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Research Article

Impact of Plant Growth-Promoting Microorganisms Inoculation on Pearl Millet (*Pennisetum glaucum* [L.]) Growth Parameters in Field Conditions

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Abstract

The utilization of plant growth-promoting microorganisms (PGPMs) holds substantial promise in enhancing agricultural sustainability, particularly in arid and semi-arid regions where pearl millet (*Pennisetum glaucum*) is a staple crop. This study aimed to assess the impact of PGPM inoculation on pearl millet growth parameters under field conditions. A consortium of nine potent bacteria strains isolated from pearl millet rhizosphere was developed. Field experiments conducted in YSR KADAPA district, India, revealed significant benefits of PGPM inoculation. Consortia with varying cell counts demonstrated superior efficacy in promoting pearl millet growth, evidenced by higher germination rates, increased plant height, enhanced branching, and elevated chlorophyll content compared to control and commercially available organic fertilizer treatments. These results underscore the potential of PGPM-based strategies in enhancing pearl millet productivity and offer insights for sustainable agricultural practices tailored to challenging environments.

Keywords: Pearl millet, plant growth-promoting microorganisms (PGPMs), field conditions, agricultural sustainability, crop productivity

1. Introduction

Pearl millet (*Pennisetum glaucum*), commonly referred to as bajra, stands as a staple cereal crop extensively cultivated in arid and semi-arid regions across Asia and Africa (Satyavathi *et al.,* 2021). This crop plays a pivotal role in providing sustenance, fodder, and income to millions of individuals, particularly in regions characterized by challenging environmental conditions marked by high temperatures, scanty rainfall, and poor soil fertility (Srivastava *et al.,* 2022). Despite its inherent resilience to adverse conditions, pearl millet productivity often encounters hindrances due to a multitude of biotic and abiotic stressors (Satyavathi *et al.,* 2021). In recent times, there has been a surge of interest in exploring sustainable agricultural practices geared towards bolstering crop productivity while mitigating environmental repercussions (Pathak *et al.,* 2018; Lykas and Vagelas, 2023). Within this context, the utilization of plant growth-promoting microorganisms (PGPMs) has emerged as a promising avenue. PGPMs comprise a diverse array of beneficial microorganisms encompassing bacteria, fungi, and archaea, which colonize the rhizosphere and foster plant growth through a plethora of mechanisms (Cantabella *et al.,* 2022). These mechanisms include nitrogen fixation (de Andrade *et al.,* 2023), phosphate solubilization (Debasis *et al.,* 2019), production of phytohormones (Cantabella *et al.,* 2022), and suppression of phytopathogens (Koskey *et al.,* 2021). Numerous studies have underscored the potential of PGPMs in augmenting the growth, yield, and resilience of various crops across different environmental settings (Rawat *et al.,* 2020; Kumawat *et al.,* 2023). However, research specifically focused on the application of PGPMs in pearl millet cultivation remains scant, particularly in field setups.

Exploring the utilization of PGPMs in pearl millet cultivation holds immense promise in addressing the productivity constraints faced by this crucial crop in arid and semi-arid regions. By harnessing the beneficial interactions between PGPMs and pearl millet, farmers can potentially enhance crop performance, improve soil fertility, and mitigate the adverse impacts of biotic and abiotic stresses. Furthermore, the integration of PGPM-based strategies into pearl millet farming practices aligns with the broader goal of advancing sustainable agriculture, promoting food security, and conserving natural resources in resource-constrained agricultural systems. Thus, further research and exploration into the application of PGPMs in pearl millet cultivation are warranted to unlock their full potential in enhancing agricultural sustainability and resilience in challenging environments. Therefore, this study aims to investigate the impact of PGPM inoculation on pearl millet plant growth parameters under field conditions. The objectives of this research include assessing the effects of PGPM inoculation on plant growth and development, yield, and yield-related traits. Understanding the influence of PGPMs on pearl millet growth and productivity in field setups is essential for developing sustainable agricultural practices tailored to the unique requirements of crops grown in arid and semi-arid regions. Furthermore, insights gained from this research can contribute to the optimization of PGPM-based biofertilizers for enhancing pearl millet production while reducing the reliance on synthetic inputs, thereby promoting environmental sustainability and food security in resource-constrained agricultural systems.

2. Materials and Methods

2.1. Chemicals

All chemicals utilized in this investigation were of analytical grade and were obtained from HiMedia, India, without further purification.

