DOI: https://dx.doi.org/10.4314/gjpas.v32i2.3

GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 32, 2026: 193-200
COPYRIGHT© BACHUDO SCIENCE CO. LTD PRINTED IN NIGERIA ISSN 1118 – 0579, e-ISSN: 2992 - 4464
www.globaljournalseries.com.ng, Email: globaljournalseries@gmail.com

EFFECT OF RHIZOSPHERE FUNGI FROM BAMBOO (*BAMBUSA VULGARIS*) ON THE GROWTH AND POLYPHENOL CONTENT OF TOMATO (*SOLANUM LYCOPERSICUM*)

OGBAJI, HENDERSON O., *IBIANG, YOUNG B., PHILIP, DEBORAH I., ONYEKENI, ALEXANDRA I., EKPO, PAUL B., ADOGA, MATILDA E., AND ATSU, MAURA U.
***Email:** youngangale@yahoo.com; ybibiang@unical.edu.ng

(Received 19 January 2026; Revision Accepted 13 March 2026)

ABSTRACT

This study evaluated the growth-promoting potentials of fungi isolated from the rhizosphere of bamboo (*Bambusa vulgaris*) on tomato (*Solanum lycopersicum*) cultivated under greenhouse conditions in Calabar, Nigeria. The fungi, tentatively identified as *Aspergillus* sp., *Penicillium* sp., *Rhizopus* sp. and *Trichoderma* sp., were used to inoculate tomato seedlings by dipping the roots of two-week-old seedlings in the respective fungal suspension for 30 secs prior to transplanting in autoclaved soil. A completely randomized design was adopted with the four fungal treatments and an uninoculated control, each with three replicates, and the plants were maintained for eight weeks, during which growth parameters and leaf polyphenol content were assessed. The data were analyzed using one-way analysis of variance at $p < 0.05$. Results showed that *Aspergillus* sp. had significantly higher leaf number, shoot length, root length and fresh weights, compared to the control. All inoculated groups had numerically higher total dry weights than the control. Between the inoculated groups, the root colonization was highest in *Penicillium* and lowest in *Rhizopus*, while leaf polyphenol content was significantly higher in *Trichoderma* sp., *Penicillium* sp., and *Rhizopus* sp. than in the control. These findings indicate that bamboo rhizosphere-associated fungi, particularly *Aspergillus* sp., possess growth-promoting potentials and could be exploited as eco-friendly bioinoculants for boosting growth and polyphenols biosynthesis in tomato.

KEYWORDS: Rhizosphere fungi; Bamboo; Tomato; Biofertilizer; Microbial inoculants.

INTRODUCTION

Fungi are members of a large group of eukaryotic organisms that play crucial ecosystem roles as decomposers and mutualists with plants, amongst others (Takamatsu, 2013; Runnel *et al*., 2025). Some fungi that benefit plant growth are found in the rhizosphere of plants where they inhabit the rhizosphere soil or the root (internally or at the surface).

Endophytic fungi infect living plant tissue internally without causing any disease and often form a mutualistic association with the plant (Sharma *et al.*, 2021). In general, plant rhizosphere is a reservoir of a large and diverse group of microorganisms including those with potential plant growth-promoting abilities including but not limited to fungi such as mycorrhiza, *Penicillium*, and *Trichoderma* (Smith and Read, 2008; Wagg *et al*., 2011; Bandara and Kang, 2024).

Ogbaji, Henderson O., Department of Genetics and Biotechnology, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Nigeria.
***Ibiang, Young B.,** Department of Genetics and Biotechnology, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Nigeria.
Philip, Deborah I., Department of Genetics and Biotechnology, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Nigeria.
Onyekeni, Alexandra I., Department of Genetics and Biotechnology, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Nigeria.
Ekpo, Paul B., Department of Genetics and Biotechnology, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Nigeria.
Adoga, Matilda E., Department of Genetics and Biotechnology, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Nigeria.
Atsu, Maura U., Department of Genetics and Biotechnology, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Nigeria.

