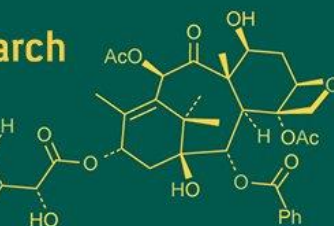
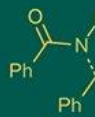
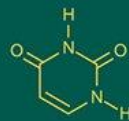
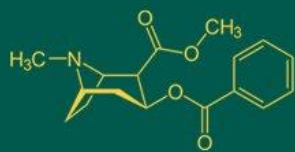


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Evaluation of phosphorus-solubilizing and phosphorus-mineralizing bacteria for improved germination and early seedling growth of rice

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Abstract

Phosphorus (P) is one of the most important macronutrients for rice development, but a large percentage of soil P is in inorganic and organic forms that are not soluble and therefore difficult to be used by plants, leading to low use efficiency of P and high reliance on chemical fertilizers. Phosphorus-solubilizing and phosphorus-mineralizing bacteria are an environmentally friendly way to make unavailable P available and to enhance early crop establishment. The aim of the present study was to evaluate the effect of nine isolates of PSB on seed germination and early growth of rice variety ISM under pot trial. All the bacterial isolates were inoculated in rice seeds and observed in completely randomized design with three replications. Germination percentage and mean germination time of root length, shoot length, fresh biomass and dry biomass were recorded at 7, 14 and 21 days after sowing. Germination was greatly enhanced by the use of seeds inoculated compared to uninoculated. Isolate 5 had the highest germination (100%) and shortest mean germination time (2.28 days) followed by Isolate 2 (99% and (2.36 days) respectively while Isolate 9 had germination of 98% and mean germination time of 2.41 days respectively, with the control having the lowest germination (84%) and longest mean germination time (3.52 days). Isolate 5 recorded the highest root length (8.83 cm), shoot length (12.40 cm), fresh weight of seeds (0.340 g) and dry weight of seedlings (0.106 g) at 7 DAS. The maximum root length (12.82 cm), shoot length (14.95 cm), seed fresh weight (0.446 g) and seedling dry weight (0.139 g) were observed at 14 DAS for Isolate 5. At 21 DAS, the root length of Isolate 9 (14.82 cm) and shoot length of Isolate 9 (19.72 cm) were the highest while the fresh biomass of Isolate 5 (0.612 g) and seedling dry biomass of Isolate 5 (0.190 g) were the highest, showing the highest biomass accumulation. The study concluded that seed inoculation with both phosphorus-solubilizing and phosphorus-mineralizing bacteria with beneficial PGPR characteristics resulted in significant improvement in germination rate, seedling growth and biomass production.

Keywords: Germination, phosphorus-solubilizing bacteria, phosphorus-mineralizing bacteria, seed inoculation, seedling vigour

Introduction

Rice (*Oryza sativa* L.) is one of the most crucial staple food crops and the main calorie source for over half the world's population. Rice is one of the most important crops for global food and nutritional security, covering about 165 million hectares and producing more than 780 million tonnes of rice annually (Sawargaonkar *et al.*, 2026). India is the 2nd largest producer of rice after China and also grown in varieties of agro climates. As the world population grows and land suitable for rice cultivation decreases, it is becoming a real challenge to increase the productivity of rice by sustainable agriculture practices (Darko *et al.*, 2025; Kumar *et al.*, 2026). Hence, to achieve sustainable rice production, nutrient use efficiency should be improved, and environmental impacts reduced [24, 7, 17].

Phosphorus (P) is a key macronutrient for plant growth and involved in many of the metabolic and biochemical pathways of the plant, such as energy transfer, photosynthesis and respiration, nucleic acid synthesis, cell division, membrane formation and root development. The proper supply of available phosphorus during germination and establishment of seedlings is especially important because it influences stand, root architecture, nutrient acquisition and grain yield. Although total phosphorus is plentiful in most agricultural soils, the amount present in plant available forms is very small. Soluble orthophosphate ions are quickly bound by precipitation

with calcium, in alkaline soils, and with iron and aluminum, in acid soils, and also adsorbed on soil colloids and thus unavailable for plant uptake. Additionally, a significant portion of soil P is present as organic P (e.g., phytates, phospholipids, nucleic acids, and phosphoesters) that is not readily available to plants.

