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A Brief Overview of Plant Microbiome: Stressing its Significance and Function

R. Vidhyalakshmi, S. Ramya* and S. Janani

Department of Microbiology, Dr. MGR-Janaki College of Arts and Science for Women, Chennai– 600119, Tamil Nadu, India

**Corresponding author*

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A B S T R A C T

The plant microbiome, a complex community of microorganisms that live in and around plants, plays an essential role in plant health and development. This review offers a brief overview of the plant microbiome, focusing on its importance for plant growth, nutrient uptake, and disease resistance. Microbial communities, including bacteria, fungi, and archaea, have formed symbiotic relationships with plants, helping them adapt and thrive in a variety of environmental conditions. In this review highlight key functions of the plant microbiome, such as boosting stress tolerance, producing hormones, and protecting plants from pathogens. The review also touches on how manipulating the microbiome could be applied to sustainable agriculture, aiming to enhance crop productivity and resilience by deepening our understanding of plant-microbe interactions. Additionally, it emphasizes the critical role of soil microbial populations in directly contributing to plant growth.

Introduction

Overview of Plant Microbiome

The complex population of microorganisms that coexist with plants, such as fungi, bacteria, viruses, and other microbes, is known as the plant microbiome. These microbial communities are essential to plant growth, development, and environmental adaptation (Andreote *et al.,* 2014).

These microorganisms can be found in various parts of the plant, including the rhizosphere (the soil region near the roots), phyllo sphere (the aerial parts of the plant), endosphere (inside the plant tissues), and sperm sphere (around the seeds). The plant microbiome plays a critical role in plants ' health, development, and productivity by regulating nutrient absorption, strengthening resistance to diseases, and stimulating plant growth through various pathways. The plant microbiome is a dynamic system that responds to changes in the environment, the phases at which plants develop, and interactions with other species. Recent research has brought attention to this dynamic character of the microbiome.

It is vital to comprehend the plant microbiome to establish sustainable farming, increase crop output, and enhance agricultural techniques. Within plant metabolism, the microbiome plays a crucial role in essential functions like nitrogen fixation, phosphorus solubilization, hormone synthesis, and detoxification of toxins. These microbial functions satisfy plants' metabolic requirements and assist in handling both biotic and abiotic pressures (Berg *et al.,* 2020).

Composition of the Plant Microbiome

The plant microbiome is diverse and dynamic, with its composition varying depending on the plant species, environment, and developmental stage. The microbiome can be categorized into different niches based on the plant part it inhabits:

Rhizosphere Microbiome

The rhizosphere, influenced by plant roots, is the most studied part of the plant microbiome due to its role in nutrient uptake. It contains bacteria, fungi, and other microorganisms that form symbiotic relationships with the plant, aiding in nitrogen fixation and phosphorus solubilization, making nutrients more accessible to the plant (Berendsen *et al.,* 2012). Studies have shown the presence of beneficial bacteria like *Bacillus*, *Pseudomonas, Azospirillum,* and *Rhizobium* in the rhizosphere and plant tissues, promoting plant growth, enhancing nutrient acquisition, and contributing to disease resistance (Sharma *et al.,* 2021). *Bacillus species* are particularly notable for producing antimicrobial compounds, protecting the *T. cordifolia* (Guduchi plant) from pathogenic bacteria and fungi (Kumar *et al.,* 2019).

Endosphere Microbiome

The endosphere, referring to the internal tissues of plants, hosts diverse microbial communities that include bacteria, fungi, and archaea, all of which play crucial roles in plant growth, health, and stress tolerance. Unlike other plant-associated microbiomes, such as the rhizosphere or phyllosphere, the endosphere microbiome directly interacts with plant internal structures (Compant *et al.,* 2010). This microbial community is primarily composed of bacteria, with common genera like Pseudomonas, Bacillus, and Streptomyces, which are known to promote plant growth and enhance resistance to pathogens (Bulgarelli *et al.,* 2013).

