



Evaluating Bacterial Isolates for Enhanced Composting Efficiency: A Comparative Study of Mushroom Compost, Vermicompost and Earthworm Gut Bacteria

Samala Manoj Kumar¹, Pole Akhila¹, Geeta Kumari¹, Jyotnarani Pradhan², Aman Jaiswal¹

10.18805/ag.D-6427

ABSTRACT

Background: Composting and vermicomposting are sustainable methods of organic waste management, which are catalyzed by complex microbial communities. Microbiota in the compost and earthworm's gut play an important role in nutrient cycling and decomposition, but the relative ability of these microbial communities to stimulate composting efficiency has not been studied vastly. The present research cultured bacterial isolates of mushroom compost, vermicompost and earthworm gut and evaluated their biochemical properties, plant-growth-promoting abilities and enzyme degrading potential.

Methods: Bacterial cultures were isolated from mushroom compost, earthworm gut and vermicompost collected from different composting units at Dr. Rajendra Prasad Central Agricultural University, Pusa. The distinct morphological colonies formed on various agar plates were tested for Gram staining. The isolates were screened for cellulose and hemicellulose degradation and the ability to solubilize phosphorus, potassium and zinc, production of siderophores were further biochemically characterised using IMViC test. The data was analyzed by using Origin Pro 2023b, version 10.0.5.157.

Result: A total of 80 isolates were obtained by culturing on different media: 20 from mushroom compost, 40 from vermicompost and 20 from earthworm gut. The isolates obtained in mushroom compost had the highest cellulose and hemicellulose degradation index, the earthworm gut isolates had the highest phosphorus and zinc solubilization index and vermicompost isolates produced the highest siderophore. Thirty-one promising isolates, demonstrating multiple degradation and solubilization activities, were further characterized through IMViC tests and substantial diversity was observed. These bacterial isolates hold potential for enhancing composting efficiency, promoting faster decomposition and nutrient release.

Key words: Cellulose degradation, Composting, Earthworm gut, Hemicellulose degradation, Mushroom compost, Vermicompost.

INTRODUCTION

Organic solid waste is a major environmental concern, with global waste generation projected to reach 3.4 billion tonnes by 2050 (Kaza *et al.*, 2018). Agricultural residues contribute nearly 998 million tonnes annually, of which India alone generates 500-620 million tonnes owing to its agro-based economy. Although part of this biomass is reused as fodder or fuel, approximately 92 million tonnes is burned each year, causing serious environmental hazards (Sinha *et al.*, 2022). This highlights the need for sustainable waste management strategies that convert nutrient-rich residues into valuable soil amendments.

Composting and vermicomposting represent efficient, eco-friendly biotechnological processes for managing organic waste. Composting is an aerobic, microbial mediated process that transforms organic matter into a stable humus-like product. Among composting systems, mushroom composting utilizes lignocellulosic residues such as wheat straw and bagasse, supporting the growth of saprophytic fungi and associated bacteria that drive organic matter degradation (Bello *et al.*, 2020). Vermicomposting, in contrast, operates under mesophilic conditions (10-32°C), where earthworms (*e.g.*, *Eisenia foetida*, *Lumbricus rubellus*) and their gut microbiota enhance organic matter decomposition and nutrient

¹Department of Microbiology, College of Basic Sciences and Humanities, Dr. Rajendra Prasad Central Agricultural University, Pusa-848 125, Bihar, India.

²Department of Botany, Plant Physiology and Biochemistry, College of Basic Sciences and Humanities, Dr. Rajendra Prasad Central Agricultural University, Pusa-848 125, Bihar, India.

Corresponding Author: Aman Jaiswal, Department of Microbiology, College of Basic Sciences and Humanities, Dr. Rajendra Prasad Central Agricultural University, Pusa-848 125, Bihar, India. Email: aman.micro@rpcau.ac.in

How to cite this article: Kumar, S.M., Akhila, P., Kumari, G., Pradhan, J. and Jaiswal, A. (2025). Evaluating Bacterial Isolates for Enhanced Composting Efficiency: A Comparative Study of Mushroom Compost, Vermicompost and Earthworm Gut Bacteria. *Agricultural Science Digest*. 1-10. doi: 10.18805/ag.D-6427.

Submitted: 11-08-2025 **Accepted:** 15-12-2025 **Online:** 02-02-2026

mineralization (Nagavallema *et al.*, 2004). The earthworm gut functions as a mutualistic microhabitat, rich in enzymes and beneficial microorganisms that improve compost quality and soil fertility (Kalika-Singh *et al.*, 2022). Vermicompost, along with beneficial microbes from the earthworm gut, enhances crop health and produce quality by stimulating plant growth-promoting (PGP) microbes,

outperforming chemical fertilizers (Raihing and Vijayalakshmi, 2022).

Despite advancements in composting technologies, the microbial mechanisms enhancing decomposition efficiency remain poorly understood, particularly those associated with the earthworm gut. Understanding these microbial communities can provide insight into nutrient cycling and accelerate compost stabilization. Therefore, the present study aims to isolate and characterize bacterial strains from mushroom compost, vermicompost and earthworm gut and to assess their biochemical and functional traits contributing to enhanced composting efficiency and reduced composting duration.

MATERIALS AND METHODS

Collection of samples

Mushroom compost samples were collected from composting heaps at AICRP on Mushroom, Dr. Rajendra Prasad Central Agricultural University (Dr. RPCAU), Pusa, Bihar. Vermicompost and earthworms (*Eisenia foetida*) were collected from university's Vermicomposting unit and brought to the laboratory for microbial isolation.

Isolation of microbes from compost samples

For isolation of bacteria from compost, one gram of compost was taken from the collected sample, serially diluted up to 10^{-6} dilutions and plated on nutrient agar, trypticase soy agar, King's B agar media plates and were incubated at 30 to 32°C for 48 to 60 h. Colonies with distinct morphology (colony colour, shape, size, texture) were selected and preserved in slants at 4°C.

