Original scientific paper
Journal of Central European Agriculture, 2021, 22(1), p.167-177

DOI: /10.5513/JCEA01/22.1.3036

Use of plant growth promoting rhizobacteria (PGPRs) in the mitigation of water deficiency of tomato plants (*Solanum lycopersicum* L.)

Növekedést serkentő rhizobaktériumok használata paradicsom növények vízhiányának mérséklésére

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Received: September 12, 2020; accepted: November 2, 2020

ABSTRACT

Plant growth promoting rhizobacteria (PGPR) can improve the growth, productivity and tolerance of plants under stress conditions. The aim of this study was to investigate the effect of PGPRs on the physiological traits related to photosynthesis, canopy temperature (CT) and yield of tomato hybrids under water scarcity in open field conditions. Seedlings of H-1015 and UG 812J F_1 tomato hybrids were treated by B1, B2, B3 bacteria strains before planting, then they were grown under regularly irrigated (RI=ET100%), deficit irrigated (DI=ET50%) and non-irrigated (I0) conditions in the field experiments. During flowering period, a higher chlorophyll fluorescence (Fv/Fm), canopy temperature and lower chlorophyll content (SPAD) were measured for plants treated by B2 and B3 treatments than for untreated plants. From flowering to ripening of tomato fruit, PGPRs influenced negatively the Fv/Fm, positively the SPAD value and canopy temperature, which resulted in a 47.8 to 75.4% increase in the green healthy fruit yield compared to the control. Under severe dry, non-irrigated conditions, B3 treatment increased the green fruits yield by 28.9%, the Brix by 16% and the vitamin C content by 13.6% in comparison with the untreated plants. Under moderate water deficiency using deficit irrigation the plants treated by B3 produced the same marketable yield and 33% lower diseased yield than untreated plants and they produced 9.5% higher Brix and 12.7% higher vitamin C content.

Keywords: tomato, water stress, chlorophyll fluorescence, canopy temperature, Brix, vitamin C

ABSZTRAKT

Stressz körülmények alatt, a növényi növekedést serkentő baktériumok (PGPR) javíthatják a növények növekedését és termőképességét. A kutatás célja, vízhiányban a PGPRs hatásának vizsgálata a paradicsom hibridek fotoszintézissel összefüggő élettani tulajdonságaira, a levélfelület hőmérsékletre és a termésre. H-1015 és UG 812J F_1 paradicsom palántákat, kiültetés előtt B1, B2, B3 rhizobaktérium törzsekkel kezeltük, ezt követően rendszeres öntözés (RI=ET100%), deficites öntözés (DI=ET50%) mellett és öntözés nélküli parcellákban szántóföldi kísérletekben neveltük fel. Virágzás alatt, a B2 és B3 baktérium törzsekkel kezelt növényeknél a klorofill fluoreszcencia (Fv/Fm) és levélfelület hőmérséklet nagyobb, a klorofill tartalom (SPAD) alacsonyabb volt, mint a kezeletlen növényeknél. Virágzástól a bogyó éréséig a PGPRs negatívan befolyásolta az Fv/Fm-t, pozitívan a SPAD értéket és levélfelület hőmérsékletet, ami a kezeletlen növényekhez képest 47,8-75,4%-kal több zöld, egészséges termést produkált. Súlyos szárazságban, öntözés nélkül a B3 kezelés 28,9%-kal növelte a zöldbogyótermést, a bogyók Brix tartalmát 16%-kal a C-vitamin tartalmát 13,6%-kal növelte a kezeletlen növényekhez képest. Mérsékelt vízhiányban, deficites öntözés alkalmazva, a B3 baktérium törzzsel kezelt növények azonos mennyiségű piacképes termést és 33%-kal kevesebb beteg termést produkáltak, mint a kezeletlenek, és 9,5% -kal nagyobb Brix és 12,7%-kal nagyobb C-vitamin tartalmú bogyók termettek.

Kulcs szavak: paradicsom, víz-stressz, klorofill fluoreszcencia, levélfelület hőmérséklet, Brix, C vitamin

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the most extensively cultivated horticultural crops in the world, and one quarter is for industrial use. Processing tomatoes are of great importance in the food industry (Helyes et al., 2010). According to international regulations, processing tomato varieties must be hard berried, ripen at the same time and be machine-harvestable.

