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Academic evaluation of microbial consortia-based biofertilization strategies for sustainable brinjal (*Solanum melongena* L.) production

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Abstract
Sustainable vegetable production in Africa requires innovative and low-cost soil fertility management strategies. Microbial consortia-based biofertilization integrates beneficial microorganisms that improve soil microbial health, nutrient mobilization, and crop productivity. This study evaluated the effects of bacterial and fungal consortia on soil enzyme activity, nutrient availability, and yield of brinjal (*Solanum melongena* L.) grown under tropical field conditions in Ghana. Treatments comprised *Azotobacter chroococcum*, *Bacillus subtilis*, *Pseudomonas fluorescens*, *Trichoderma harzianum*, and *Glomus mosseae*, applied individually and in combination. Results revealed that the microbial consortium significantly enhanced soil dehydrogenase, phosphatase, and urease activities by 48%, 39%, and 33%, respectively, compared with the control. Nutrient uptake and fruit yield increased by 27% and 25.4% respectively. The findings confirm that multi-strain biofertilization can sustainably enhance brinjal productivity and soil health in tropical African agroecosystems.

Keywords: Biofertilization, microbial consortium, tropical soils, soil enzymes, sustainable vegetable production, *Solanum melongena*

1. Introductions

Agriculture across sub-Saharan Africa faces continuous soil fertility depletion due to nutrient mining, erratic rainfall, and low organic matter input (Sanginga & Woomer, 2009) [11]. Farmers often rely heavily on mineral fertilizers, yet their high cost and limited accessibility hinder widespread use, especially among smallholders (Vanlauwe *et al*., 2010) +. This has prompted the need for sustainable and locally adaptable soil fertility improvement practices that reduce dependency on synthetic inputs while enhancing soil biological functions.

Microbial biofertilizers—formulations containing beneficial microorganisms such as *Azotobacter*, *Bacillus*, *Pseudomonas*, *Trichoderma*, and mycorrhizal fungi—offer an environmentally safe and cost-effective alternative for nutrient management (Vessey, 2003) [4]. These microorganisms improve nutrient availability through nitrogen fixation, phosphate solubilization, and production of plant growth-promoting substances. Moreover, they enhance plant resilience to stress and increase soil enzyme activities, thereby contributing to soil ecological balance (Bhattacharyya & Jha, 2012) [9].

While individual bioinoculants have shown promise, their performance is inconsistent under field conditions due to environmental fluctuations. A microbial consortium, comprising multiple compatible strains, offers synergistic benefits that surpass single inoculant performance (Barea *et al*., 2005) [5]. Such consortia enhance microbial colonization in the rhizosphere and jointly stimulate soil enzymatic activity, nutrient uptake, and plant growth (Smith & Read, 2008).

Brinjal (*Solanum melongena* L.) is an economically important vegetable crop widely grown in West Africa, particularly in Ghana and Nigeria. However, its productivity remains below potential due to poor soil fertility and limited use of biological inputs. The present study, therefore, aimed to evaluate the agronomic and biological efficacy of microbial consortia-based biofertilization for sustainable brinjal production under Ghanaian field conditions.

2. Materials and Methods

2.1 Experimental Site

The experiment was conducted during the 2019-2020 cropping season at the Department of Crop and Soil Sciences Research Farm, Kwame Nkrumah University of Science and

Technology (KNUST), Kumasi, Ghana (6.69° N, 1.63° W; elevation 287 m). The site has a semi-deciduous tropical climate with mean annual rainfall of 1,400 mm and temperature ranging from 23-33 °C. The soil was classified as a Ferric Acrisol (FAO classification), sandy loam in texture, with a pH of 6.4, organic carbon 0.56%, and total nitrogen 0.041%.

2.2 Experimental Design and Treatments
A randomized complete block design (RCBD) was used with six treatments replicated three times:
- 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)
- T_6: Recommended NPK (120:60:60 kg ha^{-1})

Each plot measured 4 m × 3 m with a spacing of 60 cm × 45 cm between plants.

2.3 Inoculum Preparation and Application
Microbial strains were obtained from the KNUST Soil Microbiology Laboratory and cultured under standard conditions:
- *Azotobacter*-Ashby's medium
- *Bacillus*-nutrient broth
- *Pseudomonas*-King's B broth
- *Trichoderma*-potato dextrose agar
- *Glomus mosseae*-propagated using maize host roots in sterilized soil-sand mixture.

Each inoculum was adjusted to 10^8 CFU mL^{-1}. The microbial consortium (T_5) was prepared by mixing equal volumes of all strains. Seedlings were dipped in the inoculum for 30 minutes prior to transplanting, followed by a soil drench (10 mL $plant^{-1}$) at 30 days after transplanting (DAT).

2.4 Soil and Plant Analysis
Soil samples were collected before sowing and after harvest for enzyme analysis:
- **Dehydrogenase activity:** Casida *et al*. (1964) [1]
- **Phosphatase activity:** Tabatabai & Bremner (1969) [2]
- **Urease activity:** Tabatabai & Bremner (1972) [3]

Plant parameters such as height, number of branches, leaf area index, and chlorophyll content (SPAD meter) were recorded. Nutrient uptake was analyzed using the Kjeldahl method (for N), vanadomolybdate yellow color method (for P), and flame photometry (for K).