Isolation of earthworm gut microbiota

Gut microbes were isolated from earthworms that were starved for 24 h on moist filter paper to clear gut contents, surface-sterilized in 70% ethanol and dissected aseptically to obtain 2.5-3 cm of the post-clitellum gut. The gut contents were homogenized in 0.85% NaCl, centrifuged at 6000 rpm for 15 min, serially diluted up to 10^{-6} and plated on nutrient agar, trypticase soy agar, King's B agar media (Singh *et al.*, 2016). Plates were incubated at 30°C for 48-60 h and distinct colonies were isolated and maintained at 4°C.

Morphological and Biochemical characterization of bacterial isolates

Gram staining was used to determine cell morphology and arrangement (Gram, 1884). Each isolate was tested for biochemical traits including Voges-Proskauer, Methyl Red, Citrate Utilization (Isenberg and Sundheim, 1958) and Indole production (MacFaddin, 2000).

Plant growth promoting abilities

Bacterial isolates were evaluated for their ability to solubilize phosphorus (P), potassium (K) and zinc (Zn) using Pikovskaya's medium (Pikovskaya, 1948), Alexandrov's medium (Hu *et al.*, 2006) and Bunt and

Rovira's medium (Bunt and Rovira, 1955), respectively. Siderophore production was assessed on chrome azurol S (CAS) agar (Schwyn and Neilands, 1987). Solubilization potential was quantified as the Solubilization Index (SI), reflecting the ability of the strains to solubilize the respective minerals (Edi Premono *et al.*, 1996).

$$\text{Solubilization index} = \frac{\text{Colony diameter} + \text{Halozone diameter}}{\text{Colony diameter}}$$

Cellulose and hemicellulose degrading activity

Cellulolytic and hemicellulolytic activities were screened on CMC agar (Sirisena and Manamendra, 1995) and xylan beechwood agar (Teather and Wood, 1982) respectively, by spot inoculation of 10 µL bacterial suspension per plate sector. Plates were incubated at 35°C for 48 h, stained with 0.1% Congo red for 15 min and destained with 1M NaCl. Clear halo zones around colonies indicated enzymatic degradation and SI was calculated.

Statistical analysis

All experiments were conducted in a Completely Randomized Design (CRD) with three replications and results are expressed as mean ($\pm$ SEM). Data was analyzed using OriginPro 2023b (version 10.0.5.157). Significant differences among treatments were determined by Tukey's test at a 5% probability level (Gomez and Gomez, 1984). Principal Component Analysis (PCA) was performed to evaluate the relationships among variables (Rodrigues *et al.*, 2014).

RESULTS AND DISCUSSION

Bacterial isolation, morphological and biochemical characterization

A total of 80 bacterial isolates were obtained from three organic sources-mushroom compost (20), vermicompost (40) and earthworm gut (20) (Fig 1). Vermicompost yielded the highest number of isolates, reflecting its nutrient-rich and microbial active environment that supports diverse bacterial communities. The lower numbers in mushroom compost and earthworm gut suggest more specialized microbial populations adapted to lignocellulosic residues and gut micro-niches.

Morphologically, Gram-negative bacteria predominated across all sources, accounting for 65-70% of the isolates (Supplementary Table 1-3). Specifically, 13 of 20 mushroom compost isolates, 27 of 40 vermicompost isolates and 14 of 20 earthworm gut isolates were Gram-negative, consistent with their adaptability to moist and nutrient-rich conditions.

Biochemical profiling revealed substrate-specific patterns (Table 1). Most mushroom compost isolates were positive for methyl red (MR) and Voges-Proskauer (VP) tests, indicating mixed acid and butanediol fermentation pathways. In contrast, vermicompost isolates displayed higher citrate utilization and indole production, while earthworm gut isolates showed pronounced VP and citrate positivity, signifying active carbon and nitrogen metabolism.

These findings corroborate with the reports of Devi *et al.* (2020) and Prachi (2023), who observed the predominance of Gram-negative and metabolically diverse bacteria in compost and earthworm gut ecosystems. The metabolic heterogeneity indicated by IMViC patterns suggests functional versatility, potentially linked to decomposition and nutrient cycling. Such substrate-driven microbial diversity underscores the ecological significance of

composting habitats as reservoirs of bioactive microorganisms (Reddy *et al.*, 2017; Satpathy *et al.*, 2020).

Functional screening for PGP traits and enzymatic activities

Screening of all 80 isolates for PGP and enzymatic traits revealed that over 70% exhibited at least one beneficial function (Fig 2). Phosphate, potassium and zinc solubilization, as well as siderophore production, were the most prevalent PGP traits. Additionally, many isolates produced hydrolytic enzymes such as cellulase and hemicellulase, which facilitate organic matter degradation and nutrient recycling.

PGP of the isolates from compost and earthworm gut bacterial isolates

Among mushroom compost isolates, phosphorus solubilization indices ranged from 1.50 (MC-7) to 3.63 (MC-10) (Fig 3a). Potassium solubilization varied between 2.20 (MC-18) and 3.00 (MC-20) (Fig 3b). Zinc solubilization was observed in 45% of isolates, with MC-20 (6.10) being the most efficient (Fig 3c). Siderophore production ranged from 13% (MC-10) to 31% (MC-17) (Fig 3d).

In vermicompost isolates, phosphorus solubilization indices ranged from 1.40 (VC-4) to 4.00 (VC-10) (Fig 4a). Potassium solubilization varied between 2.28 (VC-2) and 3.50 (VC-28), while zinc solubilization ranged from 2.57 (VC-3) to 6.25 (VC-15) (Fig 4b-c). Siderophore production was highest in VC-6 (44%) and lowest in VC-39 (12%) (Fig 4d).