Frequency of high temperatures and water deficit periods or high extent of precipitation due to the climatic changes limits the production of vegetables in open field conditions. Water supply influences the yield and quality which depends on the genetic background and water use efficiency of the varieties (Molnár et al., 2015; Nemeskéri et al., 2015; Nemeskéri et al., 2018a; Abd Al-Shammari et al., 2020). Water deficiency decreases the yield of tomato but the soluble solid content of yield is higher than that of well-irrigated plants (Murtic et al., 2018; Pék et al., 2019). Deficit irrigation is a positive way to save water and improve WUE of plants, while still producing yields with an acceptable reduction (Patanè et al., 2011; Savic et al., 2011). The flowering and fruit setting periods of the tomato are the most sensitive to water stress when the traits relating to photosynthesis significantly influence the fruits weight and marketing yield (Nemeskéri et al., 2019a). A remote sensing technique as the measurement of canopy temperatures (CT) may be an alternative method to detect early water stress in the plant (Nemeskéri and Helyes, 2019), or the measurement of chlorophyll content of leaves and spectral vegetative index (NDVI), which shows immediately the greenness without leaf destruction and if the plants suffer from the water stress (Argenta et al., 2004; Nemeskéri et al., 2018b; Nemeskéri et al., 2019b). Chlorophyll fluorescence techniques are used in plant stress analysis (Salvatori et al., 2014), to evaluate the drought tolerance of genotypes (Ogweno et al., 2009), and photosynthetic activity of plants which can improved the crop production (Baker and Rosenqvist, 2004).

Many research was carried out to decrease the negative impact of water shortage such as use of soil microbes to produce a symbiosis with the plants to improve the performance of plants under various environmental stresses (Augé, 2001), to mitigate the detrimental effect of stresses by increasing photosynthesis and productivity (Ebrahim and Saleem, 2017) and to influence the yield and fruit quality (Nemeskéri et al., 2019c). Plant growth promoting rhizobacteria (PGPR) are soil bacteria with some beneficial effects on soil properties, plant growth and the environment. PGPR are widely used as biofertilizers, plant strengtheners, phytostimulators, and biopesticides (Berg, 2009; Bakr et al., 2017; Duc et al., 2017). They live in symbiosis with plant roots and can increase plant productivity and immunity (Yang et al., 2009; Miransari, 2014). PGPR significantly improves the plant growth and yield and helps the plants to withstand biotic and abiotic stresses (Gopal et al., 2012; Aponte et al., 2017). During the last years the role and act of microbes in the mitigation of abiotic stresses mainly salinity, drought and heavy metal stress in the plants has been an area of great attention (Nadeem et al., 2014). It has been shown that rhizobacteria help to tolerate and alleviate the negative impact of drought by regulating the levels of proteins, antioxidants, polysaccharides or phytohormones of plants (Ipek, 2019; Singh et al., 2018) but its impact on the yield and quality has hardly been studied.

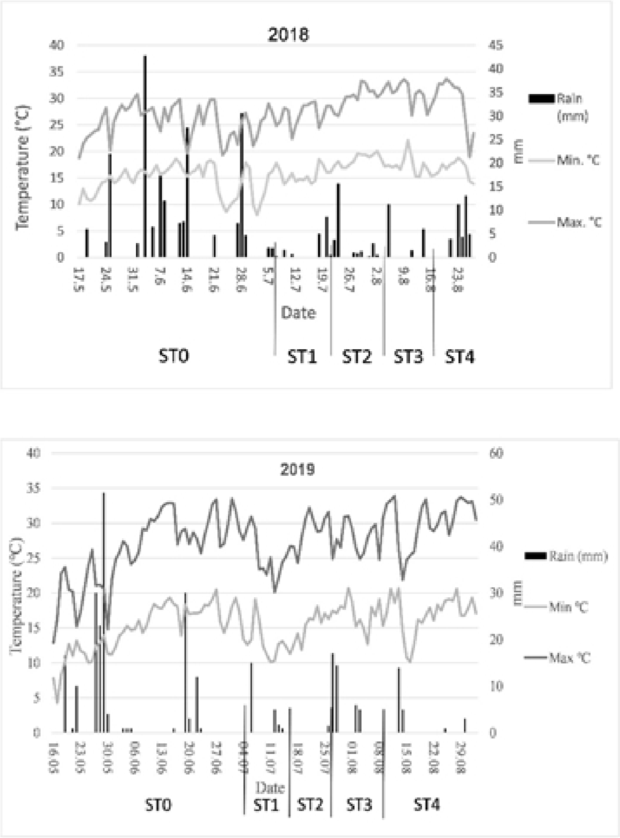
The aim of this study is to show the effect of plant growth promoting rhizobacteria on the photosynthetic activity and productivity of tomato hybrids under water shortage conditions.

