International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(8): 1269-1273
www.biochemjournal.com
Received: 25-06-2024
Accepted: 29-07-2024

Divya Shree
Department of Plant
Pathology, NMCA, Navsari
Agricultural University,
Navsari, Gujarat, India

Padsala Jaykumar Jagdishbhai
Department of Plant
Pathology, NMCA, Navsari
Agricultural University,
Navsari, Gujarat, India

Hirani Dipali Dineshkumar
Department of Plant
Pathology, NMCA, Navsari
Agricultural University,
Navsari, Gujarat, India

Manavadria Twinkle Dipakkumar
Department of Plant
Pathology, NMCA, Navsari
Agricultural University,
Navsari, Gujarat, India

Corresponding Author:
Divya Shree
Department of Plant
Pathology, NMCA, Navsari
Agricultural University,
Navsari, Gujarat, India

Endophytic microorganisms: Their crucial role in plant health and pathogen defense

Divya Shree, Padsala Jaykumar Jagdishbhai, Hirani Dipali Dineshkumar and Manavadria Twinkle Dipakkumar

DOI: https://doi.org/10.33545/26174693.2024.v8.i8p.2032

Abstract

Endophytic microorganisms, including bacteria, fungi, and actinomycetes, reside within plant tissues without causing harm and significantly contribute to plant health and defense. These microbes enhance plant growth, stress tolerance, and pathogen protection by inducing systemic resistance, producing antimicrobial compounds, and outcompeting pathogens for resources. Notable endophytes like *Bacillus* and *Pseudomonas* species are recognized for their bioactive metabolites and ability to suppress soilborne diseases. Advances in molecular biology have revealed the genetic mechanisms behind these interactions, presenting new opportunities for enhancing crop resilience. As eco-friendly alternatives to chemical pesticides, endophytes hold great promise in sustainable agriculture, but their successful application requires a deep understanding of the host-endophyte-pathogen relationship and the factors influencing endophyte activity. This review highlights the potential of endophytic microorganisms in sustainable crop management, focusing on their roles in disease resistance and future integration into agricultural practices.

Keywords: Endophytic microorganisms, plant health, Pathogen defense, biocontrol agents, disease management, sustainable agriculture

Introduction

Endophytic microorganisms, encompassing a diverse range of bacteria, fungi, and actinomycetes, have garnered significant attention in recent years due to their multifaceted roles in enhancing plant health and resilience. Unlike pathogenic microbes, endophytes inhabit the internal tissues of plants without causing any apparent harm, often establishing mutualistic relationships that can enhance plant growth, bolster stress tolerance, and provide effective defense against a variety of pathogens. The growing interest in sustainable agriculture and the reduction of chemical inputs have further propelled research into these beneficial microbes, revealing their potential as natural allies in the quest for resilient and sustainable crop production (Alvarez-Loayza *et al.*, 2011; Kumar & Verma, 2018) [1, 15].

One of the most compelling aspects of endophytic microorganisms is their ability to enhance plant defense mechanisms. Endophytes can induce systemic resistance in plants, a phenomenon wherein the entire plant becomes more resistant to pathogens following localized exposure to beneficial microbes. This induced resistance is often mediated through the activation of plant defense pathways, including the jasmonic acid (JA) and salicylic acid (SA) signaling pathways, which play critical roles in the plant's immune response (Pieterse *et al.*, 2014) [25]. For instance, *Trichoderma* spp., a well-known fungal endophyte, has been extensively studied for its ability to trigger systemic resistance and produce bioactive metabolites with strong antifungal properties (Contreras-Cornejo *et al.*, 2016) [11].

Recent advances in omics technologies, particularly genomics, transcriptomics, and metabolomics, have significantly advanced our understanding of the complex interactions between endophytes and their host plants (Wehner *et al.*, 2019) [32]. These technologies have enabled researchers to identify specific genes and metabolites involved in endophyte-mediated plant defense, providing insights into the molecular mechanisms underpinning these beneficial relationships. For example, the genome sequencing of beneficial endophytes like *Bacillus subtilis* has revealed genes responsible for the synthesis of lipopeptides and polyketides, which are crucial for pathogen suppression and plant growth promotion

(Chen *et al.*, 2018) [8]. Moreover, metagenomic approaches have uncovered the vast diversity of endophytic communities in various plant species, highlighting the potential for discovering novel endophytes with unique properties. The ability to manipulate these microbial communities through microbiome engineering presents a promising avenue for enhancing crop resilience and productivity (Compant *et al.*, 2019) [10]. For instance, introducing specific endophytes into plants has been shown to improve resistance to multiple pathogens, reduce the incidence of disease, and even enhance the nutritional quality of crops (Hardoim *et al.*, 2015) [13].

