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Effect of plant growth promoting rhizobacteria bio capsules on growth and yield of turmeric

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Abstract
The trial has been conducted at the turmeric research station, Kammarpally for the continuous of three years from 2018-19 to 2020-21 to assess the potential of plant growth promoting rhizobacteria (PGPR) capsules developed by Indian Institute of Spices Research in turmeric cultivation. PGPRs associated with plant growth processes such as nitrogen fixation, phosphate solubilization, and hormone secretion. PGPR has multiple ecological and practical functions in the soil's rhizosphere. One of PGPR's various roles in agro ecosystems is to increase the synthesis of phytohormones and other metabolites, which have a direct impact on plant growth. A field experiment has been conducted to study different PGPRs in turmeric with three varieties Duggirala Red, IISR Pragathi, IISR Prathibha and five different PGPR combinations T_1-POP + *Trichoderma* (Talc formulations) + GRB 35 (Talc formulations), T_2- POP + *Trichoderma* capsules + GRB 35 capsule, T_3- POP + *Trichoderma* capsules, T_4- POP + GRB 35 capsule, T_5- POP (Recommended package of practices). In this trial T_2V_1- POP + *Trichoderma* capsules + GRB 35 capsule with Duggirala red variety has been given highest fresh rhizome yield (38.32 t/ha) followed by T_2V_3-+ *Trichoderma* capsules + GRB 35 capsule with IISR-Prathibha variety (35.91 t/ha).

Keywords: Trichoderma, GRB-35, PGPR, fresh rhizome yield, talc formulation

Introduction
Turmeric, *Curcuma longa* L., which is a member in Zingiberaceae, was originated from South-east Asia. Turmeric is known as the "golden spice" as well as the "spice of life". Turmeric was consumed in multidisciplinary such as food, spice, cosmetic and medicine. It has been used in India as a medicinal plant and held sacred from time immemorial. It is a dye, with varied usages in drug and cosmetic industries. It is used as medicinal for external application and taken internally as a stimulant. It is now important in medical science because curcumin and volatile oils of turmeric rhizomes have anti-inflammatory, antimutagen, anticancer, antibacterial, anti-oxidant, antifungal, antiparasitic and detoxing properties. These components also promote liver and kidney function and alleviate biliary disorders, diabetic and hepatic disorders. Various supplements and drinks derived from the turmeric are widely being used for keeping good health.

Sustainable agriculture has become increasingly important in recent times due to its focus on long-term environmental and social benefits. Recognizing the importance of sustainable farming practices is crucial for meeting the future economic needs of the world, as they can help reduce the use of artificial pesticides and fertilizers while improving plant health and soil quality (De Andrade *et al.*, 2023) [2]. To secure long-term environmental health worldwide and produce adequate food for future generations, sustainable agriculture must preserve the soil's inherent diversity (Kumar, 2017) [13]. Thus, eco-friendly alternatives, including the sustainable use of beneficial microorganisms, are crucial for alleviating environmental stress. Bacteria, known as PGPR, are the most important of all the soil microbes. The benefits for the crop are achieved in many ways, such as fixing nitrogen, breaking down phosphate, getting rid of heavy metals, making phytohormones (like auxin, gibberellins, cytokinin, etc.), breaking down crop residue, and stopping phytopathogens from growing (Pantigoso *et al.*, 2019) [9]. Researchers have thoroughly studied the positive impacts of PGPR, a naturally occurring soil bacterium, on plant vitality and output. In addition to protecting plants from pathogens and harsh conditions, they can also boost nutrient availability, spur plant growth, fortify root development. Several different mechanisms are involved in how PGPR helps plants. Some PGPR form auxins, cytokinins, and gibberellins, which encourage root and shoot growth (VanPeer *et al.* 2018) [16]. PGPRs can easily use the process of "fixation" to convert nitrogen in the air into a plant-available form, thereby augmenting the plant's nitrogen needs. PGPRs solubilize phosphorus and other mineral nutrients, increasing their availability to plants. PGPR competes with dangerous microbes for oxygen, food, and room by colonizing the rhizosphere, which lowers the danger of pathogen invasion and boosts plant health in general. PGPR improves plant resistance by activating defensive systems and enhancing tolerance to a wide range of environmental factors, including dryness, salinity, and extreme heat. Soil has many different kinds of bacteria and viruses.