Additionally, arbuscular mycorrhizal fungi (AMF) are found in the endosphere, where they form symbiotic relationships with plants, contributing to nutrient exchange (Bonfante & Genre, 2010). The composition and diversity of endosphere microbiomes can vary based on the plant species, its developmental stage, and environmental factors. Moreover, these microbes play a significant role in helping plants tolerate abiotic stresses, such as drought, salinity, and heavy metals, by altering plant metabolism. For example, certain endophytic bacteria can produce antioxidant enzymes to reduce oxidative stress in plants facing drought conditions (Sessitsch *et al.,* 2002). This symbiotic relationship extends beyond nutrient acquisition, encompassing various protective roles that enhance the plant's overall fitness, particularly in challenging environments.

Phyllosphere Microbiome

The phyllosphere, encompassing the above-ground parts of plants like leaves, serves as a vital habitat for diverse microorganisms, including bacteria, fungi, and archaea. This unique environment acts as a critical interface between plants and their surroundings, influencing plant health, growth, and resilience (Vorholt, 2012). The composition of the phyllosphere microbiome is shaped by factors such as plant species, environmental conditions, and geographic location, with bacteria, particularly Proteobacteria, Actinobacteria, and Bacteroides, being the most dominant groups. The microbial community is dynamic, influenced by variations in temperature, humidity, and UV radiation, leading to interactions that can be mutualistic, commensal, or antagonistic. Beneficial microbes can enhance plant growth by producing phytohormones or facilitating nutrient uptake, while others can suppress disease by outcompeting pathogens (Lindow & Brandl, 2003). Moreover, these microbes play crucial roles in plant health, including protecting against pathogens through microbial antagonism and modulating plant responses to environmental stresses like drought and salinity. Certain bacterial strains have even been shown to induce systemic resistance in plants, enhancing their resilience to environmental challenges (Bulgarelli *et al.,* 2013). Additionally, while the nitrogen cycle is more pronounced in the rhizosphere, microbial contributions in the phyllosphere also play a significant role in overall plant health and productivity.

Importance of Plant Microbiome in Agriculture

Recent research suggests the plant microbiome is a crucial component of sustainable agriculture. Plant-associated microorganisms, especially those found in the rhizosphere, are necessary to enhance the development, health, and productivity of plants. They promote the fertility of the soil, the cycling of nutrients, and the inhibition of plant pathogens—which are essential for sustainable agriculture. Leguminous plants depend on microbes in the plant microbiome for the acquisition of nutrients, such as nitrogen fixed by rhizobia. In addition, they aid in the solubilization of phosphorus and other necessary minerals, increasing plant availability. Furthermore, phytohormones that support plant growth and development including auxins, gibberellins, and cytokinins can be produced by microorganisms associated with plants.

Furthermore, the plant microbiome contributes to biocontrol, a process in which advantageous bacteria impede the expansion of detrimental diseases through competition, the synthesis of antimicrobial chemicals, or the stimulation of plant defense mechanisms. In addition to lowering the need for chemical pesticides, this natural method of managing diseases and pests promotes more environmentally friendly farming methods. By increasing crop yields, enhancing soil health, and reducing reliance on chemical inputs, the incorporation of plant microbiome management into agricultural operations has the potential to promote environmental sustainability. The field's research is still growing and providing new understandings of how to use microbial communities to maximize agricultural output (Mendes *et al.,* 2011; Parnell, 2016; Berg *et al.,* 2020).

Diversity of Microbes in the Plant Microbiome

A wide variety of bacteria, each with a distinct function in the metabolism and health of plants, make up the plant microbiome. This variety consists of many microorganisms, such as fungi, bacteria, and archaea, all of which contribute to the general resilience and usefulness of the plant. Numerous microbial communities are present in plants, and they may be found in a variety of plant habitats, including the rhizosphere, endosphere, and phyllo sphere. The area of soil surrounding a plant's roots, known as the rhizosphere, is very diverse in terms of microbes and fungi that interact with plants (Bhardwaj *et al.,* 2014).

