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Efficacy of *Bacillus* sps. and *Pseudomonas* sps on Growth and Yield of Cherry Tomato in the sub-tropical climate of Prayagraj, U.P., India

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ABSTRACT

Prayagraj is situated at the bank of river Ganga and Yamuna, having humid, hot weather during summer and severe winter that comes under sub-tropical climatic zone. Cherry tomato is a climate-sensitive crop grown successfully in India's hilly and foothill region. In climatic zone such as Prayagraj, it experiences natural stresses which hamper its growth and development finally affecting yield and quality. PGPRs are the natural source growth regulator which has been found effective in increasing growth and is also known for reducing stresses. *Bacillus* and *Pseudomonas* are well-known PGPR that are effective in mitigating stress effects and improving growth and yield. This study is designed to understand *Bacillus* and *Pseudomonas*' efficacy in improving cherry tomato growth and yield in sub-tropical conditions like Prayagraj. Our finding states that *Bacillus* + *Pseudomonas* soil application effectively increases plant height (117.33cm), Number of Leaves (106.60), Number of fruits/plant (220), Fruit weight (8.78g), chlorophyll a(0.68 mg/g F/w), chlorophyll b(0.36 mg/g F/w), Carotenoids (0.55 mg/g F/w), Lycopene (156.33µg/g) than compared to control. We also find that soil application was more successful than foliar application.

Key words : *Bacillus, Cherry tomato, Climate, Pseudomonas, Subtropical,*

Introduction

PGPR stands for Plant Growth-Promoting Rhizobacteria, a group of naturally occurring soil bacteria that colonize the roots of plants and promote their growth and health. PGPR has been found to produce a range of beneficial effects on plants, including increased nutrient uptake, improved resistance to pests and diseases, and enhanced tolerance to environmental stress. They do this by various mechanisms, including producing plant hormones, fixing atmospheric nitrogen, and solubilizing soil minerals. PGPR can be found in a variety of soil environments, including agricultural soils, forest soils, and grasslands. They are often used as a biofertilizer or biocontrol agents in agricultural systems, as they can reduce the need for synthetic fertilizers and pesticides (Vessey *et al.*, 2003).

PGPR (Plant Growth-Promoting Rhizobacteria) plays a vital role in enhancing salt stress tolerance in

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plants. They help by promoting root growth, improving nutrient uptake efficiency, regulating osmotic balance, and producing stress-responsive compounds. PGPR also induces systemic resistance and activates stress-related genes, thereby enhancing the plant's ability to cope with salt stress (Siddikee *et al.,* 2015).

Bacillus and *Pseudomonas* are the two most common PGPR genera (Borriss *et al.,* 2011). The ability of endospore-forming B. amyloliquefaciens strains to colonize plant rhizospheres, promote plant growth, and reduce competing phytopathogenic bacteria and fungi distinguishes them from other members of the genus. *Bacillus spp.* is a common rhizobacterium that promotes plant growth. These bacteria are the most commonly used in agricultural production and have both biofertilizer and biocontrol functions (Wu H *et al.,* 2018). These microorganisms can alleviate many abiotic stresses in agricultural fields (Ashraf *et al.,* 2004). Several studies have reported that these microbes improve plant stress tolerance through various mechanisms such as the production of gibberellins, indole acetic acid, and some unidentified elements, which results in increased root surface, root length area, root tips, and, most importantly, increased nutrient content, thus improving plant health under salt stress (Shahid *et al.,* 2018).

Tomatoes also play a crucial role in the agricultural sector, being one of the most widely cultivated and commercially important crops globally. They serve as a staple food in many cuisines and are used in a wide range of processed food products such as sauces, soups, and juices, adding flavor, color, and nutritional value (FAOSTAT, 2021). Tomatoes hold significant importance both in terms of nutrition and economic value. Rich in essential vitamins, minerals, and antioxidants, tomatoes contribute to a healthy diet and help prevent chronic diseases (Rao *et al.,* 2014). They are particularly known for their high content of lycopene, a potent antioxidant linked to various health benefits, including reducing the risk of certain cancers and cardiovascular diseases (Story *et al.,* 2010).