Rice farming is a practice in which the application of large amounts of chemical phosphate fertilizers is common, as a means of overcoming phosphorus deficiency. The use efficiency of applied phosphorus fertilizers is generally low, however, with only 10-25% being used by crop during the first growing season with the excess phosphate becoming soil bound (as insoluble fraction) or loss by run-off and erosion (Cordell *et al.*, 2009). The use of chemical fertilizers is a non-renewable resource, leads to a depletion in non-renewable phosphate rock, soil nutrient imbalance and eutrophication of water bodies, as well as raises production costs. This has led to a greater interest in environmentally friendly options which will increase the availability of phosphorus and enhance fertilizer use efficiency (Gurav *et al.*, 2024, Vance *et al.*, 2003) [6, 14, 27].

The phosphorus-solubilizing and phosphorus-mineralizing bacteria (PSMB) which are beneficial soil microorganisms that are able to convert unavailable inorganic and organic phosphorus into soluble phosphorus which can be readily taken up by the plant. Phosphorus-solubilizing bacteria produce low-molecular-weight organic acids which bring about a decrease in rhizosphere pH, chelate the cations on the insoluble phosphate minerals, and release soluble phosphate ions. Phosphorus-mineralizing bacteria produce extracellular enzymes (acid phosphatases, alkaline phosphatases, phytases and phosphodiesterases) which are responsible for breaking down organic compounds of phosphorus into inorganic phosphate (Pang *et al.*, 2024, Silva *et al.*, 2023). By these complementary processes, PSMB increase the availability of phosphorus, increase nutrient uptake, stimulate root development and support sustainable nutrient cycling in agricultural soils. In addition to phosphorus mobilization, many PSMB also have multiple plant growth promoting properties including the production of phytohormones, biological nitrogen fixation, siderophore production, potassium and zinc solubilization and suppression of phytopathogens, which further promote plant growth and development (Goswami *et al.*, 2019) [20, 25, 11].

The initial growth of seedling starts as rapidly dividing cells, which demand energy and nucleic acid synthesis at a rapid pace, seed germination and early seedling growth is highly sensitive to the availability of phosphorus. Improved phosphorus nutrition during germination results in quicker radicle emergence, growth of root, shoot growth, formation of more biomass and greater vigour of seedlings (Backer *et al.*, 2018, Khoso *et al.*, 2024). Seed inoculation with efficient phosphorus-solubilizing and mineralizing bacteria has been reported to increase the germination percentage, decrease mean germination time, increase root and shoot growth and seedling biomass in several cereal crops including rice (Gupta *et al.*, 2015) [3, 16, 13]. However, the efficiency of the phosphorus mobilizing bacteria is variable between individual isolates because of their ability to mobilize phosphate, their production of phosphatase enzymes, their rhizosphere colonization capacity and their compatibility with their host plants. Therefore, screening of bacterial isolates should be performed systematically to isolate better

strains having good efficiency in phosphorus mobilization and plant growth promotion.

Identifying highly efficient isolates capable of enhancing early plant growth is an important prerequisite for developing effective biofertilizer formulations aimed at improving phosphorus use efficiency and reducing dependence on chemical phosphate fertilizers. Therefore, the present investigation was undertaken to evaluate the effect phosphorus-solubilizing and phosphorus-mineralizing bacterial isolates on seed germination and seedling growth of rice.

2. Materials and Methods

2.1 Plant Material and Bacterial Isolates

Nine bacterial isolates exhibiting phosphorus-solubilizing and phosphorus-mineralizing abilities were evaluated using the rice variety Improved Samba Mahsuri (ISM). The isolates were previously characterized and had exhibited inorganic phosphate-solubilizing efficiency and organic phosphorus-mineralizing potential, along with other beneficial plant growth-promoting traits. The bacterial cultures were maintained on nutrient agar slants and glycerol stocks and periodically sub-cultured to maintain viability. Fresh bacterial cultures were grown in nutrient broth at $28 \pm 2^\circ\text{C}$ for 24-48 h under continuous shaking at 150 rpm. The cultures were harvested by centrifugation at 8,000 rpm for 10 min, washed twice with sterile phosphate-buffered saline (PBS), and resuspended in sterile PBS. The bacterial suspension was adjusted to an optical density of $\text{OD}_{600} = 1.0$, corresponding to approximately 1×10^8 CFU mL^{-1} , and used for seed inoculation (Pole *et al.*, 2026) [22].