The rhizosphere of a plant is home to helpful microorganisms called plant growth promoting rhizobacteria (PGPR), which play a crucial role in promoting plant growth and development. The significance of PGPR for long-term agricultural viability is outlined in this review. Increased plant tolerance to biotic and abiotic stress, reduced use of chemical fertilizers and pesticides, and enhanced nutrient availability, soil fertility, and absorption are all mentioned as potential benefits of PGPR. Phytopathogens can be stopped in their tracks, a plant's natural defenses can be bolstered, and so on. PGPR also helps clean up the soil through a process called bioremediation. The PGPR's many functions include indole acetic acid (IAA) production, ammonia (NH3) production, hydrogen cyanide (HCN) production, catalase production, and more. In addition to aiding in nutrient uptake, PGPR controls the production of a hormone that increases root size and strength. Improving crop yield, decreasing environmental pollution, and guaranteeing food security are only some of the ecological and economic benefits of employing PGPR for sustainable agriculture.

Materials and Methods

The field experiment was conducted to study the effect of different PGPR biocapsules and talc formulations on growth and yield of turmeric at Turmeric research station, Kammarpally, Nizamabad district, Telangana during 3 consecutive years from 2018-19 to 2020-21. The experimental initial soil status was less alkaline pH (7.65), electric conductivity 0.15 dS m^{-1}, low organic carbon with medium available nitrogen (250 kg ha^{-1}), high available phosphorus (32.57 kg ha^{-1}) and high available potassium (332.7 kg ha^{-1}).

This experiment was laid in a randomized block design with three replications.

This experiment is formulated with three varieties V_1-Duggirala Red, V_2-IISR Pragathi, V_3-IISR Prathibha and five different PGPR combinations T_1-POP + *Trichoderma* (Talc formulations) + GRB 35 (Talc formulations), T_2- POP + *Trichoderma* capsules + GRB 35 capsule, T_3- POP + *Trichoderma* capsules, T_4- POP + GRB 35 capsule, T_5- POP (Recommended package of practices). Generally, the seed was sown in the month of June and harvested after completion of 8 months in the month of March during the experimental years.

Recommended cultural practices were adopted for all treatments. Growth parameters *viz.,* plant height, number of tillers, number of leaves, petiole length, leaf length, leaf width recorded in the second week of January month. Yield parameters data was recorded at harvesting time. In case of growth and yield parameters data was recorded from five plants from each replication and the means are used for statistical analysis.

Results

Growth characters

Significant differences were observed with all the growth parameters and the maximum mean plant height (106.6 cm), number of shoots (2.33), number of leaves (9.71), petiole length (20.33 cm), leaf length (48.63 cm) were recorded with T_2V_1-POP + *Trichoderma* capsules + GRB 35 capsule with Duggirala red variety which may be due to the direct mechanisms observed in PGPR include N2 -fixation, mobilization of nutrients via production of phosphatases, siderophores, or organic acids, and production of phytohormones and enzymes which trigger the growth of the turmeric plants (V. Jeyanthi *et al.*, 2018) [10]. Many scientists reported that plant growth promoting rhizobacteria might enhance plant height and productivity by synthesizing phytohormones (Prokryl *et al.*, 2000, Burd *et al.*, 2000, Gravel, 2007) [14, 1]. The beneficial effects of PGPR involve boosting key physiological processes, including 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) [4]. Gray and Smith (2005) [6] 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 (Kloepper, 1994; Lucy *et al*., 2004) [11, 7]. Phytohormones are responsible for plant growth development and allow plants to tolerate different stress conditions. Some rhizobacteria are able to produce phytohormones, including cytokinins, auxins, gibberellins, ethylene, and abscisic acid (ABA), which play a role in different growth processes in plants, including cell multiplication, which results in increased cell and root expansion (Glick, 2014) [3]. However, the production of ABA by rhizobacteria is considered an indirect way of promoting plant growth. Several bacteria that have the ability to produce IAA and have positive effects on shoot and root weight and nutrient uptake on maize plants. Besides, activities like phosphorus solubilization, or even other non-evaluated PGPR traits that stimulate plant growth. PGPR may promote growth directly, e.g. through fixation of atmospheric nitrogen, solubilization of minerals (phosphorus and potassium), production of siderophores that solubilize and sequester iron, or production of plant growth regulating hormones (Grover *et al*. 2009) [8].

