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Plant Growth Promoting Rhizobacteria Bio Capsules: Enhancing Ginger Growth and Yield

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The study aimed to assess the impact of plant growth promoting rhizobacteria capsules on the growth and yield of ginger. PGPRs known for their role in nitrogen fixation, phosphate solubilization, and hormone secretion. These PGPR's tested at the Turmeric Research Station, Kammarpally across three consecutive years (2018-2021) in combination with three ginger varieties (Mahima, Maran, Local type) and five different treatments 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). The treatment T_4V_1 (POP + GRB 35 capsule with Mahima variety), produced the highest fresh rhizome yield with 6.28 kg plot^{-1} and 21.53 t ha^{-1} followed by T_4V_2 (POP + GRB 35 capsule with Maran variety) at 6.16 kg plot^{-1} and 20.15 t ha^{-1}. These results suggest that GRB 35 capsules significantly enhance ginger yield, offering a sustainable approach to ginger cultivation.

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Keywords: Growth promoting rhizobacteria; bio capsules; ginger; yield enhancement.

1. INTRODUCTION

Ginger (*Zingiber officinale* Rosc.) belongs to the Zingiberaceae family, is a perennial herbaceous monoco cultivated commercially for its rhizomes. It is traditionally grown as an annual crop in tropical and subtropical climateswhere, it thrives best under humid conditions. Ginger has been grown for over 5000 years, with its origin in South East Asia. Although it is now cultivated in various regions, including Africa. Major ginger producing countries include Nigeria, which accounts for 56.23% of the world's production area, followed by Bangladesh, India, China, and Indonesia, which contribute approximately 23.6, 4.7, and 3.4 per cent of the total area of ginger cultivation, respectively. In India, ginger is widely used in pickles, food additives, confections, and traditional remedies. Its medicinal properties, such as antioxidant effects and the ability to alleviate nausea from various causes, including motion sickness, pregnancy, surgery, and chemotherapy make it a valuable ingredient in both traditional and modern medicine.

The importance of sustainable agriculture has grown in recent years due to its focus on long-term environmental and social benefits. Sustainable farming practices are crucial for reducing reliance on artificial pesticides and fertilizers, improving plant health, and maintaining soil quality [1]. Preserving soil diversity and employing eco-friendly practices are critical for ensuring long-term environmental health and food security [2]. Plant growth promoting rhizobacteria (PGPR) represent a key component of sustainable agriculture. These beneficial microorganisms enhance plant growth through various mechanisms including nitrogen fixation, phosphorous solubilization, and production of phytohormones such as auxins, gibberellins, and cytokinins (Pantigoso *et al*, 2019). 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 [3]. PGPR also improve soil health by competing with harmful microbes, thereby reducing pathogen invasion and enhancing plant resistance to environmental factors like drought, salinity, and extreme temperatures.

The rhizosphere of a plant is home to numerous PGPR that play a crucial role in plant development. They contribute to increased tolerance to biotic and abiotic stress, reduced need for chemical inputsand enhanced soil fertility, and nutrient uptake. Additionally PGPR can aid in soil bioremediation and enhance crop yield, making them a valuable tool for promoting sustainable agricultural practices. This study aims to explore the role of PGPR bio-capsules in enhancing ginger growth and yield, highlighting their potential benefits and contributions to sustainable agriculture. PGPRs serve as the most major source of biofertilizer strains, enhancing soil quality and promoting sustainable agriculture with reduced reliance on fertilizers or pesticides [4]. Promoting soil health through sustainable agricultural practices is imperative for ensuring food security and environmental sustainability. Adoption of conservation tillage techniques, crop rotation and diversification play a pivotal role in enhancing nutrient cycling, suppressing pests, and mitigating diseases. Precision agriculture technologies aid in optimizing resource utilization, minimizing inputs, and mitigating environmental impacts [5].

2. MATERIALS AND METHODS

The field experiment was conducted to study the effect of different PGPR biocapsules and talc formulations on growth and yield of ginger at Turmeric research station, Kammarpally, Nizamabad district, Telangana during 3 consecutive years from 2018-19 to 2020-21. The initial soil conditions included a slightly alkaline pH of (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-Mahima, V_2-Maran, V_3-Local type 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