Among earthworm gut isolates, phosphorus solubilization ranged from 2.62 (EWG-4) to 4.50 (EWG-9) and potassium solubilization from 2.60 (EWG-4, EWG-11)

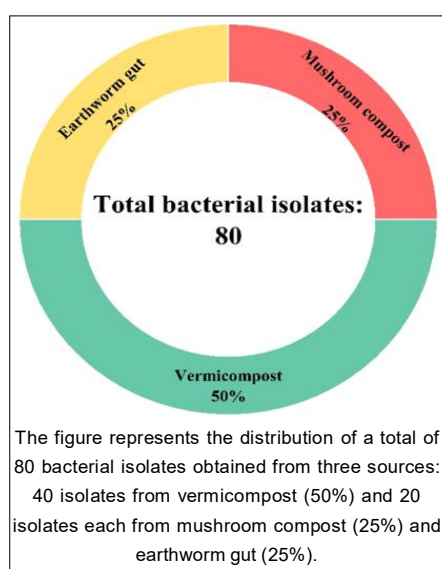


Fig 1: Source-wise distribution of the 80 bacterial cultures isolated from mushroom compost, vermicompost and earthworm gut.

Supplementary Table 1: Morphological characteristics and gram staining of different isolates obtained from mushroom compost.

Isolate	Media	Size	Shape	Colour	Texture	Gram reaction
MC-1	Trypticase soy agar	Small	Irregular	White	Smooth	+
MC-2	Nutrient agar	Medium	Circular	Pale	Smooth	-
MC-3	King's B agar	Large	Unorganized	Brown	Rough	-
MC-4	Nutrient agar	Small	Circular	Yellow	Smooth	-
MC-5	Trypticase soya agar	Small	Irregular	Cream	Smooth	+
MC-6	Nutrient agar	Small	Irregular	Cream	Rough	-
MC-7	Nutrient agar	Medium	Irregular	White	Rough	-
MC-8	Ken knight agar	Medium	Circular	Yellow	Smooth	-
MC-9	Ken knight agar	Small	Circular	Pale	Smooth	-
MC-10	Nutrient agar	Medium	Irregular	Brown	Rough	+
MC-11	Ken knight agar	Small	Circular	Cream	Smooth	-
MC-12	King's B agar	Medium	Circular	White	Smooth	+
MC-13	Nutrient agar	Small	Circular	Cream	Smooth	-
MC-14	King's B agar	Small	Rounded	Cream	Rough	+
MC-15	Ken knight agar	Medium	Rounded	Brown	Smooth	-
MC-16	Nutrient agar	Medium	Irregular	White	Smooth	+
MC-17	King's B agar	Small	Circular	Pale	Smooth	-
MC-18	Nutrient agar	Large	Unorganized	Brown	Rough	-
MC-19	Trypticase soy agar	Medium	Irregular	Cream	Rough	-
MC-20	Nutrient agar	Small	Circular	White	Smooth	+

'+' : Positive, '-' : Negative.

to 4.00 (EWG-3) (Fig 5a-b). Zinc solubilization ranged between 3.00 (EWG-6) and 6.30 (EWG-18) (Fig 5c). The highest siderophore production was observed in EWG-13 (38%) (Fig 5d).

The superior performance of vermicompost and earthworm gut isolates in nutrient solubilization highlights their potential as efficient bioinoculants. Similarly, P and Zn solubilization abilities in compost and vermicompost-derived microbes were reported by Bhakta *et al.* (2022) and Karnwal (2021). Earthworm gut isolates exhibited

strong solubilizing activity, reflecting their adaptation to enzymatically active gut environments rich in organic substrates (Kapila *et al.*, 2024; Yang *et al.*, 2023).

Siderophores, as iron-chelating compounds, enhance microbial competitiveness and plant iron uptake under deficiency conditions. The highest siderophore yield recorded in VC-6 (44%) supports the role of vermicompost bacteria in improving rhizospheric iron bioavailability and suppressing pathogens through iron sequestration (Raimi *et al.*, 2022).

Supplementary Table 2: Morphological characteristics and gram staining of different isolates obtained from vermicompost.

Isolate	Media	Size	Shape	Colour	Texture	Gram reaction
VC-1	Nutrient agar	Small	Irregular	White	Smooth	-
VC-2	Nutrient agar	Small	Circular	White	Smooth	-
VC-3	Nutrient agar	Small	Unorganized	White	Rough	+
VC-4	Nutrient agar	Medium	Circular	White	Smooth	+
VC-5	Nutrient agar	Medium	Irregular	White	Rough	-
VC-6	Trypticase soy agar	Small	Irregular	Cream	Smooth	-
VC-7	King's B agar	Medium	Irregular	Yellow	Rough	-
VC-8	Pikovskayas agar	Small	Circular	White	Smooth	+
VC-9	Nutrient agar	Medium	Circular	White	Smooth	-
VC-10	Nutrient agar	Small	Irregular	Cream	Smooth	-
VC-11	Nutrient agar	Small	Circular	Yellow	Smooth	-
VC-12	Trypticase soy agar	Medium	Circular	White	Smooth	+
VC-13	Nutrient agar	Medium	Circular	White	Slow	-
VC-14	Nutrient agar	Small	Rounded	White	Smooth	-
VC-15	King's B agar	Large	Rounded	Orange	Smooth	-
VC-16	Nutrient agar	Medium	Irregular	White	Rough	+
VC-17	Nutrient agar	Small	Circular	Cream	Smooth	-
VC-18	Trypticase soy agar	Small	Unorganized	Cream	Smooth	-
VC-19	Nutrient agar	Medium	Irregular	Orange	Smooth	-
VC-20	King's B agar	Medium	Circular	Gold	Smooth	-
VC-21	Nutrient agar	Small	Irregular	Orange	Smooth	-
VC-22	Trypticase soy agar	Small	Circular	White	Smooth	-
VC-23	Trypticase soy agar	Small	Unorganized	Cream	Rough	-
VC-24	Nutrient agar	Medium	Circular	White	Smooth	+
VC-25	Nutrient agar	Medium	Irregular	White	Rough	-
VC-26	Nutrient agar	Small	Irregular	Yellow	Smooth	+
VC-27	King's B agar	Medium	Irregular	White	Rough	-
VC-28	King's B agar	Small	Circular	Cream	Smooth	+
VC-29	Nutrient agar	Medium	Circular	Cream	Smooth	-
VC-30	King's B agar	Small	Irregular	Orange	Rough	-
VC-31	Nutrient agar	Small	Circular	White	Smooth	-
VC-32	Pikovskayas Agar	Medium	Circular	Cream	Smooth	-
VC-33	King's B agar	Medium	Circular	Yellow	Smooth	+
VC-34	Trypticase soy agar	Small	Rounded	Yellow	Smooth	+
VC-35	Nutrient agar	Large	Rounded	White	Smooth	-
VC-36	Nutrient agar	Medium	Irregular	White	Rough	+
VC-37	Trypticase soy agar	Small	Circular	White	Smooth	-
VC-38	Nutrient agar	Small	Unorganized	White	Rough	-
VC-39	Nutrient agar	Small	Irregular	Yellow	Rough	+
VC-40	Nutrient agar	Medium	Circular	White	Smooth	+