2.2 Seed Surface Sterilization and Bacterial Inoculation

Rice seeds were surface sterilized by immersion in 70% ethanol for 1 min, followed by treatment with 0.1% mercuric chloride (HgCl_2) for 1 min. The sterilized seeds were rinsed six times with sterile distilled water to eliminate residual sterilizing agents. The seeds were then soaked separately in each bacterial suspension (approximately 1×10^8 CFU mL^{-1}) for 24 h at 28°C under aseptic conditions ((Venkat *et al.*, 2026).). Seeds soaked in sterile phosphate-buffered saline served as the uninoculated control. After inoculation, seeds from each treatment were transferred onto into small pots. Seed growth parameters observations were taken at 7, 14 and 21 days after sowing [28].

2.3 Experimental Design

The experiment was conducted as a Completely Randomized Design (CRD) consisting of ten treatments, including one uninoculated control and nine bacterial inoculation treatments. Each treatment was replicated three times. The treatments comprised individual inoculation with phosphorus-solubilizing and phosphorus-mineralizing bacterial isolate, while uninoculated seeds served as the control. All experimental units were maintained under identical environmental conditions throughout the study.

2.4 Germination Attributes

Seed germination was recorded daily until it fully germinates. Daily germination counts were used to determine germination percentage (GP) and mean germination time (MGT). Seedling growth was evaluated at 7, 14, and 21 days after inoculation (DAI). At each sampling interval, five randomly selected seedlings from each replication were

carefully removed from the pots. Root length and shoot length were measured using a graduated ruler and expressed in centimetres. Fresh weights of roots, shoots, and seeds were immediately determined using an analytical balance. The plant samples were subsequently dried in a hot-air oven at $65 \pm 2^\circ\text{C}$ until constant weight was attained, after which root dry weight, shoot dry weight, and seed dry weight were recorded. These measurements were used to assess the influence of bacterial inoculation on early seedling growth, biomass accumulation, and seedling establishment over time.

2.5 Statistical Analysis

The experiment was designed in a completely randomized design (CRD) with three replications. Analysis of variance (ANOVA) was used to analyze the data and critical difference (CD) was used to compare the treatment means at 5% level of significance (Gomez and Gomez 1984)^[10].

3. Results and Discussion

3.1 Germination Percentage and Mean Germination Time

The bacterial isolates significantly influenced germination percentage (GP) and mean germination time (MGT) of rice seeds compared with the uninoculated control (Fig.1, Fig.2). Among the evaluated treatments, Isolate 5 recorded the highest germination percentage (100.0%) with the shortest mean germination time (2.28 days) closely followed by Isolate 2, which recorded 99.0% germination with an MGT of 2.36 days. Isolate 9 exhibited 98.0% germination with an MGT of 2.41 days. Intermediate responses were observed with Isolate 8 (95.0% GP; 2.68 days MGT) and Isolate 6 (94.0% GP; 2.75 days MGT), whereas Isolates 1, 3, 4, and 7 showed moderate improvements over the control. The uninoculated control recorded the lowest germination percentage (84.0%) and the highest mean germination time (3.52 days), indicating slower and less uniform germination. The enhanced germination observed in inoculated seeds demonstrates the beneficial influence of plant growth-promoting bacteria on early seed germination and seedling establishment. The highest performance of Isolate 5, followed by Isolates 2 and 9, suggests that these isolates possess strong plant growth-promoting characteristics that facilitate rapid germination and vigorous seedling emergence (Basu *et al.*, 2021). Enhanced germination may be attributed to the production of phytohormones such as indole-3-acetic acid (IAA), gibberellins, and cytokinins, which stimulate embryo growth, activate hydrolytic enzymes responsible for mobilization of seed reserves, and accelerate radicle emergence (Abd El-Mageed *et al.*, 2022). In addition, beneficial bacteria improve nutrient availability in the vicinity of germinating seeds and release metabolites that enhance seed metabolic activity, resulting in faster and more uniform germination^[4, 1].

