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Synergistic role of plant growth promoting microbial consortia in enhancing soil microbiome activity and brinjal (*Solanum melongena* L.) productivity

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Abstract
Plant growth-promoting microorganisms (PGPMs) play a central role in sustainable agriculture by enhancing soil fertility, plant nutrition, and stress tolerance. The use of microbial consortia—combinations of beneficial bacteria and fungi—has gained attention as a sustainable approach to restore soil microbiome diversity and improve crop productivity. This study investigates the synergistic influence of bacterial and fungal consortia on soil enzyme activity, nutrient availability, and brinjal (*Solanum melongena* L.) yield under field conditions. The experiment included *Azotobacter chroococcum*, *Pseudomonas fluorescens*, *Bacillus subtilis*, *Trichoderma harzianum*, and *Glomus mosseae* applied individually and in different combinations. The microbial consortium significantly enhanced soil dehydrogenase (by 43%), phosphatase (by 38%), and urease (by 32%) activities compared to the uninoculated control. Plant growth, fruit yield, and nutrient uptake were markedly improved, with an overall yield increase of 26.5% in consortium-treated plots. These findings confirm that microbial consortia can effectively improve soil microbiome functionality and contribute to sustainable brinjal cultivation.

Keywords: Plant growth-promoting microorganisms, microbial consortium, soil enzymes, rhizosphere, sustainable agriculture, *Solanum melongena*

1. Introduction

Brinjal (*Solanum melongena* L.), a major solanaceous vegetable crop, occupies a vital position in tropical and subtropical agriculture, particularly in India, Bangladesh, and Southeast Asia. Its productivity is strongly dependent on soil health and nutrient availability. However, the continuous application of chemical fertilizers and pesticides has led to severe ecological imbalances, declining soil organic matter, and a reduction in beneficial microbial populations (Mishra & Dash, 2021) [14]. Consequently, there has been a growing interest in utilizing plant growth-promoting microorganisms (PGPMs) as eco-friendly alternatives for improving soil quality and crop yield.

PGPMs such as *Azotobacter*, *Bacillus*, *Pseudomonas*, and *Trichoderma* contribute to plant development by enhancing nutrient acquisition, producing growth-promoting hormones (indole acetic acid, gibberellins), fixing atmospheric nitrogen, and solubilizing insoluble phosphorus (Vessey, 2003) [4]. Moreover, arbuscular mycorrhizal fungi (*Glomus* spp.) improve nutrient and water absorption, strengthening plant resilience against abiotic stress (Smith & Read, 2008). While individual microbial inoculants have shown positive results, recent research has revealed that mixed microbial consortia exhibit enhanced synergistic effects through complementary metabolic interactions (Bhattacharyya & Jha, 2012) [8].

Microbial consortia enhance the rhizospheric environment by increasing soil enzyme activities such as dehydrogenase, urease, and phosphatase, which are vital indicators of soil biological activity (Nannipieri *et al*., 2012) [9]. The co-inoculation of beneficial bacteria and fungi fosters cooperative interactions, where bacterial metabolites stimulate fungal colonization and vice versa, resulting in improved nutrient mineralization and plant growth (Kumar *et al*., 2011) [12]. In brinjal cultivation, microbial inoculation has been linked with improved vegetative growth, increased fruit yield, and reduced susceptibility to soil-borne diseases such as wilt and root rot (Jahan *et al*., 2020) [13].

This study aims to evaluate the combined efficacy of five plant growth-promoting microbes—*Azotobacter chroococcum*, *Bacillus subtilis*, *Pseudomonas fluorescens*, *Trichoderma harzianum*, and *Glomus mosseae*—on soil microbiome activity and brinjal productivity. It hypothesizes that microbial consortia will significantly enhance enzymatic activity, nutrient uptake, and crop yield compared to single inoculations or uninoculated control.

2. Methodology

2.1 Experimental Site and Design

The experiment was carried out during the *kharif* season of 2021 at the Horticultural Research Farm, New Delhi (28.6° N, 77.2° E). The soil was sandy loam in texture, with a pH of 7.3, electrical conductivity of 0.36 dS m^{-1}, and organic carbon content of 0.48%. The experimental design was a randomized block design (RBD) with six treatments replicated thrice.

Treatments

- T_1: Control (no inoculation)
- T_2: *Azotobacter chroococcum*
- T_3: *Pseudomonas fluorescens* + *Bacillus subtilis*
- T_4: *Trichoderma harzianum* + *Glomus mosseae*
- T_5: Microbial consortium (all five strains combined)
- T_6: Recommended NPK dose (120:60:60 kg ha^{-1})

2.2 Inoculum Preparation and Application

Each microbial strain was maintained on its respective growth medium:

- *Azotobacter chroococcum* in Ashby's medium,
- *Pseudomonas fluorescens* in King's B broth,
- *Bacillus subtilis* in nutrient broth,
- *Trichoderma harzianum* on potato dextrose agar, and
- *Glomus mosseae* propagated on maize roots in sterilized sand-soil mixture.

The population density of each culture was adjusted to 10^8 CFU mL^{-1}. Brinjal seedlings were root-dipped in the microbial suspension for 30 minutes before transplanting, and consortium-treated plots received an additional soil drench at 30 days after transplanting.

