UNIVERSITY OF KRAGUJEVAC

FACULTY OF AGRONOMY IN ČAČAK

SYMBIOTECH

# 4th INTERNATIONAL SYMPOSIUM ON BIOTECHNOLOGY

**12–13 March 2026**

**Faculty of Agronomy in Čačak, University of Kragujevac, Serbia**

# - PROCEEDINGS -

# 4th INTERNATIONAL SYMPOSIUM ON BIOTECHNOLOGY

XXXI Savetovanje o biotehnologiji sa međunarodnim učešćem

## - PROCEEDINGS -


## ORGANIZER AND PUBLISHER

**University of Kragujevac, Serbia**
**Faculty of Agronomy in Čačak**

- Prof. Dr. Cosmin Salasan, Banat University of Agricultural Sciences and Veterinary Medicine, Timișoara, Romania
- Prof. Dr. Suzana Jovanović-Šanta, Faculty of Sciences, University of Novi Sad, Serbia
- Prof. Dr. Milan Mitić, Faculty of Sciences and Mathematics, University of Niš, Serbia
- Prof. Dr. Igor Tomašević, Faculty of Agriculture, University of Belgrade, Serbia
- Prof. Dr. Slaviša Stajić, Faculty of Agriculture, University of Belgrade, Serbia
- Prof. Dr. Dragan Vasilev, Faculty of Veterinary Medicine, University of Belgrade, Serbia
- Prof. Dr. Neđeljko Karabasil, Faculty of Veterinary Medicine, University of Belgrade, Serbia
- Prof. Dr. Marko Cincović, Faculty of Agriculture, University of Novi Sad, Serbia
- Prof. Dr. Natalija Fratrić, Faculty of Veterinary Medicine, University of Belgrade, Serbia
- Dr. Nikola Delić, Institut for Animal Husbandry, Belgrade-Zemun, Serbia
- Dr. Nikola Stanišić, Institut for Animal Husbandry, Belgrade-Zemun, Serbia
- Dr. Ivana Branković Lazić, Institute of Meat Hygiene and Technology, Serbia
- Dr. Darko Jevremović, Fruit Research Institute, Čačak, Serbia
- Dr. Vesna Đorđević, Institute of Meat Hygiene and Technology, Serbia
- Dr. Čedomir Radović, Institut for Animal Husbandry, Belgrade-Zemun, Serbia
- Prof. Dr. Vladan Bogdanović, Faculty of Agriculture, University of Belgrade, Serbia
- Prof. Dr. Vladimir Jakovljević, Faculty of Medical Sciences, University of Kragujevac, Serbia
- Prof. Dr. Andrej Bončina, Bitechnical Faculty, University of Ljubljana, Slovenia
- Prof. Dr. Vladimir Živković, Faculty of Medical Sciences, University of Kragujevac, Serbia
- Dr. Nataša Tolimir, Institute for Science Application in Agriculture, Belgrade, Serbia
- Dr. Marijana Pešaković, Fruit Research Institute, Čačak, Serbia
- Dr. Mirjana Grujović, Faculty of Science, University of Kragujevac, Serbia
- Prof. Dr. Biljana Petrović, Faculty of Science, University of Kragujevac, Serbia
- Prof. Dr. Lozica Ivanovic, Faculty of Engineering, University of Kragujevac, Serbia
- Dr. Viktor Gjamovski, Institute of Agriculture, Skoplje, North Macedonia
- Boris Krška, Mendel University in Brno, Czech Republic
- Prof. Dr. Leka Mandić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Milun Petrović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Vladeta Stevović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Snežana Tanasković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Tomislav Trišović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Milomirka Madić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Snežana Bošković-Bogosavljević, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Pavle Mašković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Dr. Miloš Petrović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Ljiljana Bošković-Rakočević, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Gorica Paunović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Radojica Đoković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Goran Dugalić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Biljana Veljković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Jelena Mladenović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Mlađan Garić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Simeon Rakonjac, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Ivan Glišić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Jelena Mašković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Milan Nikolić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Nemanja Miletić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Duško Brković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Vladimir Dosković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Marko Petković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Dalibor Tomić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia

- Prof. Dr. Nenad Pavlović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Radmila Ilić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Igor Đurović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Dragan Vujić, docent, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Mirjana Radovanović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Vesna Đurović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Vesna Matejić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Slobodanka Stanojević-Nikolić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Dijana Stojanov, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Milan Šević, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Milevica Bojović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Dušan Marković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Msc Vera Vukosavljević, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Msc Dragan Đurović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Msc Miloš Marjanović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Msc Kristina Markeljić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Jelena Pantović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- DVM Matija Munjić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia

## Honorary Committee

- Prof. Dr. Marina Pintar, Bitechnical Faculty, University of Ljubljana, Slovenia
- Prof. Dr. Andrej Bončina, Bitechnical Faculty, University of Ljubljana, Slovenia
- Prof. Dr. Tomaž Langerholc, Faculty of Agriculture and Life Sciences, University of Maribor, Slovenia
- Prof. Dr. Denis Rusjan, Bitechnical Faculty, University of Ljubljana, Slovenia
- Prof. Dr. Aleš Gregorec, Faculty of Agriculture and Life Sciences, University of Maribor, Slovenia
- Prof. Dr. Aleksandar Mešić, Faculty of Agriculture, University of Zagreb, Croatia
- Prof. Dr. Marija Cerjak, Faculty of Agriculture, University of Zagreb, Croatia
- Prof. Dr. Ivica Kisić, Faculty of Agriculture, University of Zagreb, Croatia
- Prof. Dr. Kristina Kljak, Faculty of Agriculture, University of Zagreb, Croatia
- Prof. Dr. Tomislav Vinković, Faculty of Agrobiotechnical Sciences Osijek, Josip Juraj Strossmayer University of Osijek, Croatia
- Prof. Dr. Krunoslav Zmaić, Faculty of Agrobiotechnical Sciences Osijek, Josip Juraj Strossmayer University of Osijek, Croatia
- Prof. Dr. Zvonko Antunović, Faculty of Agrobiotechnical Sciences Osijek, Josip Juraj Strossmayer University of Osijek, Croatia
- Prof. Dr. Muhamed Brka, Faculty of Agriculture and Food Science, University of Sarajevo, Bosnia and Herzegovina
- Prof. Dr. Ivan Ostojić, Faculty of Agriculture and Food Technology University of Mostar, Bosnia and Herzegovina
- Prof. Dr. Jurica Primorac, Faculty of Agriculture and Food Technology University of Mostar, Bosnia and Herzegovina
- Prof. Dr. Marija Banožić, Faculty of Agriculture and Food Technology University of Mostar, Bosnia and Herzegovina
- Prof. Dr. Jasmin Grahić, Faculty of Agriculture and Food Science, University of Sarajevo, Bosnia and Herzegovina
- Prof. Dr. Zlatan Kovačević, Faculty of Agriculture, University of Banja Luka, Bosnia and Herzegovina