MATERIALS AND METHODS

Experimental designs

In 2018 and 2019, the experiments were carried out at the Experimental Farm of the Institute of Horticulture of Szent István University in Gödöllő, Hungary. The examined tomatoes were H-1015 and UG 812J F_1 hybrids with mid-late ripening. There were 3 bacteria (colony-forming unit: 10^9 CFU/mL) and one bacteria-free treatment: **B1** (containing *Pseudomonas putida B5*, *Chryseobacterium* sp. *B8/1*, *Acinetobacter* sp. *PR7/2*, *Aeromonas salmonicida PR10*, *Variovorax sp. BAR04*) **B2**, (containing *Alcaligenes* sp. *3573*, *Bacillus* sp. *BAR16*, *Bacillus* sp. *PAR11*) **B3** (containing *Pseudomonas* sp. *MUS04*, *Rhodococcus* sp. *BAR03*, *Variovorax* sp. *BAR04*) and bacteria free **B0**. The bacteria were given by BAY-BIO Division for Biotechnology (Bay Zoltán Nonprofit Ltd. for Applied Research, Szeged, Hungary) for the experiments. Seedlings were soaked in 20 liters of water containing 2 dl of bacteria suspension for 5 minutes before planting in every treatment. The treated and non-treated tomatoes were planted on May 16 and 17th in 2018 and 2019, respectively. The planting were in 120 cm x 40 cm twin rows, where the length of rows was 25 m and the space between the tomatoes was 20 cm in both years. The experiments were carried out in split-plot design with randomized complete block in four repetitions. Two irrigation treatments were used: RI-regular irrigation corresponding to the optimal water demands of plants (100% of evapotranspiration ET), and DI-deficit irrigation provided with half of the irrigated doses of RI treatment, which was calculated by potential evapotranspiration (ETc) and crop coefficient (Kc) using CROPWAT 8.0 software (FAO, Rome, Italy) and I0-represented the non-irrigated plots which were only under natural precipitation conditions (Table 1). Drip irrigation equipment was used.

In 2018 and 2019 the weather was dry, 305 mm and 276 mm of precipitation has fallen however its distribution was unequal during the growth of tomato Table 1). From planting to full bloom (ST0-ST1), more rain fell in 2018 (212 mm) than in 2019 (186 mm) which represented 70% of the total rainfall during the growing seasons. The rainfall distribution of the two years significantly differed during flowering (ST1) fruit setting (ST2) stages of development which determined the fruit yield of tomatoes. During fruit setting and fruit development periods the air temperature was over 30 °C (Figure 1) which also influenced the physiological processes of the plants.



ST0=from transplantation to start of flowering, ST1= during flowering, ST2= during flowering with fruit setting, ST3=early fruit development, ST4=fruit ripening stages

Figure 1. Meteorological data during the growth stages of processing tomato

Measurements

10-10 plants were selected and tagged in every plot in order to measure the physiological traits such as SPAD by using a portable chlorophyll meter SPAD 502 (Konica Minolta, Warrington, UK) and the chlorophyll fluorescence using a PAM-2500 fluorometer device (Heinz Walz GmgH, Effeltrich, Germany) during flowering and fruit development as described by Nemeskéri et al. (2019a). The canopy temperature was measured with a Raytek MX4 (Raytek Corporation, Santa Cruz, CA, USA) instrument.

Table 1. Water supply for tomato from planting to harvest

Years	Precipitation mm	Irrigation [a] mm		Precipitation + irrigation mm		
		DI	RI	I0	DI	RI
2018	304.6	80.2	160.3	304.6	384.8	464.9
2019	275.8	93.9	160.6	275.8	369.7	436.4

[a] DI=deficit irrigation RI=regular irrigation

All measurements were carried out between 10:00 and 14:00 hours from flowering (ST1) to fruit ripening (ST4) stages.

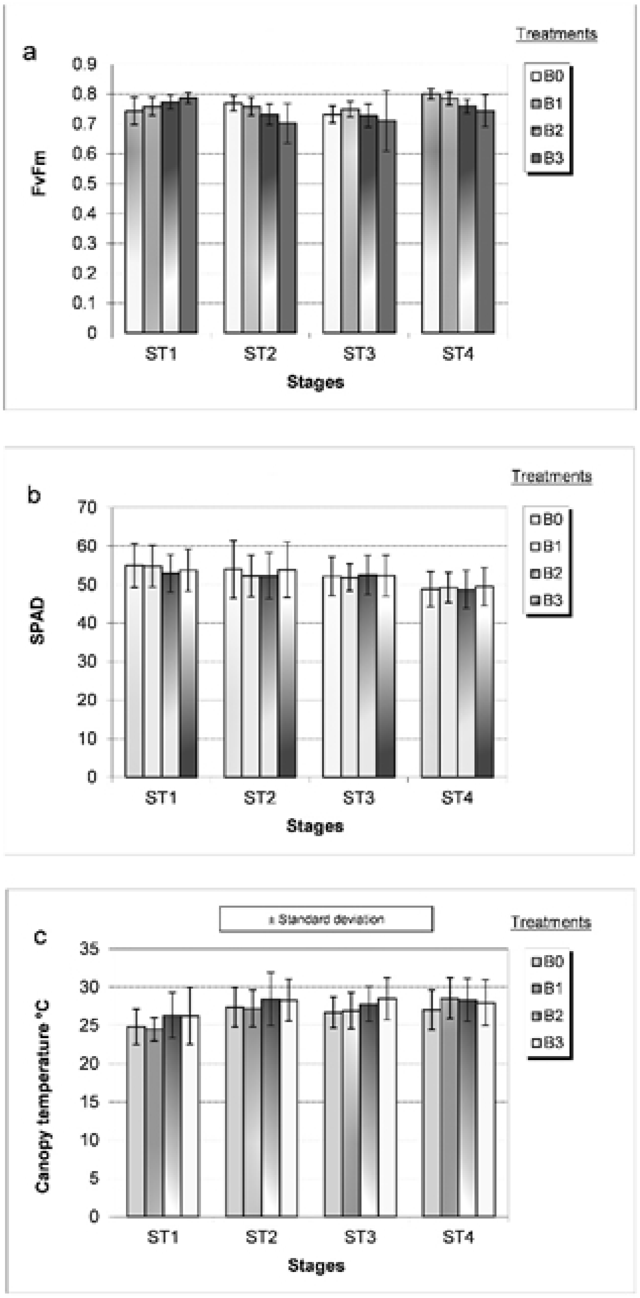
The yield of selected plants was harvested and the yield was classified and weighed. The marketable group contained the healthy red coloured tomato fruits. The healthy green coloured fruits were classified into the second group and the third group comprised of the unmarketable yield (cracked and diseased fruits).

