Gesunde Pflanzen (2021) 73:219–228
https://doi.org/10.1007/s10343-021-00543-9

ORIGINAL ARTICLE / ORIGINALBEITRAG

Evaluation of the Effects of Plant Growth Promoting Rhizobacteria (PGPR) on Yield and Quality Parameters of Tomato Plants in Organic Agriculture by Principal Component Analysis (PCA)

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Received: 27 August 2020 / Accepted: 5 January 2021 / Published online: 20 January 2021

Abstract

Our research was carried out to determine the effects of plant growth promoting rhizobacteria (PGPR) on the yield and quality parameters of tomato plants in organic farming conditions. In our study, *Bacillus megaterium* M-3, *Paenibacillus polymxa, Burkholderia cepacia, Azospirillum* sp-245 bacterial strains were applied by three different applications methods such as to the soil, root region and leaves. The research was carried out as field experiment in 37 plots and 10 plants per plot. As a result of the study, it was determined that different PGPR applications significantly affect the yield and quality parameters of tomato plant in organic agriculture. When the results were evaluated, the highest yield was obtained as 1533 kg da^{-1} with foliar application of *B. megaterium* M-3 bacteria. *B. megaterium* M-3 bacteria application to leaves increased that yield by about 20% compared to the control. It was determined that the bacteria applications did not have any significant effect on fruit size, fruit width and fruit weight. However, PGPR applications increased the amount of plant nutrients in the leaf, and pH, soluble solid contents (SSC), the rate of titratable acidity and the vitamin C values in the fruit. In conclusion, some PGPR bacteria as *B. megaterium* M-3, *P. polymxa, B. cepacia, A.* sp-245 increased the yield of the product and have a positive effect on quality parameters. As a result of the PCA (principal component analysis), PC1 alone explained 35% of the total variance and PC2 explained 24%. PC1 was found to be associated with soluble solid matter, vitamin C, titratable acidity, pH and EC, PC2 was found to be fruit yield and marketable yield, and PC3 was found to be scrap yield and marketable yield ratio.

Keywords Tomato · Organic agriculture · PGPR · Principal component analysis

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Bewertung der Auswirkungen von pflanzenwachstumsfördernden Rhizobakterien (PGPR) auf Ertrags- und Qualitätsparameter von Tomatenpflanzen im ökologischen Landbau mittels Hauptkomponentenanalyse

Zusammenfassung
Unsere Forschung wurde durchgeführt, um die Auswirkungen von pflanzenwachstumsfördernden Bakterien (*plants growth promoting rhizobacteria*, PGPR) auf die Ertrags- und Qualitätsparameter von Tomatenpflanzen im ökologischen Landbau zu untersuchen. In unserer Studie wurden verschiedene Bakterienstämme (*Bacillus megaterium* M-3, *Paenibacillus polymxa, Burkholderia cepacia* und *Azospirillum* sp-245) in drei verschiedenen Applikationsmethoden getestet (Boden, Wurzelregion und Blätter). Die Forschung wurde als Feldversuch mit 37 Parzellen und 10 Pflanzen pro Parzelle durchgeführt. Als Ergebnis der Studie wurde festgestellt, dass verschiedene PGPR-Anwendungen den Ertrag und die Qualitätsparameter von Tomatenpflanzen im ökologischen Landbau signifikant beeinflussen. Bei Auswertung der Ergebnisse wurde der höchste Tomatenertrag mit 1533 kg da^{-1} bei Blattapplikation von *B. megaterium* M-3-Bakterien erzielt, was einer Ertragszunahme von 20 % im Vergleich zur Kontrolle entsprach. Die Bakterienanwendungen hatten keinen signifikanten Effekt auf Fruchtgröße, Fruchtbreite und Fruchtgewicht. PGPR-Anwendungen erhöhten jedoch die Konzentration an Pflanzennährstoffen im Blatt, den pH-Wert, den Gehalt an löslichen Feststoffen, die Konzentration titrierbarer Säure und den Vitamin-C-Gehalt in den Früchten. Zusammenfassend lässt sich sagen, dass einige PGPR-Bakterien, wie *B. megaterium* M-3, *P. polymxa, B. cepacian* und *A.* sp-245, den Tomatenertrag erhöhten und sich positiv auf die Qualitätsparameter auswirkten. Als Ergebnis der Hauptkomponentenanalyse (*principal component analysis*, PCA) erklärte PC1 allein 35 % der Gesamtvarianz und PC2 24 %. Es wurde festgestellt, dass PC1 mit löslichen Feststoffen, Vitamin C, titrierbarer Säure, pH-Wert und elektrischer Leitfähigkeit assoziiert ist, PC2 mit dem Fruchtertrag und dem marktfähigen Ertrag und PC3 mit dem Ausschuss und der marktfähigen Renditenquote.

