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Impact of bacterial consortium on plant growth development, fruit yield and disease resistance in tomato (*Solanum lycopersicum*)

RAOUF AHMAD MIR♥, MIR KHUSHNAWAZ AHMAD, KHALID RASHID BHAT
Department of Biotechnology, GloBaL's Agri and Food Enterprises IGC Lassipoora. Pulwama 192305, India. ♥Email: kashphytochem@yahoo.com

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Abstract. *Mir RA, Ahmad MK, Bhat KR. 2023. Impact of bacterial consortium on plant growth development, fruit yield and disease resistance in tomato (*Solanum lycopersicum*). Asian J Trop Biotechnol 20: 1-9.* Agriculture plays an important role in the economic development of a country. However, using traditional fertilizers, disease resistance, and scarcity of nutrients have led to huge losses in plant productivity worldwide. *Bacillus* (*Bacillus megaterium*, *Bacillus siamensis*) are cosmopolitan species widely used as Plant Growth-Promoting Rhizobacteria (PGPR). This genus may be used along with other biocompatible microbes, including *Azotobacter* and *Trichoderma*, which can be used as consortia microbes as biofertilizers. However, the doubt remains in farmers' minds whether these biofertilizers completely replace chemical fertilizers. To gain insight into this doubt and clarify it, our study in this article is based on using Bio-NPK as an alternative to chemical fertilizers and *Trichoderma viride* as a bio-control agent. The bacterial strains and *T. viride* used in this experiment were isolated from GloBils organic farm. The plant growth parameters were measured after every 15 days. Fruit yield, weight, size, root length, root biomass, and shoot biomass were measured and compared with the control. Data analysis revealed a considerable difference between Bio-NPK-treated plants and chemical NPK-treated plants; further, a considerable difference is found in pots treated with Bio-NPK and *Trichoderma*. The Bio-NPK and *Trichoderma* showed higher disease resistance, stress tolerance, root development, biomass, and crop yield than chemical NPK. This study shows that Bio-NPK immunizes plants by re-organizing root development. At the same time, rhizobacteria stimulate defense response and simultaneously protect themselves from diseases.

Keywords: Bio-control, Bio-NPK, PGPR, soil application, *Trichoderma viride*

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most popular and widely consumed vegetable crops worldwide, and high-quality yield is an essential requirement for its economic success. It is one of the most consumable vegetables in the Asian Sub-continent, constituting about 8% of the total land under vegetable crops and 9% of the total vegetable production. In India, Tomato occupies the third position after Potatoes and Onion but ranks second after potatoes worldwide. India is the second largest tomato-producing country and ranks second in the area and the production of tomatoes. There is an increase from 596.0 thousand ha in 2006-07 to 865.0 thousand ha in 2010-11. While in terms of production, it has increased from 10,055.0 to 16,826.0 thousand tons. The current production of tomatoes does not meet the demand for its consumption due to soils in the Asian subcontinent losing their nutrient and mineral contents, adversely affecting plant growth and quality. In addition, chemical fertilizers directly affect the production yield and imbalance the soil microbiome.

The incorrect application of chemical fertilizers affects soil health and declines the availability of essential nutrients. Furthermore, inappropriate use of inorganic fertilizers leaves soil phosphorus deficient. Therefore, the Phosphate Solubilizing Bacteria (PSB) from the rice rhizosphere was isolated and characterized (Gupta and Sharma 2018).

Among different types of Plant Growth-Promoting Rhizobacteria (PGPR), *Azotabacter*, and *Bacillus* species, *Bacillus megaterium* and *Bacillus siamensis* constitute an important class. These bacteria act as growth promoters by enhancing the uptake of Phosphorus (P) and Nitrogen (N). Phosphate Solubilizing Rhizobacteria (PSRB) plays an important role in maintaining soil health. Interaction of microbes with plants and roots occurs through root colonization. Plants get multifold benefits from this interaction in terms of soil fertility and increased growth leading to a fully developed plant body (Widawati and Suliasih 2006; Parray et al. 2016). Plant microbe interactions regulate different geochemical and biophysical processes within the soil (Dutta and Podile. 2010).