The chemical analysis of tomato red fruits was performed in all years. The content of total soluble solids was determined by a Krüss DR201-95 handheld refractometer (A. Krüss Optronic GmbH, Hamburg, Germany) and it was given in °Brix. The determination of vitamin C content of the tomato yield was carried out using high performance liquid chromatography (HPLC) (Hitachi High-Technologies Europe GmbH, Budapest, Hungary) as described by Daood et al. (2014).

All data were evaluated by two-way analysis of variance (ANOVA) using SPSS 20 (IBM Hungary Ltd, Budapest, Hungary) Windows software in each year.

RESULTS

The photosynthetic activity of plants changes during the stages of development. It can be measured indirectly with the measurement of chlorophyll fluorescence (Fv/Fm) and relative chlorophyll content of leaves (SPAD value) while the water deficiency of plants is indicated by canopy temperature. In dry years, during flowering, PGPRs increased the maximum quantum efficiency of photosystem II presented by Fv/Fm value but subsequently it decreased differently (Figure 2a).



ST1=flowering, ST2=flowering and fruit setting, ST3= fruit development, ST4= fruit ripening (2018-2019) Data presented the average ± SD of years and repetitions

Figure 2. Effect of bacterial treatments on Fv/Fm (a) SPAD (b) and canopy temperature (c) during the growth stages of processing tomatoes (2018-2019)

During ST2 and ST4 periods, the plant treated by B3 treatment showed the highest decrease (8.8 and 7%, respectively) in Fv/Fm value in comparison with the untreated plants. During ST1 to ST3 periods, relative chlorophyll content of leaves (SPAD) exceeded the 50 values but PGPRs had no influence on the SPAD values except during the flowering stage (ST1) (Figure 2b). Canopy temperature of non-treated plants was near 25 °C during flowering (ST1) then it rose up to 27 °C. During this period, CT increased by 6% in the plants treated with B2 and B3 treatments compared to untreated plants but during the later stages (ST2-ST4) the difference between the treated and control plants decreased by 3-4% (Figure 2c).

Under different water supply conditions, from flowering to harvest, the effect of PGPRs on the photosynthesis, namely the maximum quantum efficiency of photosystem II (Fv/Fm) is not remarkable except under deficit irrigation where the Fv/Fm value of plants treated by B3 was lower by 6.6% than in untreated plants (Figure 3a). Independently the water supply conditions, PGPRs did not influence the SPAD values of the leaves (Figure 3b). Contrary to the expectation, the canopy temperature was higher by 5.6% and by 7.2% for plants treated by B2 and B3, respectively in comparison with the control plants under deficit irrigated and regularly irrigated conditions (Figure 3c).

The years and water supply conditions influenced significantly the SPAD values of the leaves and canopy temperature. SPAD value was higher and CT was lower in drier 2019 than in 2018 while chlorophyll fluorescence (Fv/Fm) did not differ (Table 2). Under non-irrigated conditions (I0), the SPAD value and the canopy temperature was significantly higher, while chlorophyll fluorescence (Fv/Fm) was lower than under well-water supply conditions (Table 2). Under moderate water deficiency (DI) a lower SPAD associated with low canopy temperatures and higher chlorophyll fluorescence can ensure better condition of crop.

