–Helyes, L. (2021): Performance evaluation of AquaCrop model in processing tomato biomass, fruit yield and water stress indicator modelling. *Water 13* (24), 3587. https://doi.org/10.3390/w13243587

Turk, M.A.–Assaf, T.A.–Hameed, K.M.–Al-Tawaha, A.M. (2006): Significance of mycorrhizae. *World J Agric Sci 2* (1), 16–20.

Xu, L.–Li, T.–Wu, Z.–Feng, H.–Yu, M.–Zhang, X.–Chen, B. (2018): Arbuscular mycorrhiza enhances drought tolerance of tomato plants by regulating the 14-3-3 genes in the ABA signaling pathway. *Appl Soil Ecol 125*, 213–221.

Zhou, D.–Huang, X.F.–Chaparro, J.M.–Badri, D.V.–Manter, D.K.–Vivanco, J.M.–Guo, J. (2016): Root and bacterial secretions regulate the interaction between plants and PGPR leading to distinct plant growth promotion effects. *Plant and Soil 401*, 259–272.