The reduction in mean germination time further indicates synchronized and rapid seedling emergence, which is advantageous for achieving better crop establishment under field conditions. Early and uniform germination enables seedlings to utilize available resources more efficiently and improves their competitiveness during the initial stages of growth (Lotfi *et al.*, 2025)^[19]. Plant growth-promoting bacteria are also known to produce ACC deaminase, which reduces stress-induced ethylene levels, thereby promoting faster germination and enhancing seedling establishment

(Gupta *et al.*, 2022). These physiological and biochemical mechanisms likely contributed to the increased performance of Isolates 5, 2, and 9.

The present findings are consistent with earlier reports demonstrating that PGPB enhance seed germination through phytohormone production, nutrient mobilization, and improved seed metabolic activity (Harahap *et al.*, 2023). Previous studies have shown that phosphate-solubilizing and rhizosphere-associated bacteria significantly increase germination percentage while reducing mean germination time, ultimately leading to improved seedling vigor and crop establishment (Rawat *et al.*, 2022). The enhanced germination observed in the present study was also reflected in the subsequent improvements in seedling growth and biomass accumulation, confirming the sustained beneficial effects of bacterial inoculation during early plant development^[12, 15, 23].

3.2 Effect of Phosphorous solubilizing and mineralizing bacterial inoculation on growth parameters of rice seedlings at 7 days after sowing

Phosphorus-solubilizing and mineralizing bacterial inoculation significantly enhanced the early growth and biomass accumulation of rice seedlings at 7 days after sowing (DAS) (Table 1). Significant variation was observed among the bacterial isolates for all growth parameters. Isolate 5 produced the greatest root length (8.83 cm) and shoot length (12.40 cm), followed by Isolate 9 (8.50 and 12.00 cm, respectively) and Isolate 2 (8.23 and 11.80 cm, respectively). Moderate improvements were recorded with Isolates 8 and 7, whereas Isolates 1, 3, 4, and 6 exhibited comparatively lower responses. The uninoculated control consistently recorded the lowest root and shoot growth.

A similar trend was observed for biomass accumulation. Isolate 5 recorded the highest seed fresh weight (0.340 g), root fresh weight (0.098 g), and shoot fresh weight (0.242 g), followed by Isolate 9 and Isolate 2. Likewise, maximum seedling dry weight (0.106 g), root dry weight (0.021 g), and shoot dry weight (0.085 g) were recorded in Isolate 5, whereas the control produced the lowest fresh and dry biomass. Overall, Isolate 5 exhibited the greatest plant growth-promoting potential during the initial stages of seedling establishment.

The enhancement in seedling growth and biomass following bacterial inoculation demonstrates the effectiveness of phosphorus-solubilizing and mineralizing bacteria in promoting early rice seedling establishment. The enhanced performance of Isolate 5, followed by Isolates 9 and 2, may be attributed to increased phosphorus availability resulting from phosphate solubilization and mineralization, coupled with the production of plant growth-promoting metabolites such as indole-3-acetic acid (IAA), gibberellins, and cytokinins. Enhanced phosphorus nutrition during early growth stimulates root proliferation, thereby improving water and nutrient acquisition and ultimately increasing biomass accumulation (Yavdav *et al.*, 2014, Awlachev and Mengistie, G. Y. (2022)). The present findings are in agreement with previous studies reporting that inoculation with phosphate-solubilizing bacteria enhances early seedling growth by improving phosphorus availability, stimulating root development, and increasing biomass accumulation (Phringpaen *et al.*, 2023)^[30, 2].

3.3 Effect of Phosphorous solubilizing and mineralizing bacterial inoculation on growth parameters of rice seedlings at 14 days after sowing

The growth-promoting effects of bacterial inoculation became more pronounced by 14 DAS, resulting in significant improvements in seedling growth and biomass accumulation compared with the uninoculated control (Table 2). Among the tested isolates, Isolate 5 recorded the highest root length (12.82 cm) and shoot length (14.95 cm), followed by Isolate 9 (12.46 and 14.58 cm, respectively) and Isolate 2 (12.02 and 14.12 cm, respectively). Intermediate responses were observed with Isolates 6 and 8, whereas the remaining isolates produced comparatively lower growth.