© 2026 Bachudo Science Co. Ltd. This work is licensed under Creative Common Attribute 4.0 International license

These beneficial organisms might fight pathogens, solubilize nutrients, modulate plant physiology, influence root exudation, combat abiotic stress, etc., to support plant growth and fitness under diverse conditions (Hossain and Sultana, 2020; Ibiang et al., 2024b). The bamboo is a diverse group of mostly evergreen perennial plants in the Sub-family: Bambusoideae, with notable growth capabilities. Its rhizosphere can be a profound target for bioprospecting of beneficial microbes (Verma *et al*., 2019). Although abundant in some parts of Nigeria, bioprospecting for plant growth-promoting fungi in bamboo rhizosphere is not widely reported.

Tomato (*Solanum lycopersicum*) is a plant whose fruit is an edible berry that is eaten across the globe and regarded as a good source of antioxidants like beta-carotene, polyphenols, and vitamin C, which promote human health and wellbeing (Raza *et al*., 2022). Polyphenols are an important group of plant defense secondary metabolites valuable in edible vegetables for their antioxidant potential, due to their ability to scavenge free radicals in the body (Zhang and Tsao, 2016). Tomato production in Nigeria faces challenges related to pest control, disease management, plant nutrition etc., and often requires application of chemical fertilizers (Mohammed *et al*., 2020; Ajenifujah-Solebo *et al*., 2025). These challenges coupled with its increasing population, have increased Nigeria's tomato needs, contributing to steadily higher prices over the years, and the need to boost its sustainable production (Ibiang *et al*., 2024). The exploitation of microbial inoculants in boosting plant growth is appealing due to their eco-friendly nature (Sharma et al., 2021). Reports indicate the improvement of tomato growth parameters, such as greater root length, fresh biomass and dry weights due to inoculation of beneficial fungi (Prema-Sundara and Muthukumar, 2018; Ibiang, 2018). The promotion of tomato nutritional composition using fungal microbial inoculants has also been reported (Inculet et al., 2019). Ibiang and Sakamoto (2022) reported that inoculation of an endophytic *Penicillium pinophilum* isolated from Eucalyptus, modulated the growth and phytochemicals of some tomato cultivars with increases in ascorbic acids, beta-carotene, polyphenols and lycopene. Consequently, microbial inoculant stimulation of the production of antioxidants like polyphenols in tomatoes may also benefit their nutraceutical value, aside from increasing their growth and fitness. The present study isolated fungi from the bamboo rhizosphere and evaluated their growth-promoting and polyphenols-stimulating effects on tomato plants.

MATERIALS AND METHODS

Study area and sample collection

Rhizosphere soil samples were collected from bamboo (*B. vulgaris*) stands in Yahe, Yala Local Government Area (6°42′N, 8°36′E), and Calabar Municipality (4°58′58.34″N, 8°20′4.21″E), Cross River State, Nigeria. Soil adhering closely to bamboo roots was collected at 30 cm depth into sterile containers, placed in an ice-packed cool box, and transported to the Laboratory of the Department of Microbiology, University of Calabar, for further analysis.

Isolation and cultural characterization of fungi

One gram of each soil sample was serially diluted up to 10^{-10} using sterile distilled water following standard procedures (Eja *et al*., 2006). The isolates were plated on Sabouraud Dextrose Agar and incubated at room temperature for 3 - 5 days. Distinct fungal colonies were sub-cultured to obtain pure cultures, and based on cultural and microscopic characteristics such as colony color, shape, elevation, margin, spores, and hyphal septation, were tentatively identified at the Genus level as *Penicillium* sp., *Rhizopus* sp., *Trichoderma* sp. and *Aspergillus* sp., (Fig 1a-d), according to Barnett and Hunter keys (Barnett and Hunter, 1987; Atlas and Bartha, 1992).