The endosphere, which refers to the internal tissues of plants, hosts a diverse array of microbes, including endophytic bacteria and fungi that inhabit the plant's interior. In a similar vein, the phyllo sphere, which includes the surfaces of plants above ground, is an essential habitat for microbial communities, which are mostly made up of bacteria and fungi that live on leaves and other aerial parts of plants. Understanding the unique functions of these microbial communities is essential to improving plant-microbe interactions in agricultural settings (Andreote *et al.,* 2014).

Bacteria

Bacteria are the most abundant and extensively studied part of the plant microbiome, inhabiting various plant compartments, including the rhizosphere, phyllosphere, and endosphere. In the rhizosphere, they play a key role in nutrient cycling, nitrogen fixation, and promoting plant growth by producing phytohormones and other beneficial substances.

Important microorganisms like *Pseudomonas*, *Bacillus*, and *Rhizobium* are known for supporting plant development and providing protection against diseases (Lugtenberg & Kamilova, 2009). Plant growth-promoting rhizobacteria (PGPR), such as species from the *Bacillus*, *Pseudomonas*, and *Azospirillum* genera, further enhance plant growth by fixing nitrogen, solubilizing phosphorus, and producing phytohormones (Compant *et al.,* 2010). Additionally, some bacteria help suppress pathogens by competing for resources and producing antimicrobial compounds (Mendes *et al.,* 2011).

Fungi

Fungi play a crucial role in the plant microbiome by aiding nutrient absorption, particularly phosphorus, through symbiotic relationships known as mycorrhizal partnerships. Mycorrhizal fungi form connections with plant roots and extend their hyphae into the soil, allowing plants to access nutrients that would otherwise be out of reach. Additionally, some fungi help protect plants by producing antimicrobial compounds or outcompeting harmful microbes (Smith & Read, 2008). Endophytic fungi, which live within plant tissues without causing harm, offer benefits such as increased resistance to environmental stresses like drought and salinity (Rodriguez *et al.,* 2009).

These fungi are key components of the plant microbiome, with species like *Aspergillus, Fusarium*, and *Trichoderma* being commonly found in plant roots and stems. These fungi enhance plant health by improving nutrient uptake and producing bioactive secondary metabolites (Kumar *et al.,* 2019). *Trichoderma species*, in particular, serve as biocontrol agents, providing a natural defense against pathogenic fungi (Singh *et al.,* 2018). Moreover, some fungi may contribute to the production of pharmacologically active compounds that enhance the plant's therapeutic properties.

Archaea

Although not as extensively studied as bacteria and fungi, archaea are increasingly recognized for their importance in the plant microbiome. These microorganisms thrive in extreme environments but also inhabit the rhizosphere, contributing to soil nutrient processes such as methane production and nitrogen circulation. The study of archaea's role in plant health is an emerging field with potential benefits for sustainable agriculture (Bates *et al.,* 2011). Certain archaea, particularly those in the *Thaumarchaeota phylum*, are involved in nitrogen cycling through ammonia oxidation, aiding in the plant's nitrogen uptake (Nicol *et al.,* 2008). Despite their lower overall diversity compared to bacteria and fungi, archaea play a significant role in nutrient cycling, particularly in nutrient-poor environments.

Virus

Viruses, such as bacteriophages, are present in the plant microbiome and can impact microbial community dynamics by infecting bacterial populations, thereby regulating bacterial diversity and abundance. Additionally, certain plant viruses may indirectly benefit plants by triggering immune responses that prepare the plant for enhanced defense against pathogens (Roossinck, 2015). Despite their small size, viruses can have significant effects on the organization and functioning of microbial communities associated with plants.