Fresh biomass production followed the same trend, with Isolate 5 recording the highest seed fresh weight (0.446 g), root fresh weight (0.131 g), and shoot fresh weight (0.312 g). Similarly, the highest seedling dry weight (0.139 g), root dry weight (0.027 g), and shoot dry weight (0.112 g) were obtained with Isolate 5, followed by Isolates 9 and 2. The control consistently recorded the lowest biomass values.

The sustained improvement in seedling growth at 14 DAS suggests successful rhizosphere colonization and continued activity of the inoculated bacteria. Improved phosphorus availability, together with enhanced nutrient mobilization and phytohormone production, likely contributed to increased root development and photosynthetic capacity, resulting in greater fresh and dry matter accumulation (Dobrzyński *et al.*, 2026). The consistent enhancement of Isolate 5, followed by Isolates 9 and 2, indicates that these isolates possess multiple plant growth-promoting traits that remained active throughout the early vegetative stage. Similar observations have been reported by Bhat *et al.*, 2023 and Sun *et al.*, 2024 [8, 5, 26], who demonstrated that plant growth-promoting rhizobacteria improve nutrient acquisition, root architecture, and biomass production, leading to sustained enhancement of seedling growth during the early vegetative stage.

3.4 Effect of Phosphorous solubilizing and mineralizing bacterial inoculation on growth parameters of rice seedlings at 21 days after sowing

Significant improvements in seedling growth and biomass accumulation were maintained at 21 DAS following inoculation with phosphorus-solubilizing and mineralizing bacteria (Table 3). Among the evaluated isolates, Isolate 9 recorded the greatest root length (14.82 cm) and shoot length (19.72 cm), while Isolate 5 (14.18 and 18.04 cm, respectively) and Isolate 2 (14.34 and 17.18 cm, respectively) also produced substantially greater growth than the control. Despite the greater seedling elongation observed with Isolate 9, Isolate 5 produced the highest seed fresh weight (0.612 g), root fresh weight (0.180 g), and shoot fresh weight (0.425 g). It also recorded the maximum seedling dry weight (0.190 g), root dry weight (0.036 g), and shoot dry weight (0.154 g), followed closely by Isolates 9 and 2. The uninoculated control consistently exhibited the lowest fresh and dry biomass accumulation.

The continued enhancement of growth and biomass up to 21 DAS indicates that the beneficial effects of bacterial inoculation were sustained throughout the seedling establishment period. Although Isolate 9 promoted greater root and shoot elongation, Isolate 5 consistently accumulated higher fresh and dry biomass, suggesting more efficient nutrient utilization and assimilate partitioning. The increased performance of Isolates 5, 9, and 2 demonstrates their potential as effective phosphorus-solubilizing and mineralizing bioinoculants capable of improving early rice seedling vigor and establishing a strong foundation for subsequent crop growth. The sustained improvement in seedling growth and biomass observed in the present study corroborates earlier reports indicating that phosphorus-solubilizing bacteria promote root development, nutrient uptake, and dry matter accumulation, ultimately improving crop establishment and productivity (Elhaissofi *et al.*, 2023, Li *et al.*, 2022 and Wang *et al.*, 2022) [9, 28, 29].

Table 1: Effect of Phosphorous solubilizing and mineralizing bacterial inoculation on growth parameters of rice seedlings at 7 days after sowing