Schlüsselwörter Tomate · Ökologischer Landbau · PGPR · Hauptkomponentenanalyse

Introduction

Microbial-based bio-fertilizers are among the basic nutrients that increase crop productivity and have an impact on sustainable agriculture (Çakmakçı et al. 2006). It is a component that combines a variety of microbial-based bioproducts and its bioactivity is necessary to stimulate and improve biological processes of the plant-soil continuum (Singh et al. 2016). Different types of soil microorganisms (especially bacteria and fungi) that exhibit plant growth promoting rhizobacteria (PGPR) properties can be used to produce efficient bio-fertilizers (Vessey 2003; Lucy et al. 2004; Smith and Read 2008; Khalid et al. 2009). Microbial fertilizer, which enables quality products and products to mature in a shorter period, converts them into quality fertilizer by eliminating pests in organic fertilizer. PGPR are generally included in genera such as *Bacillus, Lactobacillus, Paenibacillus, Arthobacter, Pseudomonas, Burkholderia, Enterobacter, Pantoae, Klebsiella, Xanthomonas, Serratia, Rhizobium, Bradyrhizobium, Azospirillium, Azotobacter* (Cakmakci et al. 2005a).

Many of the PGPRs can also function as very good biological control agents. These bacteria can provide significant success against plant diseases, especially soil-borne pathogens. There are many examples of PGPRs that can function as biocontrol agents. PGPRs are considered as indispensable elements at the center of agricultural techniques such as "Organic Agriculture, Integrated Pest Management", which are very popular today when considered as biopesticides in biological warfare and in terms of their productivity increasing properties (Tilak et al. 2005).

In studies conducted to date, it has been determined that microorganisms that increase the solubility of plant nutrients in soil have important contributions in increasing the efficiency of plant nutrition. When *P. polymxa* was applied, fertilizer use efficiency and soil available phosphorus fractions were increased as well as plant dry weight. To get efficient profit from organic fertilization, the use of PGPRs such as *P. polymxa* should be considered (Gunes 2013). Use of PGPR increased that taken of the nutrient availability by plant and so it has been used increasingly in agricultural systems as microbial fertilizer (Freitas et al. 2007; Yildirim et al. 2011). PGPRs can increase plant nutrition availability in various ways, including biological N_2 fixation, phosphorus solubilization, and/or production of phytohormones (Cakmakci et al. 2005b, Güneş et al. 2009; Mia et al. 2012). PGPR also promote plant nutrient uptake by different mechanisms such as ACC deaminase enzyme production, auxin synthesis, solubilizing plant nutrients through organic acid production, synthesizing siderophores that can dissolve and chelate iron from soil (Caballero-Mellado et al. 2007; Güneş et al. 2015). In addition, PGPRs can significantly increase plant nutrient uptake and plant growth due to their biochemical properties such as amino acid, organic acid and hormone. This effect can be influenced by differences in bacterial strains and bacterial species such as *Bacillus megaterium* strain TV-91C, *Pantoea agglomerans* strain RK-92, and *Bacillus subtilis* strain TV-17C (Turan et al. 2014).

The interest in organic products, organic agriculture and crop production in the world and in Turkey has increased. Producers and companies providing the necessary inputs to farmers have become more sensitive to this subject and have started to work to increase and improve the inputs that can be used in organic agriculture. As a result of these studies, plant activators and microbial fertilizers, which can be used in organic agriculture, were developed, and put into service for producers to protect the nutrition and health of plants. When the studies are examined, it is seen that the use of different PGPRs, which have specific features such as *Bacillus* OSU-142 and *Pseudomonas* BA-8, are of great importance in organic agriculture applications in terms of sustainability of organic agriculture, ensuring the continuity of resources and reducing the cost of agricultural input (Esitken et al. 2010).