Yield characters

The maximum mean fresh rhizome yield per plot (15.87 kg/plot) and maximum mean fresh rhizome yield per hectare (38.32 t/ha) have been observed with T_2V_1- POP + *Trichoderma* capsules + GRB 35 capsule with Duggirala red variety followed by T_2V_3-POP + *Trichoderma* capsules + GRB 35 capsule with IISR-Prathibha variety which recorded fresh rhizome yield per plot (14.36 kg/plot) and mean fresh rhizome yield per hectare (35.91 t/ha). The results are in conformity with Kuan *et al*. (2016) [12] who reported that plant growth-promoting bacteria may provide a biological alternative to fix atmospheric N2 and delay N remobilization in maize plant to increase crop yield based on an understanding that plant-N remobilization is directly correlated to its plant senescence promoting high up to 30.9% with reduced fertilizer-N input. Di Salvo *et al*. (2018) [15] reported that PGPR used as inoculants of cereal crops including maize can improve their growth and grain yield. The crops responses to inoculation are complex because are defined by plant-microorganisms interactions, many of them still unknown. Thus, it is necessary to improve the knowledge about the microbial ecology of the rhizosphere of crops under different agricultural practices. Various processes, such as the mineralization of organic matter, nutrient immobilization, phosphate solubilization, nitrogen nitrification, and phytohormone production, combine to enhance soil fertility and crop productivity (Van Peer *et al*. 1989) [16].

Plant growth promoting rhizobacteria in rhizosphere soil is highly dynamic, more versatile in transforming, mobilizing and solubilising the nutrients. Therefore, the rhizobacteria are the dominant deriving forces in recycling the soil nutrients and consequently, they are crucial for soil fertility. They may be extensively used in plant growth promotion as it acts as a plant nourishment and enrichment source which would replenish the nutrient cycle between the soil and plant roots, exhibits detoxifying potential, controls phytopathogen thereby exerts a positive influence on crop productivity and ecosystem functioning, hence can be implemented in agriculture (V. Jeyanthi, 2018) [10].

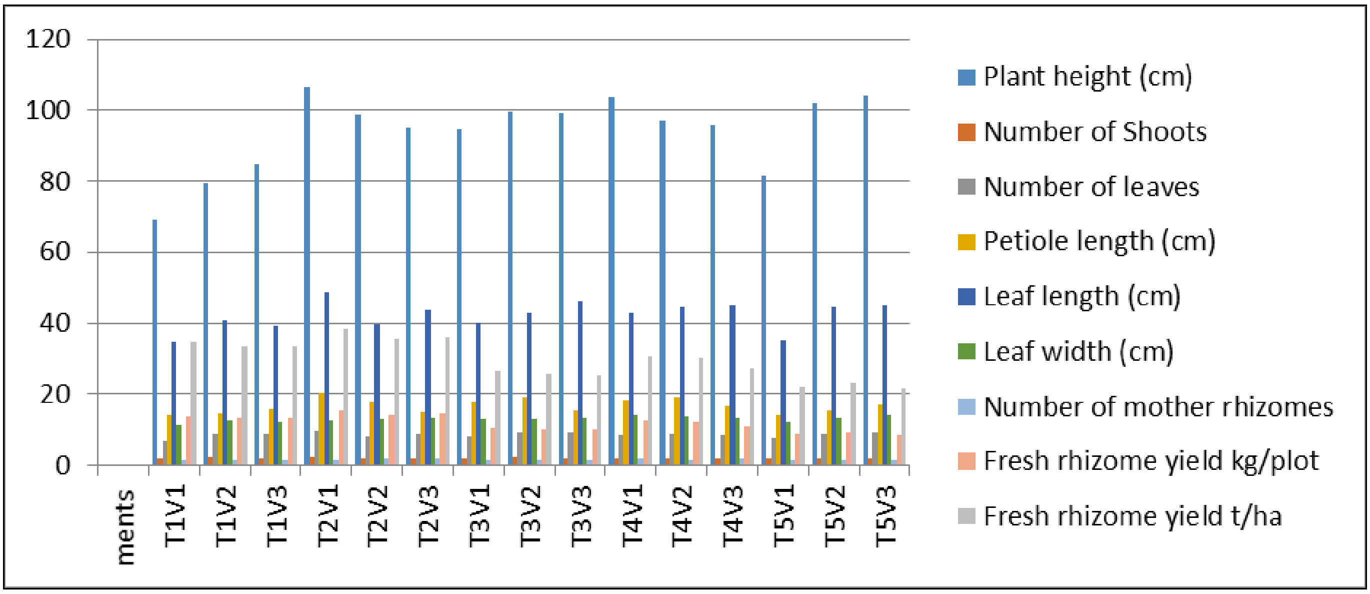

Fig 1: Effect of plant growth promoting rhizobacteria bio capsules on growth and yield characteristics of turmeric

