Mycobiota diversity in the Rhizospheric soil of medicinal plants: AReview

Mansoor Ahmad Malik*, Nusrat Ahmad, Mohd Yaqub Bhat, and Abdul Hamid Wani

ABSTRACT

The rhizospheric mycobiome of medicinal plants plays a vital role in influencing secondary metabolites and overall plant health. These fungi influence the content of bioactive chemicals and essential oils while also promoting plant growth. They improve the medicinal value and plant resistance to biotic and abiotic stressors as bioinoculants. The purpose of this review is to investigate the diversity of rhizosphere fungi in medicinal plants, recognize important fungal groups and recurring patterns, and comprehend how these fungi contribute to the diversity of above-ground plant life. These realizations may result in sustainable and environmentally favorable methods of managing medicinal plant cultivation.

Keywords: Mycobiome, metabolites, medicinal plants, rhizosphere

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INTRODUCTION

The term "rhizosphere" refers to the area of soil that is closest to roots and has the highest amount of microbial activity. The volume of soil that the root and some portions of its tissues affect, as well as the soil that surrounds the root, are now included in the broader definition of the term "rhizosphere." Root growth and activity change the physical, chemical, and biological aspects of the zone (Pinton *et al*., 2000). When compared to bulk soil, the rhizosphere is richer in nutrients due to the release of several organic compounds from the roots (Curl and Truelove, 1986). According to Patel *et al.* (2014), the rhizospheric soil of beans has a higher microbial load and quantity of macronutrients than non-rhizospheric soil. As compared to the bulk soil, the root zone has much greater microbial populations that are active and growing because to the action of these root exudates (Grayston *et al.*, 1997). The development of a varied microflora in the rhizosphere as a result of nutrients released by the roots is known as the "rhizosphere impact on plant effect" (Morgan and Whipps, 2001). A subterranean terrestrial ecosystem rhizosphere soil has a high degree of microbial diversity (Santhoshkumar and Nagarajan, 2014). Micro fungi surrounding the roots of plants also influence environmental elements, soil physiochemical properties, and biological activities of plants (Haldar and Sengupta, 2015).

Since they have been found in every plant species that has been studied, fungi are omnipresent (Stone *et al.*, 2000). Fungi are widespread in the biological world; estimates range from 2.2 million to 3.8 million species, of which only 120,000 have been described; of these, one-third is thought to be found in India (Hawksworth and Lucking, 2017). There is a broad range of interactions between the fungus and the host, from strong competition to coerced mutualism (Saikkonnen *et al.*, 1998; Clay and Schardl, 2002). While mutualistic partnerships can result in pathogenic or saprotrophic fungus, the host plants benefit from the creation of secondary metabolic products such alkaloids (Owen and Hundley, 2004). According to studies conducted by Malinowski *et al.* (2000), Redman *et al.* (2002), Arnold *et al.* (2003), Rubini *et al.*

(2005), and others, improvements have also been noted in growth and competitive ability, mineral absorption capacity, plant phenotypic characteristics, temperature and drought resistance, leaf chemistry, soil resistance to heavy metals, and tendency for vegetative reproduction and protection against harmful microorganisms by fungi. Fungal species that are linked to healthy plants are more likely to invade a wider range of host plant communities (Rudgers *et al.*, 2005; Aira *et al.*, 2010; Berendsen *et al.*, 2012; Bazghaleh *et al.*, 2015). These fungi can alter the nutrient cycle in both individual plants and ecosystems (Garcia and Langenheim, 1990; Lodge *et al.*, 1996). Fungal novel compounds have a vast potential for use in bioremediation, textiles, food, medicine, agriculture, natural cycles, and biofertilizers (Tan and Zou, 2001; Stroberl and Daisy, 2003, Kumar *et al.*, 2004. 2005; Monoharachary *et al.*, 2005).

Rhizospheric soil biodiversity

It has been discovered that one crucial factor in predicting the diversity, yield, and productivity of above-ground plants is the diversity of subterranean microorganisms, especially fungi. (Deyne *et al.*, 2004; Hooper *et al.*, 2005). Because of the host plant-fungus relationship, there is a substantial correlation between soil diversity and plant diversification (Chung *et al.*, 2007; Holland *et al.*, 2016). Soil fungus diversity is strongly influenced by the existence of a plant community (Yang *et al.*, 2017). Because the rhizosphere mycobiome safeguards plant production and yield, it is regarded as a bioindicator of soil quality. To boost crop productivity, growers alter the soil environment using a range of physical and chemical techniques. This strategy primary benefit is that it lessens the use of agricultural pesticides while simultaneously promoting sustainable management practices that increase productivity (Smith and Read, 1997; Bowen and Rovira, 1999). *In vitro* and greenhouse studies have been used to manipulate the microbial populations in the rhizospheric soil fungus by inoculating beneficial soil fungi. However, a fuller understanding of the biological interactions in the rhizosphere is needed. Therefore, in order to improve technology dependability in the field and enable the commercial cultivation of medicinal plants, it is imperative to understand the factors and biological interactions between plants and soil fungi (Nelson, 2004).