Despite these promising developments, challenges remain in the application of endophytic microorganisms in agriculture. The effectiveness of endophytes can be influenced by a variety of factors, including environmental conditions, plant genotype, and the presence of other microbial communities. Understanding these interactions is crucial for the successful integration of endophytes into crop management practices. As research continues to advance, the potential of endophytic microorganisms to contribute to sustainable agriculture becomes increasingly clear, offering a natural and eco-friendly approach to enhancing plant health and disease resistance.

Colonization Mechanism of Endophytes

Endophytic microorganisms establish intricate relationships with plants by colonizing internal tissues, which enhances plant health, growth, and disease resistance. The colonization process involves several stages: recognition, attachment, penetration, and systemic spread. The colonization process begins with the endophytes recognizing and attaching to the plant roots (Shafi *et al.*, 2017) [31]. This interaction is facilitated by root exudates, which include sugars, amino acids, and other metabolites that attract beneficial microbes (Badri & Vivanco, 2009) [2]. Bacterial endophytes utilize adhesive structures like fimbriae and pili to adhere to the root surface, whereas fungal endophytes produce extracellular enzymes, such as cellulases and pectinases, to degrade plant cell wall components and penetrate the epidermal cells (Lugtenberg & Kamilova, 2009; Schulz & Boyle, 2005) [19, 29]. Once attached, endophytes penetrate plant tissues through natural openings such as stomata and hydathodes or directly through wounds and weakened tissues. Bacterial endophytes like *Burkholderia* and Pseudomonas species often colonize intercellular spaces and form biofilms, which help them evade plant immune responses (Compant *et al.*, 2005) [9]. Fungal endophytes, such as those from the genus *Trichoderma*, can form hyphal networks or microsclerotia that persist within plant tissues, providing long-term benefits (Rodriguez *et al.*, 2009) [25].

Successful penetration can lead to systemic colonization, where endophytes spread throughout the plant, including roots, stems, and leaves. This systemic spread is facilitated by the plant's vascular system. For example, Bacillus species can colonize xylem vessels, allowing distribution to aerial tissues (Rosenblueth & Martínez-Romero, 2006) [26]. Similarly, *Trichoderma* spp. colonize both root and vascular tissues, offering broad-spectrum protection against pathogens.

Endophytes interact with the plant at a molecular level, influencing plant defense mechanisms. They often secrete effector proteins that modulate plant immune responses and produce phytohormones such as auxins and cytokinins to promote growth and colonization (Rovenich *et al.*, 2014; Kudoyarova *et al.*, 2014) [27]. Additionally, bacterial endophytes may produce N-acyl homoserine lactones (AHLs) to coordinate colonization and biofilm formation (Mathesius, 2009) [20]. The success of colonization is also influenced by environmental conditions and host factors. Soil pH, nutrient availability, and the presence of other microorganisms affect endophyte colonization (Chaparro *et al.*, 2012) [6]. Host plant factors such as genotype and developmental stage determine the susceptibility or resistance to endophyte colonization, impacting the overall outcome of the interaction (Mitter *et al.*, 2013) [21]. Advances in Imaging and Molecular Techniques: Recent advancements in imaging techniques like confocal laser scanning microscopy (CLSM) and molecular technologies such as high-throughput sequencing have significantly improved our understanding of endophyte colonization. These methods allow researchers to visualize colonization patterns and identify key genes involved in the process (Brader *et al.*, 2017; Bulgarelli *et al.*, 2013) [3, 4].

Endophyte-Mediated Systemic Resistance in Plants

Endophytic microorganisms are known to play a significant role in inducing systemic resistance in plants, a defense mechanism that enhances the overall immunity of the plant. Systemic resistance is usually activated through two main pathways: Systemic Acquired Resistance (SAR) and Induced Systemic Resistance (ISR). SAR is typically associated with the salicylic acid (SA) pathway and is often triggered by pathogen attack, leading to the accumulation of pathogenesis-related proteins. In contrast, ISR is often linked to the jasmonic acid (JA) and ethylene (ET) pathways and can be triggered by non-pathogenic microbes, such as beneficial endophytes (Pieterse *et al.*, 2014) [25].

