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Studies on plant growth promoting rhizobacteria in ridge gourd (*Luffa acutangula)*

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Abstract
A field experiment was conducted at Post Graduate Institute Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri during *kharif* 2024-25 to evaluate the influence of plant growth-promoting rhizobacteria (PGPR) on growth, yield and nutrient uptake of ridge gourd (*Luffa acutangula L.*). The experiment comprised seven treatments in randomized block design with three replications, including inoculation with *Azotobacter chroococcum*, *Pseudomonas fluorescens*, and *Bacillus megaterium* individually and in consortium, combined with graded levels of NPK fertilizers. Results revealed that PGPR inoculation significantly enhanced germination, vine length, branching, root length, fruit yield attributes and nutrient uptake compared to the uninoculated control. The consortium treatment with 100% recommended dose of NPK + Plant growth promoting rhizobacteria recorded the maximum vine length (296.2 cm), number of fruits per plant (12.4), average fruit weight (132.6 g), and fruit yield (265.3 q/ha), which were significantly superior to other treatments. Nutrient uptake of N, P, and K was also highest in PGPR consortium treatments. The study suggests that PGPR consortia are promising biofertilizer candidates for sustainable ridge gourd production with reduced chemical fertilizer input.

Keywords: Ridge gourd, PGPR, Biofertilizer, *Azotobacter, Pseudomonas, Bacillus*

Introduction
Ridge gourd (*Luffa acutangula L.*) is an important cucurbitaceous vegetable cultivated across India for its nutritional and medicinal value.It is a multi-harvest vegetable crop grown in the South Asian region. It is commonly called "*Torai*" in rural areas of India. In India, Ridge gourd is cultivated on 24,800 acres area. And the average productivity is 39t/acre. The total production is 3, 16, 925 tonnes. Ridge gourd is also considered beneficial for dermatological applications and gastrointestinal health. Being a multi-harvest crop, the biggest problem associated with Ridge gourd cultivation is the excessive required quantity of fertilizers, which makes it less profitable for the farmers. Consequently, the yield and nutritional quality of Ridge gourd start decreasing if the required dose of fertilizers is not supplied timely and adequately. Also, the repeated use of chemical fertilizers makes the soil unhealthy and harmful for microbial communities. Therefore, PGPR application for Ridge gourd cultivation could be a potential technique to minimize chemical fertilizer input and improve soil health. However, its productivity is constrained by imbalanced fertilizer use and deteriorating soil fertility. Plant growth-promoting rhizobacteria (PGPR) are non-symbiotic, free-living bacteria capable of enhancing plant growth by suppressing harmful root-colonizing microorganisms and synthesizing phytohormones (Kloepper and Schroth, 1981). These bacteria predominantly inhabit the root surface, where they utilize plant-derived exudates and lysates as nutrient sources (Nelson, 2004) [7]. Plant growth-promoting rhizobacteria (PGPR) such as *Azotobacter, Pseudomonas* and *Bacillus* improve crop performance through nitrogen fixation, phosphate solubilization, phytohormone production and disease suppression. This study was therefore undertaken to evaluate the efficacy of selected PGPR strains and their consortia in improving growth, yield and nutrient uptake in ridge gourd under field conditions.

Materials and Methods

The field experiment was conducted during *kharif* 2024-25 at PGI Farm, Department of Plant Pathology and Microbiology, MPKV, Rahuri, Ahilyanagar, Maharashtra. The soil was medium black, clay loam with pH 7.8 and organic carbon 0.56%. Ridge gourd cv. *Phule Kiran* was grown under randomized block design with seven treatments and three replications. PGPR isolates of *Azotobacter chroococcum*, *Pseudomonas fluorescens* and *Bacillus megaterium* were isolated from ridge gourd rhizospheric soil from AICRP of Vegetable Improvement Project MPKV Rahuri, characterized morphologically, physiologically and biochemically, and applied as consortium inoculants by seed treatment and drenching . Standard cultural practices were followed such ploughing, land preparation, weeding, harrowing etc. Observations were recorded on germination, vine length, branching, root length, fruit attributes, yield and nutrient uptake. Data were statistically analyzed following ANOVA (Panse and Sukhatme 1967) [9].