This study was conducted to determine the effect of some PGPR on yield and quality parameters of tomato plants grown under organic conditions.

Materials and Methods

Location and Characteristics of the Research Site

The research is located in Erciyes University at 38°42′27″ north latitudes and 35°32′32″ east longitudes in Kayseri, Turkey. The average altitude is 1114 m.

Properties of Used Tomato Variety

Pollen development, one of the processes that determine the characteristics of the fruit, is one of the most important processes in the life cycle of plants. Only normally occurring pollens contribute to proper fertilization and the formation of fully-fledged seeds and fruits (Chaban et al. 2020). The number of studies on the properties of tomatoes in the literature is not enough (Ganzalez-Cebrino et al. 2011). Considering the planting areas and the regions where the tomato cultivar is grown, tomato plants are known as to be tolerant to salinity. It has been observed that in loam soils with high organic matter content and water holding capacity, it develops better in physiological properties. So, Karabacak tomato variety was used in this study. Black pepper tomatoes constitute 6–8 branches on average in a plant. Plant height is approximately 40–60 cm. However, depending on the plant growth and fruit weight, it can grow horizontally up to 130 cm. An average of 4 to 6 fruit clusters are formed in each arm, with 3 to 5 fruit in each bunch, each fruit weighing an average of 180 to 300 g. In this sense, it is assumed that the fruit yield per plant can reach high levels with a good cultivation technique, maintenance and feeding.

Use of Bacteria Species

In this study, some PGPR species such as *Bacillus megaterium* M-3, *Paenibacillus polymxa, Burkholderia cepacia, Azospirillum* sp-245 were used. These bacteria briefly have the following characteristics (Kotan et al. 1999; Esitken et al. 2002, 2003a, b; Çakmakçı et al. 2010; Erman et al. 2010; Kotan et al. 2010; Güneş et al. 2013).

Bacillus megaterium M-3: phosphate solubilizing properties; oxidase, catalase, nitrate reduction, acetylene reduction properties are known to be positive and can develop in nitrogen-soil medium.

Paenibacillus polymxa: nitrogen fixation, phosphate solubilization, antibiotic production, hormone secretion, hydrolytic enzyme production.

Burkholderia cepacian: It is effective as plant growth regulating bacterium and for bioremediation. Since it has antifungal and anti-nematode properties, it is used as biological control agent. It prevents the formation of absisic acid with the help of the secreted ACC deaminase enzyme. It increases the availability of nutrients by releasing enzymes and hormones.

Azospirillum sp-245: It is commonly found in the rhizosphere and has a symbiotic relationship with the plant. *Azospirillum* sp-245 is more active in the wheat root zone in response to the application of *Azospirillum* sp-245. The ability to fix free nitrogen in the air and some of the organic acids such as citric and oxalic acid, its products have the effect of regulating plant growth with the help of hormones such as abscisic acid and indole acetic acid.

Method

Our research was carried out under organic farming conditions on a field of Erciyes University in Kayseri Province. The tomato cultivar Karabacak was planted at a distance of 1 m × 1 m between rows and rows by planting. In total 37 plots were placed according to the block design pattern, and treated without bacterial inoculum or 4 different PGPR preparations (*Bacillus megaterium* M-3, *Paenibacillus. polymxa, Burkholderia cepacia, Azospirillum* sp-245), applied by 3 different methods and with 3 replications (leaves, plants and soil). The experimental area was divided into plots to the trial pattern, after 10 tomato plants were planted in each plot, a distance of 1 m was left between the plots. A drip irrigation system was used in the experiment to supply the plants with water and mineral nutrients.

Bacterial Strain, Culture Conditions, Media and Treatment

PGPR strains were obtained from Yeditepe University, Dept. of Genetics and Bioengineering (Dr. Fikrettin Sahin). Bacteria were grown on nutrient agar. A single colony was transferred to flasks containing nutrient broth, and grown aerobically for 48 h at 27^0C (Merck KGaA, Germany). Then bacterial suspensions were diluted in sterile distilled water according to Straka and Stokes (1957) (final concentration of 10^9 CFU ml^{-1}). This bacterial solution (50cc) was mixed with 20 liters of water. Then bacteria were applied by spraying the plant roots, the surface around the seedling to the soil and spraying all the plant leaves soaked. 6 harvests (20/07-27/07-01/08-06/08-20/08-26/08/2018) were performed in the experiment. Marketable and discarded products were weighed and recorded separately to calculate average yields per plant.