Table 1: Effect of plant growth promoting rhizobacteria bio capsules on growth and yield characteristics of turmeric

Treatments	Plant height (cm)			Pooled mean	Number of Shoots			Pooled mean	Number of leaves			Pooled mean	Petiole length (cm)			Pooled mean
	2018-19	2019-20	2020-21		2018-19	2019-20	2020-21		2018-19	2019-20	2020-21		2018-19	2019-20	2020-21	
T_1V_1	68.9	86.8	52.0	69.23	1.9	1.9	1.45	1.75	7.55	7.525	5.7	6.92	14.45	18.9	9.1	14.15
T_1V_2	85.7	95.15	57.1	79.31	1.9	1.75	3.1	2.25	9.9	7.675	8.95	8.84	15.5	17.8	10.75	14.68
T_1V_3	84.3	96.275	73.9	84.82	1.85	1.9	1.55	1.76	8.9	9.25	8.05	8.73	13.8	19.4	13.55	15.6
T_2V_1	113.3	101.2	105.3	106.6	2.2	2.4	2.4	2.33	9.5	10.2	9.45	9.71	21.2	20.2	19.6	20.33
T_2V_2	91.75	91.65	113.2	98.86	1.9	1.55	1.7	1.71	8.85	6.52	8.75	8.04	16.55	22.1	14.2	17.64
T_2V_3	91.25	96.85	97.1	95.06	1.7	2.0	1.7	1.8	8.35	9.125	8.8	8.75	15.15	15.4	14.8	15.13
T_3V_1	80.05	90.9	112.4	94.45	1.85	1.8	1.55	1.73	9.2	6.27	8.1	7.85	14.5	24.4	14.9	17.93
T_3V_2	85.4	104.6	108.9	99.63	2.3	1.95	1.9	2.05	9.6	8.825	9.75	9.39	15.65	23.1	18.6	19.13
T_3V_3	86.0	103.8	107.7	99.16	1.65	1.9	1.7	1.75	9.15	9.2	9.35	9.23	14.35	20.4	11.45	15.4
T_4V_1	72.95	115.6	122.0	103.5	1.7	1.75	1.55	1.66	7.6	7.1	11.07	8.59	14.4	21.7	18.25	18.14
T_4V_2	86.35	97.85	107.4	97.2	1.95	1.65	1.8	1.8	9.2	8.075	9.3	8.85	15.85	23.5	17.95	19.10
T_4V_3	85.6	89.75	112.2	95.85	1.8	1.5	1.6	1.63	9.45	7.225	8.95	8.54	16.6	21.1	11.9	16.53
T_5V_1	80.2	110.25	54.5	81.65	1.85	1.65	1.6	1.7	8.0	7.45	7.225	7.55	15.75	15.4	10.65	13.95
T_5V_2	87.4	110.25	107.9	101.85	1.8	1.56	1.85	1.73	8.35	8.05	10.05	8.81	14.3	18.8	12.8	15.30
T_5V_3	85.35	106.25	120.2	103.93	1.8	1.6	1.7	1.7	9.3	9.22	9.25	9.25	16.05	22.7	11.85	16.88
SE(m)	1.89	1.89	6.537	8.772	0.17	0.17	0.43	0.145	0.75	0.75	0.59	0.527	1.10	1.10	1.704	1.164
CD	5.43	5.43	18.72	N.S.	N.S.	N.S.	N.S.	N.S.	2.16	2.16	1.70	N.S.	N.S.	N.S.	4.880	3.389
CV	9.26	9.26	13.36	16.297	18.2	18.2	50.0	14.10	16.1	16.11	13.636	10.769	15.25	15.2	25.267	12.386

Table 2: Effect of plant growth promoting rhizobacteria bio capsules on growth and yield characteristics of turmeric

