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RESEARCH ARTICLE

Growth Promotion and Disease Suppression of Tomato by Root-Colonizing Bacteria in Saline Soil

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ABSTRACT

Soil salinity and soil-borne fungal pathogens severely limit tomato production worldwide, necessitating sustainable management strategies. This study evaluated the potential of five plant growth–promoting rhizobacterial (PGPR) strains—*Pseudomonas putida* 1T1, *Stenotrophomonas rhizophila* ep-17, *S. rhizophila* e-p10, *Serratia plymuthica* RR2510, and *Pseudomonas trivialis* 3Re27—for suppressing tomato Fusarium root rot (TFRR) caused by Fusarium solani and for their ability to colonize tomato roots under saline conditions. Disease suppression assays revealed that pathogen inoculation significantly increased TFRR incidence, while bacterial inoculation markedly reduced disease severity in most treatments. Among the tested strains, *P. putida* 1T1 exhibited the strongest biocontrol activity against *F. solani.* Rifampicin-resistant mutants of all strains successfully colonized tomato roots and persisted under salt stress, with population densities ranging from 3.8 to 4.2 $\log_{10}$ CFU g^{-1} root. Higher bacterial inoculum densities further enhanced plant performance under saline conditions. Overall, the results demonstrate that salt-tolerant PGPR can effectively suppress TFRR while maintaining stable root colonization under salinity stress, highlighting their potential as sustainable bioinoculants for improving tomato resilience in saline soils.

Keywords: Plant beneficial bacteria, Stress tolerance, Biocontrol, Colonisation.

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INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is the second most important vegetable crop worldwide, playing a vital role in human nutrition and agricultural economies (Chand et al. 2021). Global tomato production is estimated at approximately 100 million tons, of which Uzbekistan contributes about 1,583,571 tonnes (FAOSTAT, 2008). However, tomato productivity in Uzbekistan is increasingly threatened by soil salinity, a major environmental constraint that leads to the degradation of agricultural lands and reduced crop yields. Soil salinization has become a serious concern in the country due to improper irrigation practices and arid climatic conditions, adversely affecting plant growth and soil fertility.

Substantial areas of vegetable-growing soils are adversely affected by salinity, posing a serious constraint to sustainable crop production. Soil salinization disrupts plant water relations and ionic balance, subjecting plants to osmotic and saline stress conditions. These stresses weaken plant defense mechanisms, rendering crops more susceptible to diseases, particularly those caused by soil-borne pathogenic fungi. In tomato, pathogens such as *Fusarium, Pythium, Rhizoctonia, Botrytis, and Verticillium* are among the most destructive agents, leading to severe reductions in fruit yield and quality (Bazzi 1981: Rattink 1997).

Tomato seedling root rot is a serious and persistent problem in Uzbekistan, frequently leading to substantial stand losses and reduced crop establishment. The disease is mainly caused by soil-borne fungal pathogens and is particularly severe under unfavorable soil conditions, such as salinity and poor drainage. Although chemical fungicides are commonly applied for disease management, their effectiveness has remained limited. Several studies have reported that the widespread and repeated use of fungicides has failed to eliminate tomato seedling root rot and other associated seedling pathogens, and in some cases has led to environmental concerns and reduced soil microbial diversity (Singh et al. 2017: Egamberdieva et al. 2010).

Chemical management of these diseases can have detrimental environmental consequences. In addition, the cost of pesticides continues to rise, posing a significant challenge, particularly in low-income countries (Choudhary and Johri

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2009). Under such circumstances, the use of beneficial bacterial inoculants represents a promising alternative strategy (Constantinescu et al. 2011). These microorganisms can act as biological control agents, suppressing plant diseases while simultaneously promoting plant growth, accelerating seed germination, enhancing seedling emergence, and protecting plants from adverse environmental stresses such as drought and salinity. Numerous studies have demonstrated that various microbial isolates are effective in controlling root rot diseases caused by *Fusarium, Rhizoctonia*, and *Botrytis* under both field and greenhouse conditions (Datnoff et al. 1995). However, most of these studies have been carried out in non-saline agricultural soils and therefore do not adequately address the challenges imposed by salinity. In the present study, we report experiments evaluating a set of salt-tolerant, plant-beneficial bacterial strains for their capacity to suppress tomato root rot caused by *Fusarium solani* and to promote tomato growth under saline soil conditions.