2.2. Development of PGPM Consortium

Bacteria were isolated from the rhizosphere of multiple Pearl millet fields located in Kamalapuram and Lingala regions of YSR-Kadapa, Andhra Pradesh. A total of nine potent bacteria strains were isolated, including: *Azospirillum* sp.; *Pseudomonas* KP sp.; *Acinetobacter* sp.; *Bacillus*-KP sp.; *Streptomyces* sp.; *Enterobacter* sp.; *Lactobacillus* sp.; *Pseudomonas* L sp.; *Bacillus*-L sp.

2.3. Experimental Grouping

For field experimentation, the Post-monsoon/Winter season (October to February- 2020-21) in the Parnapalli region of YSR Kadapa district was chosen (latitude: 14^{o} 41' N, longitude: 77^{o} 40' E, elevation: 373 m above mean sea level).

The experimental groups were structured as follows:

- Group 1 (Control): No addition of plant growth-promoting microorganisms (PGPMs).
- Group 2: Application of commercially available organic (liquid) fertilizer (OK-AZOS, India) at a rate of 15 liters per hectare (15 L/ha).
- Group 3: Application of a consortium of isolated bacteria with a lower cell count range (1 X 10^{7} to 10^{8} cells/mL) at a rate of 1.5 liters per hectare (1.5 L/ha).
- Group 4: Application of a consortium of isolated bacteria with a higher cell count range (1 X 10^{11} to 10^{12} cells/mL) at a rate of 1.5 liters per hectare (1.5 L/ha).

These groupings were designed to assess the efficacy of different treatments in promoting plant growth, with Group 1 serving as the control for comparison.

2.4. Experimental Setup
Bajra seeds (APFB-2 variety) and the developed PGPM Inoculum (Groups 3 and 4) were used for the study. The PGPM inoculum was applied once at the time of sowing seeds.

2.5. Data Collection
Parameters including germination percentage, chlorophyll content (measured using a SPAD meter), branching, and plant height were recorded at 25-day intervals over a period of 75 days, starting from the day of sowing.

2.6. Measurement of Chlorophyll Content
Chlorophyll content was assessed using a SPAD (Soil Plant Analysis Development) meter. This method involves shining light through plant leaves and analyzing the absorption spectrum. The meter provided a numerical reading corresponding to the chlorophyll concentration in the leaf tissue. Higher SPAD readings indicated higher chlorophyll content, indicative of healthier and more photosynthetically active plants.

2.7. Yield and Productivity
In this study, the methodology employed for estimating the yield of pearl millet in kilograms per hectare (Kg/ha) was systematically conducted. Throughout the growing season, standard agronomic practices were implemented, including irrigation, fertilization based on soil test recommendations, pest and disease control measures, and weed management. At maturity, random samples of plants were harvested from each plot to obtain representative measurements of parameters such as plant height, number of tillers per plant, and panicle characteristics. Subsequently, the entire crop from each plot was harvested, and the grains were threshed to separate them from the plant material. Grain yield was determined by weighing the harvested grains and expressed in kilograms.

2.8. Statistical Analysis
Statistical analysis, comprising mean comparisons and Duncan Multiple Range (DMR) analysis, was performed on the collected data.

3. Results and Discussion
The field culture experiments conducted to evaluate the efficacy of different treatments, including PGPM consortiums G3 and G4, along with a commercial organic fertilizer (G2) and a control group (G1), revealed notable differences in plant growth and productivity parameters throughout the study period (Figure 1 and 2). Consortiums G3 and G4, comprising isolated bacteria with varying cell count ranges, demonstrated superior efficacy against phytopathogens and exerted a more pronounced beneficial effect on the pearl millet plants compared to the other experimental groups. This enhanced efficacy was evident through several key observations.

Figure 1. The field culture experiments demonstrate the superior efficacy of plant growth promoting microorganism (PGPMs) consortium Group 3 and Group 4, leading to enhanced plant growth compared to Control (Group 1) and commercial biofertilizer (Group 2) treatments.