General Observations, Efficiency Measurements

Yield (kg da^{-1}): Total product amount obtained from all application plots was divided by total number of plants to calculate average yields per plant. The yield value per plant was calculated by multiplying the yield value per plant by the total number of plants per 1 da area.

Marketable fruits: Except of low marketability fruits such as cat face in fruit, flower nose rot, sunburn and green fruits on the plant were determined in kg and the ratio was calculated according to cumulative yield.

Fruit diameter, height and average weight: Fruit diameter, height and average fruit weight were determined in 10 fruit samples taken randomly from each plot.

Discard yield: Low marketability fruits such as cat face in fruit, flower nose rot, sunburn and green fruits on the plant were determined in kg.

Fruit Analysis

5 fruit samples were taken by chance from harvested samples. pH, EC, vitamin C, soluble solid matter (Cemeroğlu 1992) and titratable acidity (Anonymous 2002) of the fruits were analyzed in Erciyes University Plant Nutrition Laboratory.

Soil Analysis

Before the trial, soil samples were taken over 0–30 cm and some soil properties were determined (Table 1). Soil texture (Gee and Hortage 1986), soil pH (McLean 1982), total *N* (Bremner and Mulvaney 1982), plant-available *P* (Olsen et al. 1954), cation exchange capacity (CEC) (Sumner and Miller 1996), soil organic matter (Nelson and Sommers 1982), exchangeable cations such as Ca, Mg, Na and K (Thomas 1982), and microelements (Lindsay and Norwell 1978) were determined from these soil samples. Some of the chemical analysis results of the soil of the research area are given in Table 1.

Data Analysis

As a result of a two-factor trial design according to bacteria and application method, all data were subjected to the analysis of variance (ANOVA) and means were separated by Duncan's multiple range tests.

Results

Effects of PGPR Applications on Yield and Quality Parameters

When the yield values of tomato plants were examined, it was found that the PGPRs and different application methods had a significant effect on fruit yield, marketable yield and

Table 1 Initial soil analysis values

Soil properties		References	Analysis result (0–30 cm)	Evaluation
Texture	–	*Gee and Hortage (1986)*	–	Loam
pH	–	*McLean (1982)*	8.00	*Moderately alkaline*
$CaCO_3$	%	*Jackson (1962)*	2.90	*Limely*
Organic matter	%	*Nelson and Sommers (1982)*	2.16	*Moderate*
P_2O_5	Kg da^{-1}	*Olsen et al. (1954)*	41.63	*High*
K	Cmol kg^{-1}	*Thomas (1982)*	2.14	*High*
Ca	Cmol kg^{-1}		12.34	*Moderate*
Mg	Cmol kg^{-1}		1.25	*Moderate*
Fe	Mg kg^{-1}	*Lindsay and Norwell (1978)*	4.53	*High*
Zn	Mg kg^{-1}		5.64	*High*
Mn	Mg kg^{-1}		8.12	*Low*
Cu	Mg kg^{-1}		3.55	*High*

Table 2 Effect of PGPR applications on tomato plant yield parameters

Application	Bacterium	Fruit yield (kg da^{-1})	Marketable yield (kg da^{-1})	Scrap yield (kg da^{-1})	Marketable yield ratio (%)
Root zone	Control	1202b	1.067b	135c	88.77
	B. megaterium M-3	1400a	1269a	131c	90.63
	P. polymxa	1008c	832c	176b	82.57
	B. cepacia	1268b	1058b	210a	83.42
	A. SP-245	1456a	1211a	59d	83.17
Average		*1283A*	*1093A*	*144BC*	*84.95*
Soil	Control	1202b	1067b	135c	88.77
	B. megaterium M-3	1169b	981b	188b	83.93
	P. polymxa	1321a	1204a	118 cd	91.09
	B. cepacia	871d	769c	102d	88.26
	A. SP-245	1067c	1008b	245a	94.50
Average		*1107C*	*991B*	*163A*	*89.45*
Leaf	Control	1202	1067	135	88.77
	B. megaterium M-3	1533	1328	205	86.61
	P. polymxa	1085	887	198	81.79
	B. cepacia	1493	1333	160	89.28
	A. SP-245	978	928	50	94.85
Average		*1272A*	*1119A*	*153AB*	*88.13*