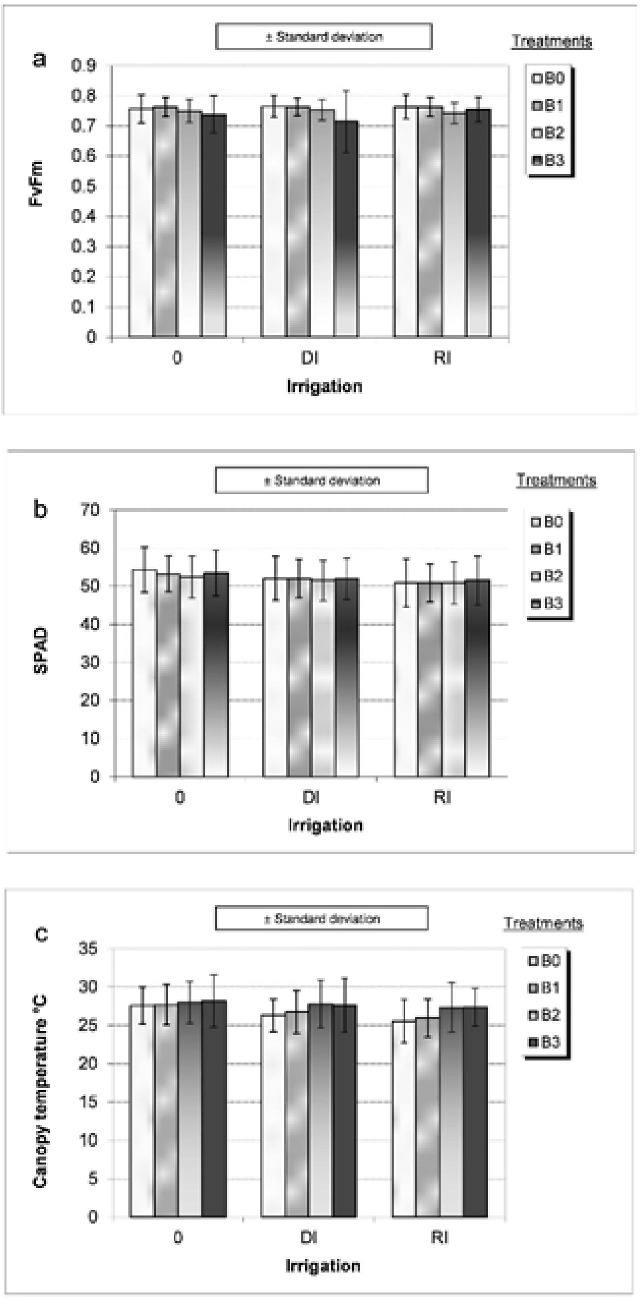


Figure 3. Effect of bacteria treatments on Fv/Fm (a) SPAD (b) and canopy temperature (c) from flowering (ST1) to fruit ripening (ST4) under non-irrigated (0) deficit irrigated (DI) and regularly irrigated (RI) conditions (2018-2019)

The hypothesis was that the rhizobacteria would maintain the photosynthetic activity during the reproductive stages under dry conditions, therefore the loss of yield would be minimal. Nevertheless the effect of PGPRs depended by the extent of drought; it significantly influenced the chlorophyll fluorescence (Fv/Fm) and canopy temperature in moderate dry 2018 but no effect was detected in drier 2019. In moderate dry 2018, the B3 treatment decreased significantly the Fv/Fm value and increased the canopy temperature in comparison with the untreated plants but a small increase in the SPAD value of leaves was detected in the drier 2019 (Table 2).

Although B2 and B3 bacterial treatments resulted in a lower Fv/Fm value and increased canopy temperature, it is likely that the reduction in the maximum quantum efficiency of photosystem II increased the energy required to produce fruits resulting in higher yields depending on the weather of the years, (Table 2 and 3). PGPRs depending on the years, predominantly influenced the amount of marketable and green yield. In 2018, under non-irrigated conditions, B2 and B3 treatments increased by 26.0 and 28% the marketable yield and increased by double the green fruit yield, while both green and diseased yield decreased significantly in the drier 2019. Under deficit irrigated conditions, all yields of plants treated by B2 and B3 were higher than that of non-treated ones in moderate dry 2018.

Table 2. Effect of water supply (WS) and plant growth promoting rhizobacteria (PGPRs) on physiological traits of tomato from flowering to harvest