The PGPR present around the plant rhizosphere release growth promoting substances that help in the overall development of a plant. (Qiao et al. 2017). Root exudates containing sugars and amino acids attract rhizospheric microbes to synthesize different growth-promoting phytohormones (Bais et al. 2004; Ortíz-Castro et al. 2009). The root exudates play an important role in the survival of rhizosphere microorganisms in nutrient-deficient conditions (Barnawal et al. 2019; Khan et al. 2020). By dissolving phosphorous and potassium, PGPR produces phytohormones, such as auxins (IAA) and cytokinins. This phytohormone will enhance the plants' developmental processes and impart disease resistance. (Saleem et al. 2007; Pérez-Montaño et al. 2014; Khanna et al. 2019a,b,c; Bhat et al. 2020; Yaseen et al. 2020). PGPR around the

cereal rhizosphere helps plant species' overall growth and development (Mehnaz et al. 2010; Zhang et al. 2012; Teng et al. 2018; Chawngthu et al. 2020). In recent years, bio-fertilizer products have emerged as an essential component in integrated nutrient management and hold great promise to improve the yield and quality of crops (Wani et al. 1995). *Trichoderma* acts as biocontrol on plant foliage (Harman et al. 2004). In many situations, combining organic and inorganic fertilizers has produced higher yields than alone (Blackshaw 2005).

Plant growth-promoting microbes play a very significant role in regulating the dynamics of various processes, such as the decomposition of organic matter, the accessibility of various nutrients of plants such as iron, magnesium, nitrogen, potassium, and phosphorus, and promote the growth of the plants (Lalitha 2017). Moreover, bio-fertilizers (part of sustainable agriculture) are the best solution for the above problems (conventional agriculture). That is because bio-fertilizers are promising, eco-friendly, cost-effective, and more economical. Moreover, bio-fertilizers fix the substantial amount of atmospheric nitrogen in the soil, improve plant growth and productivity, and help in phosphorus availability and absorption, which plays a pivotal role in growth and productivity.

Bio-fertilizers combine the advantages of recycling organic waste, introducing beneficial microbes, and providing organic material that will create additional niches for beneficial indigenous microbes (Qiu et al. 2012; Fu et al. 2017).

MATERIALS AND METHODS

Study area

The study area was selected in districts Pulwama, Jammu and Kashmir, India, with locations and coordinates as shown in Figure 1.

Plant material and bacterial culture

Tomato seeds were obtained from Agricultural office Litter, Pulwama, Jammu, and Kashmir, India. All seeds were good quality hybrid seeds. All bacterial cultures (B10AR5, B54BM3, B50BS4) and fungal culture (BF6V30) were isolated from Apple Rhizospheric soil (Chandian Pajan, Kulgam, Jammu and Kashmir, India) and characterized for its nitrogen fixing and Plant growth promoting ability by following tests using standard protocols: Growth in Jensen's media, Nitrogen fixation efficiency by Kjeldahl method auxin production, biofilm formation, phosphate solubilization and siderophore production (Meyer and Abdallah 1978; Bric et al 1991; Nautiyal 1999; Morikawa et al. 2006). The isolated cultures were maintained in King's B Agar (KBA) medium, and the glycerol stock of the culture was stored at -80°C.

Seeds grown in invitro culture for pot trial

Tomato seeds were grown in plant tissue culture in invitro conditions using MS media to generate disease-free saplings and prevent any association with microbes before transferring them into pots for trial (Figure 2). Pots were filled with soil, sand, and compost in a ratio of 1:1:1 and dried at 100°C for 3 hrs in a Hot Air oven to avoid contamination in the soil. Pots filled with soil were used for the transplantation of saplings.

