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Effect of Plant Growth Promoting Rhizobacteria, *Bacillus safensis* on Growth and Yield of Ginger (*Zingiber officinale* R.) Under the Mid-hill Zone of Himachal Pradesh

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ABSTRACT

The study was conducted during *kharif*, April–November, 2023 in the Department of Vegetable Science, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India to explore the potential of plant growth-promoting rhizobacteria, *Bacillus safensis*, on growth and yield of ginger (*cv.* Solan Giriganga). The trial was laid out in randomized complete block design (factorial) with 7 treatments including varying levels of phosphorus fertilizer (50%, 75% and 100% of the recommended dose) with or without *Bacillus safensis* along with control. Various parameters were recorded including plant height, tiller number, leaf size, rhizome yield, dry matter recovery, oleoresin content, essential oil content, soil nutrient status and nutrient uptake. Ginger yield proved to be significantly affected by combination of *Bacillus safensis* and 75% RDP producing the highest ginger yield of 23.27 t ha^{-1}, maximum net returns of ₹ 7,93,308 and benefit-cost ratio of 1.32. This study concluded that the use of *Bacillus safensis* in conjunction with reduced phosphorus fertilizer (37.5 kg ha^{-1} P_2O_5) is an effective strategy for enhancing ginger yield and economic returns.

KEYWORDS: Ginger, growth, PGPR, phosphorus, solubilization, quality, yield

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1. INTRODUCTION

Ginger (*Zingiber officinale* R.) has been used as a medicinal herb and spice for cooking since ancient times (Nour et al., 2017), belonging to family Zingiberaceae and native to South-East Asia. Botanically, ginger is an herbaceous perennial with an underground modified stem called a rhizome. It is grown annually and thrives in shaded environments (Anh et al., 2020). Globally, it is widely used for seasoning, condiments and in herbal medicine. It has various medicinal properties (Nair, 2019). It is known for its health benefits such as reducing blood clotting, lowering cholesterol, helps prevent obesity, asthma, bronchitis, motion and morning sickness, and providing antioxidant and anti-carcinogenic properties (Crichton et al., 2019; Mao et al., 2019). Fresh ginger is typically consumed locally, while dried ginger is commonly traded internationally (Ravindran et al., 2016). It is used to produce a variety of products such as ginger oil, oleoresin, ginger candy, ginger powder, brined ginger, ginger flakes and preserved ginger making it a versatile product (Dev and Sharma, 2016).

India is the leading global producer and exporter of ginger, accounting for 50% of global output. Major ginger-growing states include Madhya Pradesh, Karnataka, Assam and West Bengal. In 2022–2023, India cultivated ginger on 190.96 thousand hectares, producing 2201.19 thousand mt, with Madhya Pradesh as the top producer (Anonymous, 2023a). Other significant producers include China, Jamaica and Nigeria, while major importers are the UK, USA, Japan and Singapore. In Himachal Pradesh, ginger is a crucial cash crop in the mid and low hills, particularly in Sirmour, which is the largest producer. In 2022–2023, ginger was grown on 2.72 thousand ha in Himachal Pradesh, yielding 15.68 thousand mt (Anonymous, 2023b). Ginger thrives in tropical and sub-tropical climates at elevation up to 1500 m preferring temperatures between 28–35°C. It needs 1500–300 mm of well-distributed rainfall and benefits from dry periods before planting (Pruthi, 1998). Light sandy loam soil is the most ideal for cultivating ginger. The plant does not thrive in waterlogged conditions or in gravelly or overly sandy soils (Prasad and Bhardwaj, 2016).