'+' : Positive, '-' : Negative.

Collectively, these results demonstrate that compost and gut-associated bacteria possess multifaceted nutrient-mobilizing abilities with direct relevance for sustainable agriculture. The novelty of this study lies in the comparative evaluation of three distinct microbial habitats, revealing unique yet complementary biofertilizer potentials that can be integrated into eco-efficient composting systems.

Cellulase and hemicellulase activity of bacterial isolates

Ten mushroom compost isolates exhibited cellulose degradation, with MC-16 and MC-7 showing the highest activity (4.80), while MC-12 (2.71) had the lowest. Nineteen vermicompost isolates were positive for cellulase, led by

VC-31 and VC-34 (4.00) and eight earthworm gut isolates were positive, with EWG-16 (3.50) most active (Fig 6a).

For hemicellulose degradation, seven mushroom compost isolates were positive, ranging from MC-6 (2.71) to MC-10 (5.00). In vermicompost, 25 isolates were positive (VC-22: 4.86), while earthworm gut isolates displayed similar variation, with EWG-5 (4.50) showing maximum activity and EWG-19 (2.50) the least (Fig 6b).

These results confirm the abundance of hydrolytic enzyme producers across all tested samples. Such cellulolytic and hemicellulolytic bacteria contribute to lignocellulose degradation, a crucial step in compost stabilization and organic carbon turnover. Similar enzymatic

Supplementary Table 3: Morphological characteristics and gram staining of different isolates obtained from earthworm gut.

Isolate	Media	Size	Shape	Colour	Texture	Gram reaction
EWG-1	Nutrient agar	Large	Irregular	White	Rough	+
EWG-2	Nutrient agar	Small	Circular	Yellow	Smooth	-
EWG-3	Nutrient agar	Small	Circular	Yellow	Smooth	-
EWG-4	Nutrient agar	Small	Circular	Yellow	Smooth	-
EWG-5	Trypticase soy agar	Medium	Rounded	White	Rough	+
EWG-6	Trypticase soy agar	Small	Rounded	White	Smooth	-
EWG-7	Nutrient agar	Large	Irregular	White	Smooth	-
EWG-8	Nutrient agar	Small	Circular	Gold	Smooth	-
EWG-9	King's B agar	Large	Unorganized	Yellow	Rough	-
EWG-10	King's B agar	Medium	Irregular	Orange	Rough	-
EWG-11	Pikovskaya Agar	Small	Circular	Orange	Smooth	-
EWG-12	Nutrient agar	Medium	Irregular	White	Smooth	+
EWG-13	King's B agar	Small	Circular	White	Rough	-
EWG-14	King's B agar	Large	Unorganized	Gold	Smooth	-
EWG-15	Nutrient agar	Small	Circular	White	Smooth	+
EWG-16	Nutrient agar	Medium	Irregular	White	Rough	-
EWG-17	Pikovskaya Agar	Large	Irregular	Gold	Rough	+
EWG-18	Trypticase soy agar	Medium	Irregular	Cream	Smooth	-
EWG-19	Trypticase soy agar	Small	Circular	Gold	Smooth	-
EWG-20	Nutrient agar	Small	Circular	White	Smooth	+

'+' : Positive, '-' : Negative.

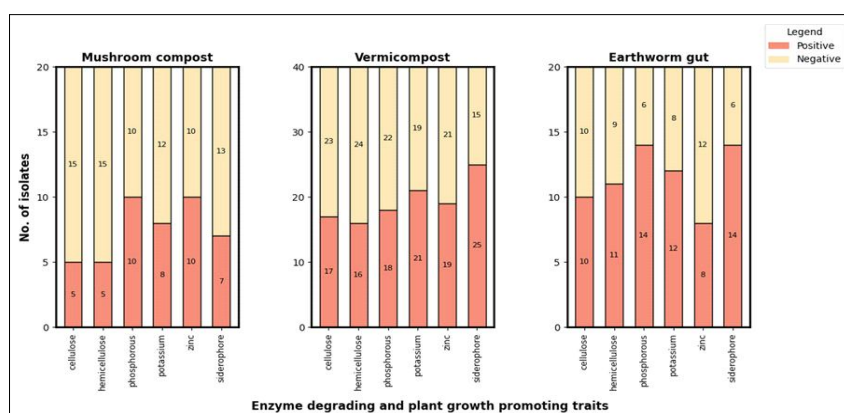


Fig 2: Comparison of number of bacterial isolates exhibiting functional trait responses among the isolates from mushroom compost, vermicompost and earthworm gut.