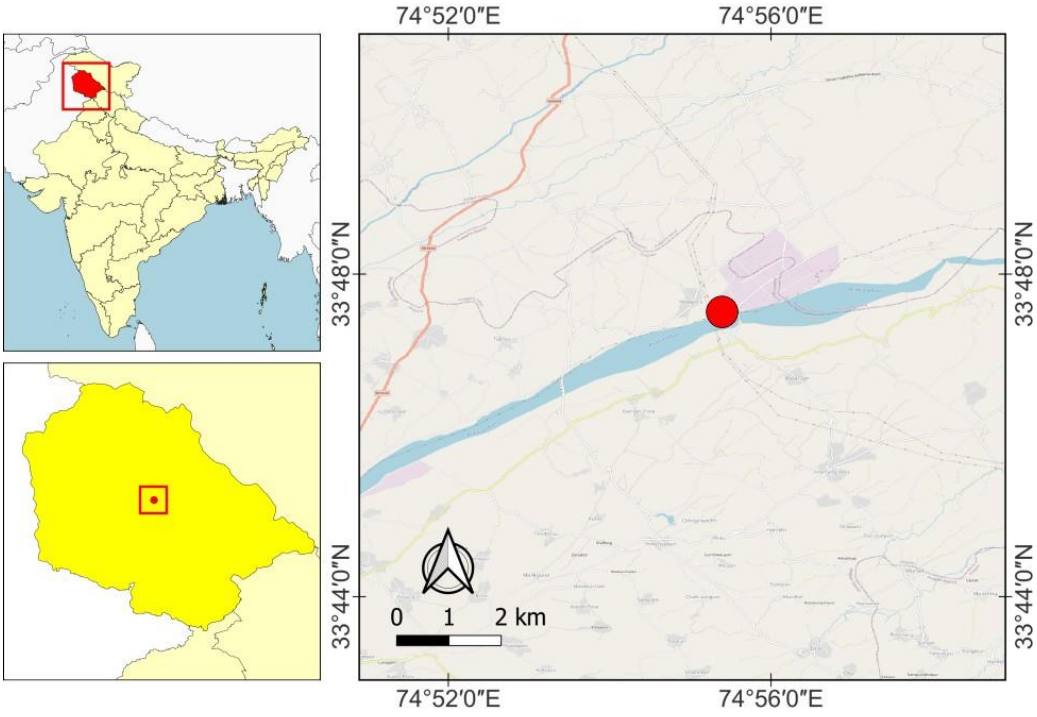


Figure 1. The location of GloBiL's Agri and Food Enterprises IGC Lassipoora Pulwama, India, indicates the field study. Field spot 1. (33°47'32.4"N 74°55'23.1"E)

Figure 2. Invitro growth of tomato seeds using MS media

Bacterial cultures with plant growth-promoting ability

The plant growth-promoting ability of bacterial cultures was tested using tomato plants grown in Plant tissue culture under controlled conditions and acclimatized in sterile soil under a greenhouse. Tomato seeds were sterilized in (70% ethanol for 5 mins and 0.1% mercuric chloride for 2-3 mins) before inoculation in plant tissue culture media (MS media). The growth-promoting ability of bacterial cultures was also checked under normal field conditions in a polyhouse. Tomato saplings grown in plant tissue culture media in test tubes were transferred into pots with two saplings in each pot in quadruplets containing sterile soil rite with soil: compost: sand in a 1:1:1 ratio and were kept in the greenhouse. The pot's moisture content was maintained by routine irrigation with the same amount of sterile water.