Ginger plants need significant nutrients due to their shallow roots and high dry matter yield. Applying organic manure boosts crop yield and improves soil properties (Dudhat et al., 1997). Plant growth-promoting rhizobacteria (PGPR) are valuable for boosting crop yields and preserving soil health. They colonize plant roots, respond to plant signals and produce metabolites that enhance growth and induce systemic resistance against pathogens (Kour et al., 2020). PGPR operate through direct mechanisms like bio-fertilization and root growth stimulation, as well as indirect methods such as disease suppression and nutrient competition. Common PGPR species include *Bacillus*, *Azospirillum* and *Rhizobium* (Giri et al., 2019). These bacteria decompose the complex molecules found in the soil, transforming them into a form that is accessible to plants, thereby enhancing soil fertility (Malua and Vessilev, 2014; Atajan et al., 2019; Sood et al., 2019). Phosphorus-based treatments have a major effect on ginger's developmental traits and enhance production results (Hashem et al., 2019). The inoculation of PGPR is commonly documented across various crops and has been shown to improve growth and yield (Fukami et al., 2018; Linu et al., 2019; Santoyo et al., 2021). PGPR have shown positive effects on cereals, fruits, vegetables and spices by boosting nutrient uptake and fertilizer efficiency, reducing the need for excessive fertilizers (Adesemoye et al., 2009). PGPRs enhance plant growth by mechanisms such as the solubilization of phosphate (Li et al., 2018), improving nutrient absorption (Li et al., 2017; Liu et al., 2016) and facilitating nitrogen fixation (Solanki et al., 2017; Li et al., 2018). Phosphorus, existing in both inorganic and organic forms, is often scarce and inaccessible to plants, but phosphorus-solubilizing microorganisms (PSM) make it available in the rhizosphere (Oliveira et al., 2009; Schachtman et al., 1998). In this research, we investigated how plant growth promoting rhizobacteria influenced the phosphorus solubilization potential, growth and yield of ginger.

2. MATERIALS AND METHODS

2.1. *Description of study site and climatic conditions*

The experiment was conducted during *kharif* (April to November), 2023 at vegetable research farm, Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India located at an elevation of 1270 m above mean sea level at the latitude of 30°5'N and longitude 77°11'E, 13 km away from Solan. The soil of the experimental field was gravelly loam to gravelly clay loam in texture. This area falls in the sub-humid, sub-temperate and mid-hill zone of Himachal Pradesh. The maximum temperature ranged from 21.4°C–31.7°C and minimum from 5.8°C–21.2°C. November emerged as the coldest, while June experienced the highest temperatures. The total rainfall during the growing season amounted 1364.8 mm with the majority occurring from May to August.

2.2. *Experimental details*

2.2.1. *Cultivar and experimental layout*

The high yielding ginger *cv.* Solan Giriganga, which was developed and recommended by Dr YSP UHF Nauni was used in this study. The planting beds were prepared of size 3×1 m^2 with drainage channels of 0.5 m in which 50 plants were accommodated. The ginger rhizomes of uniform size were planted during the first fortnight of April at a spacing of 30×20 cm^2. The study was designed using a Randomized Complete Block Design with seven treatments and three replications, encompassing twenty-one plots across.

2.2.2. The different treatments are as follows

T_1: 100% Recommended phosphorus fertilizer, T_2: 75% Recommended phosphorus fertilizer, T_3: 75% Recommended phosphorus fertilizer and *Bacillus safensis*, T_4: 50% Recommended phosphorus fertilizer, T_5: 50% Recommended phosphorus fertilizer and *Bacillus safensis*, T_6: *Bacillus safensis* alone and T_7: Control with no phosphorus and *Bacillus safensis*.

2.2.3. Details of cultural operations

All the treatments used standard cultural practices as outlined in the Package of Practices for Vegetable Crops to ensure a healthy crop stand (Anonymous, 2020).

2.3. Observations recorded

Data were collected from a random sample of 10 plants treatment^{-1} in each replication, measuring various parameters. Growth parameters viz., plant height, tiller girth, number of tillers plant^{-1}, number of leaves tiller^{-1}, leaf dimensions and incidence of rhizome rot were recorded at 90 DAP, 120 DAP and at harvest. The crop was harvested in the second fortnight of November and yield parameters viz., rhizome length and breadth, yield plant^{-1}, yield plot^{-1} and projected yield hectare^{-1} were recorded. The quality parameters viz., dry matter recovery, oleoresin content, essential oil and crude fiber content were estimated by American Spice Trade Organization. The nutrient and economic parameters were recorded viz., soil nutrients before planting, 120 DAP and at harvest, nutrient uptake of leaf and rhizome at harvest and benefit cost (B:C) ratio.