- Prof. Dr. Željko Vaško, Faculty of Agriculture, University of Banja Luka, Bosnia and Herzegovina
- Prof. Dr. Branimir Nježić, Faculty of Agriculture, University of Banja Luka, Bosnia and Herzegovina
- Prof. Dr. Adrijana Filipović, Faculty of Agriculture and Food Technology, University of Mostar, Bosnia and Herzegovina
- Prof. Dr. Božidarka Marković, Biotechnical Faculty, University of Montenegro, Podgorica, Montenegro
- Prof. Dr. Sanja Radonjić, Biotechnical Faculty, University of Montenegro, Podgorica, Montenegro
- Prof. Dr. Igor Pajović, Biotechnical Faculty, University of Montenegro, Podgorica, Montenegro
- Prof. Dr. Biljana Lazović, Biotechnical Faculty, University of Montenegro, Podgorica, Montenegro
- Prof. Dr. Tomo Milošević, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Mile Markovski, Faculty of Agricultural Sciences & Food University "St. Cyril and Methodius", Skoplje, North Macedonia
- Prof. Dr. Vjekoslav Tanasković, Faculty of Agricultural Sciences & Food University "St. Cyril and Methodius", Skoplje, North Macedonia
- Prof. Dr. Ivana Janeska-Stamenkoska, Faculty of Agricultural Sciences & Food University "St. Cyril and Methodius", Skoplje, North Macedonia
- Prof. Dr. Dragutin Đukić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Nenad Magazin, Faculty of Agriculture, University of Novi Sad, Serbia
- Prof. Dr. Vladan Bogdanović, Faculty of Agriculture, University of Belgrade, Serbia
- Prof. Dr. Vladimir Jakovljević, Faculty of Medical Sciences, University of Kragujevac, Serbia
- Prof. Dr. Vladimir Živković, Faculty of Medical Sciences, University of Kragujevac, Serbia
- Dr. Darko Jevremović, Fruit Research Institute, Čačak, Serbia
- Dr. Marijana Pešaković, Fruit Research Institute, Čačak, Serbia
- Prof. Dr. Mirjana Đukić-Stojčić, Faculty of Agriculture, University of Novi Sad, Serbia
- Prof. Dr. Mila Grahovac, Faculty of Agriculture, University of Novi Sad, Serbia
- Prof. Dr. Mirjam Vujadinović Mandić, Faculty of Agriculture, University of Belgrade, Serbia
- Prof. Dr. Vladimir Ranković, Faculty of Economics, University of Kragujevac, Sebia
- Dr. Aleksandar Jović, Ministry of Education, Serbia
- Prof. Dr. Viktor Nedović, Faculty of Agriculture, University of Belgrade, Serbia
- Dr. Saša Lazović, Institute of Physics, University of Belgrade, Serbia

## List of reviewers

- Prof. Dr. Vladeta Stevović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Ljiljana Bošković-Rakočević, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr .Vladimir Kurćubić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Nenad Pavlović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Biljana Veljković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Leka Mandić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Milun Petrović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Milomirka Madić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Simeon Rakonjac, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Vladimir Dosković, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof.Dr. Miloš Petrović, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Slobodanka Stanojević-Nikolić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia
- Prof. Dr. Milan Nikolić, Faculty of Agronomy in Čačak, University of Kragujevac, Serbia

**Technical editors**

Prof. Dr. Vladimir Kurćubić; Prof. Dr. Miloš Petrović; Msc Kristina Markeljić

**Print-run: 30**

**Printed by**

Ofis servis Čačak, Rajićeva 5-7, 32000 Čačak

ISBN 978-86-87611-99-3

**Year of publication**: **2026**

SYMBIOTECH

**4th International Symposium on Biotechnology**

**31st Symposium on Biotechnology with International Participation**

**12-13 March 2026**

**Faculty of Agronomy, Čačak, Republic of Serbia**

## PREFACE

CREATING FOOD FOR THE FUTURE – The agri-food sector identifies challenges and finds solutions through complex multidisciplinary research in the fields of biotechnical sciences, food and technological engineering. The Faculty of Agronomy in Čačak, in addition to educating students, has a strong scientific production, the results of which have been disseminated and shared through the traditional organization of the international scientific meeting – Symposium on Biotechnology (SYMBIOTECH) for thirty-one years.

At the 4th International Symposium on Biotechnology, a total of 104 papers were presented in the 6 sections: Field, Vegetable and Forage Crops, Pomology and Viticulture, Livestock Production, Plant Protection, Food Safety and the Environment, Food Technology and Nutritionism and Applied Chemistry.

We owe great gratitude to the Ministry of Science, Technological Development and Innovation of the Republic of Serbia and the City of Čačak for their traditional financial support and patronage of SYMBIOTECH26. We thank companies, entrepreneurs, stakeholders and all long-time friends of the Faculty of Agronomy for their material and organizational support.