Tomato pot trial experiment

The tomato pot trial experiment was carried out inside a greenhouse under controlled conditions wherein saplings grown in plant tissue culture were transferred into pots with sterile soil rite. Eight different combinations were prepared with quadruplets of each combination and labeled accordingly. The pots were labeled as TT1 to TT8; each combination has four replicates under TT1; four replicates are labeled as (POT1A, POT1B, POT1C, and POT1D). Similarly, all treatments got their four replicates, including the control. Among eight combinations, TT1 was treated with *Trichoderma viride*; TT2 and TT3 with Bio-NPK; TT4 and TT5 with *T. viride* and Bio-NPK; TT6 and TT7 with Chemical NPK and TT8 was kept as the control. Dosage and concentration are depicted in Table 1; after transplanting in-vitro plants cultured into pots with sterile soil rite, the pots were inoculated with different concentrations of Bio-NPK, chemical NPK, and *T. viride* as a bio-control agent in some combinations. Initial data such as root length, number of roots, and shoot length were recorded at the time of transplantation. The irrigation was done periodically with sterile distilled water when required to maintain moisture. All recommended cultural practices, such as irrigation, removal of weeds, and plant protection, were adopted uniformly according to standard crop requirements. The first treatment of Bio-NPK was given in the first week on 7 April 2020, and the second was repeated in the first week of May on 7 May 2020. The bacterial population of the inoculants used as Bio NPK *B. megaterium*, *B. siamensis*, and *Azotobacter chroococcum* was 1.2 x 10^8 cells/cm^3. Bio-NPK was applied in two different concentrations, viz. 2.5 mL, 5 mL, and *Trichoderma* were used as bio-control. The CFU of *Trichoderma* used was $2x10^6$CFU/gram. Overall eight nutrient concentrations (mixed with *T. viride* and chemical NPK) were compared with each other and the control (without a non-inoculated pot) (Figure 3).

At 30, 60, and 90 days after transplanting the seedlings into the pots, the following attributes were used to measure. (A) Vegetative growth characters: Plant height, number of leaves and branches/plant, root biomass, and total plant biomass. (B) Yield components of tomato plants were calculated as, (i) Total Fruit weight (g)/pot, (ii) Total Fruit weight (g)/plant, (iii) Average fruit yield (g)/pot, (iv) Average fruit yield/plant (g), (v) Number and length of roots/plant (cm)

The result obtained are depicted in Tables 2, 3 for pot trial and Tables 4, 5, 6, and 7 for fields trial

Data analysis

The data values were compared with the control and chemically treated plants. All data are presented as the mean ± Standard Error (SE) of replicates and were analyzed using Data Processing Software (DPS, version 7.05) following one-way Analysis of Variance (ANOVA). Significant differences ($P < 0.05$) among treatment means after controlling for multiple comparisons were determined from a Least Significant Difference (LSD) test.

Tomato field trial experiment

Inside field conditions, Tomato field trial experiments were carried out inside GloBiL's campus field to verify the results determined from Tomato Pot Trial. The experimental field was cleared, harrowed, and sterilized. The field was divided into a set of four patches. In each set of four field patches, one patch was kept as control and labeled as TMC, two patches with 250 mL 500 mL Bio-NPK liquid, and the fourth patch with 250g chemical NPK (TM1-250 mL BIO-NPK, TM2-500mL BIO-NPK and TM3-250g chemical NPK) as depicted in Table 4. Tomato plant seedlings were procured from GloBiL's plantation department. Initial data were analyzed and recorded, like the height of plants, number of branches, root health, and shoot health. Irrigation was carried out whenever required. Bio-NPK liquid was applied in two patches, and chemical NPK in one patch. The control was without application, but control irrigation was done like other field patches. The bacterial population of the inoculants used as Bio NPK *(B. megaterium*, *B. siamensis*, and *Azotobacter)* was 1.2 x 10^8 cells/cm^3. Ten randomly selected plants from each patch at 30, 60, and 90 days from seed sowing were used to measure the vegetative growth characteristics such as plant height, number of leaves and branches/plant, plant fresh weight, and plant dry weight (Table 5).

RESULTS AND DISCUSSION

Plant growth promotion by Bio-NPK

With a plant growth promotion test, an increase in vegetative growth of tomato plants was observed after 30 days of treatment with Bio-NPK. The shoot length, root length, fruit yield, fruit weight, and total biomass were observed. It revealed a significant difference between the control and treated pots. Statistical analysis has shown a significant difference concerning the control (Figure 4).