		2018			2019		
Water supply	PGPRs	SPAD	Fv/Fm	CT °C	SPAD	Fv/Fm	CT °C
I0	B0	50.6 a	0.737 a	28.5 a	55.7 a	0.772 a	25.6 a
	B1	50.2 a	0.721 a	29.9 a	54.2 a	0.780 a	25.6 a
	B2	49.7 a	0.693 a	29.2 a	55.3 a	0.780 a	26.2 a
	B3	50.1 a	0.724 a	29.7 a	57.0 a	0.773 a	26.0 a
I0		*50.1 A*	*0.719 B*	*29.3 A*	*55.5 A*	*0.776 A*	*25.9 A*
DI	B0	48.4 a	0.749 a	27.7 b	51.6 a	0.770 a	24.2 a
	B1	48.1 a	0.750 a	28.1 ab	52.2 a	0.777 a	24.7 a
	B2	48.7 a	0.731 a	29.5 a	52.8 a	0.772 a	24.6 a
	B3	48.7 a	0.714 a	29.4 a	53.4 a	0.768 a	24.3 a
DI		*48.5 B*	*0.736 A*	*28.7 B*	*52.5 B*	*0.772 A*	*24.4 B*
RI	B0	47.1 a	0.757 a	27.8 b	50.7 a	0.772 a	23.0 a
	B1	47.8 a	0.755 a	27.7 b	51.5 a	0.775 a	23.6 a
	B2	47.5 a	0.724 a	29.1 ab	52.4 a	0.759 a	24.1 a
	B3	48.0 a	0.744 a	28.5 b	51.8 a	0.773 a	24.5 a
RI		*47.6 C*	*0.745 A*	*28.3 C*	*51.6 B*	*0.770 A*	*23.8 C*
GPRs	B0	48.7 a	0.748 a	28.0 c	52.7 b	0.771 a	24.3 b
	B1	48.7 a	0.742 a	28.6 b	52.6 b	0.774 a	24.6 ab
	B2	48.6 a	0.716 b	29.2 a	53.5 ab	0.770 a	25.0 a
	B3	48.9 a	0.727 b	29.2 a	54.1 a	0.771 a	24.9 ab
Significance	WS	***	***	***	***	ns	***
	PGPRs	ns	***	***	*	ns	ns
	WS x PGPRs	ns	ns	***	ns	ns	ns

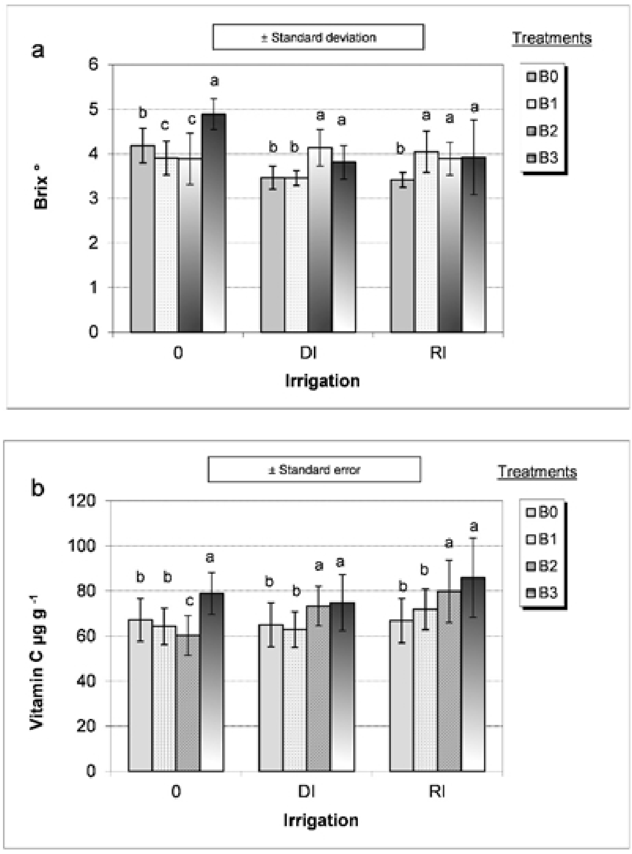
*P<0.05 ***P<0.001 CT= canopy temperature, I0= non-irrigated, DI= deficit irrigation, RI= regularly irrigated, B0= without bacterium treatment, Capital letter= significant difference of water supplies, smaller letter=significant difference of bacteria treatments

Table 3. Effect of water supply (WS) and plant growth promoting rhizobacteria (PGPRs) treatments on the yield and quality of processing tomato hybrids in dry years