Treatment	Root length (cm)	Shoot length (cm)	Seed fresh weight (g)	Root fresh weight (g)	Shoot fresh weight (g)	Seedling dry weight (g)	Root dry weight (g)	Shoot dry weight (g)
Control	5.81 ± 0.12	7.30 ± 0.15	0.190 ± 0.005	0.051 ± 0.001	0.141 ± 0.003	0.049 ± 0.001	0.008 ± 0.0003	0.041 ± 0.001
Isolate 1	6.74 ± 0.14	8.00 ± 0.17	0.210 ± 0.006	0.058 ± 0.001	0.151 ± 0.003	0.056 ± 0.002	0.010 ± 0.0004	0.046 ± 0.001
Isolate 2	8.23 ± 0.20	11.80 ± 0.21	0.310 ± 0.008	0.091 ± 0.002	0.219 ± 0.005	0.098 ± 0.002	0.019 ± 0.0005	0.079 ± 0.002
Isolate 3	7.05 ± 0.15	8.40 ± 0.16	0.220 ± 0.005	0.061 ± 0.001	0.158 ± 0.004	0.060 ± 0.001	0.011 ± 0.0004	0.049 ± 0.001
Isolate 4	6.91 ± 0.13	8.20 ± 0.18	0.210 ± 0.006	0.060 ± 0.001	0.154 ± 0.003	0.057 ± 0.001	0.010 ± 0.0004	0.047 ± 0.001
Isolate 5	8.83 ± 0.22	12.40 ± 0.24	0.340 ± 0.009	0.098 ± 0.002	0.242 ± 0.006	0.106 ± 0.003	0.021 ± 0.0006	0.085 ± 0.002
Isolate 6	6.21 ± 0.17	9.60 ± 0.18	0.250 ± 0.007	0.071 ± 0.001	0.176 ± 0.004	0.072 ± 0.002	0.013 ± 0.0004	0.059 ± 0.001
Isolate 7	7.25 ± 0.16	8.40 ± 0.17	0.220 ± 0.006	0.062 ± 0.001	0.160 ± 0.004	0.061 ± 0.002	0.011 ± 0.0004	0.050 ± 0.001
Isolate 8	7.46 ± 0.18	9.70 ± 0.19	0.250 ± 0.007	0.073 ± 0.002	0.180 ± 0.004	0.075 ± 0.002	0.014 ± 0.0005	0.061 ± 0.002
Isolate 9	8.50 ± 0.21	12.00 ± 0.22	0.320 ± 0.008	0.094 ± 0.002	0.226 ± 0.005	0.101 ± 0.002	0.020 ± 0.0005	0.081 ± 0.002
CD (P = 0.05)	0.48	0.54	0.02	0.01	0.01	0.01	0	0.01

Table 2: Effect of Phosphorous solubilizing and mineralizing bacterial inoculation on growth parameters of rice seedlings at 14 days after sowing

Treatment	Root length (cm)	Shoot length (cm)	Seed fresh weight (g)	Root fresh weight (g)	Shoot fresh weight (g)	Seed dry weight (g)	Root dry weight (g)	Shoot dry weight (g)
Control	8.41 ± 0.16	10.58 ± 0.20	0.275 ± 0.007	0.074 ± 0.002	0.204 ± 0.005	0.071 ± 0.002	0.012 ± 0.0004	0.059 ± 0.001
Isolate 1	9.73 ± 0.18	11.60 ± 0.22	0.304 ± 0.008	0.084 ± 0.002	0.219 ± 0.005	0.081 ± 0.002	0.014 ± 0.0005	0.067 ± 0.002
Isolate 2	12.02 ± 0.26	14.12 ± 0.28	0.425 ± 0.010	0.124 ± 0.003	0.298 ± 0.007	0.132 ± 0.003	0.024 ± 0.0007	0.108 ± 0.003
Isolate 3	10.15 ± 0.20	12.18 ± 0.23	0.319 ± 0.008	0.088 ± 0.002	0.229 ± 0.005	0.087 ± 0.002	0.016 ± 0.0005	0.071 ± 0.002
Isolate 4	10.01 ± 0.19	11.89 ± 0.22	0.304 ± 0.008	0.087 ± 0.002	0.223 ± 0.005	0.083 ± 0.002	0.014 ± 0.0005	0.068 ± 0.002
Isolate 5	12.82 ± 0.28	14.95 ± 0.30	0.446 ± 0.011	0.131 ± 0.003	0.312 ± 0.008	0.139 ± 0.003	0.027 ± 0.0008	0.112 ± 0.003