Bio-NPK as biocontrol

Apart from PGPR activity, Bio-NPK was found to have biocontrol activity against *Fusarium* wilt and *Verticillium* wilt of tomato. Wilt infections were found in the control and chemically treated pots, but there were no cases from Bio-NPK-treated pots. The results were verified by carrying out the in vitro anti-fusarium activity of BIO-NPK against fusarium. Bio-NPK expressed very effective anti-fusarium activity.

Bio-NPK provides resistance against blossom end rot of tomato

The rhizosphere of plant species has an extensive range of microbes, including Bacillus and Pseudomonas. That shows avid rhizosphere colonization and plays an important role in crop production and yield (Podile and Kishore 2007).

The productivity of plants depends on the environmental stress they encounter in their natural habitat. (Oerke and Dehne 2004). Research has been done on plant-microbe interactions and has mainly focussed on the PGPR- induced alterations in the plant phenotype (Ali et al. 2011). This study aims to analyze the effect of the PGPR, *A. chroococcum, B. megaterium, B. siamensis,* and *T. viride* on root multiplication, growth, yield, biomass, and resistance to biotic and abiotic stress. All the Bio-NPK treated pots were found to be free from blossom end rot disease, while the control and chemically treated pots got blossom end rot disease. Hence it was concluded that Bio-NPK provides resistance against Blossom end rot of tomatoes (Figure 5).

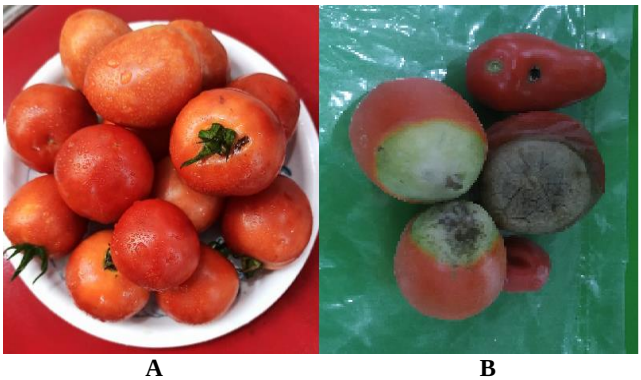
Bio-NPK and *Trichoderma* in plant growth promotion

After carrying out PGPR characterization tests, Bio-NPK was found to possess the capability to produce auxins, siderophores, and other compounds. That was supported by forming biofilms, phosphate and potassium solubilization, and nitrogen fixation. Furthermore, the plant growth promotion test performed in a greenhouse in pots showed the positive effect of Bio-NPK and *Trichoderma* on the enhancement of the growth of Tomato plants.

Figure 3. Pot trial of tomato plants

A B

Figure 4. Effect of Bio NPK on plant growth and root length. A. Untreated, B. Treated



A B

Figure 5. Resistance of plants against blossom end rots disease. A. Bio-NPK treated, B. Chemically treated

Data in (Tables 2 and 3) reveal that the total Biomass and fruit yield of Bio-NPK and *Trichoderma*-treated plant pots were significantly higher than untreated control or chemically treated pots. These results could be attributed to the synergistic effect of the microbial consortium. These results align with Barakat and Gabar (1998), who found that inoculation of tomato transplants with *A. Chroococcum, Azospirullum sps,* and *Bacillus polymyxa,* as single or mixed biofertilizers significantly increased the growth characteristics.