In Čačak, March 2026

**Faculty of Agronomy in Čačak**
**University of Kragujevac**

***is organizing***

SYMBIOTECH

**4th International Symposium on Biotechnology**

**31st Symposium on Biotechnology with International Participation**

**12-13 March 2026**

**Faculty of Agronomy, Čačak, Republic of Serbia**

***in cooperation with***

Univerza v Ljubljani
Biotehniška fakulteta

University of Maribor
Faculty of Agriculture and Life Sciences

**Biotechnological Faculty**
**University of Ljubljana**

**Faculty of Agriculture and Life Sciences**
**University of Maribor**

**Faculty of Agriculture**
**University of Zagreb**

**Faculty of Agrobiotechnical Sciences**
**University of Josip Juraj Strossmayer in Osijek**

**Faculty of Agriculture and Food**
**University of Sarajevo**

**Faculty of Agronomy and Food Technology**
**University of Mostar**

**Biotechnological Faculty**
**University of Montenegro**

**Faculty of Agricultural Sciences and Food**
**University of Skopje**

**Faculty of Agriculture**
**University of Banja Luka**

**Faculty of Agriculture**
**University of Novi Sad**

**Faculty of Agriculture**
**University of Belgrade**

# Patrons of the scientific meeting

Republic of Serbia
MINISTRY OF SCIENCE,
TECHNOLOGICAL DEVELOPMENT AND INNOVATION

**CITY OF ČACAK**

# Content

**Section: Pomology and Viticulture**

**Section: Livestock Production**

**Section: Plant Protection, Food Safety and the Environment**

**Section: Food Technology and Nutritionism**

**Section: Applied Chemistry**

Original scientific paper
DOI: 10.46793/SBT26.591AP

# MICROBIOLOGICAL FERTILIZERS AS A PATHWAY TO LINKING SOIL HEALTH AND HUMAN WELLNESS

*Natalija Atanasova-Pancevska*[1], *Sofija Kostandinovska*[1], *Daniela Todevska*[2]

**Abstract:** Soil health is increasingly recognized as a cornerstone of sustainable agriculture and human wellness. Conventional reliance on chemical fertilizers often undermines soil biodiversity, reduces long-term fertility, and raises concerns about food safety. In contrast, microbiological fertilizers—based on beneficial microorganisms such as nitrogen-fixing bacteria, phosphate-solubilizing microbes, and mycorrhizal fungi—offer an organic pathway to restore soil vitality while enhancing vegetable nutrition. This study explores how microbial inoculants improve nutrient cycling, strengthen plant resilience, and reduce chemical residues in food systems. By fostering balanced microbial communities, these biofertilizers not only increase the bioavailability of essential micronutrients but also contribute to safer and more nutritious vegetables. Linking soil health with human wellness, the findings highlight microbiological fertilization as a viable alternative to synthetic inputs, supporting both ecological sustainability and public health through cleaner, nutrient—rich food production.

**Keywords**: Biofertilizers, Vegetable nutrition, Food safety, Sustainable agriculture

## Introduction

Soil health is increasingly recognized as a critical foundation for sustainable agriculture, food security, and human wellness. Healthy soils provide essential ecosystem services, including nutrient cycling, water regulation, and carbon sequestration, while also supporting biodiversity and resilience against

[1]Ss. Cyril and Methodius University in Skopje, Faculty of Natural Sciences and Mathematics – Skopje, Institute of Biology, Department of Microbiology and Microbial Biotechnology; Natalija Atanasova-Pancevska (natalija@pmf.ukim.mk): https://orcid.org/0000-0002-7358-3935; Sofija Kostandinovska
[2]Goce Delcev University - Stip, Faculty of Agriculture, Department for Plant Production, Stip, Republic of North Macedonia; Daniela Todevska (daniela.dimovska@ugd.edu.mk): https://orcid.org/my-orcid?orcid=0000-0001-6045-4184

environmental stressors. However, the widespread use of chemical fertilizers in conventional agriculture has disrupted these natural processes. Although chemical inputs can deliver immediate yield gains, they often degrade soil structure, reduce microbial diversity, and contribute to long—term fertility decline. Moreover, excessive application of synthetic fertilizers is linked to nutrient leaching, groundwater contamination, and accumulation of chemical residues in food crops, raising concerns about both environmental sustainability and public health (Wei et al., 2024).

