Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 06, Issue: 01 (JAN-FEB, 2026)
Available online at http://www.agriarticles.com
©Agri Articles, ISSN: 2582-9882

Use of Synthetic Microbial Communities (SynComs): An approach for Sustainable Plant Disease Management

*Alisha Mohapatra
M.Sc. Scholar, Department of Plant Pathology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India-751003
*Corresponding Author's email: mohapatraalisha01@gmail.com

Agriculture faces the dual challenge of increasing food production while ensuring environmental sustainability. According to the FAO, food production must be increased by nearly 50% by 2050 so as to meet the growing population demand. However, plant diseases alone account for approximately 35–40% yield losses worldwide and up to 30% losses in India annually. These losses cause substantial economic losses along with threatening the global food security. Conventionally, chemical pesticides and fungicides have been used extensively for disease control. Although effective in the short term, indiscriminate chemical use has led to environmental pollution, development of resistant pathogen strains, residue accumulation in food products, and adverse effects on non-target organisms, including beneficial soil microbes. The limitations of chemical disease management have necessitated a shift toward sustainable and biologically driven approaches. Sustainable plant disease management (SPDM) emphasizes prevention, ecological balance, and long-term effectiveness rather than curative chemical control. In this context, the plant microbiome has gained attention as a natural resource that can be harnessed to suppress plant pathogens and enhance crop health. Synthetic microbial communities (SynComs), designed based on ecological and functional principles, offer a novel strategy to improve the reliability and consistency of biological disease control.

Concept of Sustainable Plant Disease Management (SPDM)

Sustainability refers to practices that meet present needs without compromising the ability of future generations to meet their own needs. Sustainable plant disease management integrates ecological principles with disease control strategies to minimize environmental impact and ensure long-term crop productivity. SPDM relies on a combination of cultural, biological, genetic, and minimal chemical approaches to maintain disease levels below economic thresholds. Unlike conventional disease management, which primarily focuses on eliminating pathogens, SPDM aims to strengthen the plant–soil ecosystem, enhance natural antagonistic interactions, and promote resilience against disease outbreaks. Biological agents, host resistance, crop rotation, organic amendments, and microbiome-based interventions are central components of SPDM. Among these, manipulation of the plant microbiome through SynComs represents an advanced and targeted approach aligned with sustainability goals.

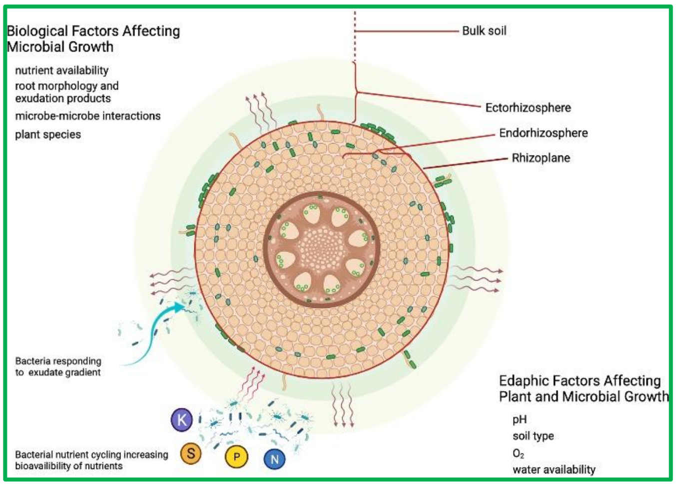
Soil Microbiome and Plant Microbiome

The soil microbiome comprises diverse microbial communities, including bacteria, fungi, archaea, protozoa, and viruses, along with their collective genetic functions. These microorganisms play crucial roles in nutrient cycling, organic matter decomposition, soil structure formation, and suppression of soil-borne pathogens. The rhizosphere is a highly dynamic zone influenced by root exudates, which serve as chemical signals and nutrient sources for microbes. Root exudates act as "communication hubs" that mediate plant–

microbe and microbe–microbe interactions. The rhizosphere is further divided into the ectorhizosphere (outer soil zone), rhizoplane (root surface), and endorhizosphere (inner root tissues). Each zone hosts distinct microbial communities with specific functional roles in plant health and disease suppression.

Core Microbiome Concept

Plants selectively recruit a subset of microorganisms from the surrounding soil, known as the core microbiome, which remains consistently associated with a particular plant species across different environments. The core microbiome contains key microbial taxa carrying essential functional traits such as pathogen suppression, nutrient acquisition, and stress tolerance. Within the core microbiome, certain highly interactive members, referred to as hub microbes or keystone species, exert a disproportionate influence on community structure and function. Understanding the core microbiome concept has provided the foundation for developing SynComs. By identifying and assembling functionally important core microbes, it is possible to design microbial consortia that replicate natural disease-suppressive communities while maintaining experimental control and predictability.

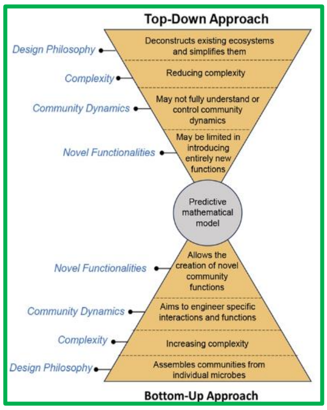


Concept and Need of Synthetic Microbial Communities (SynComs)

Synthetic microbial communities are deliberately engineered consortia of two or more microbial species designed to perform specific functions. The concept of SynComs was introduced to simplify complex natural microbiomes while retaining key ecological interactions. SynComs bridge the gap between single-strain inoculants and highly complex natural communities. The need for SynComs arises from the limitations of single biocontrol agents, which often show inconsistent performance under field conditions due to environmental stress, poor colonization, and competition with native microbiota. SynComs offer functional redundancy, division of labour, and improved stability. By combining microbes with complementary traits such as antibiosis, competition, and induction of host resistance, SynComs provide more reliable and durable disease suppression.