2.4. Statistical analysis

The recorded data was analyzed using MS-Excel and OPSTAT software. Analysis of variance for the experiment was done as per the model suggested by Panse and Sukhatme (2000) for Randomized Complete Block Design (factorial).

3. RESULTS AND DISCUSSION

The experiment was conducted to study phosphorus solubilization potential on the growth, yield and quality of ginger. The results of each parameter has been discussed and interpreted in this section.

3.1. Growth traits

3.1.1. Plant height (cm)

The effect of PGPR on phosphorus solubilization and plant height was found to be significant. The maximum plant height was recorded with 75% RDP and *Bacillus safensis* (24.83 cm at 90 DAP, 44.50 cm at 120 DAP and 78.73 cm at harvest). Whereas the minimum plant height was recorded in control i.e., 19.67 cm at 90 DAP, 38.63 cm at 120 DAP and 70.70 cm at harvest (Table 1). According to Jabborova (2022), the use PGPR significantly increased the height of *Zingiber officinale* plants. Similarly, Negi (2023) found that applying PGPR to *Curcuma longa* plants led to taller shoots compared to untreated plants, supporting the findings of present study where PGPR resulted in increased plant height.

3.1.2. Tiller girth (cm)

The effect of PGPR on phosphorus solubilization and tiller girth was found to be significant. The maximum tiller girth was recorded in 75% RDP and *Bacillus safensis* (2.65 cm at 90 DAP, 4.77 cm at 120 DAP and 5.93 cm at harvest). Whereas the minimum plant height was recorded in control i.e., 1.98 cm at 90 DAP, 3.77 cm at 120 DAP and 5.02 cm at harvest (Table 1). Shadap et al. (2018) reported that combining PSB, VAM, 75% NPK and *Azospirillum* significantly increased the tiller girth in ginger. These findings aligned with those of Sanwal et al. (2007), Jana

Table 1: Effect of PGPR on phosphorus solubilization and growth characters of ginger

	Plant height (cm)			Tiller girth (cm)			Number of tillers plant^{-1}		
	90 DAP	120 DAP	At harvest	90 DAP	120 DAP	At harvest	90 DAP	120 DAP	At harvest
T_1	23.80	43.27	76.83	2.50	4.43	5.58	3.17	6.17	10.67
T_2	22.60	42.37	73.90	2.37	4.18	5.45	2.67	5.50	9.83
T_3	24.83	44.50	78.73	2.65	4.77	5.93	3.33	6.58	11.50
T_4	22.17	40.80	73.77	2.20	4.17	5.40	2.58	5.25	9.50
T_5	23.77	43.17	76.07	2.42	4.33	5.52	2.92	6.00	10.50
T_6	20.50	40.73	73.03	2.13	4.00	5.08	2.50	5.17	9.17
T_7	19.67	38.63	70.70	1.98	3.77	5.02	2.17	4.83	8.67
SEm±	0.90	0.84	1.43	0.11	0.17	0.16	0.20	0.31	0.53
CD (p=0.05)	2.81	2.62	4.47	0.34	0.53	0.48	0.63	0.97	1.64

Table 1: Continue...

	Number of leaves tiller^{-1}			Leaf length (cm)			Leaf width (cm)			Incidence of rhizome rot (%)
	90 DAP	120 DAP	At harvest	90 DAP	120 DAP	At harvest	90 DAP	120 DAP	At harvest	
T_1	8.33	13.50	18.92	12.25	22.42	27.08	1.72	2.79	3.87	11.19 (3.49)*
T_2	8.00	13.00	17.58	11.75	22.17	26.75	1.62	2.58	3.81	12.42 (3.66)
T_3	8.67	14.00	19.42	12.50	23.08	27.50	1.83	2.83	4.00	10.95 (3.46)
T_4	7.58	12.50	17.33	11.67	22.00	26.42	1.60	2.47	3.75	13.04 (3.75)
T_5	8.17	13.25	18.33	11.92	22.25	26.83	1.66	2.62	3.83	12.05 (3.61)
T_6	7.25	12.25	17.00	11.50	21.83	26.25	1.58	2.46	3.66	13.91 (3.86)
T_7	7.08	12.00	16.92	10.97	21.25	24.83	1.54	2.40	3.63	14.13 (3.89)
SEm±	0.25	0.32	0.52	0.28	0.32	0.22	0.05	0.12	0.07	0.01
CD (p=0.05)	0.77	1.01	1.61	0.89	0.99	0.68	0.16	0.26	0.22	0.03