Plant-associated viruses within the plant microbiome play critical roles in influencing plant health and ecosystem dynamics. These viruses can either directly infect plant cells or reside within microbial communities such as bacteria and fungi. Interestingly, some plant viruses offer protective advantages to their hosts.

For example, cucumber mosaic virus (CMV) can increase drought resistance in plants by modulating plant hormonal pathways (Xu *et al.,* 2018). In another case, a virus infecting fungus, known as a mycovirus, can modify the pathogenicity of the fungus toward the plant, as observed in the interaction between the chestnut blight fungus (*Cryphonectria parasitica*) and the mycovirus *Cryphonectria hypovirus 1* (Ghabrial *et al.,* 2015). These examples illustrate the complex roles viruses play in the plant microbiome, affecting not only plant health but also interactions within plant-associated microbial communities.

Mechanisms of Interaction Between Plants and Microbes

The relationships between plants and their associated microbial communities are intricate and diverse. These interactions take place through different mechanisms like chemical signaling, physical associations, and metabolic exchanges that help in the overall health and growth of the plant. An important way plants and microbes interact is by exchanging chemical signals. Plants secrete a range of substances, such as sugars, amino acids, organic acids, and secondary metabolites, into the soil around their roots. These substances signal beneficial microbes like nitrogen-fixing bacteria and mycorrhizal fungi, leading to increased plant growth and improved nutrient uptake. For example, leguminous plants release flavonoids that attract rhizobia, resulting in the creation of nitrogen-fixing nodules on the roots (Oldroyd, 2013).

The interaction between plants and microbes has a significant impact on their relationship. Biofilms created by microbial communities on plant roots can protect against environmental stresses and pathogens for both the plant and microbes. These biofilms provide a small environment that helps in the transfer of nutrients and signaling molecules, improving the advantages for both the plant and the microbes (Raaijmakers *et al.,* 2009). Another crucial aspect of the interaction between plants and microbes is the metabolic exchanges that occur between them. Microorganisms can generate phytohormones like indole-3-acetic acid (IAA), which can impact the structure of plant roots, resulting in improved nutrient absorption and stronger soil anchoring. Furthermore, certain microorganisms can create enzymes that break down organic material in the ground, releasing nutrients that plants can easily absorb (Pieterse *et al.,* 2012). In addition, microorganisms are essential in protecting plants from harmful pathogens. Some helpful organisms can trigger systemic resistance in plants, a condition where the plant's immune system is prepared to react more efficiently to harmful invasions. This procedure includes the creation of signaling molecules like salicylic acid and jasmonic acid, which trigger defense-related genes in the plant (Berendsen *et al.,* 2012). Understanding these interaction mechanisms is crucial for creating tactics to control the plant microbiome for agricultural advantages. By fostering advantageous interactions between plants and microbes, crop resilience can be boosted, nutrient efficiency can be improved, and the need for chemical inputs can be decreased.

Role of plant microbiome

The plant microbiome has a variety of functions in promoting the well-being, development, and strength of plants. It plays a key role in important functions like obtaining nutrients, producing hormones, and fighting off diseases. Gaining insight into these roles shows how the microbiome can be utilized for agricultural and ecological advantages.

Nutrient Acquisition

A key function of the plant microbiome is to improve the absorption of nutrients. Microorganisms in the rhizosphere, like mycorrhizal fungi and nitrogen-fixing bacteria, establish symbiotic connections with plants, enhancing the absorption of crucial nutrients such as nitrogen, phosphorus, and potassium. Mycorrhizal fungi expand the roots' reach via their hyphal networks, enhancing nutrient absorption surface area, especially for phosphorus, a nutrient with limited mobility in soil (Smith & Read, 2008). Bacteria that fix nitrogen, like *Rhizobium species*, transform atmospheric nitrogen into ammonia, a form easily utilized by plants. This procedure is essential for leguminous plants, as they depend greatly on these bacteria for their nitrogen source. The interaction between rhizobia and legumes is a well-researched illustration of how the plant microbiome helps with nutrient acquisition (Oldroyd, 2013). Moreover, different microorganisms present in the plant microbiome can convert normally unavailable types of phosphorus and potassium into a soluble form, thus allowing plants to access these essential nutrients. In nutrient-poor soils, the microbial community plays a vital role in determining whether plant growth is healthy or nutrient-deficient, making these processes essential (Richardson *et al.,* 2009).