Principles and Approaches for Designing SynComs

The design of SynComs is guided by several ecological principles, including biological diversity, ecosystem functionality, microbial compatibility, division of labor, community stability, and ecological mimicry. These principles ensure that the selected microbes can coexist, function synergistically, and persist in the target environment. Two major approaches are used for SynCom design-



a. The top-down approach- This starts with selection of naturally disease-suppressive soils or plant microbiomes, followed by microbiome profiling, identification of core members, and finally the reduction to a simplified synthetic community. This approach closely mimics natural ecosystems and offers high ecological relevance.
b. The bottom-up approach – This begins with the isolation of individual microbial strains with known functions, which are then assembled and tested for compatibility and performance. While bottom-up SynComs provide better mechanistic understanding and reproducibility, they may lack ecological complexity.

Tools and Technologies for Engineering SynComs

Advances in systems biology and synthetic biology have accelerated SynCom research. Computational models, including genome-scale metabolic models and population dynamics models, help predict microbial interactions and community behavior. Genetic circuits enable precise regulation of gene expression and coordination of microbial functions within a consortium. CRISPR-Cas technology has emerged as a powerful tool for engineering SynCom members by enabling multiplex genome editing, regulation of metabolic pathways, and enhancement of stress tolerance. These tools contribute to the development of stable and efficient SynComs tailored for specific agricultural applications.

Pathogen Suppression Mechanisms of SynComs

SynComs suppress plant diseases through multiple mechanisms. These include a. antibiosis; b. competition; c. ISR and d. quorum quenching. Antibiosis involves the production of antimicrobial compounds such as antibiotics and volatile organic compounds that directly inhibit pathogens. Competition occurs when beneficial microbes outcompete pathogens for nutrients and niche space, often through rapid colonization and siderophore production. Induced systemic resistance (ISR) is a plant-mediated defence response activated by beneficial microbes through jasmonic acid and ethylene signalling pathways, leading to enhanced resistance against a broad range of pathogens. Quorum quenching disrupts pathogen communication systems by degrading or inhibiting quorum sensing molecules, thereby reducing virulence.

Application of SynComs in Sustainable Plant Disease Management

SynComs can be applied through seed treatment, soil drenching, root dipping, biopriming, compost integration, and foliar sprays. In integrated disease management systems, SynComs complement cultural practices, host resistance, and minimal chemical inputs. Their use enhances soil microbial stability, delays pathogen resistance development, and reduces dependency on chemical pesticides.

Challenges and Future Perspectives

Despite their potential, several challenges limit the large-scale adoption of SynComs, including instability under field conditions, microbial incompatibility, competition with native microbiota, and environmental stress. Future research should focus on improving SynCom resilience, developing predictive models, and integrating SynComs with precision agriculture technologies. The development of digital ecosystems and climate-resilient SynComs represents a promising direction for sustainable agriculture.

Conclusion

Synthetic microbial communities represent a transformative approach in sustainable plant disease management. By harnessing ecological principles and advanced biotechnological tools, SynComs provide multi-mechanistic, stable, and environmentally friendly disease control. Their integration into SPDM and integrated disease management systems can significantly reduce chemical inputs, improve soil health, and ensure long-term agricultural sustainability.

References

1. Contreras-Salgado, E. A., Sánchez-Morán, A. G., Rodríguez-Preciado, S. Y., Sifuentes-Franco, S., Rodríguez-Rodríguez, R., Macías-Barragán, J., & Díaz-Zaragoza, M. (2024). Multifaceted applications of synthetic microbial communities: Advances in biomedicine, bioremediation, and industry. *Microbiological Research, 15*(1), Article 00113.
2. Großkopf, T., & Soyer, O. S. (2014). Synthetic microbial communities. *Current Opinion in Microbiology, 18*, 72–77.
3. Jessup, C. M., Kassen, R., Forde, S. E., Kerr, B., Buckling, A., Rainey, P. B., & Bohannan, B. J. M. (2014). Synthetic microbial ecosystems: An exciting tool to

understand and apply microbial communities. *Environmental Microbiology*, *16*(6), 1472–1481.

4. Li, M., Hu, J., Wei, Z., Jousset, A., Pommier, T., Yu, X., Xu, Y., & Shen, Q. (2024). Synthetic microbial communities: Sandbox and blueprint for soil health enhancement. iMeta, 3(2), e172.
5. Li, X. (2024). Synthetic microbial communities: Sandbox and blueprint for soil health enhancement. *iMeta*, *3*(1), e92.
6. Nikoloudaki, O., Aheto, F., Di Cagno, R., & Gobbetti, M. (2024). Synthetic microbial communities: A gateway to understanding resistance, resilience, and functionality in spontaneously fermented food microbiomes. *Food Research International*, *192*, 114780.
7. Shayanthan, A., Ordoñez, P. A. C., & Oresnik, I. J. (2022). The role of synthetic microbial communities (SynCom) in sustainable agriculture. *Frontiers in Agronomy*, *4*, 896307.