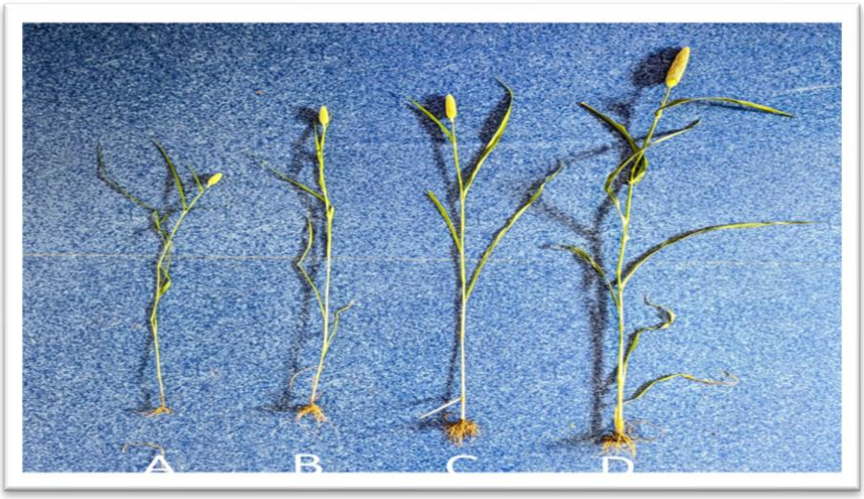

Figure 2. Influence of plant growth-promoting microorganism (PGPM) consortium on physical parameters of the plant after 50 days of sowing. (A) Control; (B) Commercial fertilizer; (C) PGPMs at low concentrations; (D) PGPMs at higher concentrations.

Firstly, both G3 and G4 exhibited higher germination rates compared to the control group, indicating improved seedling establishment and vigor. Furthermore, plants treated with G3 and G4 displayed more vigorous growth, characterized by taller plant heights and a greater number of branches per plant, after 75 days of sowing. The increased branching suggests better vegetative growth and potential for enhanced grain and biomass production. Additionally, the chlorophyll concentration in plants treated with G3 and G4 was notably higher, as measured by SPAD meter readings, indicating enhanced photosynthetic activity and overall plant health. These positive effects on plant growth and vigor translated into higher grain and stover yields in consortium-treated groups compared to the control and organic fertilizer-treated groups. Overall, the results suggest that the application of PGPM consortiums, particularly G3 and G4, significantly enhances pearl millet productivity by promoting better seedling establishment, vigorous vegetative growth, and improved photosynthetic efficiency, ultimately leading to higher grain and biomass yields. These findings underscore the potential of PGPM-based treatments as effective and sustainable strategies for enhancing crop productivity in pearl millet cultivation.

The Table 1 presents the influence of PGPMs on various traits of pearl millet crop production, categorized into four groups. The populations in Group 1 and Group 2 exhibited improved germination percentages compared to the control, with Group 2 showing the highest increase, reaching 84.4% ± 6.24. Additionally, plants in Group 4 attained the highest germination percentage of 100%, suggesting a significant positive effect of PGPMs on germination. Regarding plant height, Group 4 demonstrated the tallest plants, averaging 94.63 cm ± 6.84, followed by Group 3 with 81.45 cm ± 2.14, indicating a dose-dependent response to PGPM treatment. Similarly, chlorophyll content, as measured by Spad meter readings, increased across PGPM-treated groups, with Group 3 and Group 4 showing the highest readings of 45 ± 5 and 45 ± 3, respectively, indicating enhanced photosynthetic activity. Notably, grain yield and stover yield also exhibited positive responses to PGPM treatment, with increasing yields observed across the treated groups compared to the control. Group 4 recorded the highest grain yield of 1345 Kg/ha and stover yield of 3145 kg/ha, underscoring the substantial impact of PGPMs on overall pearl millet productivity. These results suggest that PGPMs application enhances pearl millet growth, development, and yield, highlighting its potential as a sustainable strategy for crop improvement. Further investigations are warranted to elucidate the underlying mechanisms driving these observed effects and optimize PGPM application protocols for maximizing pearl millet production in agricultural settings.

Table 1. Influence of plant growth-promoting microorganisms (PGPMs) on pearl millet crop production (Means ± S.E. in each row, followed by the same letter are not significantly different (P ≤ 0.05) from each other according to DMR test).