MATERIAL AND METHODS

Soil and Bacteria

Soil for the experiments was collected from deep-tilled (0–40 cm) irrigated agricultural fields in Tashkent Province (non-saline, EC 1.3 dS m^{-1}) and Syr-Darya Province (salinity-affected, EC 7.1 dS m^{-1}), Uzbekistan. The detailed physicochemical characteristics of these soils are provided in Table 1. Tomato seeds (*Lycopersicon esculentum*) were sourced from Agrar State University, Uzbekistan. The bacterial isolates were obtained from the culture collection of the Faculty of Biology, National University of Uzbekistan (Table 2, 3).

Plant Growth Promotion

The effects of inoculation with selected bacterial strains on tomato growth were evaluated under both non-saline and saline soil conditions. Bacterial inoculants were prepared, and tomato seeds were surface-sterilized following the procedure described by Egamberdieva et al. (2011).

Biological Control

For biocontrol assays against tomato foot and root rot, one-third of a seven-day-old Fusarium solani culture grown on PDA was homogenized and transferred to 200 ml of Czapek–Dox medium in a 1-L Erlenmeyer flask. The culture was incubated for three days at 28°C with shaking at 110 rpm. The fungal biomass was then filtered through sterile glass wool, and the spore suspension was adjusted to 5×10^5 spores/ml. For soil infestation, the spores were thoroughly mixed into soil at a concentration of 3.0×10^6 spores/kg. Tomato seeds were bacterized by immersion in a PBS suspension containing 1×10^8 CFU/ml bacteria and then air-dried under sterile conditions. One treated seed was planted per pot with 250 g of soil at a depth of about 1.5 cm. Each treatment consisted of 60 plants arranged in groups of ten for statistical analysis. Seedlings were maintained in a greenhouse at 21°C, 70% relative humidity, and a 16 h photoperiod, with watering from below. Disease incidence was assessed 4–6 weeks after sowing, once symptoms were evident in the untreated control. Plants were uprooted, washed, and roots were inspected for crown and root rot symptoms, such as browning and lesions; symptom-free roots were scored as healthy.

Survival of Bacterial Strains in the Rhizosphere Plants

Spontaneous, stable rifampicin-resistant mutants (200 µg/ml) of the wild-type strain were employed for colonization experiments. Antibiotic-marked mutants were generated by plating the parental strain on KB agar supplemented with 200 µg/ml rifampicin. Following incubation, colonies exhibiting morphology and growth characteristics comparable to those of the parent strain were selected and subsequently subcultured on rifampicin-containing medium to confirm the stability of the resistance marker. Strains were grown overnight in King B (KB) medium, harvested by centrifugation, washed, and resuspended in phosphate-buffered saline (PBS). Cell suspensions were adjusted to $OD_{620} = 0.1$ (≈10^8 cells/ml). Sterile seedlings were immersed in the bacterial suspension for 10 minutes and then planted in potting soil. Treatments were arranged in a randomized design with 10 replicates.

Plants were grown in pots with potting soil under greenhouse conditions and watered from below. After four weeks, roots were harvested, cleaned, and 1 g was suspended in 9 ml sterile PBS. Bacterial populations were quantified by dilution plating on LC agar with and without 200 µg/ml rifampicin. After 2–3 days of incubation at 28 °C, rifampicin-resistant colonies were identified by morphology, and colonization data were analyzed.

Statistical Procedures

Data were tested for statistical significance using the analysis of variance package included in Microsoft Excel 98, comparisons were done using a Student's *t*-test. Mean comparisons were conducted using a least significant difference (LSD) test (P=0,05). Standard error and a LSD result were recorded.

RESULTS

Plant Growth Promotion in Pots

The nine selected bacterial strains were screened for their ability to stimulate tomato growth using pot experiments conducted under both non-salinated and salinated soil conditions. In comparison with the untreated control, all bacterial strains promoted either shoot or root growth of tomato plants (Table 4), indicating their overall plant growth–promoting potential under both normal and salt-stress conditions. Among the tested strains, *P. trivialis* 3Re2-7 and *S. rhizophila* ep17 exhibited the strongest growth-promoting effects, significantly enhancing root length, shoot length, and total dry biomass. In addition, bacterial density of 10^8 and 10^7 demonstrated superior performance, particularly in improving plant growth parameters under salinated conditions. Overall, these results highlight the effectiveness of selected bacterial inoculants in enhancing tomato growth and stress tolerance.