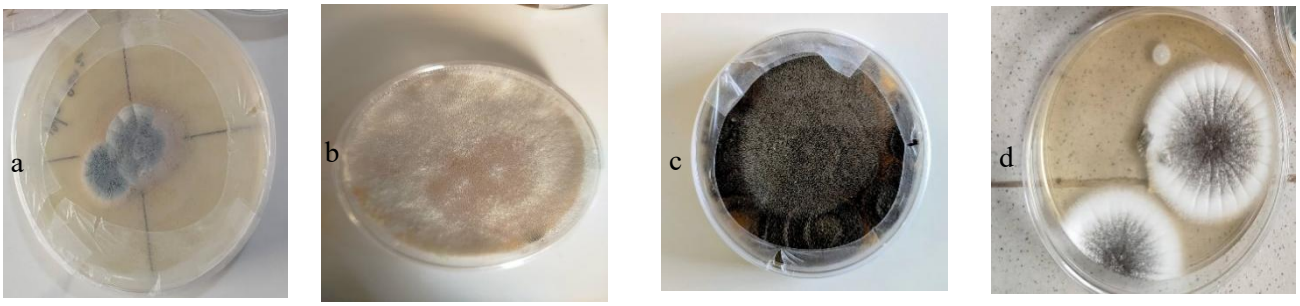


Fig 1: Cultures on PDA of fungi isolated from the rhizosphere of bamboo used for the study. (a) *Penicillium* sp. (b) *Rhizopus* sp. (c) *Trichoderma* sp. (d). *Aspergillus* sp.



Fig 2: Tomato plants in the greenhouse at 3 weeks after transplant.

Preparation of tomato nursery, soil, fungal inoculation and experimental design

Tomato seeds (Platinum 701 F1) were obtained from a seed shop at Watt Market Calabar, authenticated in the Department of plant and Ecological Studies, University of Calabar, Calabar, sterilized in 90% ethanol for 5 mins, rinsed twice with distilled water, before seeding in previously autoclaved vermiculite to make the nursery. The nursery was moistened with a water daily and maintained for two weeks. The soil utilized for this study was sandy-loam topsoil (pH(H_2O) (5.6), total organic carbon (1.6%), total nitrogen (0.14%), and phosphorus (15.91 mg kg^{-1}) collected from the experimental farm of the Faculty of Biological Sciences, University of Calabar, Nigeria. The soils were sieved using a 2 mm lab mesh to remove stones & other debris, and autoclaved before dividing into black polythene bags (22 cm tall and 19 cm wide) each carrying 4 kg of soil. Fungal suspension was prepared from 21-day old cultures with spore/conidia harvested using sterile distilled water as described by Bandara and Kang (2024) and the spore/conidia concentrations were adjusted with sterile water to 1.0×10^3 spores per mL across board, in a hemocytometer under the light microscope (LABOMED iVu 5100). Tomato seedlings (two weeks old), raised in a vermiculite nursery, were inoculated by dipping their roots into the respective fungal suspensions for 30 s prior to transplanting into nursery bags. The control plants received no fungal treatment and were dipped in sterile water prior to transplanting. The experiment was arranged in a completely randomized design (CRD) consisting of five treatments; uninoculated control, *Aspergillus* sp., *Penicillium* sp., *Rhizopus* sp., and *Trichoderma* sp., each with three replicates, set up in a greenhouse.

Plant cultivation and measurement of growth parameters

After sowing, all pots were watered once with modified Hoagland solution (after Epstein, 1972) at the rate of 100 mL/pot and kept in the greenhouse of the Department of Genetics and Biotechnology, University of Calabar, for a total of eight weeks until harvest. Daily watering was done with borehole water, and the plant heights and number of leaf petioles were measured weekly for the first five weeks after transplant (WAT). After 8 weeks, all plants were harvested and leaf number, shoot and root lengths, fresh weights and dry weights of the shoots and roots were measured using a measuring tape and an electronic weighing balance (Golden-Mettler, USA). Shoots were excised to measure shoot length and fresh weight, after which the polythene bags were cut open to recover the roots. The roots were washed with water, subsampled (1 g) for root colonization assessment, and oven-dried (Gallenkamp hotbox) at 70 °C for 48 h to determine dry weight.