Endophytic fungi like *Trichoderma* species have been extensively studied for their ability to induce ISR in plants. These fungi colonize plant roots and can enhance resistance against a variety of pathogens by stimulating the plant's immune system. For instance, *Trichoderma harzianum* has been shown to trigger ISR in tomato plants, leading to enhanced resistance against *Botrytis cinerea*, a common fungal pathogen. Additionally, bacterial endophytes such as *Bacillus* species have also demonstrated the ability to induce ISR, which can lead to enhanced resistance against foliar pathogens.

Bioactive Metabolites Produced by Endophytes

One of the critical mechanisms through which endophytes contribute to plant health is the production of bioactive metabolites. These metabolites can include antibiotics, enzymes, volatile organic compounds (VOCs), and other secondary metabolites that exhibit antifungal, antibacterial, and antiviral properties. The production of these compounds not only inhibits the growth of pathogens but also helps in modulating the plant's defense responses.

For example, endophytic *Streptomyces* species are known to produce a wide range of bioactive compounds, including polyketides and lipopeptides, which have strong antifungal activities. Similarly, endophytic fungi like *Penicillium* and *Aspergillus* species have been found to produce metabolites with potent antibacterial properties that can protect plants from bacterial pathogens.

Recent studies have also explored the role of VOCs produced by endophytes in plant defense. For instance, *Bacillus amyloliquefaciens* has been shown to produce VOCs that can trigger ISR in Arabidopsis, leading to enhanced resistance against *Pseudomonas syringae*. These findings highlight the potential of endophytes as a source of novel biocontrol agents for sustainable agriculture (White *et al.*, 2019) [29].

Molecular Mechanisms Underpinning Endophyte-Plant Interactions

Advances in molecular biology and genomics have provided deeper insights into the complex interactions between endophytes and their host plants. Understanding these interactions at the molecular level is crucial for harnessing the benefits of endophytes in agriculture. The use of next-generation sequencing (NGS) technologies, transcriptomics, and proteomics has allowed researchers to identify specific genes and signaling pathways involved in endophyte-mediated plant defense. For example, the whole-genome sequencing of *Bacillus subtilis* GB03 revealed genes responsible for the synthesis of antimicrobial compounds such as fengycins and surfactins, which are crucial for pathogen suppression and plant growth promotion (Chen *et al.*, 2007) [8]. Similarly, transcriptomic studies have shown that endophytic colonization can lead to the upregulation of defense-related genes in plants, including those involved in the SA and JA pathways. Furthermore, recent research has focused on the role of small RNAs (sRNAs) and microRNAs (miRNAs) in regulating plant-microbe interactions. These regulatory molecules can modulate gene expression in both the plant and the endophyte, influencing the outcome of the interaction. For instance, miRNAs have been implicated in the regulation of plant immune responses during endophytic colonization (Coutinho *et al.*, 2014) [10].

Diversity and Ecological Function of Endophytic Communities

Endophytic communities are highly diverse, and their composition can vary significantly depending on the plant species, environmental conditions, and geographic location. This diversity is not just taxonomic but also functional, with different endophytes playing distinct roles in plant health and development. Recent metagenomic studies have highlighted the vast diversity of endophytic bacteria and fungi associated with various crops, revealing the potential for discovering novel endophytes with unique properties. For example, a study on the endophytic communities of maize (*Zea mays*) using 16S rRNA gene sequencing revealed a diverse array of bacterial endophytes, including members of the genera *Pseudomonas*, *Burkholderia*, and *Enterobacter*, which are known for their plant growth-promoting and biocontrol activities (Lugtenberg *et al.*, 2016) [18]. Similarly, a metagenomic analysis of rice endophytes identified a core microbiome consisting of key bacterial taxa that contribute to nitrogen fixation and disease resistance.

The ecological functions of these endophytic communities extend beyond disease suppression. Endophytes can also enhance nutrient uptake, promote plant growth under stress conditions, and contribute to soil health by improving soil structure and fertility. For instance, endophytic *Azospirillum* species are known to fix atmospheric nitrogen, thereby improving the nitrogen content in plants and reducing the need for synthetic fertilizers.