		2018				2019				Average of years			
Water supply	PGPR	Total yield t/ha	Market-able yield t/ha	Green yield t/ha	Diseased yield t/ha	Total yield t/ha	Market-able yield t/ha	Green yield t/ha	Diseased yield t/ha	Total yield t/ha	Market-able yield t/ha	Green yield t/ha	Diseased yield t/ha
I0	B0	50.71 b	45.45 b	4.40 c	0.86	116.49 a	102.60 a	6.57 a	7.32 a	83.60	74.10 a	5.45 b	4.06
	B1	50.95 b	46.71 b	2.89 d	1.36	104.14 a	90.04 a	7.85 a	5.37 b	77.48	68.48 a	5.44 b	3.30
	B2	68.62 a	57.46 a	11.05 a	1.70	95.66 b	87.88 a	4.84 b	2.94 c	82.19	72.73 a	8.02 a	2.23
	B3	68.83 a	58.27 a	8.32 b	2.25	79.34 c	68.22 b	5.54 b	5.58 b	74.04	63.38 a	7.03 a	4.00
I0		59.78 B	51.97 B	6.66 B	1.54	98.91 A	87.18 A	6.2 A	5.30 C	79.33 B	69.67 B	6.49 B	3.40 B
DI	B0	64.97 b	59.26 c	4.65 d	1.06	111.47 a	95.88 a	2.74 c	12.86 a	88.23	77.63 a	3.70 b	7.03
	B1	77.41 b	67.49 b	8.42 c	1.50	123.74 a	108.37 a	7.03 a	8.34 b	100.58	88.00 a	7.71 a	4.87
	B2	83.54 a	65.30 b	15.36 a	2.89	109.02 a	98.15 a	5.51 a	5.36 c	96.27	81.77 a	10.43 a	4.19
	B3	93.28 a	82.56 a	10.28 b	2.36	80.32 b	68.75 b	4.45 b	7.12 b	86.85	75.78 a	7.39 a	4.68
DI		79.78 A	68.65 A	9.68 A	1.95	106.14A	92.79 A	4.93 A	8.42 B	92.98 A	80.79 A	7.31 A	5.19 A
RI	B0	72.43 b	59.75 b	9.92 b	2.71	74.82 b	59.51 c	2.73 d	12.50 a	73.72	59.50 b	6.34 b	7.48
	B1	61.62 c	51.45 b	7.87 c	2.30	110.74 a	92.58 a	5.17 b	12.99 a	86.19	71.85 a	6.56 b	7.78
	B2	76.37 b	62.99 a	10.41 b	14.44	110.65 a	95.02 a	6.93 a	8.71 b	93.44	78.99 a	8.70 a	11.59
	B3	85.01 a	69.72 a	13.16 a	2.14	79.83 b	69.48 b	3.69 c	6.66 c	82.38	69.73 a	8.45 a	4.44
RI		73.86 A	60.98 AB	10.34 A	5.40	94.01 A	79.15 B	4.63 A	10.22 A	83.93 A	70.02 B	7.51 A	7.82 A
GPRs	B0	62.70 c	54.82 c	6.32 c	1.54	100.92 a	86.00 a	4.02 b	10.89 a	81.85 a	70.41 a	5.16 b	6.19
	B1	63.33bc	55.22 bc	6.39 bc	1.72	112.87 a	97.00 a	6.68 a	8.91 a	88.08 a	76.11 a	6.57 ab	5.32
	B2	76.18ab	61.91 ab	12.27 a	6.34	105.11 a	93.68 a	5.76 a	5.67 b	90.63 a	77.83 a	9.05 a	6,00
	B3	82.35 a	70.18 a	10.58ab	2.25	79.68 b	68.82 b	4.56 b	6.45 b	81.09 a	69.63 a	7.63 a	4.37
Significance	WS	**	**	*	ns	ns	†	ns	***	ns	†	†	*
	PGPR	*	*	*	ns	**	***	*	***	ns	ns	*	ns
	WS x PGPR	ns	ns	ns	ns	†	*	ns	ns	ns	ns	†	ns

† P<0.1 *P<0.05, **P<0.01, I0= non-irrigation, DI= deficit irrigation, RI= regularly irrigation, B0= without bacterium treatment,
Capital letter= significant difference of water supplies, smaller letter=significant difference of bacteria treatments

In a drier year (2019) under the same growing conditions, B2 and B3 treatments affected differently the marketable yield but increased the green yield and decreased the diseased yield (Table 3). The accumulation of the soluble solid content expressed by Brix and vitamin C concentration of fruits seemed to be influenced by the weather of the years. In a drier year (2019), B2 and B3 treatments increased significantly the soluble solid content (Brix°) and vitamin C concentration of the fruits but the Brix decreased and vitamin C did not change considerably in moderate dry 2018 (data not shown). Nevertheless, under dry conditions without irrigation, B3 treatment increased significantly the Brix and vitamin C while under deficit irrigated condition both B2 and B3 treatments improved the yield quality compared to the untreated control plants (Figure 4 a,b).



Different letters indicate the significant difference between the bacterial treatments at P<0.05 level 0=non-irrigation DI=deficit irrigation RI=regular irrigation

Figure 4. Effect of bacterial treatments on soluble solid content (Brix) (a) and vitamin C (b) concentration of processing tomato fruits under different water supply conditions

On the basis of the average of two dry years, B2 and B3 treatments while maintaining the marketable yield significantly increased the green fruit yield in comparison with the control (B0) (Table 3) however the effect of B3 treatment was more intensive on the accumulation of Brix and vitamin C in the fruits than B2 treatment. Plants treated with B3 produced fruits with 13.8% higher Brix and 19.2% vitamin C than untreated control plants while those treated with B2 produced a 7 and 8% increase.