At present, cherry tomato is also gaining pace in the indian market and is liked by groups of people. Cherry tomato (*Solanum lycopersicum* cv. cerasiforme) is a tomato botanical variety. It is considered to be the ancestor of all cultivated tomatoes. It has grown in popularity around the world due to its high vitamin A and C content, solids content, good taste, and fruit set even at high temperatures (Prema *et al.,* 2011). It is sold at a higher price than regular tomatoes. Cherry tomatoes are grown extensively in Central America and exported to California, Korea, Germany, Mexico, and Florida. In addition to its economic importance, cherry tomato consumption has recently been demonstrated to be beneficial to human health, because of its content of phytochemicals such as lycopene, β-carotene, flavonoids, vitamin C, and many essential nutrients (Beutner *et al.,* 2001). This composition explains the high antioxidant capacity in both fresh and processed tomatoes, associating the fruit with lower rates of certain types of cancer and cardiovascular disease (Rao *et al.,* 2004). On the other hand, the characteristic property of cherry tomatoes is a much higher fruit quality than that of standard tomato fruit (Hobson *et al.,* 1989).

The cherry tomato is cultivated mostly in foothills and hilly regions of India at present because of the suitability of climatic zone for better growth and yield. Hot summer and severe winter of the semiarid arid sub-tropical zone of Prayagraj are a bit harsh for cherry tomatoes until in polyhouse conditions**.** Plant Growth-Promoting Rhizobacteria (PGPR) play a crucial role in stress regulation for tomato plants. PGPR are beneficial bacteria that colonize the rhizosphere, the region of soil surrounding the plant roots, and establish a symbiotic relationship with the plant. They offer numerous benefits to plants, including enhanced nutrient uptake, disease resistance, and stress tolerance. Moreover, they stimulate the activity of antioxidant enzymes, thereby minimizing oxidative damage caused by salinity stress (Egamberdiyeva *et al.,* 2007). The beneficial microorganisms live in the plant rhizosphere and stimulate plant growth through a variety of indirect and direct mechanisms (Upadhyay *et al.,* 2012). Recent research has found that microbial communities can help to activate plant stress-responsive genes, resulting in increased plant growth, yield, and development under stress conditions (Mayak *et al.,* 2004).

The present study was conducted to evaluate the potential of *Bacillus* and *Pseudomonas* in enhancing plant growth and yield under natural stress, which can contribute to the development of effective and eco-friendly agricultural practices.

Materials and Methods

Experiment was conducted during the kharif season of 2022 at the Crop Research Farm of SHUATS, Prayagraj, located at 250 28’4" N latitude, 810 50' 56" E longitude and 98 m altitude above mean sea level. Research farm area is located on the right bank of the Yamuna River about 5 km from Prayagraj city that come under semi-arid subtropical climate. For study 7 treatments viz; Control, *Bacillus* spp (soil), *Bacillus* spp (folliar), *Pseudomonas* spp (soil), *Pseudomonas* spp (foliar), *Bacillus* spp+ *Pseudomonas* spp (soil), *Bacillusspp+ Pseudomonas* spp (foliar) were taken. Different parameters related to Vegetative growth (Plant Height, No. of Leaves, No. of Branches). Anthesis (Days to 1st flowering, Days to end of flowering, No. of Flower per Plant, No. of Flower per Cluster) Yield (No. of Fruits, No. of Fruits per Cluster, Yield. Fruit Diameter, Fruit Weight) and Biochemical (Chlorophyll a, Chlorophyll b Carotenoids, and lycopene) are recorded and analyzed by standard procedures (Table 1) and analytical methods and finally subjected to Statistical analysis.

Results and Discussion

Plant growth promoting rhizobacteria (PGPR) Plant growth promoting rhizobacteria (PGPR), a diverse group of soil bacteriaengaged in an intense network of interactions in the rhizosphere, thus affecting plant growth and yield (Kloepper *et al.,* 1991). Numerous species of soil bacteria flourish in the rhizosphere of plants, but it may grow in, on, or around plant tissues, and stimulate plant growth by a plethora of mechanisms (Vessey *et al.,* 2003). *Bacillus* and *Pseudomonas* are two such groups of rhizobacteria which are been used in a number of research successfully for improving growth in diverse conditions. Our findings also in conjecture of such as compared to control PGPR treated plants were showing more growth and yield.

Some plants may grow reasonably well under more extreme growth conditions as they have evolved the plasticity to manage these variations. However, the productivity of most agricultural plants will decline, as more extreme environmental pressures will exceed their capacity to respond to stress. The rhizosphere, rhizoplane, and endospheric, the soil near the roots, the root surfaces, and the spaces between plant cells, respectively, are the plant-influenced areas with the greatest microbial diversity.