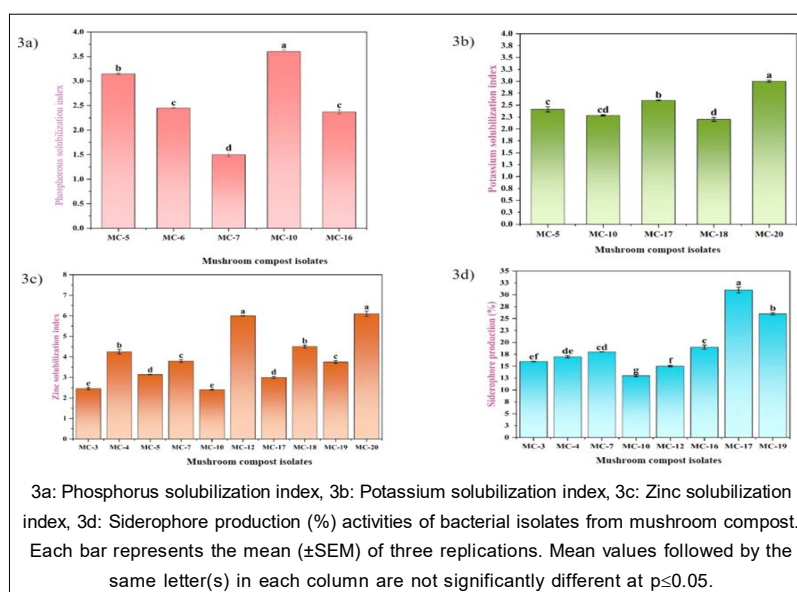


Fig 3: Comparison of plant growth-promoting abilities of potential bacterial isolates obtained from mushroom compost.

Table 1: IMViC tests results for bacterial isolates from mushroom compost, vermicompost and earthworm gut.

Isolate code	Indole test	Methyl Red	Voges-proskauer	Citrate
MC-4	+	+	+	-
MC-6	-	+	+	-
MC-10	+	+	+	-
MC-12	-	-	-	-
MC-16	+	+	+	-
MC-18	-	+	+	-
MC-19	-	+	+	-
VC-5	-	+	+	-
VC-6	+	-	+	+
VC-10	-	-	+	-
VC-17	+	+	-	-
VC-20	-	-	+	-
VC-21	+	+	+	-
VC-22	-	+	-	-
VC-23	+	+	-	-
VC-26	-	+	+	+
VC-28	-	+	+	-
VC-30	-	-	+	+
VC-33	+	-	-	-
VC-34	+	-	+	+
VC-35	+	+	+	+
VC-39	-	+	+	+
VC-40	+	-	-	+
EWG-4	+	+	+	+
EWG-7	+	-	+	+
EWG-9	-	-	+	+
EWG-10	+	-	+	+
EWG-11	+	-	+	+
EWG-13	+	-	+	+
EWG-14	-	-	+	+
EWG-17	-	+	-	-

'+' : Positive, '-' : Negative.

MC- Mushroom compost isolates, VC- Vermicompost isolates, EWG- Earthworm gut isolates.

capacities were reported by Jyotsna *et al.* (2015) and Long *et al.* (2024), identifying *Bacillus*, *Pseudomonas*, *Chryso bacterium* and *Cellulomonas* as dominant degraders in compost environments. Moreover, hemicellulase activity enhances cellulose accessibility and reduces compost bulk density, improving compost maturity and nutrient availability (Ordoñez-Arévalo *et al.*, 2022).

The predominance of such degraders, especially in vermicompost and earthworm gut isolates, indicates their

integral role in accelerating organic matter decomposition, ultimately enhancing compost quality and nutrient recovery efficiency.

Principal component analysis (PCA) of microbial and biochemical traits

Principal Component Analysis was performed to understand the interrelationships among microbial traits and isolate sources. The first two components, PC1

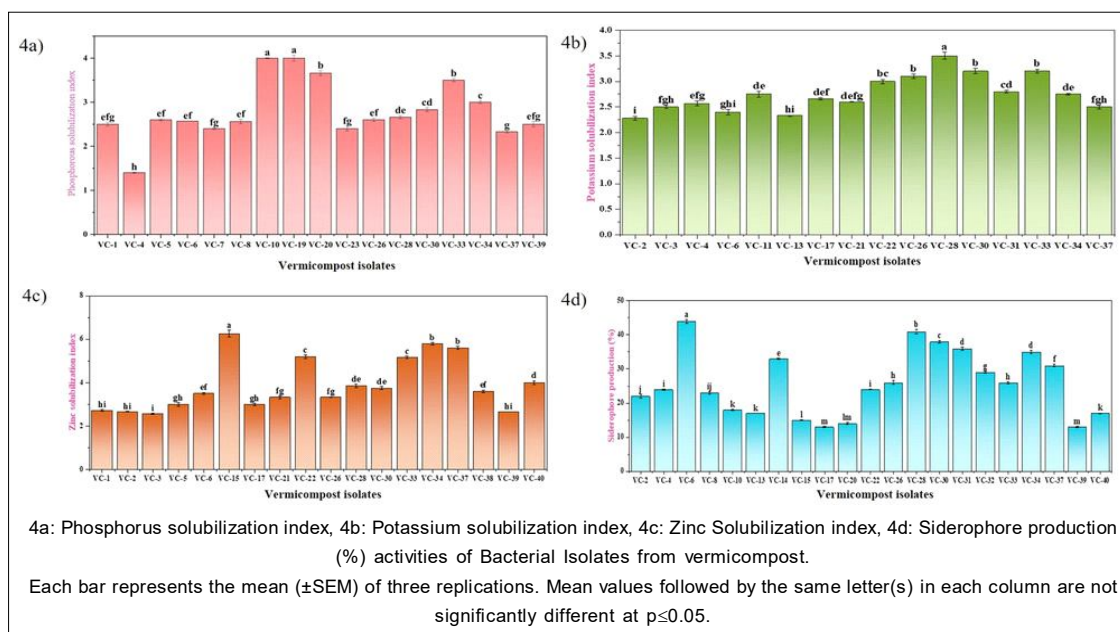


Fig 4: Comparison of plant growth-promoting abilities of potential bacterial isolates obtained from vermicompost.