Lower and upper case letters indicate the level of importance between the columns ($0.01 < p < 0.05$)

Table 3 Effect of PGPR applications on some quality parameters of fruit

Application	Bacterium	Soluble solid matter	Vitamin C (mg 100 g^{-1})	Titratable acidity	pH	EC
Root zone	Control	6.57b	24.63b	0.52b	3.75b	32.23a
	B. megaterium M-3	7.67a	30.75a	0.66a	3.90a	33.20a
	P. polymxa	8.14a	30.51a	0.64a	3.99a	27.52b
	B. cepacia	7.79a	34.10a	0.65a	4.07a	25.05b
	A. SP-245	8.50a	31.91a	0.73a	3.88ab	26.43b
Average		*8.02*	*31.82*	*0.67*	*3.96*	*28.05AB*
Soil	Control	6.57b	24.63b	0.52c	3.75b	32.23a
	B. megaterium M-3	8.41a	29.81a	0.64b	3.54c	23.44b
	P. polymxa	8.01a	32.57a	0.67b	3.80b	25.26b
	B. cepacia	8.59a	31.48a	0.59bc	4.47a	24.54b
	A. SP-245	8.45a	31.70a	0.85a	3.94ab	26.10b
Average		*8.36*	*31.39*	*0.69*	*3.94*	*24.84B*
Leaf	Control	6.57b	24.63c	0.52b	3.75a	32.23a
	B. megaterium M-3	7.84a	32.52ab	0.55b	3.77a	19.97b
	P. polymxa	8.71a	31.93ab	0.78a	4.02a	23.66ab
	B. cepacia	8.39a	35.45a	0.65a	3.90a	31.85a
	A. SP-245	7.96a	31.53b	0.61a	3.79a	22.82ab
Average		*8.22*	*32.86*	*0.65*	*3.87*	*24.57B*

Lower and upper case letters indicate the level of importance between the columns ($0.01 < p < 0.05$)

non-marketable yield in tomato plants ($p < 0.01$) comparing to untreated control groups. When the effect of PGPRs on the yield of tomato plants was examined depending on different application methods, the highest yield was obtained from PGPR application compared to the control group (Table 2). Depending on PGPR applications from root, soil and leaf, the highest fruit yield was obtained from root area application (1.283 kg da^{-1}) and the lowest fruit yield was obtained from soil application (1.107 kg da^{-1}) when the general averages were considered (Table 2). The highest in-

Table 4 Eigenvalue and percentage of variance values and factor loadings generated by PCA

	PC1	PC2	PC3
Eigenvalue	3.180	2.202	1.168
Variability (%)	35.329	24.463	12.980
Cumulative %	35.329	59.792	72.772
Fruit yield	–0.294	*0.927*	–0.041
Marketable yield	–0.371	*0.905*	0.155
Scrap yield	0.296	0.214	*–0.656*
Marketable yield ratio	–0.271	–0.054	*0.749*
Soluble solid matter	*0.929*	0.180	0.140
Vitamin C	*0.773*	0.495	0.243
Titratable acidity	*0.736*	0.235	0.096
pH	*0.566*	–0.375	0.228
EC	*–0.686*	–0.031	0.109

crease rate was obtained from *Azospirillum* sp-245 bacteria with 17% increase in root application, *Paenibacillus polmxa* bacteria with 10% increase in soil application and *Bacillus megaterium* M3 bacteria application with 28% increase in leaf application compared to the control group.

The products affected by cat face, flower rot, sunburn, (etc.) were discarded and the marketable fruits other than the green fruits remaining on the plant were determined in kg and their ratio to total yield was calculated. The highest marketable yield and marketable yield ratio average values were obtained from leaf (1.119 kg da^{-1}) and soil applications (89.45%), respectively. Discard yield value was obtained from the lowest root zone application (144 kg da^{-1}) and the highest soil application (163 kg da^{-1}) according to the averages (Table 2).