Isolate 6	11.89 ± 0.22	13.92 ± 0.25	0.362 ± 0.009	0.103 ± 0.003	0.255 ± 0.006	0.104 ± 0.003	0.019 ± 0.0006	0.086 ± 0.002
Isolate 7	10.44 ± 0.20	12.18 ± 0.23	0.319 ± 0.008	0.090 ± 0.002	0.232 ± 0.005	0.088 ± 0.002	0.016 ± 0.0005	0.072 ± 0.002
Isolate 8	11.18 ± 0.23	14.06 ± 0.26	0.362 ± 0.009	0.106 ± 0.003	0.261 ± 0.006	0.109 ± 0.003	0.020 ± 0.0006	0.088 ± 0.002
Isolate 9	12.46 ± 0.27	14.58 ± 0.29	0.435 ± 0.011	0.127 ± 0.003	0.304 ± 0.007	0.135 ± 0.003	0.025 ± 0.0007	0.110 ± 0.003
CD (P = 0.05)	0.65	0.73	0.028	0.007	0.018	0.011	0.003	0.008

Table 3: Effect of Phosphorous solubilizing and mineralizing bacterial inoculation on growth parameters of rice seedlings at 21 days after sowing

Treatment	Root length (cm)	Shoot length (cm)	Seed fresh weight (g)	Root fresh weight (g)	Shoot fresh weight (g)	Seedling dry weight (g)	Root dry weight (g)	Shoot dry weight (g)
Control	11.62 ± 0.22	14.60 ± 0.27	0.380 ± 0.010	0.102 ± 0.003	0.282 ± 0.007	0.098 ± 0.003	0.016 ± 0.0005	0.082 ± 0.002
Isolate 1	13.41 ± 0.25	15.22 ± 0.30	0.420 ± 0.011	0.116 ± 0.003	0.302 ± 0.008	0.112 ± 0.003	0.020 ± 0.0006	0.092 ± 0.002
Isolate 2	14.34 ± 0.35	17.18 ± 0.39	0.585 ± 0.014	0.173 ± 0.004	0.410 ± 0.010	0.182 ± 0.004	0.034 ± 0.0009	0.148 ± 0.004
Isolate 3	14.05 ± 0.27	15.86 ± 0.31	0.440 ± 0.011	0.122 ± 0.003	0.316 ± 0.008	0.120 ± 0.003	0.022 ± 0.0007	0.098 ± 0.002
Isolate 4	13.83 ± 0.26	16.40 ± 0.30	0.420 ± 0.011	0.120 ± 0.003	0.308 ± 0.008	0.114 ± 0.003	0.020 ± 0.0006	0.094 ± 0.002
Isolate 5	14.18 ± 0.37	18.04 ± 0.41	0.612 ± 0.015	0.180 ± 0.004	0.425 ± 0.011	0.190 ± 0.005	0.036 ± 0.0010	0.154 ± 0.004
Isolate 6	13.61 ± 0.30	17.23 ± 0.34	0.500 ± 0.013	0.142 ± 0.004	0.352 ± 0.009	0.144 ± 0.004	0.026 ± 0.0008	0.118 ± 0.003
Isolate 7	13.45 ± 0.27	16.85 ± 0.31	0.440 ± 0.011	0.124 ± 0.003	0.320 ± 0.008	0.122 ± 0.003	0.022 ± 0.0007	0.100 ± 0.003
Isolate 8	12.80 ± 0.31	17.43 ± 0.35	0.500 ± 0.013	0.146 ± 0.004	0.360 ± 0.009	0.150 ± 0.004	0.028 ± 0.0008	0.122 ± 0.003
Isolate 9	14.82 ± 0.36	19.72 ± 0.40	0.598 ± 0.015	0.176 ± 0.004	0.418 ± 0.010	0.186 ± 0.005	0.035 ± 0.0010	0.151 ± 0.004
CD (P = 0.05)	0.92	1.03	0.04	0.01	0.03	0.02	0	0.01