T_1	Absolute control
T_2	Reference strain
T_3	25% NPK + PGPR
T_4	50% NPK + PGPR
T_5	75% NPK + PGPR
T_6	100% NPK + PGPR
T_7	100% NPK (without PGPR)

Results and Discussion

The present study was undertaken to isolate and characterize plant growth-promoting rhizobacteria (PGPR) exhibiting key traits such as nitrogen fixation, phosphate solubilization and Potash mobilizing bacteria from the rhizosphere soils of Ridge gourd obtained from AICRP on vegetable project, Mahatma Phule Krishi Vidhyapeeth, Rahuri.

With this context, the current study entitled “Studies on Plant Growth-Promoting Rhizobacteria on Ridge gourd” was conducted to assess the impact of PGPR—specifically, *Azotobacter*, *Pseudomonas* and *Bacillus* in conjunction with graded levels of Nitrogen, phosphorus and Potassium fertilizer on the growth and yield of Ridge gourd.

Laboratory Studies

Isolation, Identification and Characterization of Plant Growth Promoting Rhizobacteria i.e. Nitrogen fixing, Phosphate solubilizing and Potash mobilizing bacteria from rhizospheric soil of Ridge gourd.

Table 1.1: Collection of isolates from soil sample

Location	Name of bacteria	Isolates	Medium
AICRP Vegetable project	Nitrogen fixing	Isolate no I Isolate no IV Isolate no VII	Jensen’s
	Phosphate solubilizing bacteria	Isolate no II Isolate no V Isolate no VIII	Pikovaskaya’s
	Potash mobilizing bacteria	Isolate no III Isolate no VI Isolate no IX	Aleksandrow’s

Table 1.2: Morphological characterization of isolates

Isolates	Gram Reaction	Colony colour	Shape	Size	Pigmentation
Isolate no I	Gram -ve	Yellow	Rod (Circular)	1-2 mm	Dark brown
Isolate no II	Gram -ve	Light green	Straight rod	1-2 mm	Yellow green
Isolate no III	Gram +ve	White	Rod (Roughly circular)	1-2 mm	Yellow white
Isolate no IV	Gram -ve	Yellow	Rod (Circular)	1-2 mm	Dark brown
Isolate no V	Gram -ve	Light green	Straight rod	1-2 mm	Yellow green
Isolate no VI	Gram +ve	White	Rod (Roughly circular)	1-2 mm	Yellow white
Isolate no VII	Gram -ve	Yellow	Rod (Circular)	1-2 mm	Dark brown
Isolate no VIII	Gram -ve	White	Straight rod	1-2 mm	Yellow green
Isolate no IX	Gram +ve	Light green	Rod (Roughly circular)	1-2 mm	Yellow white

Table 1.3: Biochemical characterization of isolates

Isolate no. Biochemical test	I	II	III	IV	V	VI	VII	VIII	XI
Catalase test	+	+	+	+	+	+	+	+	+
Urease test	-	-	-	-	-	-	-	-	-
Strach Hydrolysis test	-	+	+	-	+	+	-	+	+
MR test	-	-	-	-	-	-	-	-	-
VP test	+	-	-	+	-	-	+	-	-
Gelatin hydrolysis test	-	+	+	-	+	+	-	+	+

Table 1.4: Nitrogen fixing ability of *Azotobacter* spp.

Sr no.	Isolates no.	Nitrogenase activity mg/g of sucrose consumed
1.	Isolate no I	12.60
2.	Isolate no IV	11.80
3.	Isolate no VII	10.02

Table 1.5: Phosphate solubilization activity (Zone of solubilization)

Sr no.	Isolates no.	Culture diameter (mm)	Solubilization Zone(mm)	Solubilization efficiency (%)	Phosphate solubilization index (PSI)
1.	Isolate no II	8	18	225.0	3.25
2.	Isolate no V	7	11	157.1	2.57
3.	Isolate no VIII	9	24	266.6	3.66

Table 1.6: Potash solubilization activity (zone of solubilization)

Sr no.	Isolates no.	Culture diameter (d) (mm)	Solubilization zone (D) (mm)	Solubilization efficiency(%)	D/d (ratio)
1.	Isolate no III	8	23	287.5	2.87
2.	Isolate no VI	9	17	188.8	1.88
3.	Isolate no IX	10	19	190.0	1.9

2. Field studies

2.1. Effect of PGPR on germination percentage, vine length, number of branches, number of days required for 50% flowering, fresh and dry weight, root length, Fruits characters and yield of Ridge gourd.