Fig. 1. Treatments used for randomized block design with three replications

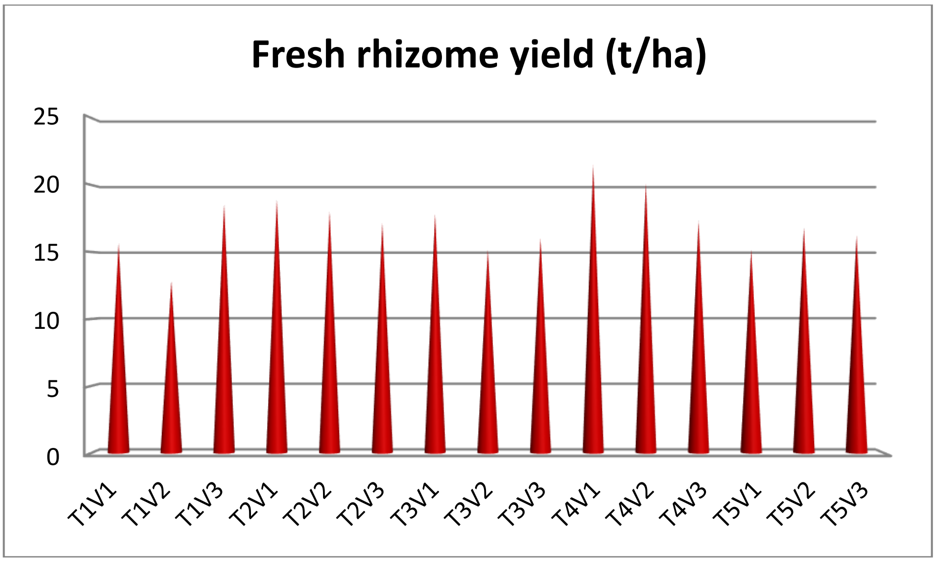

Fig. 2. Effect of plant growth promoting rhizobacteria bio capsules on growth and yield characteristics of ginger

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 (Panse and Sukhatme 1957).

Table 1. Effect of plant growth promoting rhizobacteria bio capsules on growth and yield characteristics of ginger

	Plant height (cm)			Number of shoots			Height of shoot (cm)			Leaf length (cm)		
	2019-20	**2020-21**	**Pooled mean**	**2019-20**	**2020-21**	**Pooled mean**	**2019-20**	**2020-21**	**Pooled mean**	**2019-20**	**2020-21**	**Pooled mean**
T_1V_1	40.85	40.5	40.675	10.32	10.36	10.34	21.17	20.8	20.985	15.65	15.4	15.525
T_1V_2	53.65	50.8	52.225	8.65	8.69	8.67	20.2	19.2	19.7	15.95	16.3	16.125
T_1V_3	44.52	43.8	44.16	9.54	10.21	9.875	22.22	21.4	21.81	15.9	17.2	16.55
T_2V_1	44.05	43.0	43.525	10.36	9.65	10.005	15.42	16.4	15.91	17.52	18.4	17.96
T_2V_2	42.52	42.6	42.56	10.23	11.23	10.73	16.87	17.4	17.135	16.3	16.6	16.45
T_2V_3	37.17	38.5	37.835	7.69	8.54	8.115	20	20.1	20.05	14.21	16.34	15.275
T_3V_1	35.25	36.0	35.625	8.54	7.36	7.95	18.92	20.7	19.81	15.5	15.4	15.45
T_3V_2	46.3	45.4	45.85	9.63	10.25	9.94	18.45	20.7	19.575	14.27	15.1	14.685
T_3V_3	45.27	45.3	45.285	11.21	10.45	10.83	20.57	1.4	10.985	16.52	15.21	15.865
T_4V_1	55.23	56.78	56.005	13.21	12.69	12.95	25.36	24.15	24.75	20.12	21.33	20.725
T_4V_2	54.36	53.96	54.16	12.56	12.36	12.46	23.31	24.21	23.76	19.36	20.45	19.905
T_4V_3	45.65	49.0	47.325	10.36	9.21	9.785	22	21.6	21.8	16.75	18.1	17.425
T_5V_1	49.07	48.3	48.685	8.52	7.63	8.075	19.8	21.3	20.55	12.31	13.45	12.88
T_5V_2	44.45	35.2	39.825	7.65	8.12	7.885	21.25	20.1	20.675	16.3	16.4	16.35
T_5V_3	41.5	42.7	42.1	9.21	10.36	9.785	16.97	16.5	16.735	14.55	16.4	15.475
SE(m)	1.251	1.070	1.128	0.538	0.636	0.563	0.566	0.525	0.542	0.556	0.548	0.521
CD (5%)	3.584	3.065	3.345	1.540	1.823	1.634	1.622	1.505	1.534	1.593	1.569	1.563
CV %	5.682	4.927	5.178	6.175	7.282	7.165	5.851	5.434	5.634	6.634	6.388	6.513

T1-POP + Trichoderma (Talc formulations) + GRB 35 (Talc formulations), T2- POP + Trichoderma capsules + GRB 35 capsule, T3- POP + Trichoderma capsules, T4- POP + GRB 35 capsule, T5- POP (Package of Parctice)

Table 2. Effect of plant growth promoting rhizobacteria bio capsules on growth and yield characteristics of ginger