Treatments	Leaf length (cm)			Pooled mean	Leaf width (cm)			Pooled mean	Number of mother rhizomes			Pooled mean	Fresh rhizome yield kg/plot			Pooled mean	Fresh rhizome yield t/ha			Pooled mean
	2018-19	2019-20	2020-21		2018-19	2019-20	2020-21		2018-19	2019-20	2020-21		2018-19	2019-20	2020-21		2018-19	2019-20	2020-21	
T_1V_1	31.1	43.32	29.45	34.62	12.7	12.4	9.05	11.38	1.55	1.55	1.4	1.5	13.56	14.25	13.98	13.93	33.89	35.62	34.94	34.81
T_1V_2	39.4	45.35	37.2	40.65	13.05	12.42	11.9	12.45	1.67	1.4	1.4	1.49	13.23	13.98	13.12	13.44	33.07	34.94	32.79	33.6
T_1V_3	39.6	42.95	35.4	39.31	13.6	12.67	10.6	12.29	1.475	1.3	1.55	1.44	14.23	13.45	12.68	13.45	35.57	33.62	31.69	33.62
T_2V_1	50.2	48.5	47.2	48.63	12.55	12.65	12.9	12.7	1.15	1.5	1.6	1.41	15.23	14.89	15.87	15.33	38.07	37.22	39.67	38.32
T_2V_2	41.1	35.37	42.85	39.77	13.25	12.1	13.2	12.85	1.575	1.6	1.85	1.67	14.23	14.35	13.96	14.18	35.57	35.87	34.89	35.44
T_2V_3	38.6	48.6	43.52	43.57	12.9	12.8	14.0	13.23	1.85	1.7	1.65	1.73	14.36	13.89	14.85	14.36	35.89	34.72	37.12	35.91
T_3V_1	36.65	46.42	37.5	40.19	12.73	12.95	12.7	12.79	1.25	1.55	1.75	1.51	10.23	11.12	10.32	10.55	25.57	27.79	25.79	26.38
T_3V_2	38.8	49.225	40.45	42.82	13.25	12.55	13	12.93	1.37	1.5	1.5	1.45	10.23	9.66	10.65	10.18	25.57	24.14	26.62	25.44
T_3V_3	40.05	53.72	45.15	46.30	13.02	13.35	13.8	13.39	1.3	1.55	1.45	1.43	10.36	9.4	10.52	10.09	25.89	23.49	26.29	25.22
T_4V_1	35.55	45.72	47.8	43.02	12.6	12.62	16.67	13.96	1.65	1.7	2.0	1.78	12.36	12.56	11.98	12.3	30.89	31.39	29.94	30.74
T_4V_2	39.95	47.55	45.8	44.43	13.9	13.35	14.27	13.84	1.5	1.5	1.8	1.6	12.36	11.85	12.02	12.07	30.89	29.62	30.04	30.18
T_4V_3	41.8	50.275	42.15	44.74	13.65	13.05	13.5	13.4	1.65	1.45	1.9	1.66	10.98	11.23	10.32	10.84	27.44	28.07	25.79	27.1
T_5V_1	36.55	38.025	31	35.19	13.1	12.15	10.5	11.91	1.3	1.45	1.3	1.35	8.96	9.03	8.54	8.84	22.39	22.57	21.34	22.1
T_5V_2	40.4	51.325	41.7	44.47	13.26	13.07	13.25	13.19	1.37	1.5	1.75	1.54	10.23	9.23	8.52	9.32	25.57	23.07	21.29	23.31
T_5V_3	40.75	44.27	49.25	44.75	13.15	13.32	16.05	14.17	1.475	1.3	1.6	1.45	7.99	9.23	8.54	8.58	19.97	23.07	21.34	21.46
SE(m)	1.89	1.89	3.293	2.135	0.822	0.822	0.92	0.649	0.064	0.064	0.16	0.06	1.16	1.16	0.554	0.285	4.22	4.22	1.385	0.714
CD	5.43	5.43	9.432	6.218	2.355	2.355	2.65	N.S.	0.184	0.184	N.S.	0.24	3.32	3.32	1.588	0.848	0.822	0.822	3.966	2.121
CV	9.26	9.26	16.313	8.930	14.13	14.13	14.242	8.668	7.901	7.901	19.95	9.53	16.06	16.06	11.88	3.887	14.13	14.137	11.881	3.890

Conclusion

Application of *Trichoderma* bio capsules and GRB 35 capsules along with package of practices is proved to improve growth and fresh rhizome yield in turmeric. In case of varieties Duggirala red found to give higher growth and fresh rhizome yield followed by IISR Prathibha. Hence the use of trichoderma and GRB-35 capsules recommended in turmeric cultivation for higher yield

Future scope

Further field research and testing must be conducted to completely discover the potential of PGPR and develop feasible, widespread applications. Eco-friendly PGPR approaches that significantly enhance plant growth and increase crop yields are now achievable due to these improvements.

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