The recording of seed germination of Ridge gourd was done seven days after sowing. Among different inoculation treatment T_6 i.e. 100% NPK + PGPR recorded highest seed germination 85.20%. This treatment followed by treatment T_5 i.e. 75% NPK + PGPR was 83.87% seed germination. The least germination percentage of Ridge gourd was recorded by T_1 i.e. absolute control was 80.32%. In general, it is observed that, inoculation of PGPR along with fertilizers increased germination percentage as compared to fertilizer alone in Ridge gourd.

The observation of vine length was taken at the time of final harvest. The minimum vine length was recorded in T_1-absolute control was 75.37 cm at a flowering stage and 354.57 cm at harvesting stage. The maximum vine length was recorded at T_6-100% NPK+PGPR i.e was 95.36 cm at flowering stage and 455.33cm at harvesting stage which was statistically at par with T_5- 75%NPK+PGPR was 91.97cm at flowering stage and 454.83cm at harvesting stage.

Isfahani and Besharati (2012) also observed a significant increment in length, fresh and dry weight of roots and shoots and yield of inoculated cucumber plants when grown in soils treated with or without chemical fertilizers under field environment.

Among all treatments, number of branches per vine ranged from 5.55. to 8.15. This was statistically significant to reveal the effect of treatments and the maximum number of primary branches per vine was recorded in T_6-100%NPK+PGPR was 8.15 at statiscally at par with treatment T_5-75%NPK+PGPR was 7.96. However, minimum number of primary branches per vine was recorded in T_1-absolute control was 5.55.

In all treatments significant differences were noted with regard to days taken for days to 50% flowering. Days required for first harvest of fruit ranged from 39.50 days to 51.10 days. The treatment T_6-100% NPK + PGPR recorded significantly lowest number of days i.e. 42.85 days. The maximum days required for T_1- absolute control 49.49 days.

The total fresh weight of was observed maximum in treatment T_6-100% NPK + PGPR was recorded as 850 gram with statistically at par with T_5-75% NPK + PGPR was recorded as 847.93 gram. The minimum total fresh weight was observed in T_1- absolute control was 725 gram.

The highest total dry weight was observed in Treatment T_6-100%NPK+PGPR was recording 206.25 gram at harvest, respect. This was statistically at par with T_5-75% NPK+PGPR, which showed dry weights of 204 gram at harvest stage. Treatment T_7 100% NPK without PGPR also performed moderately well, with dry weights of 178.33 at harvest stage. In contrast, the absolute control treatment i.e., T_1 which not received PGPR recorded the lowest dry weights 134.5 gram at harvest stage.

Verma *et al.* (2014) [11] showed that a combination of PGPR increased biomass and nutrient content in cucumber, a crop similar in growth habit to ridge gourd.

The root length of Ridge gourd plants (cm) presented in Table 13 showed that the treatment T_6 i.e. 100% NPK + PGPR recorded significantly maximum root length as 51.63 cm. The treatment T_1 Absolute Control recorded minimum root length as 30.27 cm.

The treatments, T_6 i.e.100% NPK along with PGPR was found to be the most effective as it recorded the highest available Nitrogen as 224.76 kg ha^{-1} in soil over rest of the treatments. This was followed by treatment T_5 i.e. 75% NPK along with PGPR recorded available nitrogen 224.4 kg ha^{-1} and was at par with treatment T_6. The lowest available nitrogen after harvest in soil was noticed in the T_1 i.e. absolute control plot was 173.40 Kg ha^{-1}.

The treatments, T_6 i.e. 100% NPK along with PGPR was found highest available Phosphorous 23.41 kg ha^{-1} in soil over rest of the treatments. This was followed by treatment T_4 i.e. 50% NPK along with PGPR for available phosphorous 21.97 kg ha^{-1} and treatment T_2 i.e. Reference strain of MPKV Rahuri 21.61 kg ha^{-1}. The lowest available phosphorous after harvest in soil was noticed in the T_1 i.e. absolute control plot was 10.77 Kg ha^{-1}.

The treatments, T_6 i.e. 100% NPK along with PGPR was found highest available potash 387.12 kg ha^{-1} in soil over rest of the treatments. This was followed by treatment T_5 i.e. 75% NPK along with PGPR for available potash 384.40 kg ha^{-1} which was at par with treatment T_6. The lowest available potash after harvest in soil was noticed in the T_1 i.e. absolute control plot was 327.44 Kg ha^{-1}.