Vegetative Parameters (Table 2 and Figures 1 and 2): Plant height: At 30 DAT compared to control T_0 (21.6 cm) plants treated with PGPR showed positivity as T_5 (40.6cm) followed by T_1 (37.6cm) and T_3

Table 1. Description of method adopted

Parameters	Procedure	Measurement unit
Vegetative		
Plant Height(cm)	Measure through scale	cm
No. of leaves	Counted per plant	Leave/plant
No. of branches	Counted per planr	Branch/plant
Anthesis parameter		
No. of flowers / Plant	Observed the day of flowering initiation and further counting was done a regular intervals	Till the end of flowering
No. of flowers/cluster	5 clusters are randomly selected and flowers were counted	Flower/cluster
Yield parameter		
No. of fruits	Counted in every harvest	No. of fruit/plant
Fruit weight	10 randomly selected tomatoes were weight in digital weighing machine	g/fruit
Yield	Addition of total weight of tomatoes harvested	g/plant
Biochemical Parameters		
Chlorophyll a	Estimated bt DMSO method (Arnon, 1941) at the time of vegetative growth	mg/g Fw
Chlorophyll b	Estimated bt DMSO method at the time of vegetative growth	mg/g Fw
Carotenoids	Estimated bt DMSO method at the time of vegetative growth	mg/g Fw
Lycopene	spectrophotometric determination	microgram/g Fw

(34.6) where at par. A similar trend followed at 90 DAT with T_0 (94.3) and T_5 (116.cm) followed by T_1 (110.6 cm) and T_3 (108.3) where at par. No. of leaves at 30 DAT to 90 DAT for control T_0 (14.3 to 78.6) while T_6 (30.0 to 106.6). No. of branches increase for 30 DAT to 90 DAT for control T_0 (2.0 to 6.6) stressed T_5 (7.6 – 10.0) followed by T_1 and T_3 (9.3) where at par.

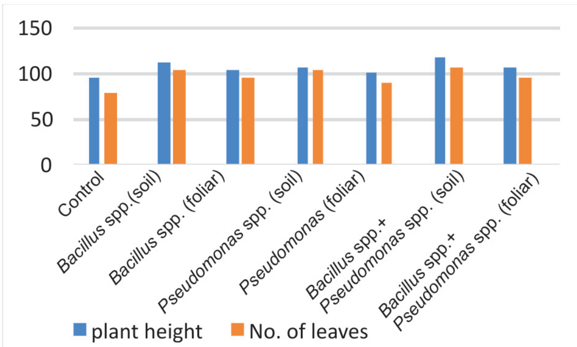

Fig. 1. Effect of *Bacillus* spp. and *Pseudomonas* spp. on different vegetative parameter (plant height. No of leaves) of Cherry tomato at different growth intervals

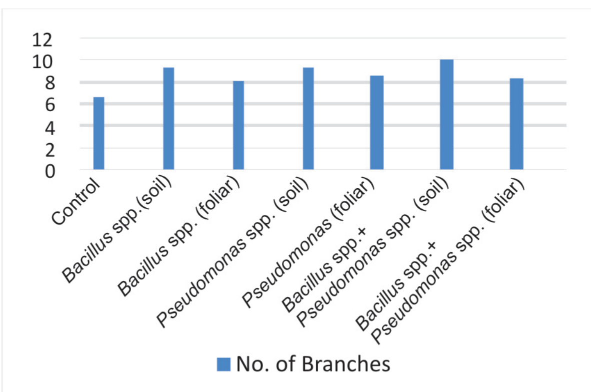

Fig. 2. Effect of *Bacillus* spp. and *Pseudomonas* spp. on different vegetative parameter (No.of branches) of Cherry tomato at different growth intervals

Table 2. Statistical Analysis of different vegetative parameters of Cherry tomato treated with *Bacillus* sps. and *Pseudomonas* sps.