Bacterial Control of CFRR in Pots

The five selected bacterial strains were screened for their ability to suppress tomato Fusarium root rot (TFRR) caused

Table 1: Soil chemical analysis

soil	*Corg.*	*% C_t*	*% N_t*	*% CO_3-C*	*pH*	*EC dS/m*	*Cl*	*Ca*	*Mg*	*K*	*Na*	*P*
							g/kg					
Non salinated	0.88	2.52	0.10	1.62	7.8	1.5	0.04	53.6	23.6	5.7	0.4	1.3
Salinated	0.79	2.39	0.07	1.59	8.0	5.6	0.1	54.3	26.1	6.7	0.8	1.2

Table 2: The antagonistic activity of bacterial strains against pathogenic fungi

Bacteria	*Strain*	*Forl*	*V03- 2g*	*B. cinerea*	*P. ultimum*	*P.cryptogra*	*F. culmorum*	*F. solani*	*Ggt*	*A. alternata*
P. trivialis	3Re2-7	A	-	A	A	A	A	A	A	A
S. rhizophila	e-p10	A	-	A	A	A	A	A	A	A
S. rhizophila	e-p17	-	-	-	-	A	-	A	-	-
P. putida	1T1	-	-	-	-	A	-	A	-	A
S. plymuthica	RR2-5-10	A	A	A	A	A	A	A	A	A

Table 3: The plant beneficial traits of bacterial strains

Bacteria	*Strain*	*HCN* [a]	*Phase variation* [a]	*Exo-enzymes* [a]				*PGP lettuce*[b]	
				Lipase	*Protease*	*Cellulase*	*Glucanase*	*Root*	*Shoot*
P. trivialis	3Re2-7	-	-	-	+	+	-	-	-
S. rhizophila	e-p10	-	+	-	-	-	-	+	-
S. rhizophila	e-p17	+	-	-	+	-	-	-	-
P. putida	1T1	-	+	+	+	-	-	+	+
S. plymuthica	RR2-5-10	-	-	-	+	-	-	-	-

a) All tests conducted with addition of 1.5% NaCl; b) Root and shoot length of seedling (3 days growth, 3% NaCl supplemented to media;

by *Fusarium solani* (Table 5). In the absence of *F. solani* inoculation, 21% of the plants grown in non-infested soil exhibited disease symptoms, whereas the introduction of the pathogenic fungus resulted in a marked increase in disease incidence, with 46% of the plants showing typical TFRR symptoms (Table 5). Inoculation with bacterial strains significantly reduced disease severity in most treatments. All selected bacterial isolates, with the exception of *Pseudomonas trivialis* 3Re27, demonstrated statistically significant disease suppression compared with the Fusarium-infected control plants (Table 5). Among the tested strains, *Pseudomonas putida* 1T1 showed the highest level of disease control, indicating its strong potential as a biological control agent against TFRR caused by *F. solani* (Figure 1).

Survival of Bacterial Strains

Rifampicin-resistant mutants were obtained from the bacterial strains Pseudomonas putida 1T1, *Stenotrophomonas rhizophila* ep-17, *S. rhizophila* e-p10, *Serratia plymuthica* RR2510, and *Pseudomonas trivialis* 3Re27, and their survival in tomato roots grown under saline conditions was evaluated. The results demonstrated that all tested bacterial strains were able to successfully colonize and survive in the roots of tomato plants under salt stress. Among the strains, *P. putida* 1T1 showed a population density of 3.9 ± 0.1 $\log_{10}$ (CFU g^{-1} root), *S. rhizophila* e-p10 reached 3.8 ± 0.3 $\log_{10}$ (CFU g^{-1} root), *S. plymuthica* RR2510 exhibited 3.9 ± 0.1 $\log_{10}$ (CFU g^{-1} root), while *P. trivialis* 3Re27 showed the highest colonization level at 4.2 ± 0.1 $\log_{10}$ (CFU g^{-1} root).