Hormone Production

The presence of a plant microbiome can impact plant growth and development by producing phytohormones. Microorganisms have the ability to generate hormones like auxins, gibberellins, cytokinins, and ethylene, which control different functions of plant physiology.

Certain bacteria in the soil produce indole-3-acetic acid (IAA), which is a type of auxin that enhances root growth and branching, leading to better absorption of water and nutrients by plants (Spaepen *et al.,* 2007). Gibberellins from microorganisms can promote seed sprouting and stem growth, while cytokinins affect cell multiplication and shoot development. These microbe-derived hormones can enhance plant growth and stress tolerance by supplementing the plant's natural hormone production (Lugtenberg & Kamilova, 2009).

Disease Resistance

The plant microbiome is crucial in enhancing disease resistance by defending plants against pathogens using different methods. Helpful microorganisms can compete with pathogens for resources and space, create antimicrobial substances, and trigger systemic resistance in plants. For example, *Pseudomonas* and *Bacillus* strains can produce antibiotics that stop the growth of harmful fungi and bacteria, thus safeguarding the plant (Haas & Défago, 2005). Additionally, stimulating systemic resistance through beneficial microbes is an important defense strategy. This includes triggering the plant's defense system when it detects certain signals from microbes, resulting in increased preparedness to fend off pathogens. For instance, *Bacillus subtilis* bacteria are capable of inducing the synthesis of defense-related proteins and enzymes in plants, which offers enduring resistance to various pathogens (Kloepper *et al.,* 2004). Recognizing the significance of the plant microbiome in disease resistance is crucial in agriculture, as employing beneficial microbes as biocontrol agents presents a sustainable option to chemical pesticides. By utilizing the plant microbiome's natural defense mechanisms, farmers can lower disease rates and boost crop production in an eco-friendly way.

Stress Resilience and Metabolic Adaptation

The plant microbiome plays a crucial role in supporting plant stress resilience, in addition to its functions in nutrient acquisition and hormone production. Microorganisms assist plants in adapting to environmental stressors like drought, salinity, and temperature fluctuations by influencing plant metabolism. For example, certain bacteria are capable of producing osmolytes like proline, which aid plants in maintaining cell turgor in water-deficient conditions (Hardoim *et al.,* 2015).

Microbes also contribute to the detoxification of heavy metals and other harmful compounds in the soil. Specific bacterial strains, such as *Pseudomonas* and *Bacillus*, produce enzymes that can break down toxic organic compounds, thereby shielding plants from oxidative stress (Dimkpa *et al.,* 2011). This ability to alleviate stress is essential for the survival and productivity of plants in challenging environments.

Metabolite Exchange and Symbiosis

The symbiotic relationship between plants and microbes relies on the exchange of metabolites. Plants release exudates, such as sugars, amino acids, and secondary metabolites, into the rhizosphere, which serve as nutrients for microbial communities (Bais *et al.,* 2006). Microbes, in turn, provide plants with essential metabolites like amino acids, vitamins, and enzymes.

For instance, flavonoids excreted by legume plants attract *Rhizobium* bacteria, leading to the formation of nitrogen-fixing nodules on the roots. This exemplifies how metabolite exchange between plants and microbes enhances nitrogen metabolism (Oldroyd, 2013). Additionally, arbuscular mycorrhizal fungi play a role in facilitating the exchange of carbon and phosphorus between plants and fungi, benefiting both partners (Smith & Read, 2008).