	Plant height (cm)	No. of leaves	No. of branches
Average mean	123.58	112.28	10.02
SEm±	4.14	3.74	0.44
CV	5.80	5.78	7.55
CD	12.75	11.54	1.34
F TEST	S	S	S

Anthesis Parameters (Table 3 and Figures 3& 4) Days to First Flowering**:** Compare to control T_0 (50) plants treated with PGPR showed delays in flowering T_6 and T_1 (60) followed by T_3 (59). A total number of Flowers/plants was highest at T_7 (270) followed by T_3 (265) and T_5 (250) compare to control T_0 (165), the total number of flowers/clusters was also maximum in T_7(14.50) compare to control T_0 (11.7).

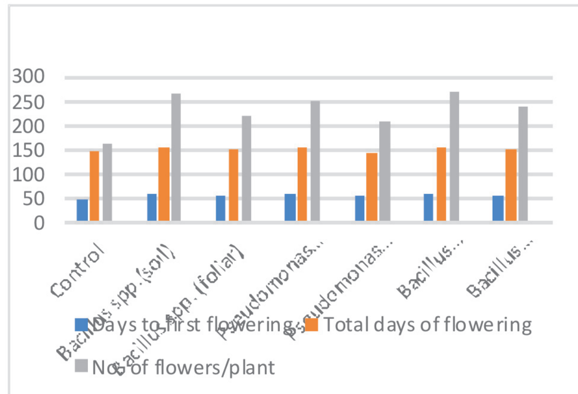

Fig. 3. Effect of *Bacillus* spp. and *Pseudomonas* spp. on different Anthesis parameter (Days to first flowering, Days to end of flowering and No. of Flowers / plant) of Cherry tomato at different growth intervals

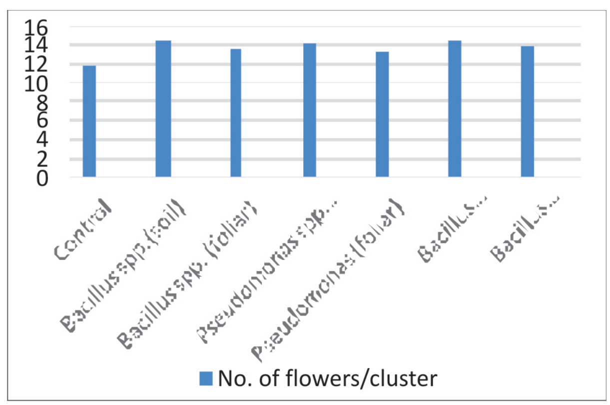

Fig. 4. Effect of *Bacillus* spp. and *Pseudomonas* spp. on different vegetative parameter (No. of flower / cluster) of Cherry tomato at different growth intervals

Yield Parameters (Table 4 and Figures 5, 6, & 7)**:** Number of fruits/plants in T_0(150) that weighed 1067g (7.04g/fruit) while in T_5 (220) weighed 1790 g (8.78 g/fruit) followed by T_1 (1698g) and T_3 (1680g). there was an increase in the size of fruit with PGPR treatment with fruit average diameter of fruit for T_0(18.65 mm) while T_5 (22.83 mm), while treatment T_1 (22.70 mm) and T_3 (21.80 mm) were at par.

Biochemical parameters (Table 5 and Figures 8 & 9)**:** Chlorophyll a, b, and carotenes were analyzed in mg/g of F/W for leaves at a vegetative stage to understand growth conditions and plant health. For control T_0 Chlorophyll a, b and carotenes were 0.43, 0.20, and 0.47 respectively while for T_7 0.68, 0.36, and 0.69.

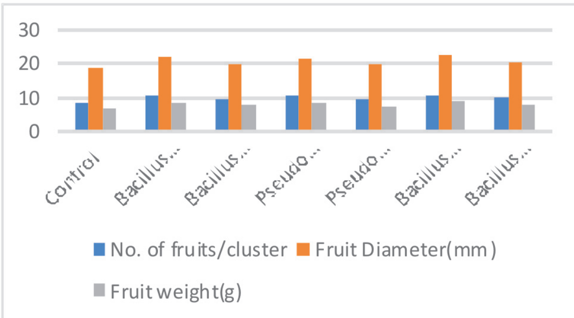

Fig. 5. Effect of *Bacillus* spp. and *Pseudomonas* spp. on different Yield parameter (No. of fruits /Cluster and Fruit diameter, fruit weight) of Cherry tomato at different growth intervals.

Bacillus exhibit both direct and indirect control mechanisms that suppress disease caused by pathogen it may synthesis many secondary metabolites hormone cell wall degrading enzyme and anti-oxidant that improve resistance and stimulate plant growth (Hashem *et al.*, 2019).

