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Influence of microbial consortia on growth, yield and quality of wheat (*Triticum aestivum* L.) under calcareous condition

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ABSTRACT

A field experiment was conducted during the Rabi season of 2025–26 at Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra to evaluate the effect of individual and combined microbial inoculants on growth, yield and quality parameters of wheat (*Triticum aestivum* L.) grown under calcareous soil conditions. The experiment comprised ten treatments, including absolute control, recommended dose of fertilizer (RDF), individual microbial inoculants, their combinations and soil application of zinc and iron fertilizers, and was laid out in a randomized block design with three replications. The results revealed that microbial consortia significantly improved the growth, yield and quality attributes of wheat compared with the absolute control and RDF alone. Among the different treatments, the combined application of *Pseudomonas striata* + *Pseudomonas fluorescens* + *Aspergillus niger* + *Azospirillum lipoferum* along with 100% RDF recorded the highest plant height (62.40 cm), number of tillers (3.78 plant⁻¹), chlorophyll content (44.00 SPAD units), grain yield (4370.21 kg ha⁻¹), straw yield (6407.16 kg ha⁻¹), test weight (43.89 g), protein content (15.52%) and protein yield (588.24 kg ha⁻¹). The performance of RDF + consortium of *Pseudomonas striata* + *Pseudomonas fluorescens* + *Aspergillus niger* + *Azospirillum lipoferum* was found statistically at par with the treatments, RDF + consortium of *Pseudomonas striata* + *Pseudomonas fluorescens* and RDF + consortium of *Aspergillus niger* + *Azospirillum lipoferum* for several growth and yield attributes. The findings indicate that combined microbial inoculation with RDF improved crop growth, productivity and grain quality of wheat under calcareous soil conditions. Thus, microbial consortia showed potential for enhancing wheat performance through their complementary effects on plant growth, yield and quality of wheat.

Keywords: Calcareous soil, Microbial consortium, Plant growth, Yield, Quality, Protein content

Introduction

Wheat (*Triticum aestivum* L.) is an important cereal crop contributing significantly to global and Indian food security. India produced about 114 million tonnes of wheat from 31.40 million hectares during 2023–2024 (USDA, 2024; Corporation of India, 2024). However, micronutrient deficiencies, particularly zinc (Zn) and iron (Fe), are important constraints to crop productivity and nutritional quality. Their availability is often limited in calcareous soils because of high pH, calcium carbonate and formation of poorly soluble nutrient compounds (Kiran *et al.*, 2019) [1]. Microbial inoculants offer a sustainable approach to overcome these constraints. Zn²⁺ and Fe-solubilizing microorganisms can enhance nutrient availability through organic acid production, acidification and siderophore secretion, while plant growth-promoting microorganisms such as *Azospirillum* can improve plant growth and nutrient uptake (Kapulnik *et al.*, 1983; Kamran *et al.*, 2023; Kumar *et al.*, 2023) [2, 3]. The combined use of functionally diverse microorganisms may provide greater benefits than individual inoculation through complementary mechanisms of nutrient solubilization and plant growth promotion (Upadhyay *et al.*, 2022) [4].

Microbial inoculants can also stimulate plant growth by enhancing root development, nutrient acquisition and physiological activity, which may ultimately improve yield and grain quality. Beneficial microorganisms such as *Pseudomonas*, *Aspergillus* and *Azospirillum* perform complementary functions through nutrient solubilization, siderophore production, biological nitrogen fixation and phytohormone synthesis. These activities can promote greater plant height, tiller production, chlorophyll content and biomass accumulation, thereby contributing to improved grain and straw yield. Combined inoculation of functionally diverse microorganisms may further enhance these effects through synergistic interactions in the rhizosphere. Therefore, the present investigation was undertaken to evaluate the effect of individual and combined microbial inoculants on growth, yield and quality parameters of wheat (*Triticum aestivum* L.) under calcareous soil conditions.