(2006) and Negi (2023) who also observed larger tiller girth following PGPR inoculation.

3.1.3. *Number of tillers plant^{-1}*

The effect of PGPR on phosphorus solubilization and number of tillers plant^{-1} was found to be significant. The maximum number of tillers plant^{-1} was recorded in 75% RDP and *Bacillus safensis* (3.33 at 90 DAP, 6.58 at 120 DAP and 11.50 at harvest). Whereas the minimum number of tillers plant^{-1} was recorded in control i.e., 2.17 for 90 DAP, 4.83 for 120 DAP and 8.67 at harvest (Table 1). Tamang and Manivannan (2020) found that combining PGPR with other organic inputs significantly increased the number of tillers in ginger. Similarly, Negi (2023) reported that turmeric plants inoculated with *B. safensis* had more tillers than the control. These results were consistent with our findings.

3.1.4. *Number of leaves tiller^{-1}*

The effect of PGPR on phosphorus solubilization and number of leaves tiller^{-1} was found to be significant. The maximum number of leaves tiller^{-1} was recorded in 75% RDP with *Bacillus safensis* (8.67 at 90 DAP, 14.00 at 120 DAP and 19.42 at harvest). Whereas the minimum number of leaves tiller^{-1} was recorded in control i.e., 7.08 for 90 DAP, 12.00 for 120 DAP and 16.92 at harvest (Table 1). These findings were consistent with those Shadap et al. (2018), Sanwal et al. (2007) and Jana (2006), who found that ginger had the highest number of leaves tiller^{-1}. Likewise, Negi (2023) noted that turmeric plants inoculated with *B. safensis* had more leaves plant^{-1} compared to the control.

3.1.5. *Leaf length (cm)*

The effect of PGPR on phosphorus solubilization and leaf length was found to be significant. The maximum leaf length was achieved with 75% RDP and *Bacillus safensis* (12.50 cm at 90 DAP, 23.08 cm at 120 DAP and 27.50 cm at harvest). Whereas the minimum leaf length was recorded in control i.e., 10.97 cm for 90 DAP, 21.25 cm for 120 DAP and 24.83 cm at harvest (Table 1). These results aligned with the observations of Jabborova et al. (2021) who found that PGPR treatment significantly increased leaf length in ginger and legume crops (Egamberdieva et al., 2017; Raza et al., 2004; Egamberdieva et al., 2013). Additionally, *B. subtilis* PTS-394 enhanced leaf length in tomatoes (Qiao et al., 2017), while *B. safensis* improved leaf length in turmeric (Negi 2023).

3.1.6. *Leaf width (cm)*

The effect of PGPR on phosphorus solubilization and leaf width was found to be significant. The maximum leaf width was recorded in 75% RDP with *Bacillus safensis* (1.83 cm at 90 DAP, 2.83 cm at 120 DAP and 4.00 cm at harvest). Whereas the minimum leaf width was recorded in control i.e., 1.54 cm for 90 DAP, 2.40 cm for 120 DAP and 3.63 cm at harvest (Table 1). Jabborova et al. (2022) found PGPR significantly increased leaf width in ginger compared to the control. Kumar et al. (2010) reported AMF enhanced leaf width in *Jatropha curcas*. Similarly, Chen et al. (2020) noted improved leaf width in *Catalpa bungei* and Negi (2023) found *B. safensis* boosted leaf width in turmeric. These findings supported the present study, where PGPR application led to increased leaf width.