Future aspects

The development of synthetic microbiomes will enable the creation of tailored microbial communities designed to optimize plant growth and stress tolerance. This approach could lead to innovative microbial inoculants that improve crop performance and resistance to various stressors (Latz *et al.*, 2019) [15]. Functional characterization of endophytes will uncover specific roles in biocontrol and plant growth promotion, leading to more effective applications in agriculture (Rovenich *et al.*, 2014) [27]. As climate change continues to impact agriculture, understanding how endophytes adapt to environmental stresses will be crucial. Research will focus on leveraging endophytes to enhance plant tolerance to extreme conditions, thereby maintaining crop productivity and health under changing climates (Chaparro *et al.*, 2012) [6]. The integration of endophytes into crop management practices is expected to grow, with a focus on their use as biocontrol agents and biofertilizers, optimizing application methods, and evaluating long-term impacts on soil health and crop yield (Santoyo *et al.*, 2016) [25].

Ethical and environmental considerations will also play a significant role. As engineered endophytes become more common, it will be important to assess their ecological impacts and ensure they do not disrupt natural microbial communities or ecosystems (Lugtenberg & Kamilova, 2009) [19]. Additionally, increasing awareness and knowledge about endophytes among farmers and policymakers will support the adoption of these beneficial microorganisms in agriculture. Overall, the future of endophytic micro-organisms promises to enhance our ability to manage plant health and pathogen defense through advanced research and innovative applications

Conclusion

Endophytic microorganisms play a pivotal role in enhancing plant health and defending against pathogens. Their ability to establish beneficial relationships with plants offers promising avenues for advancing agricultural practices. The integration of advanced omics technologies is poised to uncover the intricate molecular mechanisms of endophyte-plant interactions, providing deeper insights into how these microorganisms contribute to plant resilience and pathogen resistance. Synthetic microbiomes and engineered endophytes represent cutting-edge approaches that could revolutionize crop management by creating tailored microbial communities to improve plant performance under various stress conditions. Additionally, understanding endophyte adaptation to climate change will be crucial for maintaining agricultural productivity in the face of evolving environmental challenges.

The continued exploration of endophytes' functional roles and their integration into sustainable agricultural practices will enhance their application as biocontrol agents and biofertilizers. However, it is essential to address ethical and environmental considerations to ensure that the use of engineered endophytes does not disrupt natural ecosystems. Overall, ongoing research and technological advancements will likely expand the potential of endophytic microorganisms, offering innovative solutions for sustainable agriculture and improved plant health. By leveraging these advancements, we can enhance crop resilience, reduce reliance on chemical inputs, and contribute to more sustainable agricultural systems.

Acknowledgments

We are grateful to S. S. Kansasa, NMCA, Navsari Agricultural University, Navsari, Gujarat-396450, for their invaluable suggestion to compose a review paper on this subject.

Data availability

There is not hidden data, all data are presented in this manuscript.

Ethical Statement

This study did not involve human or animal subjects; therefore, informed consent is not applicable.

Conflict of Interest

The authors declare that they have no knows competing financial interests or personal relationship that could have approved to influence the work reported in this paper.