Determination of polyphenol content

The second fully expanded leaf at the top of the shoot was cut with a scissors for the estimation of total polyphenols concentration, just prior to harvest. Total polyphenol content was determined using the Folin–Ciocalteu method described by Amerine and Ough (1980). Fresh leaf samples were extracted in 70% acetone, after which 2.5 mL of tenfold-diluted Folin–Ciocalteu reagent was added and allowed to react for 2 min. The reaction was terminated by adding 2 mL of sodium carbonate solution (75 g L^{-1}), and absorbance was measured at 760 nm using a spectrophotometer (Lasany 1-290).

Estimation of root colonization

To verify that the roots colonization was successful, 1 gram of fresh roots was excised from each plant for estimation of fungal root colonization on the day of harvest. Ten to twelve root fragments were washed with sterile distilled water and placed on already prepared PDA media and kept for 48-72 hours and root colonization was scored based on the occurrence of colony growth on root fragments in the PDA media as shown below.

$$RC\ \% = \frac{\text{No. of root fragments colonized}}{\text{Total no. of root fragments}} \times 100$$

Statistical analysis

Data were subjected to one-way analysis of variance (ANOVA), using SPSS ver. 24 and mean separation was performed using least significant difference (LSD) at $p < 0.05$.

RESULTS

Plant growth and root colonization

Plant height at one WAT (Table 1) showed no significant ($p > 0.05$) differences between the treatment groups, but Trichoderma had the highest value (15.00 cm) and control had the lowest (12.33 cm). The plant heights at two 2 and 3 WAT also showed no significant ($p > 0.05$) differences, but inoculated groups generally had higher values than the control. At 4 and 5 WAT, significant ($p < 0.05$) differences were observed in the plant heights, with higher values in *Aspergillus sp., Penicillium sp.* and *Trichoderma sp.* compared with the control. The number of leaf petioles at 1 to 3 WAT showed no significant ($p > 0.05$) differences between the treatment groups (Table 1), but at 4 and 5 WAT, significant differences were observed, with *Aspergillus*-treated plants recording the highest leaf numbers, while the control recorded the lowest values.

The effects of fungal inoculation on tomato growth indices at harvest (8 WAT) are presented in Table 2. Significant ($p < 0.05$) differences were observed among treatments for most growth parameters. Leaf petiole number was significantly influenced by fungal treatments, with *Aspergillus*-inoculated plants recording the highest number of leaves (14.00 ± 0.58) compared with the control (8.67 ± 0.67) and *Penicillium* (8.67 ± 0.33) treatments with the lowest mean values. Shoot length also differed significantly among treatments. The highest shoot length was recorded in *Aspergillus*-treated plants (35.00 ± 1.53 cm), followed by *Trichoderma* (32.17 ± 3.24 cm), which were significantly higher than control, whereas the lowest shoot length was observed in *Rhizopus*-treated plants (26.50 ± 0.50 cm). Root length varied significantly across treatments, with *Trichoderma* producing the longest roots (27.00 ± 0.58 cm), when compared with the control plants with the shortest roots (11.67 ± 1.67 cm). Shoot fresh weight was significantly higher in *Aspergillus* (6.50 ± 0.45 g), *Penicillium* (5.62 ± 0.24 g), and *Trichoderma* (6.19 ± 0.29 g) compared to the control (5.00 ± 0.38 g). Root fresh weight also showed significant differences, with the highest value observed in *Rhizopus* (4.67 ± 0.50 g) and the lowest in the control (1.57 ± 0.39 g). No significant differences ($P > 0.05$) were recorded for shoot dry weight, root dry weight, or total dry biomass. However, numerically higher dry weights were observed in the treated groups than in the control. The root colonization assay revealed successful colonization of tomato roots by all fungal isolates, except the control. *Penicillium* exhibited the highest root colonization, followed by *Aspergillus,* while the lowest was *Rhizopus* treatment (Table 2).