3.1.7. *Incidence of rhizome rot (%)*

The effect of PGPR on phosphorus solubilization and incidence of rhizome rot was found to be significant. The lowest disease incidence was recorded in 75% RDP with *Bacillus safensis* showing a rate of 10.95%. Whereas the maximum incidence of disease was observed in control with 14.13% (Table 1). These findings were consistent with Ramulu et al. (2010) who observed that *T. viride* and *P. fluorescens* inhibited *Fusarium solani* by 80–88%. Patil et al. (2012) noted 83.33% inhibition of *Pythium* by *T. viride*, while Maurya et al. (2014) found *P. fluorescens* effective against multiple fungi.

3.2. *Yield traits*

3.2.1. *Rhizome length and breadth (cm)*

The effect of PGPR on phosphorus solubilization and rhizome length and breadth was found to be significant. The maximum rhizome length (21.74 cm) and breadth (11.57 cm) were observed in 75% RDP and *Bacillus safensis*. Whereas minimum rhizome length (18.94 cm) and breadth (9.68 cm) were observed in control (Table 2). The findings aligned with those of Belimov et al. (2000) and Zahir et al. (2004) who observed that PGPR strains had different effects when combined with mineral fertilizers compared to when used alone. Similarly, Negi (2023) found that inoculating turmeric with *B. safensis* significantly increased both rhizome length and breadth.

Table 2: Effect of PGPR on phosphorus solubilization and yield and quality characters of ginger

	Yield traits					Quality traits			
	Rhizome length (cm)	Rhizome breadth (cm)	Yield plant^{-1} (g)	Yield plot^{-1} (kg)	Yield ha^{-1} (t)	Dry matter recovery (%)	Essential oil (%)	Oleoresin content (%)	Crude fibre content (%)
T_1	21.33	11.14	209.52	9.22	19.95	22.40 (4.84)*	1.50 (1.58)	3.00 (2.00)	4.57 (2.36)
T_2	20.33	10.68	182.82	8.83	17.41	22.07 (4.80)	1.35 (1.53)	2.70 (1.92)	4.65 (2.38)
T_3	21.74	11.57	244.35	9.96	23.27	22.74 (4.87)	1.55 (1.60)	3.10 (2.02)	4.44 (2.33)
T_4	19.56	10.62	169.64	8.64	16.16	21.99 (4.79)	1.33 (1.53)	2.67 (1.91)	4.83 (2.41)
T_5	21.28	11.11	202.50	8.97	19.29	22.13 (4.81)	1.39 (1.54)	2.78 (1.94)	4.64 (2.37)
T_6	19.43	10.34	164.21	8.32	15.64	20.29 (4.61)	1.30 (1.52)	2.60 (1.90)	4.91 (2.43)
T_7	18.94	9.68	149.59	7.67	14.25	18.70 (4.44)	1.27 (1.51)	2.55 (1.88)	4.94 (2.44)
SEm±	0.53	0.30	5.63	0.40	5.37	0.06	0.01	0.02	0.003
CD (p=0.05)	1.67	0.95	17.55	1.26	16.72	0.18	0.04	0.06	0.01

*Figure given in the parenthesis are Square root transformed values

3.2.2. *Yield [plant^{-1} (g), plot^{-1} (kg) and projected yield ha^{-1}(t)]*

The effect of mulching on phosphorus solubilization and yield plant^{-1}, plot^{-1} as well as yield ha^{-1} was found to be significant. The maximum yield plant^{-1} (244.35 g), yield plot^{-1} (9.96 kg) and yield ha^{-1} was recorded in 75% RDP and *Bacillus safensis* reaching 23.27 t. Whereas the minimum was recorded in control (149.59 g plant^{-1}, 7.67 kg plot^{-1} and 14.25 t ha^{-1}) (Table 2). The findings aligned with Tamang and Manivannan (2020) who found that PGPR combined with VAM and *Trichoderma* significantly boosted ginger yield. Negi (2023) reported that using 75% RDP with *B. safensis* achieved the highest turmeric yield and benefit-cost ratio of 1.54.