It can be concluded that under severe dry conditions (dry years + non-irrigation), B3 treatment increased by 28.9% the green fruits yield, by 16% the Brix and by 13.6% the vitamin C concentration of fruits in comparison with the untreated plants. Under moderate water scarcity (dry years + deficit irrigation) the plants treated by B3 produced the same marketable yield, 33% lower diseased yield but the green healthy fruits yield was double than in the untreated plants. Under this growing condition B3 treatment improved the fruit quality resulting in 9.5% higher Brix and 12.7% higher vitamin C concentrations of fruits than in the untreated plants.

DISCUSSION

The growth and productivity of plants depends on their photosynthetic activity which can be determined by the measurement of chlorophyll fluorescence and light absorption of photosynthetic pigments such as chlorophyll and accessory pigments (Mishra et al., 2012). Under environmental stress conditions, the chlorophyll fluorescence (Fv/Fm) can decrease due to the decrease in photochemistry in the leaves (Maxwell and Johnson, 2000) and the degree of the decrease depends on the intensity of stress and genotypes (Estrada et al., 2015; Nemeskéri et al., 2018a). Under drought stress conditions, stomatal closure decreases the transpiration and impedes the uptake and diffusion of air CO_2 into the cell (Singh and Reddy, 2011) therefore the rising canopy temperature and reducing photosynthesis can lead to a low yield.

Prolonged drought stimulates the bacteria living in symbiosis with plants in the rhizosphere to secrete various phytohormons, osmolytes or antioxidants to increase the stress tolerance (Yang et al., 2009; Goswami and Deka, 2020). It was found that PGPR efficiently stimulates the production of abscisic acid (ABA) in the root under drought stress conditions (Forni et al., 2017) that is transported to the leaves where the rising ABA induce stomatal closure (Davies and Zhang, 1991; Sauter et al., 2002), thereby leaf transpiration decreases (Bresson et al., 2013) resulting in an increase in the canopy temperature. The results showed that in dry years, during the fruit setting and fruit development of tomato the chlorophyll fluorescence decreased and the canopy temperature increased which reduced the maximum quantum efficiency of photosystem II in particular under water deficiency however rhizobacteria treatments mitigated these negative effects. Tahir et al. (2019) found that PGPR strains reduced not only the water loss in the leaves but increased the relative chlorophyll content of leaves under well-watered and drought conditions compared to non-inoculated plants. Nevertheless the increase in the relative chlorophyll contents of leaves expressed by SPAD value indicates the damage of photosynthetic pigments occurring under drought and heat stress while undisturbed photosynthesis is associated with low SPAD values under well-irrigated growing conditions. Contrary to the result of Tahir et al. (2019), our results showed that B2 and B3 rhizobacteria treatments did not change remarkably the SPAD value under all water supply conditions but it presumably indirectly influenced the photosynthesis of plants. These rhizobactria treatments influenced positively the photosynthesis during flowering of tomato then the decrease in the maximum quantum efficiency of photosystem II expressed by Fv/Fm and rising canopy temperature accelerated the translocation of assimilates from leaves to the fruits that affected the amount and distribution of yield under different water supply conditions. The finding shows that B2 and B3 treatments providing similar marketable yield as in untreated plants significantly increased the green fruit yield and decreased the diseased yield particularly under water deficiency conditions (Table 3). Kurokua et al. (2017) also emphasized that PGPR had a potential to improve the yield but the results concerning the yield quality differed. They did not show the positive effect of PGPR on the Brix of strawberry fruits. According to Le et al. (2018) PGPR had high positive affect on the vitamin C content of tomato under irrigated conditions however it decreased Brix to a lesser extent than without PGPR. We also found a significantly higher Brix and vitamin C concentration in tomato treated by B2 and B3 rhizobacteria under irrigated conditions (DI, RI) than in untreated plants. Nevertheless, B3 treatment had the highest effect on the quality of tomato fruit resulting in 13.8% higher Brix and 19.2% higher vitamin C compared to the control (B0).

CONCLUSIONS

PGPRs resulting in a decrease in the chlorophyll fluorescence and rise of canopy temperature influenced the photosynthesis of the plants and increased significantly the amount of green fruits yield and decreased the diseased yield. In dry years PGPRs contributed to accelerate the ripening processes and accumulation of the soluble solid content (Brix) and vitamin C of red marketable fruits. B2 and B3 rhizobacteria treatments had a significant impact on the yield and quality of tomato depending on the weather of dry years. Using deficit irrigation, B3 treatment while maintaining the marketable yield significantly decreased the amount of diseased yield and increased the Brix and vitamin C concentration of red fruits, however produced a higher ratio of green healthy yield than in the untreated control.

ACKNOWLEDGEMENTS

This research was funded by the Ministry of Human Capacities grant Higher Education Institutional Excellence Program in the framework of the water related research of Szent István University, GINOP_2.2.1_15_2016_00003 and grant number TUDFO/47138/2019-ITM and also by EFOP-3.6.3-VEKOP-16-2017-00008 project which is co-financed by the European Union and the European Social Fund.

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