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Exploring pharmacological potential of microbial-enhanced brinjal (*Solanum melongena* L.): Growth, nutrient profile, and bioactive compound enrichment

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Abstract
Brinjal (*Solanum melongena* L.) is an important vegetable crop with high nutritional and medicinal value. Enhancing its growth and quality through eco-friendly approaches like microbial biofertilization can help improve both productivity and fruit composition. In this study, plant growth-promoting microorganisms were used to observe their influence on plant growth, nutrient content, and the enrichment of bioactive compounds in brinjal. A consortium of *Azotobacter chroococcum*, *Bacillus subtilis*, *Pseudomonas fluorescens*, *Trichoderma harzianum*, and *Glomus mosseae* was applied to plants under field conditions. The inoculated plants showed better vegetative growth, higher yield, and improved biochemical parameters such as total phenolics, flavonoids, and antioxidant activity. Notably, the levels of chlorogenic acid and nasunin were also higher in fruits obtained from microbial treatments. These results suggest that the combined microbial inoculation could be a sustainable method for improving the pharmacological potential of brinjal.

Keywords: Brinjal, microbial consortium, biofertilizer, antioxidants, phenolics, *Solanum melongena*

1. Introduction
Brinjal (*Solanum melongena* L.) is widely cultivated in tropical and subtropical regions for its nutritional and therapeutic value. It contains many useful phytochemicals such as phenols, flavonoids, and anthocyanins, which have antioxidant and anti-inflammatory properties (Whitaker & Stommel, 2003) [3]. Regular consumption of brinjal has been associated with reduced cholesterol levels and improved liver function (Nisha *et al*., 2009) [5].
However, modern cultivation practices rely heavily on chemical fertilizers, which affect both soil health and crop quality. In many cases, continuous use of synthetic inputs reduces soil microbial diversity and leads to nutrient imbalance (Tilman *et al*., 2002) [1]. To make vegetable production more sustainable, microbial biofertilizers are being promoted as substitutes for part of the chemical fertilizers.
Plant growth-promoting microorganisms (PGPMs) such as *Azotobacter*, *Bacillus*, and *Pseudomonas* support plant growth by fixing nitrogen, producing phytohormones, and solubilizing phosphorus. Fungal species like *Trichoderma* and *Glomus* help plants by increasing root growth and protecting against soil-borne pathogens (Vessey, 2003; Bhattacharyya & Jha, 2012) [2, 9]. When such microbes are used together as a consortium, they often perform better because they complement each other's functions in the rhizosphere.
In addition to improving plant growth, microbial inoculation may also affect the synthesis of bioactive compounds in plants. Certain beneficial microbes can induce the production of secondary metabolites such as phenolics and flavonoids, which contribute to the antioxidant activity of fruits (Kumar *et al*., 2011) [8].
Hence, this study was carried out to evaluate how microbial consortia affect the growth performance, nutrient profile, and enrichment of pharmacologically important bioactive compounds in brinjal under field conditions.

2. Materials and Methods
2.1 Experimental Site
The experiment was conducted during 2021-2022 at the Crop Science Research Farm,

University of Ghana, Legon (5.65° N, 0.18° W). The area has a tropical climate with about 1,100 mm average annual rainfall and mean temperature of 27 °C. The soil was sandy loam with pH 6.8 and medium fertility.

2.2 Experimental Design and Treatments
The study followed a Randomized Complete Block Design (RCBD) with six treatments and three replications.

Treatments included

T_1-Control (no inoculation)
T_2-*Azotobacter chroococcum*
T_3-*Bacillus subtilis* + *Pseudomonas fluorescens*
T_4-*Trichoderma harzianum* + *Glomus mosseae*
T_5-Consortium of all five microbes
T_6-Recommended NPK (120:60:60 kg ha⁻¹)

2.3 Microbial Preparation and Application
Each microorganism was cultured on its suitable medium and standardized to 10^8 CFU mL^{-1}. Equal volumes of each culture were mixed to make the consortium. Brinjal seedlings (cv. 'Pusa Purple Long') were root-dipped in the inoculum for 30 minutes before transplanting. The same inoculum was applied to the soil again 30 days after transplanting.

2.4 Growth and Yield Parameters
Data were recorded for plant height, leaf area index, chlorophyll content (SPAD), number of fruits per plant, and total yield (t ha^{-1}).