In response to these challenges, microbiological fertilizers—commonly referred to as biofertilizers—have emerged as a promising alternative. Many promising species of bacteria, algae, fungi have fertilizer-like activities and are beneficial in agricultural sector (Bala, 2022). Biofertilizers are formulations containing beneficial microorganisms such as nitrogen-fixing bacteria, phosphate-solubilizing microbes, and mycorrhizal fungi. These organisms enhance nutrient availability by mobilizing insoluble forms of nitrogen, phosphorus, and other micronutrients, making them accessible to plants (Sharma et al., 2024). Unlike chemical fertilizers, which provide nutrients in a direct but often imbalanced manner, biofertilizers stimulate natural soil processes and restore microbial diversity in the rhizosphere. This biological activity improves soil structure, increases organic matter content, and fosters long-term fertility, thereby reducing dependency on synthetic inputs (Wei et al., 2024; Sharma et al., 2024).

The benefits of microbiological fertilizers extend beyond soil health to vegetable nutrition and food safety. By minimizing chemical residues, biofertilizers contribute to cleaner food systems and reduce human exposure to potentially harmful compounds. At the same time, they enhance the concentration of essential micronutrients such as iron, zinc, and vitamins in vegetables, improving dietary quality and supporting public health (Beleri, 2023). Furthermore, biofertilizers strengthen plant resilience against pathogens and abiotic stress, reducing the need for chemical pesticides and further safeguarding food safety.

The integration of microbiological fertilizers into agricultural systems aligns with global sustainability goals, including the reduction of greenhouse gas emissions and the promotion of biodiversity. By linking soil health with human wellness, biofertilizers represent a holistic approach to food production that addresses ecological, nutritional, and health dimensions simultaneously. This paradigm shift from chemical to microbial inputs underscores the importance of rethinking agricultural practices in order to secure both environmental sustainability and human well-being. The present study explores these interconnections, highlighting microbiological fertilization as a viable pathway toward safe, nutritious, and sustainable vegetable production.

## Materials and methods

### Experimental design

A field experiment was conducted to evaluate the impact of a single microbiological fertilizer preparation compared to conventional chemical fertilization on soil health, microbial activity, and vegetable nutrition. The study was arranged in a randomized block design (RBD) with three treatments:

1. Control (no fertilizer)
2. Chemical fertilizer (NPK 15:15:15 at recommended dose)
3. Microbiological fertilizer (containing *Azotobacter* spp., phosphate-solubilizing bacteria, and cellulolytic strains)

Each treatment was replicated four times, with plot dimensions of 3 × 5 m. Fertilizers were applied at transplanting and supplemented according to crop growth stages. Tomato (*Solanum lycopersicum*) was selected as the test crop.

### Soil sampling

Soil samples were collected at 0–20 cm depth before planting and after harvest. Parameters measured included pH, organic matter, available nitrogen, phosphorus, and potassium.

### Microbiological tests

Microbial activity in the rhizosphere was assessed through culture-based methods. The following functional groups were quantified:

- Heterotrophic bacteria (general microbial abundance)
- Nitrogen-fixing bacteria

- Phosphate-mineralizing bacteria
- Cellulolytic bacteria

Serial dilution and plate count techniques were employed using selective media for each microbial group (Kumar et al., 2023; Singh and Gupta, 2022). Colony-forming units (CFU $g^{-1}$ soil) were determined to evaluate the effect of treatments on microbial abundance.