Bio-NPK and *Trichoderma* help in the biological control of diseases in tomato

The disease rate and severity of root rot and blossom end rot were the highest in untreated pots, and no cases were found in Bio-NPK and *Trichoderma* treated pots. However, the control without fertilizers and the control with chemical NPK were infected with blossom end rot (Figure 6). The *A. chroococcum* combined with *B. megaterium* and *B. siamensis* significantly controlled tomato plants' disease rate and severity compared to other treatments. These results are in harmony with those reported by Gupta et al. (1995), who found the combination of *A. chrocooccum* and biological agents (*T. harzanium and B. subtilis*) significantly decrease severity compared to the individual ones. The application of the biocontrol agent *T. harzanium* could control damping off and root rot disease of plants and enhance their survival rate (Niknejad et al. 2000)

Bio-NPK and *Trichoderma* enhance the quantity and quality of tomato yield

Data in (Table 2) indicated that yield components of tomato plants, i.e. number of fruits, the weight, fruits yield per plant, and size and color of the fruit, were the best in Bio-NPK treated plants as compared to the control (chemically treated and untreated or individually treated). Consortium inoculation (*B. megaterium, B. siamensis, Azotobacter,* and *Trichoderma*) significantly increased plants' yield and their components more than individual inoculation and chemically treated ones.

Fruit weight/pot

The effect of biofertilizers on average fruit weight was significant. The mean values showed that minimum and maximum average fruit numbers were observed in the first inflorescence in the control (311.625 ± 87.85) and BIO-NPK (748.925 ± 87.93), respectively. Table 2 shows the highest yield values with the quality and quantity of tomato plants observed in the inoculation treatment with BIO-NPK (*A. chroococcum, B. megaterium,* and *B. siamensis)* and *T. viride*. That is due to the synergistic effect of Bio-NPK and *T. viride.*

Martinez et al. (1994) and Radzi and Hisyamuddin. 2021 have found plants treated with biofertilizer containing *A. chroococcum, A. lipoferum,* and NPK results in the better crop in terms of yield and weight. In addition, these inoculants could also result in the early bloom of flowers as compared with the plants treated with nitrogen application only.

Bio-NPK and *Trichoderma* initiate the number and length of roots

Application of BIO-NPK increased plant yield, and mean value comparison was shown that minimum and maximum plant number and length of roots were in control (19.75 ± 1.31, 6.25 ± 0.75) and Bio-NPK (27 ± 0.57, 9 ± 0.20). The number and length of roots in Bio-NPK *Trichoderma* treated pots were more than individually treated pots and untreated pots (Tables 2 and 3; Figure 7).

Environmental stresses and a decline in soil health are becoming a major concern in declining productivity to a highly concerned level. Applying more chemical fertilizers and pesticides has further declined soil health and productivity. Biofertilizers are the solution at this moment when productivity is decreasing, and soil health is declining day by day. Biofertilizers provide a solution for sustainable agriculture with more productivity and soil health. The data obtained from the pot trial was analyzed in field conditions where two concentrations of Bio-NPK in liquid, amounting to 250 mL and 500 mL, were applied. In addition, the treatment was compared with the control and chemically NPK. The result is depicted in Tables 4, 5, 6 and 7.

Fruit number and weights

The effect of biofertilizers on average fruit number in field conditions was significant. The mean values showed minimum and maximum average fruit numbers in the first inflorescence in the control (TMC, 654 ± 14.62) and Bio-NPK(TM2, 810 ± 28.944), respectively (Table 6). The highest values of yield with quality and quantity of tomato plants were observed in the inoculation treatment with Bio-NPK (*A. chroococcum, B. megaterium,* and *B. siamensis)* at 500 mL concentration. The effect of liquid bio-fertilizer as Bio-NPK was significant in total fruit weight. The patch inoculated with 500mL BIO-NPK showed maximum fruit weight/patch (22917 ± 2869.72) compared to the control (11140 ± 1029.64) shown in Table 7.