DISCUSSIONS

The present study demonstrates that all nine selected bacterial strains exhibited plant growth–promoting effects on tomato under both non-salinated and salinated soil conditions, confirming their functional potential as beneficial rhizobacteria. The observed enhancement of shoot and root growth compared with the untreated control is consistent with numerous reports highlighting the ability of plant growth–promoting rhizobacteria (PGPR) to improve plant performance through multiple direct and indirect mechanisms, including phytohormone production, improved nutrient acquisition, and stress mitigation (Shalaby et al. 2022: Egamberdieva et al. 2008, 2010: De Curtis et al. 2010).

Among the tested strains, *Pseudomonas trivialis* 3Re2-7 and *Stenotrophomonas rhizophila* ep17 showed the strongest growth-promoting effects, significantly increasing root length, shoot length, and total dry biomass. Enhanced root development is particularly important under saline conditions, as salt stress often restricts root elongation and reduces water and nutrient uptake (Etebarian et al. 2020: El Ammari et al. 2025). PGPR-mediated stimulation of root architecture has been linked to the production of indole-3-acetic acid (IAA) and other phytohormones, which can compensate for stress-induced growth inhibition (Egamberdieva et al., 2017).

Notably, bacterial densities of 10^8 and 10^7 CFU performed particularly well under salinated conditions, indicating that an adequate inoculum level is critical for maximizing plant–microbe interactions under salt stress. Salt-tolerant

Table 4: The effect of bacterial strains on plant growth of tomato in non salinated and salinated soil

	Non salinated soil			*Salinated soil*			
	Shoot	*Root*	*Dry matter*	*Shoot*	*Root*	*Dry matter*	
control	6.34	5.16	0.125	5.26	3.69	0.099	
P. putida 1T1	6.19	5.16	0.123	5.62	4.29	0.112	a
	6.19	4.65	0.119	5.68	4.22	0.11	b
	6.26	5.23	0.123	5.95	4.25	0.111	c
S. rhizophila e-p 17	7.19*	5.23	0.139*	6.39*	5.52*	0.117*	a
	6.26	4.54	0.115	5.63	4.18	0.105	b
	5.75	4.14	0.106	5.663	3.95	0.105	c
S. rhizophila e-p10	5.85	4.4	0.11	5.76	3.8	0.105	a
	6	4.07	0.107	6.1*	4.05	0.111	b
	5.96	4.45	0.111	5.93	4.02	0.11	c
S. plymuthica RR2510	6.18	5.1	0.118	5.61	3.98	0.104	a
	6.25	4.91	0.118	5.59	4.26	0.106	b
	6.03	4.5	0.116	5.94	4.63	0.113	c
P. trivialis 3Re2-7	8.35*	6.51*	0.148*	7.74*	6.06*	0.139*	a
	9.83*	7.50*	0.164*	8.08*	6.64*	0.147*	b
	6.1	3.91	0.107	5.73	4.10	0.101	c

BD- Bacterial density; a -10^8, b- 10^7, c- 10^6 CFU/ml; UZB- tomato variety "Toshkent"

plant growth–promoting rhizobacteria (PGPR) are widely recognized for their ability to enhance plant tolerance to salinity through multiple physiological mechanisms. These include the reduction of stress-induced ethylene levels via ACC deaminase activity, improved osmotic adjustment, and the modulation of antioxidant defense systems, which collectively mitigate salt-induced oxidative damage (Kumar et al. 2021). In addition, several species within the genera *Pseudomonas* and *Stenotrophomonas* have been reported to improve ion homeostasis by restricting Na^+ uptake while maintaining a favorable K^+/Na^+ ratio, a key determinant of plant performance under saline conditions (Egamberdieva & Kucharova, 2009; Shurigin et al. 2018, 2019). The enhanced performance observed at higher bacterial densities in this study suggests that sufficient colonization may be necessary to effectively activate these protective mechanisms, thereby improving plant resilience to salinity stress.

The results of this study demonstrate that most of the selected bacterial strains were effective in suppressing tomato Fusarium root rot (TFRR) caused by *Fusarium solani*. The marked increase in disease incidence observed following pathogen inoculation confirms the aggressive nature of *F. solani* and validates the experimental infection model. Although a baseline level of disease symptoms was detected in non-infested soil, the substantially higher disease incidence in pathogen-inoculated plants highlights the importance of effective disease management strategies (Valan Arasu et al. 2023).