Consortium/Traits assayed	Group 1	Group 2	Group 3	Group 4
Population (germination percentage)	78.5±3.24[a]	84.4±6.24[b]	100[c]	100[c]
Height of the plant in centimetre	54.31±5.21[a]	63.57±3.54[b]	81.45±2.14[c]	94.63±6.84[d]
Chrolophyll content (Spad meter reading)	38±3[a]	42±2[b]	45±5[c]	45±3[c]
Grain yield (Kg/ha)	1120[a]	1210[b]	1285[c]	1345[d]
Stover yield (Kg/ha)	2356[a]	2671[b]	2987[c]	3145[d]

The observed enhancements in pearl millet growth, development, and yield following plant growth-promoting microorganism (PGPM) treatment warrant a discussion on potential underlying mechanisms. PGPMs encompass a diverse array of beneficial microorganisms such as rhizobacteria, mycorrhizal fungi, and certain strains of bacteria and fungi known for their ability to promote plant growth through various mechanisms. One possible mechanism contributing to the improved germination percentages seen in PGPM-treated groups could be the stimulation of seed germination by PGPMs through the production of phytohormones such as auxins and cytokinins (Farooq *et al.,* 2022; Reed *et al.,* 2022). These hormones play pivotal roles in regulating seed germination processes by influencing cell elongation, cell division, and nutrient mobilization, thus facilitating early seedling establishment (Majumdar and Kar, 2021). Additionally, PGPMs may enhance germination by suppressing the growth of seed-borne pathogens or by stimulating the plant's defense mechanisms against pathogen attacks, resulting in healthier seedlings (Ajee and Kaushik, 2021).

The observed increase in plant height and chlorophyll content in PGPM-treated groups may be attributed to several mechanisms. PGPMs are known to promote root development and enhance nutrient uptake by improving soil nutrient availability and facilitating the solubilization of insoluble phosphates and other essential minerals (Dhawi *et al.,* 2023). This improved nutrient acquisition leads to enhanced plant growth and vigor, resulting in taller plants with increased chlorophyll content (Teraiya *et al.,* 2023). Furthermore, PGPMs can induce systemic resistance in plants, priming them for better stress tolerance and improved photosynthetic efficiency, which is reflected in higher chlorophyll levels (Chakraborti *et al.,* 2023). Regarding grain and stover yield, PGPMs may positively influence yield components through multiple mechanisms (Mitra *et al.,* 2023; Hett, *et al.,* 2023). Enhanced nutrient uptake and utilization by PGPM-treated plants can lead to increased biomass accumulation and improved reproductive growth, ultimately resulting in higher grain and stover yields (Kumar *et al.,* 2022). Additionally, PGPMs can enhance plant resistance to environmental stresses such as drought, salinity, and disease, thereby reducing yield losses associated with adverse growing conditions (Meena *et al.,* 2020; Kumawat *et al.,* 2023). Furthermore, PGPMs may directly or indirectly promote nutrient cycling and soil fertility, creating a conducive environment for sustained crop productivity over successive growing seasons (Rawat *et al.,* 2020; de Andrade *et al.,* 2023). The observed benefits of PGPM treatment on pearl millet production likely stem from a combination of mechanisms involving improved seed germination, enhanced nutrient uptake and utilization, increased photosynthetic efficiency, and enhanced stress tolerance. Understanding these mechanisms is essential for optimizing PGPM application strategies and harnessing their full potential for sustainable agriculture. Further research is needed to elucidate the specific interactions between PGPMs and pearl millet plants and to explore their broader implications for agricultural sustainability and food security.

4. Summary and Conclusion

The study investigated the impact of PGPMs inoculation on pearl millet growth parameters under field conditions. The results demonstrated significant benefits of PGPM inoculation, particularly consortiums with varying cell counts, in promoting pearl millet growth. Consortiums G3 and G4 exhibited superior efficacy compared to the control and commercially available organic fertilizer treatments, as evidenced by higher germination rates, increased plant height, enhanced branching, and elevated chlorophyll content. These findings highlight the potential of PGPM-based strategies in enhancing pearl millet productivity and offer insights for sustainable agricultural practices in arid and semi-arid regions. The utilization of PGPMs in pearl millet cultivation holds immense promise for addressing productivity constraints in challenging environments. Further research is warranted to optimize PGPM application protocols, explore the mechanisms underlying their effects on pearl millet growth, and assess their long-term impacts on soil health and crop resilience. Additionally, investigations into the interactions between PGPMs and pearl millet plants at the molecular level could provide valuable insights into the specific pathways involved in promoting plant growth and stress tolerance. By leveraging the potential of PGPM-based strategies, farmers can enhance pearl millet productivity, improve soil fertility, and mitigate the adverse effects of biotic and abiotic stresses, thereby contributing to agricultural sustainability and food security in resource-constrained regions.

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Conflict of Interest: The authors declare no conflict of interest.

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