There was an increase in total biomass in the chemically treated patch compared to liquid BIO-NPK and the control. However, the chemically treated patch and the control showed Blossom end rot disease. That is due to the synergetic effect of excess nitrogen (Taylor et al. 2004). In addition to imparting tolerance to several abiotic stress such as drought, salinity, and so on, *Trichoderma* seed treatment also ameliorates physiological stress such as aging and seed dormancy (Delgado-Sanchez et al. 2010, 2011)

The application of microorganisms as bio-fertilizers is a promising approach to assist in agricultural production; these applications have contributed to the growth of several crop species (Xiao et at. 2013) and increased plant biomass and total P contents (Jain et al. 2012). Bio-fertilizers keep the soil environment rich in all macro and micronutrients via nitrogen fixation; phosphate and potassium solubilization or mineralization; the release of plant growth regulating substances; production of antibiotics, and biodegradation of organic matter in the soil (Sinha et al. 2014).

Figure 6. Disease rate and disease severity of root rot, Blossom end rot. A: control, B, C, D: Chemical,NPK treated pots, E: Bio-NPK and *Trichoderma* treated pot

Figure 7. Comparison of root length of plants using different treatments

Table 1. Treatment information pot trial

Pot	TT1 POT A-D		TT2 POT A-D		TT3 POT A-D		TT4 POT A-D		TT5 POT A-D		TT6 POT A-D		TT7 POT A-D		TT8 POT A-D	
	TV	Bio-NPK	TV	Bio-NPK	TV	Bio-NPK	TV	Bio-NPK	TV	Bio-NPK	TV	Chemical-NPK	TV	Chemical-NPK	TV	Bio-NPK/chemical NPK

Note: -: indicate no treatment was given. TV: *Trichoderma viride*

Table 2. The yield of tomato plants grown under different fertilization treatments

Treatment	Total fruit weight (g)/plant	Total fruit weight (g)/pot	No. of roots/plant before treatment	No. of roots/plant after treatment
TT1	174.5 ± 21.01	349 ± 42.02	12.875 ± 1.06	22.5 ± 0.86
TT2	321.8125 ± 26.38	643.625 ± 52.76	13.25 ± 0.66	25.5 ± 0.86
TT3	374.4625 ± 43.96	748.925 ± 87.93	15 ± 0.97	27 ± 0.57
TT4	265.5 ± 43.34	531 ± 86.68	12.5 ± 1.17	24.5 ± 1.19
TT5	335.1375 ± 11.87	670.275 ± 23.75	16.625 ± 1.54	26.25 ± 0.47
TT6	236.25 ± 57.75	472.5 ± 115.50	9.25 ± 1.19	22.75 ± 1.25
TT7	263.5625 ± 41.84	527.125 ± 83.68	13 ± 2.35	24.25 ± 0.47
TT8	155.8125 ± 43.92	311.625 ± 87.85	11 ± 0.88	19.75 ± 1.31

Note: Data are means ± SE. Statistically significant differences between treatments ($P<0.05$)

Table 3. The root length, root biomass, and total plant biomass of tomato plants grown under different fertilization treatments

Treatment	Main root length/plant (cm) before treatment	Main root length/plant (cm) after treatment	Root biomass/plant	Total biomass/ treatment
TT1	1.825 ± 0.14	7.575 ± 0.64	174.4 ± 1.61	1626 ± 35.42
TT2	2.05 ± 0.18	8.375 ± 0.23	107.875 ± 0.65	2290 ± 54.94
TT3	1.875 ± 0.13	9 ± 0.20	134.125 ± 1.39	2568 ± 45.91
TT4	1.425 ± 0.19	8.375 ± 0.23	144.875 ± 3.35	2258 ± 15.19
TT5	1.85 ± 0.11	8.45 ± 0.47	133.25 ± 1.37	2522 ± 77.52
TT6	1.725 ± 0.04	7.75 ± 0.77	153.375 ± 0.89	2065 ± 36.42
TT7	1.575 ± 0.04	7.75 ± 0.47	137.125 ± 1.08	2251 ± 23.89
TT8	1.475 ± 0.06	6.25 ± 0.75	184.5 ± 25.38	1468 ± 20.44

Note: Data are means ± SE. Statistically significant differences between treatments (P<0.05)