It was observed that while the marketable yield average of PGPR bacteria was 1067 kg da^{-1} in the control parcel, it was positively affected in response to root application of *B. megaterium* M-3 and *A.* sp-245 bacteria from root application. It was found that other bacteria did not affect the marketable yield in response to root zone application (Table 2).

Effects of PGPR Applications on Some Quality Parameters in Fruit

When the results of the variation analysis of PGPR bacteria used in our research, application methods and the combined effects of these sources were evaluated on some quality parameters in tomato fruit, statistically significant differences were found ($p < 0.05$).

According to the application methods of PGPR bacteria based on average values of some quality parameters in fruit; the highest soluble solid matter and titratable acidity values were obtained from soil application and the highest vitamin C values were obtained from foliar application. The highest pH and EC values in the fruit was found in response to root zone application (Table 3).

When the effects of PGPR bacteria on some quality parameters in tomato fruit were examined, the highest soluble solid matter and titratable acidity values were obtained from leaf application of *P. polymxa* bacteria with 8.71 and 0.78, respectively. The highest amount of vitamin C were achieved in response to *B. cepacia* bacteria (35.45 mg 100 gr^{-1}). However, *B. cepacia* bacteria significantly increased the pH value (4.47) of tomato fruit from when applied as soil treatment. The highest EC value was obtained from *B. megaterium* M-3 root zone application while the lowest EC value was obtained from leaf application of the same bacteria. In all parcels except *B. megaterium* M-3 bacterial root application, EC value was lower than control parcel (Table 3).

While the highest water-soluble dry matter and pH values were obtained from *B. cepacia* bacteria in soil application, *A. sp 245* bacterium was the application that increased the maximum amount of titratable acidity and EC. The bacterium that affects pH value most in tomato fruit was determined as *B. cepacia*. In leaf application, *P. polymxa* bacteria were found to be the most effective application on the quality parameters in the fruit of the study. The highest TSS, titratable acidity and pH values were obtained from this bacterial application.

Evaluation of Results by PCA

The changes in yield and yield parameters of tomato plant were investigated by PCA (principal component analysis). When Table 4 is examined PC1, 2 and 3 explained 72.77% of the total variance. PC1 alone explained 35.33% of the total variance and PC2 explained 24.46%. When Eigenvalue values (the length of a principal component which measures the variance of a principal component) were examined in Table 4, it was 3.180 in PC1, 2.202 in PC2 and 1.168 in PC3 (Fig. 1).

PC1 was found to be associated with soluble solid matter, vitamin C, titratable acidity, pH and EC, PC2 was found to be fruit yield and marketable yield, and PC3 was found to be scrap yield and marketable yield ratio.

Discussion

The application of plant growth regulating bacteria is of great importance for plant growth especially in disturbed soils, such as unbalanced microflora in response to monocultures and narrow crop rotations. This effect has been tried to be revealed in different studies on this subject. As reported by Chabot et al. (1993), *B. cepacia* strains increased the yield of tomatoes, onions, bananas and some