The highest values were observed when the carrot wasco-inoculated with *Bacillus subtilis* and *Pseudomonas* in which plant height was observed (73.22cm) as compared to control. Similar results were found compared to control co-inoculation with only p fluorescence was improved the number of leaves by 70% (Correa *et al.*, 2010). Soil application *Bacillus subtilis* shows better results for total chlorophyll (4.56c) as compared to control (2.80ab) andan increase in yield of maize from 5.5 to 13.4% compared to control treatment (Efthimiadou *et al.*, 2020)

PGPR's are the potential tools for sustainable agriculture and trend for the future; they not only ensure the availability of essential nutrients to plants but also enhance nutrient use efficiency (Khalid *et al.*, 2009). The beneficial effects of PGPR involve boosting key physiological processes, including

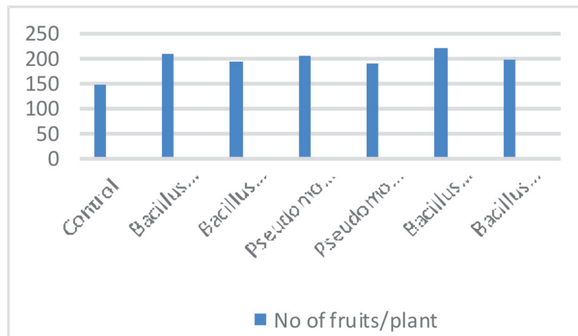

Fig. 6. Effect of *Bacillus* spp. and *Pseudomonas* spp. on different Yield parameter (No. of fruits /Weight) of Cherry tomato at different growth intervals.

Table 3. Statistical Analysis of different anthesisparameters of Cherry tomato treated with *Bacillus* sps. and *Pseudomonas* sps.

	Days to first flowering	Days to end of flowering	No. of flowers/plant	No. of flowers/cluster
Average mean	66.24	176.9	270	15.86
SEm±	3.08	1.20	2.28	0.21
CV	8.05	1.18	1.46	2.28
CD	9.49	3.70	7.02	0.64
F TEST	S	S	S	S

Table 4. Statistical Analysis of Different Yield Parameters of Cherry tomato treated with *Bacillus*sps. and *Pseudomonas* sps.

	No of Fruits/ Plant	No of Fruits/Cluster	Total No. of Fruits	Fruit Diameter	FRU Fruit Weight
Average mean	225.22	11.63	1724.83	24.39	9.38
SEm±	7.04	0.61	3.78	1.10	0.22
CV	5.42	6.48	0.38	7.78	4.03
CD	21.70	1.34	11.65	3.38	0.67
F TEST	S	S	S	S	S

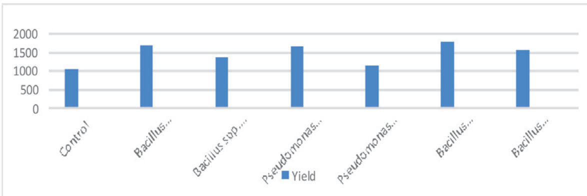

Fig. 7. Effect of *Bacillus* spp. and *Pseudomonas* spp. On yield of Cherry tomato at different growth intervals.

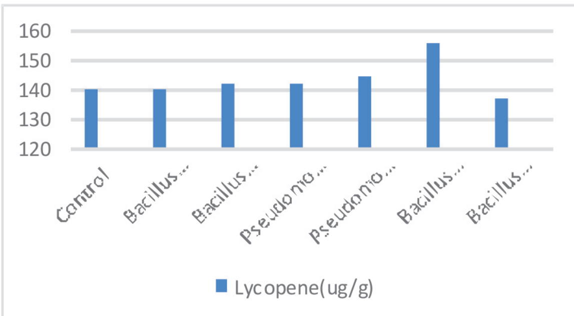

Fig. 8. Effect of *Bacillus* spp. and *Pseudomonas* spp. on (Lycopene) of Cherry tomato at different growth intervals.