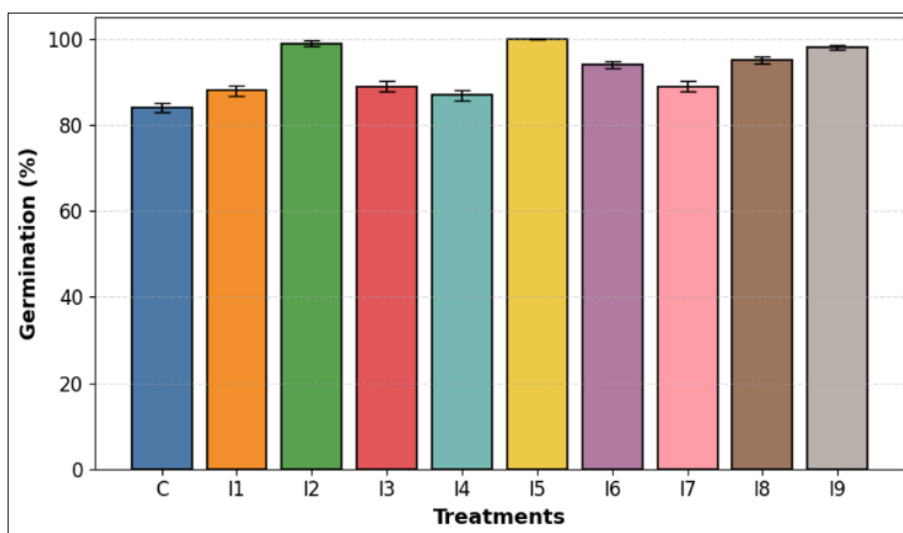


Fig 1: Effect of Phosphorous solubilizing and mineralizing bacterial inoculation on germination percentage

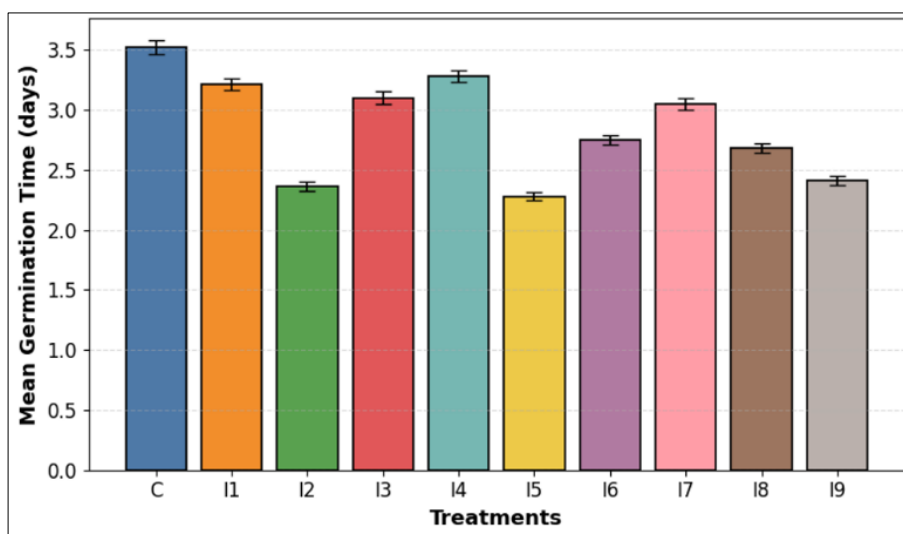


Fig 2: Effect of Phosphorous solubilizing and mineralizing bacterial inoculation on Mean germination time

Conclusion

The present study demonstrated that seed inoculation with phosphorus-solubilizing and phosphorus-mineralizing bacteria significantly improved germination, seedling growth, and biomass accumulation in rice under pot conditions. Among the nine bacterial isolates evaluated, Isolate 5 consistently exhibited superior performance by recording the highest germination percentage, the shortest mean germination time, and the greatest fresh and dry biomass at 7, 14, and 21 DAS. Although Isolate 9 recorded the highest root and shoot lengths at 21 DAS, Isolate 5 maintained the highest overall biomass accumulation, indicating its greater efficiency in promoting early seedling vigor. Isolate 2 also performed consistently well across all growth parameters. The enhanced performance of the inoculated seedlings highlights the potential of phosphorus-solubilizing and phosphorus-mineralizing bacteria with plant growth-promoting traits to stimulate early crop establishment. These beneficial microorganisms can serve as sustainable bioinoculants to reduce dependence on chemical phosphorus fertilizers while improving nutrient use efficiency and seedling development.

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