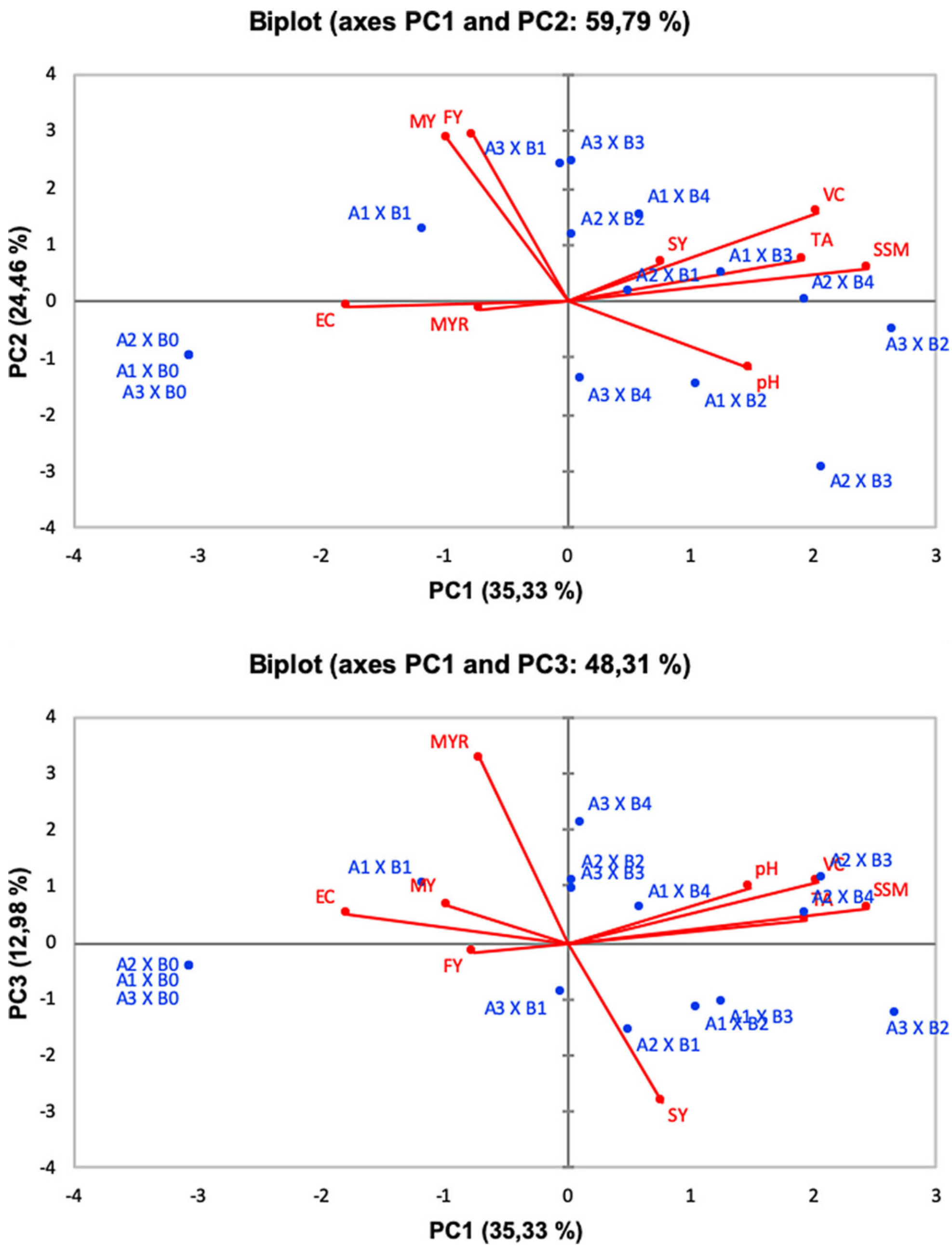

Fig. 1 PCA graphics of applications (A) × bacteria (B) interaction for yield and yield parameters (*FY* fruit yield, *MY* marketable yield, *SY* scrap yield, *MYR* marketable yield ratio, *SSM* soluble solid matter, *VC* Vitamin C, *TA* titratable acidity)

other crop plants. Similarly, in the results of this study, *B. cepacia* bacteria increased the yield of tomato plant when applied to leaf and root area. In another study in which the effects of *B. megaterium* on the yield of tomato plant was examined, similar results like in the present studies were obtained and the increase the yield was attributed to the of phosphorus dissolving capacity of these bacteria (Turan et al. 2004). Cakmakci et al. (2001) carried out a study to determine the efficacy of *Bacillus, Burkholderia*, and *Pseudomonas* bacteria in barley and sugar beet production in the open field. In the study carried out during the two production seasons, it was determined that inoculation with bacterial breeds in both years significantly increased the yield in sugar beet and barley and showed similarities with the results of our study. The bacterial groups that are widely studied in our country are nitrogen fixers, phosphate solubilizing and plant hormone producing *Bacillus* species. *B. subtilis* has been reported to significantly increase the yields of tomato, cucumber, and pepper (Turan et al. 2007; Kidoğlu et al. 2008). Even if the amount of phosphorus in the soil is high, it can sometimes turn into forms that cannot be taken by the plant, depending on the amount of lime in the soil. However, depending on the bacterial activity in the soil, the phosphorus can be released by the bacteria and presented to the benefit of the plant. In this study, the lack of phosphorus in the plants has not been seen and the high flowering level strengthened the idea that bacteria dissolve the phosphorus in the soil and affect the yield.