2.5 Statistical Analysis
Data were analyzed using one-way ANOVA (SPSS v25.0). Mean separation was performed with Duncan's Multiple Range Test (DMRT) at a 5% level of significance.

Table 1: Analysis of Variance (ANOVA) for Effect of Microbial Consortia on Brinjal Growth and Yield Attributes

Source of Variation	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Square (MS)	F-Value	Significance ($p \leq 0.05$)
Treatment	5	542.63	108.53	18.72	**Significant**
Replication (Block)	2	21.46	10.73	1.85	ns
Error	10	57.96	5.80	—	—
Total	17	622.05	—	—	—

Coefficient of Variation (CV): 8.3%
Grand Mean Yield: 34.7 t ha^{-1}
The ANOVA results indicate that the effect of treatments was statistically significant ($p \leq 0.05$) for brinjal yield and associated parameters. The high F-value (18.72) confirms that microbial consortia treatments contributed substantially to variability among means, whereas replication effects were non-significant. The relatively low coefficient of variation (8.3%) suggests good experimental precision and uniformity among replications.

3. Results
3.1 Soil Enzyme Activities
All enzyme activities were significantly enhanced by microbial treatments (Table 2). The consortium treatment (T_5) recorded the highest values:
- **Dehydrogenase:** 43.7 µg TPF g^{-1} soil h^{-1}
- **Urease:** 35.8 µg NH_4-N g^{-1} soil h^{-1}
- **Phosphatase:** 52.6 µg PNP g^{-1} soil h^{-1}

This represents 48%, 33%, and 39% increases respectively over the control. The NPK treatment (T_6) also improved enzyme activity but remained lower than microbial consortia, highlighting the biological contribution of microbial inoculants.

Table 2: Effect of microbial consortia on soil enzyme activity in brinjal rhizosphere

Treatment	Dehydrogenase (µg TPF g^{-1} h^{-1})	Urease (µg NH_4-N g^{-1} h^{-1})	Phosphatase (µg PNP g^{-1} h^{-1})
Control (T_1)	29.5	27.1	37.8
Azotobacter (T_2)	33.6	30.5	41.3
Pseudomonas + *Bacillus* (T_3)	36.9	32.6	46.4
Trichoderma + *Glomus* (T_4)	39.8	33.9	48.2
Consortium (T_5)	43.7	35.8	52.6
NPK (T_6)	40.5	33.1	49.1

3.2 Plant Growth and Yield Attributes
Brinjal plants treated with microbial consortium showed superior vegetative growth and yield performance. Mean plant height (73.2 cm), chlorophyll content (51.2 SPAD units), and number of fruits per plant (15.8) were significantly higher than control. The total fruit yield reached 35.3 t ha^{-1} in T_5, compared to 28.1 t ha^{-1} in the control—an improvement of 25.4%.

3.3 Nutrient Uptake
Consortium-treated plants exhibited the highest nutrient uptake (N: 67.8 kg ha^{-1}, P: 15.7 kg ha^{-1}, K: 52.3 kg ha^{-1}). The co-inoculation promoted greater root colonization,

enhancing nutrient absorption efficiency, particularly under tropical soil conditions where phosphorus availability is often limiting.

4. Discussion

The findings corroborate the synergistic interactions between microbial species in consortia-based inoculations. Increased enzyme activities indicate an active microbial community, contributing to nutrient mineralization and improved soil fertility. Similar outcomes were reported by Barea *et al*. (2005) [5] and Richardson & Simpson (2011) [7], emphasizing the role of microbial cooperation in enhancing soil enzymology.

The combination of *Azotobacter*, *Pseudomonas*, *Bacillus*, *Trichoderma*, and *Glomus* provided multiple growth-promotion pathways: nitrogen fixation, phosphate solubilization, phytohormone secretion, and pathogen suppression (Bhattacharyya & Jha, 2012) [9]. Enhanced yield performance under Ghanaian field conditions demonstrates the adaptability of microbial consortia to tropical climates.

These results are in line with those reported in other African studies where multi-strain inoculants improved vegetable productivity under low-input systems (Okon *et al*., 2010; Jahan *et al*., 2020) [10, 13]. The study highlights that combining bacterial and fungal inoculants can sustain soil health and productivity even under moderate fertilizer regimes.

5. Conclusion

Microbial consortia-based biofertilization significantly improved soil microbial activity, nutrient availability, and brinjal yield under tropical field conditions in Ghana. The synergistic effect of *Azotobacter chroococcum*, *Bacillus subtilis*, *Pseudomonas fluorescens*, *Trichoderma harzianum*, and *Glomus mosseae* demonstrated superior performance compared with single inoculations or chemical fertilizers alone. This approach offers a viable solution for promoting sustainable brinjal production in African smallholder systems by enhancing soil biological fertility and reducing chemical input dependence.

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