Materials and Methods

The investigation was carried out during the *Rabi* season of 2025–26 at the Research Farm of the Department of Soil Science, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra. The experiment was conducted on a calcareous Vertisol under wheat (*Triticum aestivum* L.) cultivation. The experiment was laid out in a randomized block design comprising ten treatments, each replicated three times. The recommended dose of fertilizer (RDF) was 100 N : 50 P₂O₅ : 50 K₂O kg ha⁻¹. The treatments includes of RDF alone, individual microbial inoculants, combinations of microbial inoculants and soil application of zinc and iron fertilizers. The treatment were T₁: Control; T₂: RDF (100 N : 50 P₂O₅ : 50 K₂O kg ha⁻¹); T₃: RDF + *Pseudomonas striata* (Zn solubilizer); T₄: RDF + *Pseudomonas fluorescens* (Fe solubilizer); T₅: RDF + *Aspergillus niger* (Zn + Fe solubilizer); T₆: RDF + *Azospirillum lipoferum* (PGPR + micronutrient solubilizer); T₇: RDF + *Pseudomonas striata* + *Pseudomonas fluorescens*; T₈: RDF + *Aspergillus niger* + *Azospirillum lipoferum*; T₉: RDF + *Pseudomonas striata* + *Pseudomonas fluorescens* + *Aspergillus niger* + *Azospirillum*

lipoferum; and T₁₀: RDF + ZnSO₄ @ 20 kg ha⁻¹ + FeSO₄ @ 15 kg ha⁻¹.

Five plants were randomly selected and tagged from each experimental plot for recording biometric observations. Plant height was recorded at tillering, flowering and harvest stages and expressed in centimetres. The number of tillers was recorded by manually counting the tillers of the selected plants. Chlorophyll content of wheat leaves was measured non-destructively at the flowering stage using a SPAD chlorophyll meter and expressed as SPAD values. At maturity, the wheat crop from each net plot was harvested separately and subjected to threshing and winnowing. Grain yield was recorded by weighing the cleaned grains from each plot and expressed as kg ha⁻¹. Straw yield was calculated from the biological yield after deducting the grain yield and expressed as kg ha⁻¹.

Protein content in wheat grain was determined from the nitrogen content estimated by the Micro-Kjeldahl method. The protein content was calculated by multiplying the nitrogen percentage by the conversion factor of 6.25 for wheat. Protein yield was calculated from grain yield and protein content using the following formula:

$$\text{Protein yield (kg ha}^{-1}\text{)} = \left[\text{Grain yield (kg ha}^{-1}\text{)} \times \text{Protein content (\%)} \right] / 100$$

Test weight was determined by weighing 1000 grains from each treatment and expressed in grams.

Statistical analysis

The data obtained for growth, yield and quality parameters were statistically analysed using the procedures applicable to a randomized block design as described by Panse *et al.* (1985) [5]. The standard error and critical difference at the 5% level of significance were calculated wherever the treatment effect was significant. Treatment means were compared to determine the significance of differences among treatments.

Results and Discussion

Growth characters of wheat

The application of individual and combined microbial inoculants significantly improved the growth of wheat. Plant height ranged from 53.60 to 62.40 cm at harvest of wheat as presented in Table 1. The maximum plant height was recorded in T₉ (RDF + consortium of *Pseudomonas striata* + *Pseudomonas fluorescens* + *Aspergillus niger* + *Azospirillum lipoferum*), with values of 40.41, 58.90 and 62.40 cm at tillering, flowering and harvest, respectively, while the minimum was recorded in control (T₁). The number of tillers ranged from 1.90 to 3.78 plant⁻¹, with the highest value in T₉ (3.78 plant⁻¹), which was at par with T₇ (3.59 plant⁻¹), followed by T₈ (3.05 plant⁻¹). Chlorophyll content at flowering ranged from 34.70 to 44.00 SPAD values, with the maximum in T₉ (44.00 SPAD), at par with T₇ (43.89), T₈ (43.05), T₆ (42.45) and T₅ (40.23), whereas the minimum was recorded in T₁ (34.70 SPAD). Overall, the combined microbial inoculants, particularly T₉, resulted in superior growth and chlorophyll content compared with individual inoculants and control.

The increase in plant height, number of tillers and chlorophyll content may be attributed to the balanced supply of nutrients and enhanced root growth, which added root exudates and organic biomass to the soil, thereby increasing overall crop vigour in the calcareous soil. The increase may also be due to the solubilisation of native and fixed nutrient pools through the release of organic acids by *Aspergillus niger* and *Pseudomonas striata*, alongside siderophore production by *Pseudomonas fluorescens* and plant growth-promoting hormone synthesis by *Azospirillum lipoferum*. Similar results were reported by Bhosale (2021) [6], Bagmare *et al.* (2023) [7] and Satwadhar *et al.* (2023) [8]. Comparable findings were also reported by Dawlatzai *et al.* (2017) [9], Khandare *et al.* (2015) [10] and Prasad *et al.* (2020) [11]. Growth parameters were notably enhanced under T₉, showing that the combination of bio-inoculants and inorganic fertilisers improved

growth performance in calcareous soil. These findings were in accordance with Bhosale (2021) [6] and Bagmare *et al.* (2023) [7].