Table 5: Control of tomato foot and root rot in salinated soil by selected bacterial isolates.

Treatments[a]	*F. solani*	*Diseased plants (% ± SD)*
Positive control	-	21 ± 4.8
Negative control	+	46 ± 10.8
P. trivialis 3Re27	+	33 ± 9.6
P. putida 1T1	+	15 ± 4.2*
S. rhizophila ep 17	+	20 ± 4.8*
S. rhizophila e-p10	+	19 ± 4.2*
S. plymuthica RR2-5-10	+	33 ± 6.8

[a] Bacteria were coated on pre-germinated tomato seeds, and plants were grown under open natural conditions in pots containing salinated soil (EC value 659 mS/m) infested with *F. solani* spores (3.0×10^7 spores per kg), except for the positive control in which no spores were added to the soil.
* Significantly different from the negative control at P<0.05

Inoculation with bacterial strains significantly reduced disease severity in the majority of treatments, indicating their potential role in biological control (Saidi et al. 2009: Marzouk et al. 2021). The ability of these bacteria to suppress TFRR may be attributed to multiple mechanisms commonly associated with plant growth–promoting rhizobacteria (PGPR), including competition for nutrients and niches, production of antifungal metabolites, secretion of lytic enzymes, and induction of systemic resistance in host plants (Solanki et

Figure 1: Biological control of tomato plants by beneficial bacteria

al. 2015: Gao et al. 2021). The lack of significant disease suppression by *Pseudomonas trivialis* 3Re27 suggests strain-specific differences in antagonistic activity, emphasizing the importance of careful strain selection when developing biocontrol agents. Among the tested isolates, *Pseudomonas putida* 1T1 exhibited the highest level of disease control, underscoring its strong potential as a biological control agent against TFRR. Members of the genus *Pseudomonas* are well documented for their biocontrol efficacy against soil-borne fungal pathogens, largely due to their metabolic versatility and ability to produce a broad spectrum of antifungal compounds (Shukla et al. 2022). The superior performance of *P. putida* 1T1 in this study suggests that it may possess particularly effective antagonistic or plant defense–stimulating traits, warranting further investigation under greenhouse and field conditions.

The successful recovery of rifampicin-resistant mutants from all tested bacterial strains confirms their ability to effectively colonize and persist in tomato roots under saline conditions. Root colonization is a critical prerequisite for the expression of plant growth–promoting and stress-alleviating functions, particularly under adverse environmental conditions such as salinity (Chin-A-Woeng et al. 1998: Lecomte et al. 2016). Among the isolates, *Pseudomonas trivialis* 3Re27 exhibited the highest colonization level, highlighting its strong root-colonizing ability under salt stress. Effective colonization by *Pseudomonas* spp. has frequently been associated with traits such as motility, biofilm formation, and efficient utilization of root exudates, which may confer a competitive advantage in saline environments (Kamilova et al. 2005: 2008). The ability of these strains to survive and persist in the rhizosphere under saline conditions supports their potential application as bioinoculants for mitigating salt stress in tomato cultivation (Teixidó et al. 2016). However, differences in colonization levels among strains suggest that root persistence alone may not directly correlate with biocontrol efficacy or plant growth promotion, emphasizing the importance of combining colonization studies with functional assessments of plant response under stress conditions (Diabankana et al. 2021).

CONCLUSION

This study demonstrates that selected plant growth–promoting rhizobacteria (PGPR) possess strong potential to enhance tomato performance under both biotic and abiotic stress conditions. Several bacterial strains effectively suppressed tomato Fusarium root rot caused by *Fusarium solani*, with *Pseudomonas putida* 1T1 showing the highest level of disease control. Enhanced plant responses observed at optimal bacterial densities further emphasize the importance of effective root colonization for maximizing stress-mitigating effects. Collectively, these findings highlight the multifunctional role of salt-tolerant PGPR in disease suppression and stress resilience, supporting their potential use as sustainable bioinoculants in tomato cultivation under saline environments. Future studies should focus on elucidating the underlying molecular mechanisms and evaluating the performance of these strains under field conditions to validate their practical applicability.

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