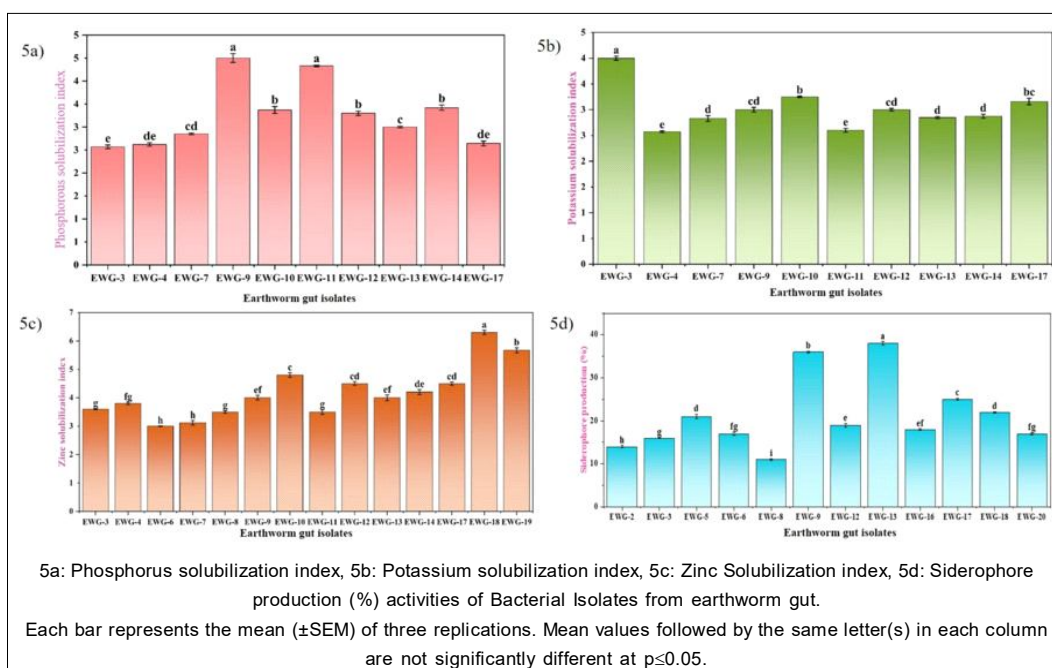


Fig 5: Comparison of plant growth-promoting abilities of potential bacterial isolates obtained from earthworm gut.

(38.3%) and PC2 (21.0%), together explained 59.3% of total variance.

The biplot (Fig 7) shows that positive PC1 values correlated with high cellulase and hemicellulase activities, while negative PC1 values were associated with solubilization traits, indicating functional divergence among

isolates (Ghosh *et al.*, 2022). Earthworm gut isolates clustered around siderophore and solubilization vectors, whereas vermicompost isolates grouped with hydrolytic enzyme activities. Mushroom compost isolates showed moderate variability, suggesting functional overlap between solubilizers and degraders.

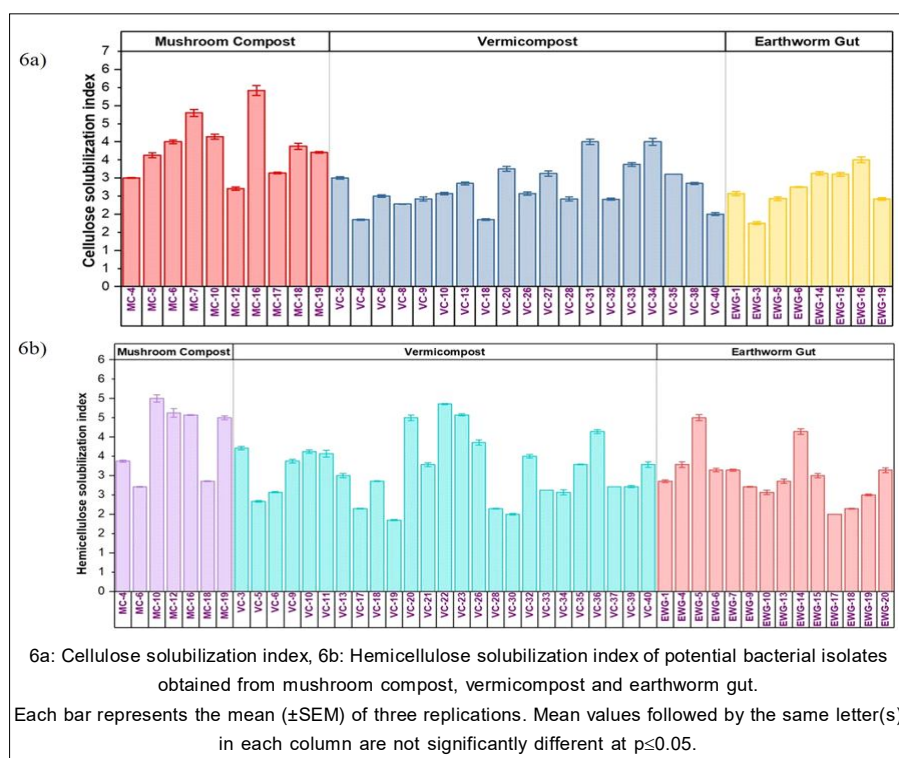


Fig 6: Comparison of cellulose and hemicellulose solubilization of potential bacterial isolates obtained from mushroom compost, vermicompost and earthworm gut.