3.2.3. *Quality traits [Dry matter recovery (%), essential oil content (%), oleoresin content (%) and crude fibre content (%)]*

The effect of PGPR on phosphorus solubilization and dry rhizome recovery, essential oil content, oleoresin content and crude fibre content were found to be significant. The highest dry matter recovery (22.74%), essential oil content (1.55%) and oleoresin content (3.10%) were achieved in 75% RDP and *Bacillus safensis* and also resulted in the lowest crude fiber content of 4.44% (Table 2). Biari et al. (2008) and Negi (2023) found that PGPR strains enhanced the absorption of essential nutrients such as N, P and K.

3.3. *Soil analysis traits*

3.3.1. *Soil nutrients (Available NPK before planting, 120 DAP and at harvest)*

The effect of PGPR on phosphorus solubilization and available NPK before planting, 120 DAP and at harvest were found to be significant. Before planting, the available amounts of N, P and K were 402.66 kg ha^{-1}, 49.82 kg ha^{-1} and 310.24 kg ha^{-1}, respectively. At 120 DAP, the highest available N, P and K were 523.56 kg ha^{-1}, 65.77 kg ha^{-1} and 353.19 kg ha^{-1} and at harvest, the highest amounts were 492.05 kg ha^{-1} for N, 82.13 kg ha^{-1} for P and 277.76 kg ha^{-1} for K with 75% RDP and *Bacillus safensis* (Table 3). The findings were consistent with Jabborova et al. (2022) who reported that PGPR combinations improved ginger nutrition. Studies also showed that combining PGPB and AMF enhanced nutrient uptake in wheat (Yadav et al., 2021). Gao et al. (2020) observed improved maize growth with bio-fertilizers, while *B. megaterium*, *B. pumilus* and *B. amyloliquefaciens* boosted soil nutrients (Qaiser et al., 2018). Negi (2023) similarly found *B. safensis* improved soil nutrition.

3.3.2. Nutrient uptake (of leaf and rhizome at harvest)

The effect of PGPR on phosphorus solubilization and nutrient uptake by the leaves were found to be significant. The maximum N, P and K uptake by the leaves were observed in 75% RDP and *Bacillus* safensis (19.90 kg ha^{-1}, 2.71 kg ha^{-1} and 17.66 kg ha^{-1}, respectively), whereas control showed the lowest values of N (4.15 kg ha^{-1}), P (1.33 kg ha^{-1}) and K (6.43 kg ha^{-1}).

The effect of PGPR on phosphorus solubilization and N and K uptake by the rhizomes were found to be significant. The maximum N and K uptake by the rhizomes were observed in 75% RDP and *Bacillus* safensis (31.01 kg ha^{-1} and 39.80 kg ha^{-1}, respectively), whereas control showed the lowest values of N (15.47 kg ha^{-1}) and K (16.78 kg ha^{-1}). The effect of PGPR on phosphorus solubilization and P uptake by the leaves were found to be non-significant.

The study showed that the highest uptake of nutrients for N, P and K was observed in 75% RDP and *Bacillus safensis* at 50.91 kg ha^{-1}, 7.11 kg ha^{-1} and 57.47 kg ha^{-1}, respectively. The lowest uptake of N, P and K was recorded in control at 19.62 kg ha^{-1}, 4.64 kg ha^{-1} and 23.76 kg ha^{-1}, respectively (Table 3).

Jabborova et al. (2022) found dual inoculation with PGPR improved nutrient uptake in ginger. Combining PGPB and AMF enhanced plant nutrition as shown by Lopez-Arredondo et al. (2014) who reported better N, P and K absorption with *B. megaterium* and *B. pumilus* solubilizing phosphorus. Nacoon et al. (2020) observed increased *Helianthus tuberosus* growth with PSB and AMF, while Wahid et al. (2016) and Dhawi et al. (2016) found improved P uptake in maize and sorghum. Negi (2023) also found that 75% RDP with *B. safensis* boosted nutrient uptake in turmeric.