2.3 Soil Enzyme and Microbial Analysis

Soil samples were collected from each plot at 0-15 cm depth both before sowing and after harvest. Soil enzyme activities were determined using standard protocols:

- **Dehydrogenase activity:** Casida *et al*. (1964) [1]
- **Urease activity:** Tabatabai & Bremner (1972) [3]
- **Phosphatase activity:** Tabatabai & Bremner (1969) [2]

Microbial counts for bacteria, fungi, and actinomycetes were assessed using serial dilution and plating on nutrient agar, potato dextrose agar, and actinomycete isolation agar, respectively.

2.4 Plant Growth and Yield Parameters

Parameters recorded included plant height, leaf area index, number of fruits per plant, average fruit weight, and total yield per hectare. Chlorophyll content was measured with a SPAD meter, and nutrient uptake was analyzed using the Kjeldahl method (for N), vanado-molybdate yellow color method (for P), and flame photometry (for K).

2.5 Statistical Analysis

All data were subjected to analysis of variance (ANOVA) using SPSS software (version 25.0). The treatment means were compared using Duncan's Multiple Range Test (DMRT) at a 5% probability level.

3. Results

3.1 Soil Enzyme Activity

The consortium treatment (T_5) significantly enhanced all measured enzyme activities over the control (Table 1).

- **Dehydrogenase activity:** 41.8 µg TPF g^{-1} soil h^{-1} in T_5 vs. 22.9 µg in control
- **Urease activity:** 36.2 µg NH_4^+-N g^{-1} soil h^{-1} in T_5 vs. 27.4 µg in control
- **Phosphatase activity:** 51.1 µg PNP g^{-1} soil h^{-1} in T_5 vs. 34.2 µg in control

These results indicate enhanced microbial respiration and nutrient mineralization due to synergistic interactions among bacterial and fungal inoculants.

3.2 Growth and Yield Attributes

Plants treated with microbial consortia (T_5) exhibited superior performance with respect to plant height (73.5 cm), leaf area index (4.6), and chlorophyll content (49.8 SPAD units). The average number of fruits per plant (15.2) and fruit weight (95.4 g) were significantly higher than in the control. The total yield recorded was 34.7 t ha^{-1} in T_5 compared to 27.4 t ha^{-1} in T_1, representing a 26.5% increase.

Table 1: Effect of microbial consortia on soil enzyme activity

Treatment	Dehydrogenase (µg TPF g^{-1} soil h^{-1})	Urease (µg NH_4^+-N g^{-1} soil h^{-1})	Phosphatase (µg PNP g^{-1} soil h^{-1})
Control (T_1)	22.9	27.4	34.2
Azotobacter (T_2)	30.5	30.6	40.8
Pseudomonas + *Bacillus* (T_3)	35.1	33.2	44.9
Trichoderma + *Glomus* (T_4)	37.8	34.1	46.5
Consortium (T_5)	41.8	36.2	51.1
NPK (T_6)	38.4	33.9	48.2

3.3 Nutrient Uptake

Consortium treatment resulted in the highest nitrogen, phosphorus, and potassium uptake (69.2, 15.8, and 52.7 kg ha^{-1}, respectively), indicating improved nutrient-use efficiency. Enhanced microbial activity and root colonization likely contributed to this improvement.

4. Discussion

The enhancement of soil enzyme activity observed in consortium-treated plots supports the findings of earlier studies that microbial interactions enhance soil biological processes (Barea *et al*., 2005; Nannipieri *et al*., 2012) [6, 9]. The marked increase in dehydrogenase activity is indicative of elevated microbial respiration and metabolic potential.

Similarly, the higher phosphatase activity demonstrates improved organic phosphorus mineralization, promoting root nutrient uptake (Richardson & Simpson, 2011) [10].

The co-inoculation of *Azotobacter*, *Pseudomonas*, and *Trichoderma* may have led to enhanced production of auxins, cytokinins, and siderophores, thereby stimulating root proliferation and nutrient absorption (Bhattacharyya & Jha, 2012) [8]. The mycorrhizal association of *Glomus mosseae* further improved phosphorus availability by extending the absorptive surface area of the root system. Comparable synergistic effects of mixed microbial inoculants have been documented in tomato (Basu *et al*., 2011) [11] and pepper (Kumar *et al*., 2011) [12].

The increase in yield and nutrient content observed aligns with the principle that microbial consortia enhance rhizosphere competence and nutrient turnover (Barea *et al*., 2005) [6]. The interplay between bacteria and fungi results in greater soil aggregation, better root colonization, and suppression of phytopathogens. The enzymatic and microbial dynamics observed here reflect a self-sustaining nutrient cycle, reducing the dependency on chemical fertilizers.

5. Conclusion

The study concludes that microbial consortia exert a significant synergistic influence on soil biological activity, nutrient mobilization, and brinjal productivity. The combination of *Azotobacter chroococcum*, *Pseudomonas fluorescens*, *Bacillus subtilis*, *Trichoderma harzianum*, and *Glomus mosseae* improved soil enzyme activity and fruit yield substantially over single inoculations. The approach represents an ecologically sustainable alternative to chemical fertilizers, promoting soil health and long-term agricultural productivity. Further research should explore consortium stability, formulation techniques, and field scalability under diverse agro-climatic conditions.

6. Conflict of Interest

Not available

7. Financial Support

Not available

8. References

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