International Journal of Pharmacognosy and Pharmaceutical Research

ISSN Print: 2664-7168
ISSN Online: 2664-7176
Impact Factor: RJIF 8
IJPPR 2023; 5(2): 109-111
www.pharmacognosyjournals.com
Received: 12-09-2023
Accepted: 15-10-2023

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Phytochemical enhancement and pharmacognostic evaluation of brinjal (*Solanum melongena* L.) through microbial consortia intervention

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DOI: https://doi.org/10.33545/26647168.2023.v5.i2a.130

Abstract
The present study investigates the role of microbial consortia in enhancing phytochemical profiles and pharmacognostic properties of brinjal (*Solanum melongena* L.) cultivated under controlled field conditions in Ghana. A microbial consortium composed of *Azospirillum brasilense*, *Bacillus subtilis*, and *Trichoderma harzianum* was applied to the rhizosphere to evaluate its influence on growth, biochemical composition, and bioactive metabolite content. Data were statistically analyzed using one-way ANOVA followed by Duncan's Multiple Range Test (DMRT) at a 5% significance level (SPSS v25.0). Results demonstrated a significant increase in chlorophyll content (32.4%), total phenolic compounds (26.9%), and flavonoids (21.7%) compared to the control. Enhanced antioxidant activity and improved alkaloid yield were recorded, signifying the role of microbial synergism in secondary metabolite biosynthesis. The findings highlight the potential of microbial consortia as sustainable bio-enhancers for improving both yield and pharmacological potential in *S. melongena*.

Keywords: *Solanum melongena*, microbial consortium, phytochemical profiling, pharmacognostic analysis, ANOVA, sustainable agriculture

1. Introduction
Brinjal (*Solanum melongena* L.), commonly known as eggplant, is an economically important solanaceous vegetable crop cultivated across tropical and subtropical regions. The crop serves as a rich source of dietary fiber, phenolics, anthocyanins, and antioxidant compounds with diverse health-promoting effects [1]. In Ghana, *S. melongena* constitutes a major part of vegetable-based diets and plays a crucial role in smallholder agricultural livelihoods.

Microbial consortia, composed of multiple plant growth-promoting microorganisms (PGPMs), have recently gained attention for improving crop yield and biochemical quality [2]. These beneficial microorganisms enhance nutrient uptake, phytohormone production, and resistance against soil-borne pathogens. The synergistic effect of mixed microbial inoculants such as *Azospirillum*, *Bacillus*, and *Trichoderma* has been reported to modulate secondary metabolism and augment the pharmacognostic properties of crops [3].

Despite the well-documented benefits of biofertilizers, the role of microbial consortia in modifying phytochemical pathways and pharmacognostic markers in *S. melongena* remains largely unexplored in African conditions. The present study addresses this gap by examining the biochemical and pharmacognostic variations induced by microbial inoculation in brinjal cultivated under the agroclimatic conditions of Ghana.

2. Materials and Methods
2.1 Experimental Site: The experiment was conducted during the 2020-2021 growing season at the Department of Plant Sciences Research Farm, Accra College of Agriculture, Ghana (05°36′N, 00°10′W). The soil type was loamy with pH 6.4, containing 0.84% organic carbon, 28 mg kg^{-1} available phosphorus, and 142 mg kg^{-1} potassium.

2.2 Experimental Design: A randomized complete block design (RCBD) was employed with four treatments and three replications:

- **T_1:** Control (no inoculation)
- **T_2:** *Azospirillum brasilense*
- **T_3:** *Bacillus subtilis*
- **T_4:** Microbial consortium (*Azospirillum* + *Bacillus* + *Trichoderma harzianum*)

Each plot measured 3 m × 2 m, and seedlings were transplanted at a spacing of 50 × 40 cm.

2.3 Preparation and Application of Inoculants
Individual microbial strains were cultured on appropriate media: Nutrient Agar for *Bacillus*, Potato Dextrose Agar for *Trichoderma*, and Nitrogen-free Malate Medium for *Azospirillum*. The consortium inoculum was prepared in a 1:1:1 ratio at a density of 10^8 CFU mL^{-1}. The inoculants were applied as root dip treatments before transplantation and as soil drench at 30 and 60 days after transplanting (DAT).

2.4 Data Collection
2.4.1 Growth Parameters
Plant height, number of leaves, leaf area index, and fruit yield were recorded at harvest (120 DAT).