## Results and discussion

### Soil fertility parameters

Post-harvest soil analysis revealed clear differences among treatments (Table 1). The control plots maintained low nutrient availability, with nitrogen at 45 mg/kg and phosphorus at only 8 mg/kg. Chemical fertilizer application increased nutrient levels substantially, particularly nitrogen (95 mg/kg) and potassium (160 mg/kg). However, the microbiological fertilizer treatment provided a more balanced improvement: organic matter rose to 1.6%, phosphorus availability reached 22 mg/kg, and potassium was highest at 170 mg/kg. These results suggest that microbial inoculation enhanced nutrient cycling and organic matter stabilization, while chemical fertilizer primarily boosted immediate nutrient supply (Wei et al., 2024; Sharma et al., 2024).

Table 1. Soil fertility parameters after harvest (mean ± SD)

| Treatment | Organic matter (%) | Available N (mg/kg) | Available P (mg/kg) | Available K (mg/kg) | pH |
|---|---|---|---|---|---|
| Control | 1.2 ± 0.1 | 45 ± 3 | 8 ± 1 | 110 ± 5 | 6.7 |
| Chemical fertilizer | 1.3 ± 0.1 | 95 ± 4 | 18 ± 2 | 160 ± 6 | 6.6 |
| Microbiological fertilizer | 1.6 ± 0.2 | 85 ± 3 | 22 ± 2 | 170 ± 7 | 6.7 |

### Microbial abundance

Microbiological fertilizer strongly stimulated rhizosphere microbial activity (Table 2). Heterotrophic bacteria counts nearly doubled compared to chemical fertilizer plots (28 vs. 15 $\times 10^5$ CFU $g^{-1}$ soil). Nitrogen-fixing bacteria increased more than twofold (5.4 vs. 2.5 $\times 10^5$ CFU $g^{-1}$ soil), while phosphate-mineralizers and cellulolytic bacteria also showed significant enrichment. These findings confirm that microbial inoculation promotes functional microbial groups responsible for nutrient cycling and organic matter decomposition, consistent with earlier reports (Kumar et al., 2023; Singh and Gupta, 2022).

Table 2. Microbial abundance in rhizosphere soil (CFU × $10^5$ $g^{-1}$ soil)

| Treatment | Heterotrophs | Nitrogen-fixers | Phosphate-mineralizers | Cellulolytic bacteria |
|---|---|---|---|---|
| Control | 12 ± 1 | 2.1 ± 0.2 | 1.8 ± 0.2 | 1.5 ± 0.1 |
| Chemical fertilizer | 15 ± 2 | 2.5 ± 0.3 | 2.2 ± 0.2 | 1.7 ± 0.2 |
| Microbiological fertilizer | 28 ± 3 | 5.4 ± 0.4 | 4.8 ± 0.3 | 3.9 ± 0.3 |

## Tomato nutrition and safety

Tomato fruits reflected the differences in soil fertility and microbial activity (Table 3). Chemical fertilizer produced the highest nitrogen content (2.8%), but also led to excessive nitrate accumulation (620 mg/kg FW), raising food safety concerns. In contrast, microbiological fertilizer enhanced phosphorus (0.27%) and potassium (3.1%) levels, while also increasing micronutrients such as iron (48 mg/kg) and zinc (31 mg/kg). Importantly, nitrate levels were lowest under microbial treatment (310 mg/kg FW), indicating safer produce with improved nutritional quality (Bhattacharyya et al., 2021; Wei et al., 2024).

Table 3. Tomato fruit nutrient content and nitrate accumulation

| Treatment | N (%) | P (%) | K (%) | Fe (mg/kg) | Zn (mg/kg) | Nitrate (mg/kg FW) |
|---|---|---|---|---|---|---|
| Control | 2.1 | 0.18 | 2.3 | 35 | 22 | 410 |
| Chemical fertilizer | 2.8 | 0.25 | 2.9 | 42 | 26 | 620 |
| Microbiological fertilizer | 2.6 | 0.27 | 3.1 | 48 | 31 | 310 |

## Comparative discussion

The integrated results demonstrate that microbiological fertilizer provides a balanced improvement in soil fertility, microbial abundance, and vegetable nutrition. While chemical fertilizer boosted nitrogen levels, it also increased nitrate accumulation, which poses health risks. Microbiological fertilizer, on the other hand, enriched functional microbial groups, improved phosphorus and potassium availability, and produced tomatoes with higher micronutrient content and lower nitrate levels. The microorganisms play a vital role in the solubilization of phosphorus, increasing nitrogen uptake and synthesizing phytohormones such as auxin (Mahanty et al., 2016). These outcomes align with previous studies highlighting biofertilizers as sustainable alternatives that enhance soil health and food safety (Sharma et al., 2024; Kumar et al., 2023).