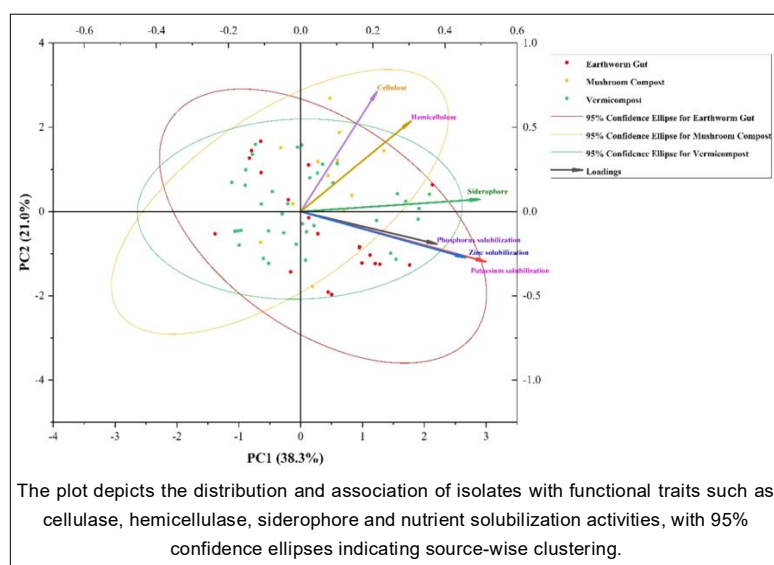


Fig 7: PCA biplot of microbial isolates from mushroom compost, vermicompost and earthworm gut based on their plant growth-promoting and enzyme degradation abilities.

This reflects substrate-specific microbial functional guilds: (i) vermicompost had enzyme-dominant degraders; (ii) earthworm gut had nutrient solubilizers; and (iii) mushroom compost had balanced degradative and solubilizing traits. These relationships reveal how compost micro-environments shape microbial specialization, contributing collectively to enhanced composting efficiency and nutrient recycling.

CONCLUSION

This study comparatively evaluated bacterial isolates from mushroom compost, vermicompost, and earthworm gut for morphological, biochemical, plant growth-promoting, and enzymatic traits. Functional screening revealed multiple beneficial traits, including nutrient solubilization, siderophore production, and hydrolytic enzyme activities. Vermicompost and earthworm gut isolates exhibited superior nutrient-solubilizing potential, while vermicompost isolates showed strong cellulolytic and hemicellulolytic activities. PCA analysis revealed clear functional differentiation, with vermicompost bacteria associated with enzymatic degradation and earthworm gut isolates with nutrient solubilization. Overall, these findings demonstrate the complementary roles of these microbial communities and their potential as bioinoculants for improving composting efficiency and sustainable soil fertility management.

ACKNOWLEDGEMENT

The authors express their gratitude to the Department of Microbiology, Dr.Rajendra Prasad Central Agricultural University, Pusa, Bihar, India is recognized for funding and providing facilities for carrying out the research work.

Conflict of interest

All authors declare that they have no conflict of interest.

REFERENCES

- Bello, A., Han, Y., Zhu, H., Deng, L., Yang, W., Meng, Q., Sun, Y., Egbeagu, U.U., Sheng, S. and Wu, X. (2020). Microbial community composition, co-occurrence network pattern and nitrogen transformation genera response to biochar addition in cattle manure-maize straw composting. *Science of The Total Environment*. **721**: 137759.
- Bhakta, J.N., Sarkar, B. and Brahma, P. (2022). Isolation and characterization of potential phosphate solubilizing bacteria from earthworm (*Metaphire posthuma*) for applying as biofertilizer. *Organic Agriculture*. **12**(3): 431-444.
- Bunt, J. and Rovira, A. (1955). Microbiological studies of some subantarctic soils. *Journal of Soil Science*. **6**(1): 119-128.
- Devi, J., Deb, U., Barman, S., Das, S., Bhattacharya, S.S., Tsang, Y.F., Lee, J.H. and Kim, K.H. (2020). Appraisal of lignocellulosic biomass degrading potential of three earthworm species using vermireactor mediated with spent mushroom substrate: Compost quality, crystallinity and microbial community structural analysis. *Science of The Total Environment*. **716**: 135215.
- Edi Premono, M., Moawad, A. and Vlek, P. (1996). Effect of phosphate-solubilizing *Pseudomonas putida* on the growth of maize and its survival in the rhizosphere. *Indonesian Journal of Crop Science*. **11**(1): 13-23.
- Ghosh, S., Paria, D.S. and Chatterjee, S. (2022). Comparative study on bacterial population dynamics of foregut, midgut and hindgut content of *Perionyx excavatus* (Perrier) isolated from eco-friendly, non-hazardous vermicompost. *Applied Biochemistry and Biotechnology*. **194**(12): 6126-6139.
- Gomez, K.A. and Gomez, A.A. (1984). Statistical Procedures for Agricultural Research. John Wiley and Sons.
- Gram, C. (1884). Ueber die isolirte Färbung der Schizomyceten in schnitt-und trockenpräparaten. *Fortschritte der Medicin*. **2**: 185-189.
- Hu, X., Chen, J. and Guo, J. (2006). Two phosphate-and potassium-solubilizing bacteria isolated from Tianmu Mountain, Zhejiang, China. *World journal of Microbiology and Biotechnology*. **22**(9): 983-990.
- Isenberg, H.D. and Sundheim, L.H. (1958). Indole reactions in bacteria. *Journal of Bacteriology*. **75**(6): 682-690.
- Jyotsna, K.P., Rao, A.R., Krishna, T.M. and Devaki, K. (2015). A comparative study on physiological and bio-chemical properties of cellulose producing bacteria and actinomycete from the gut of earthworm, *Eisenia foetida*.
- Kalika-Singh, S., Ansari, A. and Maharaj, G. (2022). Vegetable crop cultivation using vermicompost in comparison to chemical fertilizers: A review. *Agricultural Reviews*. **43**(4): 480-484. doi: 10.18805/ag.RF-234.
- Kapila, R., Verma, G., Sen, A. and Nigam, A. (2024). Compositional evaluation of vermicompost prepared from different types of organic wastes using *Eisenia fetida* and studying its effect on crop growth. *Indian Journal of Agricultural Research*. **58**(3): 468-473. doi: 10.18805/IJARe.A-5708.
- Karnwal, A. (2021). Zinc solubilizing *Pseudomonas* spp. from vermicompost bestowed with multifaceted plant growth promoting properties and having prospective modulation of zinc biofortification in *Abelmoschus esculentus* L. *Journal of Plant Nutrition*. **44**(7): 1023-1038.
- Kaza, S., Yao, L., Bhada-Tata, P. and Van Woerden, F. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. World Bank Publications.
- Long, J., Wang, X., Qiu, S., Zhou, W., Zhou, S., Shen, K., Xie, L., Ma, X., and Zhang, X. (2024). Construction of cellulose-degrading microbial consortium and evaluation of their ability to degrade spent mushroom substrate. *Frontiers in Microbiology*. **15**: 1356903.
- MacFaddin, J. (2000). Biochemical Tests for identification of medical bacteria. 3rd Edition, Lippincott Williams and Wilkins, Philadelphia. *Advances in Microbiology*. **113**(7).
- Nagavallema, K., Wani, S., Lacroix, S., Padmaja, V., Vineela, C., Rao, M.B. and Sahrawat, K.L. (2004). Vermicomposting: Recycling wastes into valuable organic fertilizer. Global Theme on Agroecosystems Report no. 8. Monograph. International Crops Research Institute for the Semi-Arid Tropics, Patancheru Andhra Pradesh, India.
- Ordoñez-Arévalo, B., Huerta-Lwanga, E., de los Angeles Calixto-Romo, M., Dunn, M.F. and Guillén-Navarro, K. (2022). Hemicellulolytic bacteria in the anterior intestine of the earthworm *Eisenia fetida* (Sav.). *Science of The Total Environment*. **806**: 151221.