Polyphenol concentrations

Leaf polyphenol concentration differed significantly among treatments (Table 2). The highest polyphenol content were observed in Trichoderma-treated plants (12.55 ± 0.27 µg g^{-1}) compared with the control plants (9.51 ± 0.26 µg g^{-1}).

Table 1: Weekly growth indices of tomato inoculated with bamboo rhizosphere-associated fungi

No. of weeks	Control	*Aspergillus*	*Penicillium*	*Rhizopus*	*Trichoderma*	*P-values*
Plant height (WAT)						
1	12.33±0.83^{a}	14.00± 0.76^{a}	13.67±0.33^{a}	13.50±1.04^{a}	15.00 ±0.00^{a}	0.193 (NS)
2	17.33±0.67^{a}	19.17 ±0.93^{a}	19.50±1.04^{a}	18.33 ±0.44^{a}	19.33 ±0.67^{a}	0.320 (NS)
3	21.50±0.29^{a}	24.33 ±0.44^{a}	24.17±0.17^{a}	23.17±0.93^{a}	23.83 ±1.17^{a}	0.098 (NS)
4	22.00±0.58^{b}	25.33 ±1.20^{a}	24.33±0.33^{a}	24.17±0.93^{ab}	26.67 ±1.67^{a}	0.040*
5	24.00±0.58^{b}	31.33 ±0.67^{a}	28.67±0.88^{a}	27.00±1.15^{ab}	29.00 ±2.08^{a}	0.017**
Leaf petiole (WAT)						
1	7.00 ±0.58^{a}	7.33 ±0.33^{a}	7.33 ±0.33^{a}	8.00 ±0.58^{a}	6.00 ±0.58^{a}	0.145 (NS)
2	8.67 ±0.33^{a}	9.00 ±0.58^{a}	8.00 ±0.58^{a}	9.00 ±0.58^{a}	8.00 ±0.58^{a}	0.507 (NS)
3	8.67 ±0.33^{a}	10.67 ±0.67^{a}	8.33 ±0.33^{a}	9.00 ±0.58^{a}	8.33 ±1.33^{a}	0.198 (NS)
4	7.00 ±0.58^{b}	11.00 ±0.00^{a}	7.67 ±0.33^{b}	8.67 ±0.88^{ab}	9.33 ±1.33^{ab}	0.034*
5	6.67 ±0.58^{b}	12.67 ±0.088^{a}	8.67 ±0.88^{b}	8.67 ±0.88^{b}	9.67 ±1.67^{ab}	0.019**

Results are presented as mean ± standard error (n=3). Values with different superscripts indicate significant difference (p<0.05) based on LSD test. NS = Not significant. WAT (weeks after transplant).

Table 2: Plant growth indices, root colonization and polyphenol content of tomato inoculated with bamboo rhizosphere-associated fungi