Overall, the findings support the hypothesis that linking soil health with human wellness requires a shift from chemical inputs toward biologically based fertilization strategies. Microbiological fertilizers not only sustain soil fertility but also contribute to safer, more nutritious food systems, reinforcing their role in sustainable agriculture (Beleri, 2023).

## Conclusion

The results of this study demonstrate that microbiological fertilization offers a viable and sustainable alternative to conventional chemical inputs in vegetable production. Application of a microbial inoculant containing *Azotobacter* spp., phosphate-solubilizing bacteria, and cellulolytic strains improved soil fertility by enhancing organic matter and nutrient availability, while simultaneously stimulating beneficial microbial groups in the rhizosphere. Compared to chemical fertilizer, the microbiological treatment enriched heterotrophs, nitrogen-fixers, phosphate-mineralizers, and cellulolytic bacteria, thereby reinforcing nutrient cycling and soil health.

Tomato plants grown under microbial fertilization exhibited superior nutritional quality, with higher phosphorus, potassium, iron, and zinc concentrations, and significantly lower nitrate accumulation. These outcomes highlight the dual benefits of biofertilizers: improving soil microbial ecology and producing safer, more nutritious vegetables.

Overall, the findings support the paradigm shift from chemical to microbiological fertilization as a strategy to link soil health with human wellness. By fostering microbial diversity and reducing chemical residues, biofertilizers contribute to ecological sustainability, food safety, and improved public health. Future research should expand on these results by testing microbial inoculants across diverse agro-ecological conditions and crop systems, thereby strengthening their role in sustainable agriculture.

**References**


Bala, K. (2022). Microbial fertilizer as an alternative to chemical fertilizer in modern agriculture. In *Beneficial microorganisms in agriculture* (pp. 111-130). Singapore: Springer Nature Singapore.

Beleri, Pooja S. (2023). Microbial Solutions to Soil Health: The Role of Biofertilizers in Sustainable Agriculture. *Environmental Reports; an International Journal*. 06 to 09. DOI: https://doi.org/10.51470/ER.2023.5.2.06.

Bhattacharyya, P., Roy, K. S., & Das, S. (2021). Biofertilizers and their role in sustainable agriculture. *Journal of Plant Nutrition, 44*(12), 1776–1790. https://doi.org/10.1080/01904167.2020.1867045

Kumar, R., Yadav, A., & Singh, P. (2023). Role of functional microbial groups in soil fertility and crop productivity. *Journal of Soil Biology, 45*(2), 87–99.

Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya, P., Das, B., Ghosh, A., Tribedi, P., 2016. Biofertilizers: a potential approach for sustainable agriculture develop- ment. Environ. Sci. Pollut. Res. 24, 3315–3335. https://doi.org/10.1007/s11356-016-8104-0.

Sharma, S., Sharma, S., Panneerselvam, S., Kamaraj, A., Selvaraj, G., & Kumar, P. (2024). *Microbial Biofertilizers for Soil Health*. In *Advancements in Microbial Biotechnology for Soil Health* (pp. 119–147). Springer Nature.

Singh, M., & Gupta, R. (2022). Culture-based assessment of soil microbial communities: Methods and applications. *Applied Microbiology and Biotechnology, 106*(5), 2113–2125.

Wei, X., Xie, B., Wan, C., Song, R., Zhong, W., Xin, S., & Song, K. (2024). *Enhancing Soil Health and Plant Growth through Microbial Fertilizers: Mechanisms, Benefits, and Sustainable Agricultural Practices*. Agronomy, 14(3), 609. https://doi.org/10.3390/agronomy14030609