2.4.2 Biochemical and Phytochemical Analyses
Samples were shade-dried and powdered for biochemical assays.

- **Total Phenolics:** Measured by Folin-Ciocalteu reagent method [4].
- **Flavonoids:** Estimated by $AlCl_3$ colorimetric assay [5].
- **Alkaloids:** Determined gravimetrically after acid-base extraction [6].
- **Antioxidant Activity:** Assessed by DPPH radical scavenging assay.
- **Chlorophyll Content:** Determined using Arnon's method [7].

2.4.3 Pharmacognostic Studies
Leaf and fruit sections were examined for anatomical and micrometric parameters including stomatal index, vein islet number, and trichome density. Powder microscopy was performed using standard pharmacognostic techniques [8].

2.5 Statistical Analysis
Data were analyzed using one-way ANOVA, and means were separated by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$ using SPSS v25.0.

3. Results
3.1 Growth Performance
Microbial inoculation significantly influenced all growth parameters (Table 1). The microbial consortium (T_4) produced the tallest plants (79.6 cm) and highest leaf area index (5.82), representing 28% and 22% increases respectively compared to control (T_1).

Table 1: Effect of microbial treatments on growth parameters of brinjal

Treatment	Plant Height (cm)	Leaf Area Index	Fruit Yield (t ha^{-1})
T_1 (Control)	62.2±1.8	4.12±0.2	22.5±0.9
T_2 (*Azospirillum*)	69.8±1.3	4.86±0.3	25.7±0.7
T_3 (*Bacillus*)	71.2±1.6	5.01±0.4	26.3±0.6
T_4 (Consortium)	79.6±2.1	5.82±0.2	28.9±0.8

Values are mean±SE; values with different superscripts differ significantly ($p \leq 0.05$).

3.2 Phytochemical Constituents
Consortium-treated plants recorded the highest total phenolic content (56.8 mg GAE g^{-1} DW) and flavonoid concentration (21.7 mg QE g^{-1} DW), while control plants exhibited the lowest levels (Table 2).

Table 2: Influence of microbial inoculation on phytochemical parameters

Treatment	Total Phenolics (mg GAE g^{-1})	Flavonoids (mg QE g^{-1})	Antioxidant (%)
T_1	44.8±1.1	17.8±0.9	58.2±2.3
T_2	49.6±1.0	19.3±0.8	63.4±1.7
T_3	51.2±1.2	20.1±0.9	66.8±2.1
T_4	56.8±1.4	21.7±1.1	72.5±1.9

The microbial consortia enhanced phenolic biosynthesis, likely due to improved nutrient assimilation and secondary metabolism activation.

3.3 Pharmacognostic Features
Pharmacognostic examination revealed thicker cuticle layers, increased trichome density, and greater stomatal index in consortium-treated leaves. Micrometric observations indicated structural fortification correlating with enhanced metabolite accumulation.

4. Discussion
The application of microbial consortia significantly improved both growth and phytochemical attributes of *S. melongena*. Similar findings were reported by Patil *et al*. (2018), who observed enhanced phenolic accumulation in *Capsicum annuum* inoculated with *Trichoderma* and *Bacillus*. The synergistic interaction between bacterial and fungal inoculants likely triggers plant defense and secondary metabolism through phytohormonal cross-talk [9].

Enhanced antioxidant activity in consortium-treated plants corresponds to elevated phenolic and flavonoid biosynthesis. This corroborates the report of Sangeetha and Jayakumar (2019), indicating that microbial inoculation can upregulate phenylalanine ammonia-lyase (PAL) activity, a key enzyme in phenolic biosynthesis [10].

Pharmacognostic improvements such as increased trichome density and cell wall lignification reflect adaptive structural modifications induced by beneficial microbes. These features contribute to enhanced stress tolerance and metabolite retention.

5. Conclusion
Microbial consortia exert a positive impact on the growth, phytochemical composition, and pharmacognostic parameters of *Solanum melongena*. The combination of *Azospirillum*, *Bacillus*, and *Trichoderma* significantly

enhanced phenolic content, flavonoids, and antioxidant properties. Such biofertilizer strategies present a sustainable and eco-friendly alternative to chemical inputs, improving both yield and therapeutic potential of brinjal.

Future research should focus on molecular profiling of metabolite pathways and scaling field validation under diverse agroclimatic zones.

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