Parameters	Control	*Aspergillus*	*Penicillium*	*Rhizopus*	*Trichoderma*	*p*-values
Leaf number	8.67 ± 0.67^{b}	14.00 ± 0.58^{a}	8.67 ± 0.33^{b}	9.33 ± 0.88^{b}	9.60 ± 1.27^{b}	0.004**
Shoot length (cm)	29.00 ± 1.00^{b}	35.00 ±1.53^{a}	28.00 ± 1.00^{b}	26.50 ± 0.50^{b}	32.17 ± 3.24^{a}	0.037**
Root length (cm)	11.67 ± 1.67^{c}	21.67 ± 2.03^{b}	21.67 ±2.19^{b}	19.33 ± 0.33^{b}	27.00 ± 0.58^{a}	0.001**
Shoot fresh weight (g)	5.00 ± 0.38 ^{b}	6.50 ± 0.45^{a}	5.62 ± 0.24^{a}	5.04 ± 0.31^{b}	6.19 ± 0.29^{a}	0.040**
Root fresh weight (g)	1.57 ± 0.39^{c}	3.21 ±0.33 ^{ab}	4.36 ± 0.24^{a}	4.67 ± 0.50^{a}	2.89 ± 0.66^{bc}	0.004**
Shoot dry weight (g)	0.88 ± 0.19^{b}	1.35 ± 0.01^{a}	1.31 ± 0.11^{a}	1.30 ± 0.06^{a}	1.35 ± 0.17^{a}	0.110 (NS)
Root dry weight (g)	0.15 ± 0.00^{b}	0.45 ± 0.29^{ab}	0.68 ± 0.09^{a}	0.48 ± 0.05^{ab}	0.29 ± 0.06^{b}	0.157 (NS)
Total biomass (g)	1.03 ± 0.19^{b}	1.79 ±0.29^{a}	1.96 ± 0.19^{a}	1.77 ± 0.12^{a}	1.64 ±0.22^{ab}	0.075 (NS)
Root colonization (%)	-	76.67 ±3.33^{b}	87.78 ±2.22^{a}	51.51 ±1.51^{d}	67.88 ±2.12^{c}	0.000***
Polyphenol (µg/g)	9.51 ± 0.26^{c}	9.88 ± 0.33^{c}	12.38 ± 0.03^{ab}	11.48 ± 0.40^{b}	12.55 ± 0.27^{a}	0.000***

Results are presented as mean ± standard error (n=3). Values with different superscripts indicates significant difference (p<0.05) based on LSD test. NS = Not significant.

DISCUSSION

The findings of this study indicate that bamboo rhizosphere soils harbor functionally diverse fungi capable of positively influencing tomato growth indices and secondary metabolites biosynthesis. The significant improvements in leaf petiole number, shoot length, root length, and fresh weights, from 4 to 5 weeks following fungal inoculation and also after 8 weeks, indicate that effective plant–fungus interactions developed gradually, from 1 to 2 months post-inoculation. Although shoot and root dry weights did not differ significantly among treatments, numerical increases in total dry biomass in inoculated plants suggest that longer experimental duration may better actualize significantly higher dry biomass production by the inoculated fungi. Similar observations have been reported where short-term greenhouse studies limited biomass production (Prema-Sundara and Muthukumar, 2018). The superior performance of *Aspergillus*-treated plants in terms of shoot length, leaf production, and fresh weights agrees with previous study reporting the role of *Aspergillus* species in promoting plant growth through enhanced nutrient uptake and stress tolerance (Busby *et al*., 2016). *Trichoderma* species are widely recognized for their root-colonizing ability and production of bioactive metabolites that stimulate root architecture and plant vigor (Chadha *et al*., 2015). The increased root length we observed in *Trichoderma*-treated plants suggests enhanced root development due to the inoculant, and is in-line with the findings of Bandara and Kang (2024) who reported that *Trichoderma* inoculation of tomato at the time of transplant better improves tomato growth indices. The successful root colonization by all fungal isolates confirms their endophytic nature and supports their potential application as bioinoculants. While the growth enhancement differences across board highlights the functional differences among the fungi, the strong colonization ability of the *Penicillium* may explain its association with higher polyphenol production (Ibiang and Sakamoto, 2022). In contrast, the lower colonization rate by *Rhizopus* may indicate lower fungus-plant compatibility, and/or the host desire to modulate photosynthates consumption by the fungal partner by minimizing the extent of root colonization (Nair and Padmavathy, 2014). Most plant phenols are synthesized via the shikimic acid pathway where simple carbohydrates derived from glycolysis and the pentose phosphate pathway are converted into phenylalanine, tyrosine and tryptophan (Taiz and Zeiger, 2010). The generated phenylalanine are converted by the action of phenylalanine ammonia lyase (PAL) to cinnamic acid which is used for phenols synthesis (Taiz and Zeiger, 2010; Ibiang 2018). Previous reports indicate microbial inoculant can modulate these physiological pathways in plant host (Hossain and Sultana, 2020). The significant increase in leaf polyphenol content, particularly in *Trichoderma* and *Penicillium* treatments, also indicates enhanced activation of plant defense mechanisms, as polyphenols play an important role in plant stress tolerance and resistance to pathogens, and their accumulation is often associated with induced systemic resistance triggered by beneficial endophytes (Berg, 2009; Sharma *et al*., 2021).