- Pikovskaya, R. (1948). Mobilization of phosphorus in soil in connection with vital activity of some microbial species. *Mikrobiologiya*. **17**: 362-370.
- Prachi, S. (2023). Isolation and characterization of mushroom growth promoting bacteria and their effect on growth and quality of shiitake mushroom (*Lentinula edodes*) UHF Nauni].
- Raihing, P. and Vijayalakshmi, A. (2022). Influence of vegetable and fruit wastes vermicompost on the growth and yield of black gram (*Vigna mungo* L.). *Agricultural Science Digest-A Research Journal*. **42(3)**: 322-326. doi: 10.18805/ag.D-5492.
- Raimi, A., Atanda, A., Ezeokoli, O., Jooste, P., Madoroba, E. and Adeleke, R. (2022). Diversity and predicted functional roles of cultivable bacteria in vermicompost: Bioprospecting for potential inoculum. *Archives of Microbiology*. **204(5)**: 261.
- Reddy, G.S., Pranavi, S., Srimoukthika, B. and Reddy, V.V. (2017). Isolation and characterization of bacteria from compost for municipal solid waste from Guntur and Vijayawada. *Journal of Pharmaceutical Sciences and Research*. **9(9)**: 1490.
- Rodrigues, F.W., Otuki, G.F., Morais, G.F., de Morais, M.A.C. and Zafalon, R. (2014). Using the software OriginPro® 9.1.0 as a tool for optimization of the process of removing uranium contaminated water sour-phases and loading elution. *Iberoamerican Journal of Applied Computing*. **4(1)**: 1-10.
- Satpathy, J., Saha, M.H., Mishra, A.S. and Mishra, S.K. (2020). Characterization of bacterial isolates in vermicompost produced from a mixture of cow dung, straw, Neem leaf and vegetable wastes. *BioRxiv*. 2020.2007. 2001.183467.
- Schwyn, B., and Neilands, J. (1987). Universal chemical assay for the detection and determination of siderophores. *Analytical Biochemistry*. **160(1)**: 47-56.
- Singh, A., Tiwari, R., Sharma, A., Adak, A., Singh, S., Prasanna, R., Saxena, A.K., Nain, L. and Singh, R.V. (2016). Taxonomic and functional diversity of the culturable microbiomes of epigeic earthworms and their prospects in agriculture. *Journal of Basic Microbiology*. **56(9)**: 1009-1020.
- Sinha, A.K., Rakesh, S., Mitra, B., Roy, N., Sahoo, S., Saha, B., Dutta, S. and Bhattacharya, P. M. (2022). Agricultural Waste Management Policies and Programme for Environment and Nutritional Security. In: Input use Efficiency for Food and Environmental Security. Springer. (pp. 627-664).
- Sirisena, D. and Manamendra, T. (1995). Isolation and characterization of cellulolytic bacteria from decomposing rice straw. *Journal of the National Science Foundation of Sri Lanka*. **23(1)**. doi: 10.4038/jnsfsr.v23i1.5568.
- Teather, R.M. and Wood, P.J. (1982). Use of Congo red-polysaccharide interactions in enumeration and characterization of cellulolytic bacteria from the bovine rumen. *Applied and Environmental Microbiology*. **43(4)**: 777-780.
- Yang, Y., Callaham, J.M.A., Wu, X., Zhang, Y., Wu, D. and Wang, D. (2023). Gut microbial communities and their potential roles in cellulose digestion and thermal adaptation of earthworms. *Science of The Total Environment*. **903**: 166666.