In similar studies, it has been determined that PGPR application can increase product and plant growth in canola, tomato and wheat plants (Abbas and Okon 1993). The results obtained from this study are similar to the results of our study. 4 different bacterial species used in our study have had an effect in different applications to increase product yield. Therefore, it has been confirmed once more by our research that PGPRs increase product yield. Cakmakci et al. (2007) reported that the effects of *B. megaterium, B. licheniformis, P. polymyxa, P. putida, B. cereus, B. subtilis, Bacillus* OSU-142, *Bacillus* M3 PGPR isolates on spinach and wheat growth were examined. As a result, it was stated that significant increases in yield were obtained with PGPR applications in both plant species. In our research, *B. megaterium* M-3 in soil application and *P. polymyxa* bacteria in leaf and root area applications decreased tomato yield. This indicates that the effects of PGPRs on the yield of crops may vary depending on the host plant species and the method applied.

In some studies, effects of some PGPRs such as *Azospirillum, Azotobacter* spp., *Bacillus* spp., *Pseudomonas* spp. have been studied on barley, tomato and pepper plants. In the present study, *Azosprillum* bacteria, which were applied by 3 different methods, decreased yield in soil and leaf application and increased tomato yield in root application. These results show that *Azospirillum* bacteria are more active at the level close to the plant root area.

Şahin et al. (2004) and Cakmakci and Erdogan (2006) have been stated that the effects of bacteria promoting plant growth vary depending on the number of bacteria, plant-bacteria combination, plant genotype, development period, harvest date, plant parameters, soil type, soil organic matter and environmental conditions, and these complex processes have an effect on the product amount. The reason why the total yield values obtained from the experiment is low corresponds to the situations mentioned in the literature above.

According to the results of our research, it has been found that PGPR applied in some experimental plots did not have a positive effect on total and marketable yield of tomato plants and caused some yield losses in some applications. The reason for this is that bacteria are active in certain plant species (Lucy et al. 2004) and activity is thought to be dependent on plant species (Khalid et al. 2004).

The bacteria that increased vitamin C and EC values the most were *B. cepacia*. PGPRs applied in tomato plants are reported to increase fruit yield and quality compared to control (Mena-Violante and Olalde-Portugal 2007).

PGPR applications are carried out in laboratory, greenhouse and field conditions, but some unpredictable conditions sometimes make it difficult to obtain the most desirable and expected results. However, it is a known fact that some bacterial species that can be effective under controlled conditions are insufficient under field conditions. The efficiency levels of PGPRs can vary according to the adverse environmental conditions occurring in agricultural areas and the current climatic conditions (Miransari 2013; Ahemad and Kibret 2014).

Conclusion

It is very important to use biofertilizers instead of chemical fertilizers to increase the amount of product to be taken from a unit area in agricultural production. The use of biofertilizers is widespread to eliminate the negative effects of overused chemical fertilizers. In today's studies, it is seen that PGPR bacteria are significantly effective in increasing yield-quality parameters with the efficiency of fertilizers used in different plants such as tomato plants grown in organic farming systems. However, as seen in other studies, the activities of bacteria vary according to plant species, bacterial species, application method, climatic factors and differences in soil properties. According to the results obtained from our research, it was determined that *Azospirillum* sp-245 and *B. megaterium* M-3 bacteria had the highest effect on root yield, *P. polymxa* when applied as soil treatment and *B. cepacia* when applied as leaf (foliar) treatment. It is concluded that if the PGPRs used in our study in organic farming tomato cultivation are applied with the mentioned methods, yield increase between 10% and 28% can be achieved and it can be used as organic fertilizer in organic farming.

Acknowledgements We would like to thank Erciyes University BAP (FYL-2017-7209) for providing financial support in conducting this study. We also thank Assist. Prof. Dr. Erman Beyzi, for the PCA used in the study.

Conflict of interest B. Yagmur and A. Gunes declare that they have no competing interests.

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