	Leaf width (cm)			Leaf petiole length (cm)			Fresh rhizome yield kg plot^{-1}			Fresh rhizome yield (t ha^{-1})		
	2019-20	2020-21	Pooled mean	2019-20	2020-21	Pooled mean	2019-20	2020-21	Pooled mean	2019-20	2020-21	Pooled mean
T_1V_1	1.72	1.55	1.63	1.7	1.6	1.65	4.8	4.6	4.7	16.0	15.33	15.66
T_1V_2	1.35	1.45	1.4	1.65	1.7	1.675	3.8	3.91	3.855	12.66	13.03	12.85
T_1V_3	1.65	1.65	1.65	1.77	1.7	1.735	5.6	5.56	5.58	18.66	18.53	18.6
T_2V_1	1.5	1.65	1.57	1.55	1.7	1.625	5.7	5.67	5.685	19.0	18.9	18.95
T_2V_2	1.6	1.55	1.57	1.8	1.9	1.85	5.5	5.34	5.42	18.33	17.8	18.06
T_2V_3	1.5	1.6	1.55	1.6	1.8	1.7	5.2	5.12	5.16	17.33	17.06	17.2
T_3V_1	1.65	1.55	1.6	1.8	1.8	1.8	5.4	5.32	5.36	18.0	17.73	17.86
T_3V_2	1.52	1.35	1.43	1.5	1.7	1.6	4.5	4.63	4.565	15.0	15.43	15.21
T_3V_3	1.65	1.65	1.65	1.77	1.6	1.685	4.9	4.75	4.825	16.33	15.83	16.08
T_4V_1	1.82	1.77	1.79	1.77	1.8	1.785	6.2	6.32	6.28	20.66	22.41	21.53
T_4V_2	1.4	1.35	1.37	2.1	2.1	2.1	5.9	6.42	6.16	19.66	20.65	20.15
T_4V_3	1.57	1.58	1.57	1.82	1.8	1.81	5.3	5.12	5.21	17.66	17.06	17.36
T_5V_1	1.67	1.62	1.64	1.75	1.8	1.775	4.6	4.53	4.565	15.33	15.1	15.21
T_5V_2	1.65	1.7	1.67	1.67	1.7	1.685	5.1	5.01	5.055	17.0	16.7	16.85
T_5V_3	1.65	1.65	1.65	1.5	1.6	1.55	4.9	4.87	4.885	16.33	16.23	16.28
SE(m)	0.122	0.126	0.116	0.132	0.090	0.108	0.437	0.340	0.397	1.16	0.906	0.964
CD (5%)	N.S.	N.S.	N.S	N.S.	N.S.	N.S	1.251	0.974	1.145	3.33	2.596	3.174
CV %	15.29	15.991	15.234	15.36	10.094	12.654	13.12	10.016	11.964	13.1	10.016	11.234

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 (Package of parctice)

3. RESULTS AND DISCUSSION

3.1 Growth Characters

"Significant differences were observed with the growth parameters plant height, number of shoots, height of shoot, leaf length, leaf width. The maximum mean plant height (56.0 cm), number of shoots (12.95), height of shoot (24.75), leaf length (20.72 cm), leaf width (1.79 cm) were recorded with T_4- POP + GRB 35 capsule with Mahima variety which may be due to the direct mechanisms observed in PGPR include N_2-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" [6]. "Many scientists reported that plant growth promoting rhizobacteria might enhance plant height and productivity by synthesizing phyto-hormones" [7-9]. "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" (Illangumaran and Smith, 2017). "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" [10]. Gray and Smith [11] 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" [12,13]. "Phytohormones are responsible for plant growth development and allow plants to tolerate different stress conditions" (Shaterian *et al*., 2005). "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" [14] Kaur et al., (2016). "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" [15,16]. "An understanding of ecological conditions effecting on bacterial inoculants is important when introducing microbes for increasing plant growth and productivity. The bacteria strains Pseudomonas alcaligenes PsA15, Bacillus polymyxa BcP26 and Mycobacterium phlei MbP18 had a much better stimulatory effect on plant growth and nitrogen (N), phosphorus (P) and potassium (K) uptake of maize in nutrient deficient calcisol soil. Their stimulatory efficiency reduced in relatively rich loamy sand soil where bacterial inoculants stimulated only root growth and N, K uptake of root" [17-19].

3.2 Yield Characters

The maximum mean fresh rhizome yield per plot (6.28 kg/plot) and maximum mean fresh rhizome yield per hectare (21.53 t/ha) have been observed with T4V1- POP + GRB 35 capsule with Mahima variety followed by T4V2- POP + GRB 35 capsule with Maran variety which recorded fresh rhizome yield per plot (6.16 kg/plot) and mean fresh rhizome yield per hectare (20.15 t/ha). The results are in conformity with Kuan et al. [20-22] 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. [23,24] 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" [3]. "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" [6].

4. CONCLUSION

The application of GRB 35 capsules, combined with recommended practices, significantly improves ginger growth and rhizome yield. Among the ginger varieties tested, 'Mahima' exhibited the highest growth and yield, followed by 'Maran'. In order to increase yields and improve crop performance overall, it is suggested to use and incorporate GRB 35 capsules into ginger cultivation practices.

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.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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