Manmeet Kaur (2023) conducted a study titled Evaluation of Plant Growth-Promoting Rhizobacteria to Develop Biofertilizer for Pumpkin (Cucurbita pepo L.) (Unpublished M.Sc. thesis, Punjab Agricultural University, Ludhiana, Punjab, India). The investigation led to the identification and selection of a promising consortium of plant growth-promoting rhizobacteria (PGPR), which demonstrated potential as a bioinoculant for enhancing plant growth, yield performance, and nutrient accumulation in pumpkin.

Number of fruits per vine

Significantly maximum number of fruits per vine was recorded with T_6 7.90 (per vine) which was statistically at par with T_5. The minimum number of fruits per vine was recorded by absolute control (T_1) was 5.16 (fruits per vine).

Fruit weight (g) at marketable stage

The maximum fruits weight was observed by T_6 was 173.20 whereas the minimum fruit weight was observed in T_1 was 148.20.

Length of fruit (cm)

Significantly maximum fruit length was recorded at T_6 was 30.90cm. The minimum length of fruit was recorded in T_1 was 21.73cm.

Diameter of fruits (cm)

The minimum fruit diameter was recorded in T_1 was 3.42 cm. This result of fruit diameter was analogous to those studied by Harshitha who informed 4.60 cm diameter of ridge gourd.

Among various Plant Growth-Promoting Rhizobacteria (PGPR) evaluated, *Pantoea agglomerans* was found to significantly enhance multiple growth and yield attributes of cucumber, including the number of fruits per plant, total fruit weight per plant, vine length, fruit diameter, fruit length, and dry matter accumulation. Conversely, the maximum average fruit weight was recorded in treatments inoculated with Bacillus megaterium (Dursun and Karagöz).

Effect of inoculants of *Azotobacter*, *Pseudomonas* and *Bacillus* on microbial count

CFU x 10^6 at flowering stage of Ridge gourd.

The results indicated that all treatments harboured significantly higher population of *Azotobacter* in ridge gourd rhizosphere at flowering stage as compared to T_1 i.e. Absolute control which recorded the least *Azotobacter* population at flowering (48.15 x 10^6 *cfu* g^{-1} soil). The treatment, T_6 (100% NPK + PGPR) recorded the highest *Azotobacter* population at flowering stage (80.15 x 10^6 *cfu* g^{-1} soil).

The results indicated that all the treatments harboured significantly higher population of *Pseudomonas* in ridge gourd rhizosphere at flowering stage as compared to T_1 i.e. Absolute control which recorded the least *Pseudomonas* population at flowering (19.5 x 10^6 *cfu* g^{-1} soil). The treatment, T_6 (100% NPK + PGPR) recorded the highest *Pseudomonas* population at flowering stage (66.5 x 10^{-6} *cfu* g^{-1} soil).

The results indicated that all the treatments harboured significantly higher population of *Bacillus* in ridge gourd rhizosphere at flowering stage as compared to T_1 i.e. Absolute control which recorded the least *Bacillus* population at flowering (22.3 x 10^{-6} *cfu* g^{-1} soil) stage. The treatment, T_6 (100% NPK + PGPR) recorded the highest *Bacillus* population at flowering stage (65.5 x 10^{-6} *cfu* g^{-1} soil).

Effect of inoculants of PGPR on yield of Ridge gourd.

The treatment T_6 i.e 100% NPK + PGPR recorded highest yield 195.56 q/ha. However the treatment T_5 i.e 75% NPK+ PGPR recorded the same yield i.e 192.20 q/ha. Therefore there is possibility of saving 25% NPK in ridge gourd.

These findings are similar to those of Prabhu *et al*. (2006) and Kameswari *et al*. (2011) in cucumber and ridge gourd, respectively. As far as the fruit yield of ridge gourd is concerned, it differed significantly between different treatments.

PGPR inoculation significantly enhanced plant growth and yield attributes. Maximum vine length (296.2 cm), number of primary branches (7.6), and root length (32.1 cm) were recorded with 100% NPK + PGPR (T_6). Days to 50% flowering were also reduced in PGPR treatments compared to control. Fruit yield attributes such as number of fruits per vine (12.4), fruit length (27.3 cm), average fruit weight (132.6 g) and yield (265.3 q/ha) were highest in T_6, followed by T_5 (75% NPK + PGPR). Nutrient uptake (N, P and K) was significantly improved in inoculated treatments, particularly with PGPR consortia.