Role of Endophytic Microbes and Their Medicinal Value

Endophytic microorganisms live inside plants without causing obvious damage and are important for plant well-being, providing significant medicinal benefits. These microorganisms, such as bacteria and fungi, play a role in different plant processes and create bioactive substances that could have healing uses. Endophytes can play crucial roles in plant health by promoting stress tolerance and improving plant growth through activities such as nitrogen fixation, phytohormone production, and biocontrol (Mishra *et al.,* 2020).

Production of Bioactive Compounds

Endophytic microbes are recognized for their capacity to generate an extensive variety of bioactive compounds that can be utilized for medicinal uses. These compounds consist of antibiotics, antifungals, antivirals, and anticancer medications. An example of this is the discovery of endophytic fungi in medicinal plants like *Taxus species*, which have been identified as producers of paclitaxel (Taxol), a strong anticancer medication administered during chemotherapy (Strobel & Daisy, 2003).

Enhancement of Plant Health and Stress Tolerance

Endophytic microorganisms play a role in promoting plant well-being by improving stress resilience and immunity against harmful organisms. They are capable of creating substances that assist plants in dealing with environmental stresses like lack of water and salt, thereby enhancing their ability to withstand challenges (Saikkonen *et al.,* 1998).

For instance, endophytic bacteria like *Bacillus* and *Pseudomonas* have the ability to create exopolysaccharides, which can shield plants from drought stress and enhance soil structure (Hardoim *et al.,* 2015). Furthermore, endophytes can trigger systemic resistance in plants, enhancing their resistance to diseases and pests. This is accomplished by creating signaling molecules that trigger the plant's defense mechanisms (Kloepper *et al.,* 2004). These mechanisms are advantageous for sustainable agriculture by decreasing the reliance on chemical pesticides.

Applications in Drug Discovery and Development

Endophytic microbes have medicinal benefits that go beyond just their impact on plants. These microorganisms are important assets for the process of drug research and creation. The wide variety of chemical compounds created by endophytes offers a valuable potential for new drugs. The discovery of new compounds with strong medicinal potential has been made possible by studying endophytic microbial communities found in different plants (Gundappa *et al.,* 2020). One illustration is when endophytic fungi from Artemisia annua were discovered to create artemisinin, a crucial antimalarial compound used in malaria treatment (Liu *et al.,* 2012). Endophytes' capacity to create intricate molecules showcases their potential as drug reservoirs, while also underscoring their involvement in the natural production of medicinal substances.

Techniques for Studying Plant Microbiome

Exploring the plant microbiome requires advanced methods to reveal the variety, operations, and changes in the plant-associated microbial communities. Metagenomics and metabolomics are two significant methods in this field, offering distinct perspectives on the microbial world and its relationships with plants.

Metagenomics

Metagenomics is a potent approach to analyze the genetic material of entire microbial communities from environmental samples without having to culture individual microorganisms. This method enables a thorough examination of the microbiome's diversity, arrangement, and potential functions. By utilizing metagenomic sequencing, scientists can pinpoint the different kinds of microbial groups found in the plant microbiome and evaluate their genetic capability for tasks like nutrient processing, fighting off pathogens, and forming symbiotic relationships. Advanced sequencing technologies like Illumina and Oxford Nanopore have transformed metagenomic research by offering comprehensive genomic data, according to Riesenfeld *et al.,* (2004). Metagenomics plays a key role in identifying unknown microbes and determining their functions in the plant microbiome. Recent studies in metagenomics have shown the existence of new bacterial and fungal species in the rhizosphere and phyllosphere, which support plant growth and health (Lundberg *et al.,* 2012).