Table 3: Effect of PGPR on phosphorus solubilization and soil nutrient analysis of ginger

	Available soil nutrients (kg ha^{-1})					
	N		P		K	
	120 DAP	At harvest	120 DAP	At harvest	120 DAP	At harvest
T_1	512.54	472.58	59.70	78.40	350.15	276.27
T_2	442.58	394.24	43.86	58.99	327.38	250.88
T_3	523.56	492.05	65.77	82.13	353.19	277.76
T_4	410.11	368.11	42.86	57.49	325.09	251.63
T_5	498.10	456.96	45.43	61.36	331.14	259.84
T_6	288.16	253.12	39.85	54.51	323.68	244.16
T_7	283.67	243.41	26.21	41.84	320.71	243.41
SEm±	12.71	11.51	1.96	2.65	5.37	3.86
CD (p=0.05)	39.61	35.85	6.11	8.27	16.72	12.04

Table 3: Continue...

	Nutrient uptake (kg ha^{-1})						Total nutrient uptake (kg ha^{-1})		
	Leaf uptake			Rhizome uptake			N	P	K
	N	P	K	N	P	K			
T_1	17.32	2.55	14.53	28.10	4.17	26.13	45.42	6.71	40.66
T_2	16.40	1.62	8.30	27.00	3.67	21.52	43.40	5.29	29.82
T_3	19.90	2.71	17.66	31.01	4.40	39.80	50.91	7.11	57.47
T_4	7.13	1.49	6.57	18.85	3.55	21.20	25.98	5.05	27.77
T_5	16.62	1.83	8.49	27.71	3.89	22.38	44.33	5.73	30.88
T_6	5.93	1.35	7.98	17.50	3.32	16.82	23.43	4.68	24.25
T_7	4.15	1.33	6.43	15.47	3.31	16.78	19.62	4.64	23.76
SEm±	0.12	0.03	0.09	1.24	0.28	0.51	1.27	0.29	0.57
CD (p=0.05)	0.36	0.09	0.29	3.87	NS	1.59	3.97	0.89	1.78

NS: Non-significant

The effect of PGPR on phosphorus solubilization and rhizome yield was found to be significant. The maximum yield was recorded in 75% RDP and *Bacillus* safensis (23.27 t ha^{-1}) along with B:C ratio of 1.32. The minimum yield was recorded in control i.e., 14.25 t ha^{-1} with B:C ratio of 0.44 (Table 4). These finding aligned with Negi (2023) who found that using 75% RDP and *Bacillus* safensis increased the rhizome yield in turmeric.

Table 4: Effect of PGPR on phosphorus solubilization and economics of ginger

	Yield ha^{-1} (t)	Gross return ha^{-1} @ ₹ 60 kg^{-1} (₹)	Cost of cultivation ha^{-1} (₹)	Net returns ha^{-1} (₹)	B:C ratio
T_1	19.95	11,97,240	5,97,938	5,99,302	1.00
T_2	17.41	10,44,680	5,96,972	4,47,708	0.75
T_3	23.27	13,96,280	6,02,972	7,93,308	1.32
T_4	16.16	9,69,400	5,96,036	3,73,364	0.62
T_5	19.28	11,57,120	6,02,036	5,55,117	0.76
T_6	15.64	9,38,320	6,00,164	3,38,156	0.56
T_7	14.25	8,54,800	5,94,164	2,60,636	0.44
SEm±	5.22	32,199	-	32,198	0.07
CD (p=0.05)	16.27	1,00,313	-	1,00,311	0.22

4. CONCLUSION

Treating ginger *cv.* Solan Giriganga with plant growth-promoting rhizobacteria *Bacillus safensis* and applying 37.5 kg ha^{-1} of P_2O_5 yielded the highest rhizome yield (23.27 t ha^{-1}), along with the greatest net returns (₹ 7,93,308) and B:C ratio of 1.32 under the mid-hill conditions of Himachal Pradesh. Furthermore, it increased the availability of nutrients (492.05 kg ha^{-1}, 82.13 kg ha^{-1} and 277.76 kg ha^{-1} NPK respectively), which benefited the health of the soil.

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