Yield of wheat

The data presented in Table 1 and Fig 1 revealed that the highest grain yield (3790.20 kg ha⁻¹) and straw yield (5907.16 kg ha⁻¹) were also recorded under RDF + consortium of *Pseudomonas striata* + *Pseudomonas fluorescens* + *Aspergillus niger* + *Azospirillum lipoferum*, followed by RDF + consortium of *Pseudomonas striata* + *Pseudomonas fluorescens* and RDF + consortium of *Aspergillus niger* + *Azospirillum lipoferum*. The improvement in yield may be due to complementary nutrient-solubilizing and growth-promoting activities of the inoculated microorganisms, resulting in better nutrient uptake and photosynthetic activity. Application of RDF along with microbial inoculants enhanced grain and straw yield in wheat by improving root development, enzymatic activity and overall nutrient balance, leading to better nutrient uptake, photosynthetic efficiency and reduced nutrient fixation in calcareous soils. Similar results were reported by Game *et al.* (2020) [12] and Halge *et al.* (2024) [13], who observed that integrated bio-fertilisation optimizes productivity and biomass accumulation. The balanced use of chemical fertiliser combined with multi-strain microbial consortia was beneficial for higher yield performance. The results are in conformity with Dhamak *et al.* (2014) [14] and Satwadhar *et al.* (2023) [8], who concluded that crop productivity on Vertisols improved when beneficial microorganisms were integrated with recommended fertilizer packages. Furthermore, Game *et al.* (2020) [12] found that integration of macro- and micronutrient fertilisation with biofertilizers significantly increased yield attributes.

In general, application of different microbial consortia along with RDF decreased nutrient availability bottlenecks after harvest of the wheat crop by continuously mobilizing native reserves. Overall, the results indicated that application of microbial inoculants along with RDF improved the physiological activity and biomass partitioning in soil. Similar results were reported by Dhamak *et al.* (2014) [14], who showed enhanced productivity with integrated bio-organic treatments. Similar observations were reported by Game *et al.* (2020) [12] and Halge *et al.* (2024) [13], who found that targeted nutrient and biological interventions effectively buffer against soil nutrient constraints.

Quality parameters

The data presented in Table 2 revealed that, among the quality parameters, T₉ recorded the highest protein content (15.52%), protein yield (588.24 kg ha⁻¹) and test weight (43.89 g), whereas the control recorded the lowest values. The improvement in protein content may be associated with enhanced nitrogen availability and uptake, while

higher test weight could be related to improved photosynthate accumulation and grain filling. The data indicate that nutrient fortification via microbial consortia, particularly the multi-strain treatment T₉, improved the quality parameters of wheat under calcareous soil conditions. The higher values may be attributed to the complementary functions of the microbial inoculants, which improved nutrient availability and uptake. Similar quality responses of crops to integrated nutrient levels were reported by Waghmare *et al.* (2020) [15]. Kaur *et al.* (2020) [16] reported that application of plant growth-promoting microbial strains recorded higher protein content and quality attributes compared with the absolute control and other individual combinations. Game *et al.* (2020) [12] and Waghmare *et al.* (2020) [15] also showed that integrated biofertilizer applications yielded maximum test weight and protein output, whereas the minimum values for quality parameters were consistently recorded under the uninoculated control.

Thus, the combined application of functionally diverse microbial inoculants with RDF, particularly T₉, improved growth, productivity and grain quality of wheat under calcareous soil conditions.

Conclusion

The study concluded that integration of microbial inoculants with the recommended dose of fertilizer improved the growth, yield and quality of wheat under calcareous soil conditions. The combined application of *Pseudomonas striata*, *Pseudomonas fluorescens*, *Aspergillus niger* and *Azospirillum lipoferum* with 100% RDF showed superior

performance, indicating the complementary role of nutrient-solubilizing and plant growth-promoting microorganisms. The microbial consortium enhanced crop growth, productivity and grain quality compared with RDF alone. Thus, combined microbial inoculation along with balanced fertilization can be considered a promising nutrient management approach for improving wheat performance in calcareous Vertisols.