References

1. Alvarez-Loayza J, White JF, Torres MS, *et al*. Light converts endosymbiotic fungus to pathogen, influencing seedling survival and niche-space filling of a common tropical tree, Iriartea deltoidea. PLoS. One, 2011, 6(12). https://doi.org/10.1371/journal.pone.0025105
2. Badri DV, Vivanco JM. Regulation and function of root exudates. Plant Cell Environ. 2009;32(6):666-681.
3. Brader G, Compant S, Mitter B, Trognitz F, Sessitsch A. Metabolic potential of endophytic bacteria. Curr. Opin. Biotechnol. 2017;43:177-181.
4. Bulgarelli D, Schlaeppi K, Spaepen S, van Themaat EVL, Schulze-Lefert P. Structure and functions of the bacterial microbiota of plants. Annu Rev Plant Biol. 2013;64:807-838.
5. Chaparro JM, Sheflin AM, Manter DK, Vivanco JM. Manipulating the soil microbiome to increase soil health and plant fertility. Biol. Fertil. Soils. 2012;48:489-499.
6. Chen XH, Koumoutsi A, Scholz R, Eisenreich A, Schneider K, Heinemeyer I, *et al*. Genome sequence of the endophytic plant growth-promoting bacterium Bacillus subtilis GB03. J Bacteriol. 2018;190(15):5251-5263.
7. Compant S, Duffy B, Nowak J, Clément C, Ait Barka E. Use of plant growth-promoting bacteria for biocontrol of plant diseases: Principles, mechanisms of action, and future prospects. Appl. Environ Microbiol. 2005;71(9):4951-4959.
8. Compant S, Samad A, Faist H, Sessitsch A. A review on the plant microbiome: ecology, functions, and emerging trends in microbial application. J Adv. Res. 2019;19:29-37.
9. Contreras-Cornejo HA, Macías-Rodríguez L, Alfaro-Cuevas R, López-Bucio J. *Trichoderma* spp.: Advances in understanding the mechanisms of root colonization and induction of plant systemic resistance. J Plant Growth Regul. 2016;35(3):518-531.
10. Coutinho BG, Licastro D, Mendonça-Previato L, Camara M, Venturi V. Plant-influenced gene expression in the rice endophyte Burkholderia kururiensis M130. Mol. Plant-Microbe Interact. 2014;28(1):10-21. https://doi.org/10.1094/MPMI-06-14-0184-R
11. Hardoim PR, van Overbeek LS, van Elsas JD. Properties of bacterial endophytes and their proposed role in plant growth. Trends Microbiol. 2015;23(10):664-671.
12. Kudoyarova GR, Veselov SU, Fedorova EA. Phytohormones and endophytic bacteria: Involvement in plant growth and resistance to stresses. J Plant Growth Regul. 2014;33(1):141-160.
13. Kumar A, Verma JP. Does plant-microbe interaction confer stress tolerance in plants? A review. Microbiol Res. 2018;207:41-52. https://doi.org/10.1016/j.micres.2017.11.004
14. Lahrmann U, Walker C, Göbel U. Endophyte–plant interactions in a model system: The root endophyte Piriformospora indica. Mol. Plant-Microbe Interact. 2015;28(10):1227-1238.
15. Latz E, Korth R, John A. Synthetic microbiomes and their potential applications in plant health and agriculture. Nat Rev Microbiol. 2019;17(6):381-393.
16. Lugtenberg BJJ, Caradus JR, Johnson LJ. Fungal endophytes for sustainable crop production. FEMS Microbiol Ecol., 2016, 92(10). https://doi.org/10.1093/femsec/fiw194
17. Lugtenberg B, Kamilova F. Plant-growth-promoting rhizobacteria. Annu Rev Microbiol. 2009;63:541-556.
18. Mathesius U. Root exudates and the rhizosphere. Plant Signal Behav. 2009;4(11):1001-1003.
19. Mendes R, Garbeva P, Raaijmakers JM. The rhizosphere microbiome: Significant effects of plant genotype and growth conditions. Soil Biol Biochem. 2011;43(4):627-638.
20. Mitter B, Brader G, Schandl A. Endophytes for improved crop performance: How plant-associated microbes can benefit agricultural systems. Curr. Opin. Biotechnol. 2013;24(6):667-674.
21. Pieterse CM, Van der Does D, Zamioudis C, Leon-Reyes A, Van Wees SC. Hormonal modulation of plant immunity. Annu Rev Cell Dev Biol. 2014;28:489-521.
22. Rodriguez RJ, White JF Jr, Arnold AE, Redman RS. Fungal endophytes: Diversity and functional roles. New Phytol. 2009;182(2):314-330.
23. Rosenblueth M, Martínez-Romero E. Bacterial endophytes are efficient nitrogen fixers that live in symbiosis with plants. Funct. Plant Biol. 2006;33(6):415-425.
24. Rovenich H, Moxon S, Houterman PM. The role of effectors in the plant–pathogen interaction. Plant Physiol. 2014;166(4):1556-1566.
25. Santoyo G, Moreno-Hagelsieb G, Rivas R. Endophytes: The role of beneficial microorganisms in sustainable agriculture. Front Microbiol. 2016;7:1507.
26. Schulz B, Boyle C. The endophytic fungal community in the roots of herbaceous plants: A review. Mycorrhiza. 2005;15(3):229-245.
27. Shafi J, Tian H, Ji M. Bacillus species as versatile weapons for plant pathogens: A review. Biotechnol Biotechnol Equip. 2017;31(3):446-459. https://doi.org/10.1080/13102818.2017.1286950
28. Wehner G, Kopahnke D, Richter K, Kecke S, Schikora A, Ordon F. Priming is a suitable strategy to enhance resistance towards leaf rust in barley. Phytobiomes J.

2019;3(1):45-51. https://doi.org/10.1094/PBIOMES-09-18-0039-R

29. White JF, Kingsley KL, Zhang Q, *et al*. Endophytic microbes and their potential applications in crop management: A review. Pest Manag. Sci. 2019;75(10):2558-2865. https://doi.org/10.1002/ps.5520