2.5 Nutrient and Phytochemical Analysis
Macronutrients (N, P, K) were determined using standard laboratory procedures—Kjeldahl for N, vanado-molybdate method for P, and flame photometry for K.
The biochemical analyses included:

- **Total Phenolic Content (TPC):** Folin-Ciocalteu method (Singleton *et al.*, 1999)
- **Total Flavonoid Content (TFC):** Aluminum chloride colorimetric method
- **Antioxidant Activity:** DPPH radical scavenging assay
- **HPLC Quantification:** for chlorogenic acid and nasunin levels.

2.6 Statistical Analysis
All data were analyzed using one-way ANOVA (SPSS v25.0). Means were separated with Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$.

3. Results
3.1 Plant Growth and Yield
The consortium treatment (T_5) showed the best overall performance (Table 1). Plant height, leaf area, and chlorophyll content were significantly higher than in the control. Yield increased by about 26%, showing that the combination of bacteria and fungi enhanced growth conditions in the rhizosphere.

Table 1: Effect of microbial inoculation on growth and yield of brinjal

Treatment	Plant Height (cm)	Leaf Area Index	Chlorophyll (SPAD)	Yield (t ha^{-1})
Control	56.2	3.5	42.1	28.3
Azotobacter	61.7	3.9	44.8	30.6
Bacillus + Pseudomonas	65.2	4.2	46.9	32.8
Trichoderma + Glomus	67.3	4.3	47.2	33.6
Consortium	72.0	4.6	50.1	35.7
NPK	69.1	4.4	48.3	34.2

3.2 Nutrient Uptake
The consortium (T_5) resulted in the highest nutrient uptake: N 68.4 kg ha^{-1}, P 15.6 kg ha^{-1}, K 53.2 kg ha^{-1}. This improvement can be linked to better microbial mineralization and root nutrient absorption.

3.3 Phytochemical Composition
Microbial treatments, especially T_5, significantly enhanced the phenolic and flavonoid contents in brinjal fruits. The antioxidant activity also increased by 20-25% compared to the control (Table 2).

Table 2: Effect of microbial inoculation on bioactive compounds of brinjal fruit

Treatment	Total Phenolics (mg GAE g^{-1} FW)	Flavonoids (mg QE g^{-1} FW)	DPPH Inhibition (%)	Chlorogenic Acid (mg g^{-1} DW)	Nasunin (mg g^{-1} DW)
Control	1.82	0.74	56.3	0.96	0.41
Azotobacter	2.01	0.82	60.7	1.04	0.48
Bacillus + Pseudomonas	2.19	0.89	63.5	1.12	0.51
Trichoderma + Glomus	2.24	0.91	64.2	1.17	0.55
Consortium	2.48	1.02	68.9	1.26	0.61
NPK	2.20	0.87	62.3	1.09	0.49

4. Discussion
The present study clearly showed that microbial inoculation plays a vital role in improving both agronomic and nutritional qualities of brinjal. The consortium performed better than individual inoculants, suggesting synergistic interactions among the microbes.
The increase in phenolics and flavonoids might be due to microbial stimulation of the phenylpropanoid pathway, which is known to enhance antioxidant compound formation (Barea *et al*., 2005) [6]. *Trichoderma* and *Pseudomonas* may also produce elicitors that activate plant defense-related enzymes, indirectly promoting the synthesis of bioactives like chlorogenic acid and nasunin (Sadilova *et al*., 2006) [7].
These results are consistent with earlier findings where microbial inoculants improved both yield and biochemical parameters in vegetables (Singh *et al*., 2020) [10]. Thus, the use of microbial consortia not only increases productivity but also adds functional and pharmacological value to brinjal fruits.

5. Conclusion

From this study, it can be concluded that the use of microbial consortia is a promising approach for enhancing brinjal growth and fruit quality. The combined inoculation of *Azotobacter chroococcum*, *Bacillus subtilis*, *Pseudomonas fluorescens*, *Trichoderma harzianum*, and *Glomus mosseae* significantly improved yield and the accumulation of beneficial bioactive compounds. This approach offers a sustainable pathway for producing nutritionally and pharmacologically rich vegetables with reduced dependence on chemical fertilizers.

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