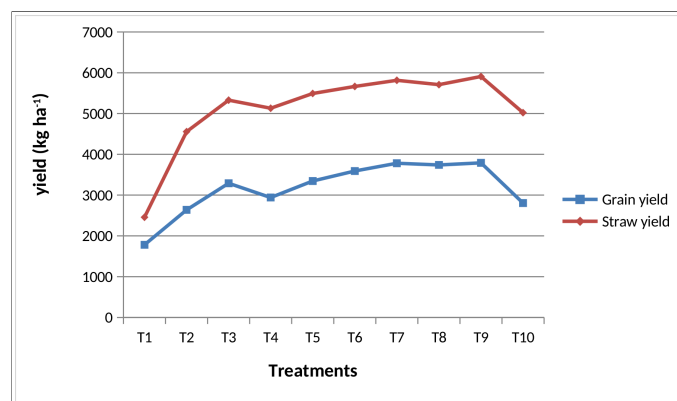


Figure 1. Effect of individual and combined microbial inoculants on grain and straw

yield of wheat

Table 1. Effect of individual and combined microbial inoculants on growth parameters

Treatment	Plant height at harvest (cm)	Tillers plant ⁻¹	Chlorophyll content (SPAD value))	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
T ₁ – Control	53.60	1.9	34.7	1780.45	2457.18
T ₂ - RDF (100 N : 50 P ₂ O ₅ : 50 K ₂ O kg ha ⁻¹)	55.09	2.07	35.67	2638.13	4556.21
T ₃ - RDF + <i>Pseudomonas striata</i> (Zn solubilizer)	59.59	2.30	39.00	3290.18	5327.65
T ₄ - RDF + <i>Pseudomonas fluorescens</i> (Fe solubilizer)	58.20	2.11	38.20	2940.48	5130.11
T ₅ - RDF + <i>Aspergillus niger</i> (Zn + Fe solubilizer)	60.90	2.65	40.23	3345.35	5492.10
T ₆ - RDF + <i>Azospirillum lipoferum</i> (PGPR + micronutrient solubilizer)	61.06	2.89	42.45	3590.12	5664.04
T ₇ - RDF+ Consortium of <i>Pseudomans striata</i> + <i>Pseudomonas fluorescens</i>	62.07	3.59	43.89	3780.21	5814.78
T ₈ - RDF + Consortium of <i>Aspergillus niger</i> + <i>Azospirillum lipoferum</i>	61.75	3.05	43.05	3740.12	5708.23
T ₉ - RDF + Consortium of <i>Pseudomonas striata</i> + <i>Pseudomonas fluorescens</i> + <i>Aspergillus niger</i> + <i>Azospirillum lipoferum</i>	62.40	3.78	44.00	3790.20	5907.16
T ₁₀ - RDF + ZnSO ₄ @ 20 kg ha ⁻¹ + FeSO ₄ @ 15 kg ha ⁻¹ .	57.05	2.10	37.90	2805.73	5021.05
SEm ±	1.3	0.08	1.32	72.5	102.2
CD at 5%	3.9	0.24	3.93	209.7	306.0

Table 2. Effect of individual and combined microbial inoculants on quality parameters

Treatment	Protein content (%)	Protein yield (kg ha ⁻¹)	Test weight (g)
T ₁ – Control	10.40	185.17	40.49
T ₂ - RDF (100 N : 50 P ₂ O ₅ : 50 K ₂ O kg ha ⁻¹)	10.74	283.34	40.80
T ₃ - RDF + <i>Pseudomonas striata</i> (Zn solubilizer)	12.75	419.00	41.97
T ₄ - RDF + <i>Pseudomonas fluorescens</i> (Fe solubilizer)	12.18	358.15	41.60

(continued on next page)

Treatment	Protein content (%)	Protein yield (kg ha ⁻¹)	Test weight (g)
T ₅ - RDF + <i>Aspergillus niger</i> (Zn + Fe solubilizer)	13.11	438.58	42.45
T ₆ - RDF + <i>Azospirillum lipoferum</i> (PGPR + micronutrient solubilizer)	13.90	498.03	42.99
T ₇ - RDF+ Consortium of <i>Pseudomonas striata</i> + <i>Pseudomonas fluorescens</i>	14.85	561.36	43.55
T ₈ - RDF + Consortium of <i>Aspergillus niger</i> + <i>Azospirillum lipoferum</i>	14.20	531.10	43.20
T ₉ - RDF + Consortium of <i>Pseudomonas striata</i> + <i>Pseudomonas fluorescens</i> + <i>Aspergillus niger</i> + <i>Azospirillum lipoferum</i>	15.52	588.24	43.89
T ₁₀ - RDF + ZnSO ₄ @ 20 kg ha ⁻¹ + FeSO ₄ @ 15 kg ha ⁻¹ .	11.30	317.05	41.22
SEm ±	0.3	11.6	0.3
CD at 5%	0.8	33.7	1.0

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