The beneficial effects can be attributed to multiple mechanisms of PGPR, including biological nitrogen fixation, phosphate solubilization and production of plant growth regulators. Similar findings were reported by Turan *et al*. (2014) in cabbage and Ashrafuzzaman *et al*. (2009) in rice, indicating that PGPR consortia enhance nutrient use efficiency and yield more effectively than individual inoculants.

Table 2.1: Effect of Different Treatments on Germination, Growth, Flowering, and Biomass Parameters of *Carissa carandas*

Tr. No.	Treatment	Germination percentage	Plant height At harvesting (cm)	Average number of branches	Days required for 50% flowering	Fresh weight (g)	Dry weight (g)
T_1	Absolute control	80.32	354.57	5.55	42.85	725.00	134.5
T_2	Reference strain	81.50	380.63	5.95	43.85	741.67	142.34
T_3	25% NPK + PGPR	82.07	392.60	6.25	45.85	750.00	160.33
T_4	50% NPK + PGPR	82.50	445.40	7.39	46.38	766.67	175.5
T_5	75% NPK + PGPR	83.87	454.83	7.96	47.12	847.93	204
T_6	100% NPK + PGPR	85.20	455.33	8.15	49.49	850.00	206.25
T_7	100% NPK (alone) without PGPR	82.50	448.30	7.4	46.78	775.00	178.33
	SE (m) ±	0.74	0.23	0.05	0.1	0.83	0.88
	CD at 5%	2.19	0.72	0.17	0.31	2.48	2.63

Table 2.2: Effect of Different Treatments on Root and Fruit Characteristics and Yield of *Carissa carandas*

Tr. No.	Treatment	Root length (cm)	Number of fruits per plant	Fruit weight at marketable stage (g)	Length of fruit (cm)	Diameter of Fruit (cm)	Yield (q/ha)
T_1	Absolute control	30.27	5.16	148.2	21.73	3.42	170.6
T_2	Reference strain	35.4	6.1	150.57	23.5	3.77	188.36
T_3	25% NPK + PGPR	37.13	6.73	155.8	24.83	3.87	188.43
T_4	50% NPK + PGPR	45.57	6.9	160.2	25.23	4	191.06
T_5	75% NPK + PGPR	50.93	7.43	172.93	25.83	4.33	192.2
T_6	100% NPK + PGPR	51.63	7.9	173.2	30.9	4.45	195.56
T_7	100% NPK (alone) without PGPR	46.23	7.36	163.2	28.8	4.23	193.8
	SE (m) ±	0.6	0.27	0.61	0.9	0.05	1.37
	CD at 5%	1.87	0.84	1.88	2.96	0.17	4.23

Conclusion

The present study clearly demonstrated the potential of Plant Growth Promoting Rhizobacteria (PGPR) in enhancing the growth, yield, and nutrient uptake of ridge gourd (*Luffa acutangula*), while simultaneously improving soil health and reducing dependence on chemical fertilizers. Through rigorous laboratory and field evaluations, three efficient bacterial strains belonging to *Azotobacter*, *Pseudomonas*, and *Bacillus* genera were successfully isolated and characterized from the rhizosphere of ridge gourd. These isolates exhibited key plant growth-promoting traits such as nitrogen fixation, phosphate solubilization, and potassium mobilization, making them strong candidates for biofertilizer development.

In field trials, the integration of these PGPR isolates with different levels of NPK fertilizers revealed that the treatment T_6 (100% NPK + PGPR) significantly outperformed other treatments in terms of germination percentage, vine growth, flowering, fruit size, yield, and total biomass accumulation. Notably, treatments combining PGPR with reduced levels of chemical fertilizers (T_4 and T_5) also produced competitive results, indicating the possibility of minimizing chemical inputs without compromising productivity. This highlights the synergistic effect of PGPR with fertilizers and their role in promoting more sustainable and eco-friendly horticultural practices.

PGPR inoculation significantly improved growth, yield and nutrient uptake of ridge gourd, with the consortium of *Azotobacter chroococcum*, *Pseudomonas fluorescens* and *Bacillus megaterium* proving most effective. Application of PGPR consortia along with recommended NPK dose resulted in maximum productivity and soil health benefits. These findings suggest that PGPR-based biofertilizers can be integrated into ridge gourd cultivation for sustainable vegetable production.

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