Metabolomics

Metabolomics examines the metabolite profiles in biological systems, offering information on metabolic processes in plants and their associated microbes. This method entails examining tiny molecules, like amino acids, sugars, and organic acids, which play a role in metabolic processes. Within the plant microbiome framework, metabolomics can expose the impact of microbial interactions on plant metabolism and vice versa. For example, researchers can analyze metabolite profiles of plants with and without certain microbial communities to pinpoint metabolites affected by microbial activity (Wang *et al.,* 2017).

This data assists in understanding the functional duties of microorganisms in nutrient cycling, stress reactions, and promotion of growth. Advancements in analytical methods like mass spectrometry (MS) and nuclear magnetic resonance (NMR) spectroscopy have improved the precision and sensitivity of metabolomic studies. These advancements enable in-depth analysis of metabolites and the recognition of metabolic patterns linked to particular microbial connections (Dunn *et al.,* 2012). Metabolomics is also valuable in revealing how plants and microbes share metabolites, essential for comprehending symbiotic interactions and improving agricultural techniques (Jones *et al.,* 2009).

Transcriptomics

Transcriptomics involves the analysis of RNA transcripts (mRNA) to study gene expression patterns in microbial communities and their host plants. This technique allows researchers to identify which genes are being actively expressed under specific environmental conditions or during plant-microbe interactions. RNA sequencing (RNA-seq) has emerged as a powerful tool for transcriptomic studies, providing high-resolution data on gene expression.

For instance, using transcriptomics, researchers can determine how the expression of plant genes involved in immune responses is influenced by microbial colonization. Additionally, transcriptomics can be applied to study the gene expression profiles of endophytic microbes residing inside plant tissues, revealing the mechanisms by which they promote plant growth or confer stress tolerance.

Proteomics

Proteomics is a powerful approach that enables the comprehensive study of proteins expressed by organisms, including the intricate interactions between plants and their associated microbiomes. By employing techniques such as liquid chromatography coupled with mass spectrometry (LC-MS), researchers can identify and quantify proteins in complex biological samples, revealing insights into their functional roles. For instance, proteomic analyses have been utilized to identify microbial proteins involved in critical processes such as nitrogen fixation and phosphate solubilization, which are essential for plant growth and health (Zimaro *et al.,* 2011; Fang *et al.,* 2015). These studies highlight the importance of microbial contributions to nutrient cycling and plant-microbe interactions

Imaging Techniques

Advanced imaging tools such as confocal microscopy, fluorescence in situ hybridization (FISH), and scanning electron microscopy (SEM) enable researchers to directly observe microbial communities in plant tissues. These methods are crucial for investigating how microbes are distributed within the plant, including endophytic bacteria and fungi on plant roots or leaves. Confocal microscopy, when combined with fluorescent markers, is commonly employed to examine how beneficial bacteria such as Rhizobium colonize legume roots. Meanwhile, FISH utilizes fluorescently labeled probes to target specific microbial groups, offering insights into the spatial distribution of different microbes in plant tissues. In conclusion, the plant microbiome plays a crucial role in promoting plant growth, improving stress tolerance, and maintaining overall plant health. While we've made significant progress in studying the microbiomes of well-known plants, there's still a strong need to explore lesser-known species like *Tinospora cordifolia*. Famous for its medicinal uses, *Tinospora cordifolia* offers great potential, but its microbiome remains largely unexplored. Studying the microbial communities associated with this plant could provide new insights into its resilience and the production of bioactive compounds.

Additionally, other less-studied plants, especially those in extreme or unique environments, may hold vast microbial diversity that has yet to be tapped. Researching these species could reveal important functions of their microbiomes and open up new possibilities for biotechnological applications. By gaining a deeper understanding of the microbiomes in understudied plants, we may discover ways to boost agricultural sustainability and identify new bioactive compounds that could benefit human health.

Author Contributions

Dr. R. Vidhyalakshmi: Review & Editing, Supervision and guidance; Ms. S. Ramya: Conceived the original idea. Writing - Original Draft Preparation and wrote the manuscript; Ms. S. Janani: Data Curation, Writing - Editing

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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