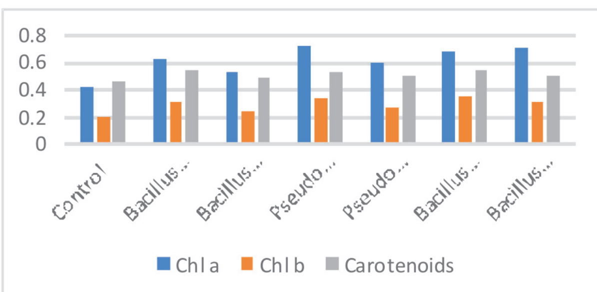

Fig. 9. Effect of *Bacillus* spp. and *Pseudomonas* spp. on different biochemical parameter (chlorophyll a, chlorophyll b, Total Chlorophyll, Carotenoids of Cherry tomato at different growth intervals.

water and nutrient uptake, photosynthesis, and source-sink relationships that promote growth and development. One of the mechanisms by which bacteria are adsorbed onto soil particles is by ion exchange. A soil is said to be naturally fertile when the soil organisms are releasing inorganic nutrients from the organic reserves at a rate sufficient to sustain rapid plant growth (Goswami *et al.*, 2016). (Gray *et al.*, 2005) have shown that the PGPR associations range in the degree of bacterial proximity to the root and intimacy of association. The three distinct characteristics of PGPR are they must be able to colonize the root, they must survive and multiply in microhabitats associated with the root surface, in competition with other microbiota, at least for the time needed to express their plant promotion/protection activities and they must promote plant growth (Lucy *et al.*, 2004).

Major mechanism of PGPR Although both direct and indirect mechanism of PGPR equally provides benefits for plants' health nitrogen fixation is the major mechanism of all PGPR (Mahmud *et al.*, 2020), because all rhizobacteria have the capacity to fix atmospheric nitrogen, hence called rhizobacteria and there is the likelihood that each of the direct and indirect mechanism may present or absent in all rhizobacteria. Most of the proteins, signaling molecules, carry nitrogen as a key component. Nitrogen is also one of the crucial macronutrients for plant growth. To preserve the health of the environment, PGPR is a natural biofertilizer to accomplish the requirement of nitrogen and other nutrients for plants without harming their productivity and the health of the environment (Monterio *et al.*, 2021).

In the study compare to foliar, soil application was much more successful than compare to foliar as the living bacteria used were rhizospheric and not able to survive in plant parts for long as a spray. Compare to *Pseudomonas*, *Bacillus* was performing better in solo conditions may be because of the spore-forming ability of *Bacillus* is distinguished from that of *Pseudomonas*. Members of this genus also survive for a long time under unfavourable environmental conditions. *Bacillus* spp. secretes several metabolites that trigger plant growth and prevent

Table 5. Statistical Analysis of Different Biochemical Parameters of Cherry tomato treated with *Bacillus* sps. and *Pseudomonas* sps.

	CHL a	CHL b	Carotenoids	Lycopene
Average mean	0.72	0.34	0.62	168.78
SEm±	0.02	0.02	0.02	2.67
CV	5.71	7.60	5.88	2.74
CD	0.07	0.05	0.06	8.24
F TEST	S	S	S	S

pathogen infection. In addition, the synthesis of indole-3-acetic acid, gibberellic acid and 1-aminocyclopropane-1-carboxylate (ACC) deaminase by *Bacillus* regulates the intracellular phytohormone metabolism and increases plant stress tolerance.

Nutrient availability in the soil plays a major role in the maintenance of soil health and its productivity. Inherently less fertile soils tend to have smaller PGPR populations (Bhattarai *et al*., 2015), and the introduction of new microbes through soil inoculation results in poor microbial colonization of the area due to a lack of nutrients. Therefore, the efficacy of PGPR depends not only on less competition for resources (Ashman and Puri, 2013) and lower levels of antagonistic effects from other microbes, but also on the availability of nutrients in the soil; hence rapid rhizosphere colonization ultimately benefits the host plant. However, a higher diversity of microbial taxa in fertile soils results in a more complex inter- and intraspecies interactions which permit suppression antagonistic microbes. Furthermore, many studies of the legume-rhizobia symbiosis indicate that BNF efficiency tends to decrease in soils with high levels of soil N (Guinet *et al.,* 2018; Romanyà and Casals, 2019). This emphasizes that sometimes scarcity of resources/stress creates more demand for the PGPR, to increase efficiency in assisting plants.

Conclusion

soil application of *Bacillus* and *Pseudomonas* enhances productivity by suppressing the effects of the unsuitable condition of natural climate up to a certain extent and helped cherry tomato plants sustain and flourished in sub-tropical climate of extreme winter and summer at Prayagraj.

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