CONCLUSION

This study showed that bamboo rhizosphere-associated fungi, particularly *Aspergillus* species, possess growth-promoting potentials and could be exploited as eco-friendly bioinoculants for boosting tomato growth and polyphenols contents, in Cross River State, Nigeria.

DECLARATION OF COMPETING INTERESTS

None.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge the assistance of Mr. Bassey Ubi of the Department of Microbiology, University of Calabar, with the isolation and culture of fungi from the soil.

REFERENCES

Ajenifujah-Solebo S.O., Akin-Idowu, P.E, Aduloju, A.O, Adedeji, V.O, Akinyode, E.T, Ibitoye, D.O, … Bello, F. 2025. Tomato Crop Improvement Efforts in Nigeria: Past, Current and Future Perspectives. IntechOpen. doi: 10.5772/intechopen.1009299

Amerine M.A. and Ough C.S. 1980. Phenolic compounds: Methods of analysis of musts and wines. John Wiley and Sons, New York.

Atlas, R. M., and Bartha, R. 1992. Microbial Ecology: Fundamentals and Applications. 2 (30): 281-324.

Bandara A.Y. and Kang S. 2024. Trichoderma application methods differentially affect the tomato growth, rhizomicrobiome, and rhizosphere soil suppressiveness against Fusarium oxysporum. Frontiers in Microbiology, 15:1366690. https://doi.org/10.3389/fmicb.2024.1366690

Barnett H.L., and Hunter B.B. (eds) 1987. Illustrated genera of imperfect fungi, 4th Edition. MacMillian incorporation, USA.

Berg G. 2009. Plant-microbe interactions promoting plant growth and health: perspectives for controlled use of microorganisms in agriculture. Applied Microbiology and Biotechnology, 84(1): 11–18.

Busby PE, Ridout M, and Newcombe G. 2016. Fungal endophytes: modifiers of plant disease. Plant Molecular Biology, 90(6): 645–655.

Chadha N, Mishra M, Rajpal K, Bajaj R, Choudhary DK, and Varma A. 2015. An ecological role of fungal endophytes to ameliorate plants under biotic stress. Archives of Microbiology, 197(7): 869–881.

Eja, M. E., Arikpo, G. E., and Enyi-idoh, K. H. 2006. The use of serial dilution technique in the assessment of antimicrobial susceptibility of microorganisms. Journal of Applied Sciences and Environment Management, 10(3): 131-134

Epstein E. 1972. Mineral Nutrition of Plants: Principles and Perspectives. J. Wiley and Sons Inc., New York. p412.

Ibiang S.R. and Sakamoto K. 2022. Modulation of phytochemicals and essential trace elements in fruits of different tomato cultivars by the endophytic fungus Penicillium pinophilum EU0013. Microbes and Environments, 37(3): https://doi.org/10.1264/jsme2.ME22026

Ibiang Y.B. 2018. Effect of dual and single inoculation of rhizobia and arbuscular mycorrhizal fungi on soybean (Glycine max (L.) Merr.) and tomato (Solanum lycopersicum L.) under various soil zinc conditions. PhD Thesis, Chiba University, p128. https://doi.org/10.20776/105843