Table 4. Treatment information field trial

Characters	TAG NAME	TM-C	TM-1	TM-2	TM3
Treatment/ concentration	BNPK-L	-	250ml	500ml	-
	NPK-C	-	-	-	250g
	WATER	500ml	500ml	500ml	500ml
No.of plants		20	20	20	20

Note: -: indicate no treatment was given. BNPKL: Bio-NPK liquid, NPK-C: Chemical NPK

Table 5. The height, number of branches, and leaf number of tomato plants grown under different fertilization treatments

Treatment	Plant height (cm) (DAT)			Number of leaves/plant (DAT)			Number of branches/plant (DAT)		
	30d	60d	90d	30d	60d	90d	30d	60d	90d
TMC	23.9 ± 1.15	28.5 ± 1.318	41.8 ± 2.85	24 ± 0.39	35.5 ± 1.10	42.3 ± 2.96	2.9 ± 0.23	4.4 ± 0.37	5.6 ± 0.37
TM-1	24.4 ± 1.06	32.1 ± 1.187	49 ± 1.17	24 ± 0.85	36 ± 1.06	49 ± 1.17	3.7 ± 0.3	5 ± 0.53	6.2 ± 0.24
TM-2	27.35 ± 0.93	33.85 ± 1.080	49.7 ± 1.15	26.3 ± 0.80	38.5 ± 0.94	49.7 ± 1.15	3.8 ± 0.29	5.5 ± 0.40	6.7 ± 0.36
TM3	27.1 ± 0.80	32.3 ± 1.258	48.8 ± 0.90	26.1 ± 0.50	40.3 ± 1.04	48.8 ± 0.90	4.3 ± 0.36	6.2 ± 0.44	7.1 ± 0.31

Note: Data are means ± SE. Statistically significant differences between treatments (P<0.05)

Table 6. The yield of tomato plants grown under different fertilization treatments

Treatment	No fruits/plant	No fruits/patch	Biomass/plant(g)	Biomass/patch(g)
TMC	32.7 ± 0.73	654 ± 14.62	217.1 ± 18.17	4342 ± 363.40
TM-1	33.5 ± 1.07	670 ± 21.55	294.1 ± 28.84	5800.2 ± 1010.12
TM-2	40.5 ± 1.44	810 ± 28.944	337 ± 33.20	5882 ± 576.85
TM3	38.4 ± 1.51	768 ± 30.28	360.6 ± 45.53	8017 ± 377.19

Note: Data are means ± SE. Statistically significant differences between treatments (P<0.05)

Table 7. The yield of tomato plants grown under different fertilization treatments

Treatment	Fruit weight/plant (g)	Fruit weight/patch (g)
TMC	557 ± 51.48	11140 ± 1029.64
TM-1	813.77 ± 178.11	16275.4 ± 3562.30
TM-2	1145.85 ± 143.48	22917 ± 2869.72
TM3	962.697 ± 176.51	19253.94 ± 3530.24

Note: Data are means ± SE. Statistically significant differences between treatments (P<0.05)

Long-term chemical fertilizer usage greatly reduced bacterial colonies and their richness in brown soil (Tang et al. 2021). The added inputs of fertilizers accumulate with time and result in environmental pollution, causing problems to human and animal health (Alori and Bababola 2017). Moreover, chemical fertilizer significantly decreased the Chao and ACE richness indexes of the bacterial community but increased the fungal community (Wang et at. 2017).

Moreover, using this study method on tomato plants with Bio-NPK and *Trichoderma* interaction, the bacterial consortium's positive impact on Tomato growth, yield, disease resistance, and biocontrol could be reported. Activation of multiple defense signals by Bio-NPK and

Trichoderma proves their role in plant defense and as a biocontrol agent. Further, the Bio-NPK and *Trichoderma* impact on an increase in overall biomass and product yield proves their role in plant growth promotion. With all these data, we can conclude that PGPR influences plants' defense mechanisms and confer plants' immunity to protect themselves against attack by phytopathogens.

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