Ibiang Y.B., Sokari B.W., Udeze P.M., and Egbaji C.I. 2024a. Effect of single and dual inoculations of arbuscular mycorrhizas on soil phosphatase, growth, and root colonization of tomato. Agro-Science, 23(1): 65-70. https://dx.doi.org/10.4314/as.v23i1.9

Ibiang Y.B., Ali S., Agbor R.B., Edu N.E. and Onyekeni A.I. 2024b. Claroideoglomus etunicatum regulates Cu uptake, Fe-Mn homeostasis and phosphorus nutrition to mitigate Cu phytotoxicity and aggravating water limitation in soybean (Glycine max L. Merr.). Agro-Science, 23 (4): 20-26. https://dx.doi.org/10.4314/as.v23i4.4

Inculet, C.-S., Mihalache, G., Sellitto, V. M., Hlihor, R.-M., and Stoleru, V. 2019. The Effects of a Microorganisms-Based Commercial Product on the Morphological, Biochemical and Yield of Tomato Plants under Two Different Water Regimes. Microorganisms, 7(12), 706. https://doi.org/10.3390/microorganisms7120706

Mohammed US, Umaru I, and Zango IT. 2020. Assessment of tomato production in northern Nigeria. Journal of Agricultural Extension, 24(2): 132-14.

Hossain, M.M, and Sultana, F. 2020. Application and Mechanisms of Plant Growth Promoting Fungi (PGPF) for Phytostimulation. Intech Open. https://doi.org/10.5772/intechopen.92338

Nair D.N. and Padmavathy S. 2014. Impact of endophytic microorganisms on plants, environment and humans. The Scientific World Journal, 2014: 250693. https://doi.org/10.1155/2014/250693

Prema-Sundara V.B., and Muthukumar T., 2018. Endophytic fungi: A new hope for sustainable tomato cultivation. Journal of Applied Biology and Biotechnology, 6(2): 12–18.

Raza B., Hameed A., and Saleem M.Y. 2022. Fruit nutritional composition, antioxidant and biochemical profiling of diverse tomato (Solanum lycopersicum L.) genetic resource. Front. Plant Sci. 13: 1035163. https://doi.org/10.3389/fpls.2022.1035163

Runnel Kadri, Leho Tedersoo, Franz-Sebastian Krah, Meike Piepenbring, J.F. Scheepens, Henner Hollert, Sarah Johann, Nele Meyer, and Claus Bässler, 2025. Toward harnessing biodiversity–ecosystem function relationships in fungi. Trends in Ecology and Evolution, 40(2): 180-190. https://doi.org/10.1016/j.tree.2024.10.004.

Sharma, R., Singh, A., and Sharma, A., 2021. Endophytic fungi and their role in agriculture and environmental sustainability. Journal of Fungi, 7(11): 915.

Smith, S.E. and Read, D.J. 2008. Mycorrhizal Symbiosis 3rd edn. Academic Press, San Diego.

Taiz L., and Zeiger E. 2010. Plant Physiology 5th edition. Sinauer Asociates, Sunderland M.A.

Takamatsu, S. 2013. Overview of the taxonomy of the fungi. Mycoscience, 54(4): 210–215.

Verma S., Kumar V., and Singh R. 2019. Comparative evaluation of plant growth-promoting potential of bamboo-associated bacteria and other PGPB strains. Journal of Environmental Science and Health, Part B, 54(4): 236-245.

Wagg C., Bender S.F., Widmer F., and van der Heijden M.G.A. 2011. Soil biodiversity and soil community composition determine ecosystem multifunctionality. Proceedings of the National Academy of Sciences, 111(14): 5266–5270.

Zhang H. and Tsao R. 2016. Dietary polyphenols, oxidative stress and antioxidant and anti-inflammatory effects. Current Opinion in Food Science, 8: 33-42. https://doi.org/10.1016/j.cofs.2016.02.002.