Microorganisms have a significant role in the sustainability and operation of ecosystems. According to Dighton and Krumins (2014), the variety of organisms that live in soil is enormous, and so is the range of roles that these creatures play. According to Lynch and Whipps (1990), rhizosphere is more than just the thin layer of soil that borders the root; it is made up of three primary zones. This definition of rhizosphere is the most widely accepted and refers to the soil that is nearest to and greatly influenced by plant roots (Nicolitch *et al.*, 2016; Pascual *et al.*, 2016). The endorhizosphere is the soil closest to the root, whereas the rhizoplane, which includes the root epidermis and related mucilage, is cortical with the rhizoplane. Each of the three the soil, the microorganisms, and the root influences theother's existence and functionality on a constant basis. The types of organisms that could live in the rhizosphere are determined by plant exudates, which serve as food for microorganisms. The longevity of both plants and microorganisms is also influenced by the soil. Furthermore, microbes control soil fertility, which affects plant growth. It is now understood that plants manipulate the organisms in their immediate soil environment (Chapparro *et al.*, 2014). It is well known that plants alter the microbial richness at the rhizosphere from their native origins. Plant species thus support distinct microbial populations. Different types of root exudates (Bais *et al.*, 2006; Rasmann and Turlings, 2016) and plant uptake rates of nutrients (Bell *et al.*, 2015) combine to produce the resulting microbiome. In turn, root exudates influence the crop's genetic diversity (Bouffaud *et al.*, 2012).

Components of rhizosphere soil

According to Bowen and Rovira (1999), soil is a biological matrix that modifies the diversity of helpful microorganisms involved in agriculture and food security. It takes hundreds of years to finish the laborious, continuous process of soil growth. The land's rocky parent materials underwent chemical and physical weathering first (e.g., erosion caused by wind, rain, freezing and thawing, glacial ice, etc.). Later on, primitive terrestrial plants and microorganisms became significant players in the deterioration of rocks. Environmental influences have a significant impact on the physio-chemical, biological, and interactions components with the rhizosphere root-soil system (Buscot, 2005; Barea *et al.,* 2005). Although they make up a relatively small portion of the soil, microorganisms like bacteria and fungi are essential to the cycling of nutrients like nitrogen, phosphorus, and sulfur as well as the health of ecosystems. In addition to fixing nitrogen in the environment, accumulating organic residue, stabilizing soil structure, and removing toxins are all made possible by microorganisms (Doran and Zeiss, 2000; Gomes *et al.*, 2003; Sainia *et al.*, 2004; Wakelin *et al.*, 2008; Yang *et al.*, 2016).

Fungal flora of rhizospheric soil

Understanding fungal diversity in relation to plants is essential for understanding the biodiversity of terrestrial ecosystems, which are comprised of six distinct vegetation zones, each with its own unique combination of abiotic elements and plant communities (Zachow *et al.,* 2009). Among the fungal species isolated from the Aloe vera rhizosphere region were *A. niger*, *Rhizopus nigricans, Mucor racemosus, Penicillium Terrestre, Fusarium solani*, *Epicocum nigrum*, *Cephalosporium* sp., and *Choanephora cucurbitarum* (Srivastava and Kumar, 2013). In the soil, fungi play a number of functions, one of which is the breakdown of decomposing plant matter (Bridge and Spooner, 2001). Although pathogen populations are declining, plant diseases are managed in agriculture using chemical or biological methods, both of which significantly affect the rhizospheric microbiota (Matei and Matei, 2010). Furthermore, plant species specialization and the nutritional state of the soil may contribute to changes in the fungal microbiota (Shekh *et al.*, 2012).

Colonization of microflora of the rhizospheric soils

Bacterial cells have the ability to adhere to surfaces during division and proliferation, forming dense clusters referred to as macro-colonies or biofilms. Phases include attraction, recognition, adhesion, invasion (limited to pathogens and endophytes), colonization, and growth are all part of colonization. By releasing signals that the bacteria recognize, plant roots communicate with soil microbes through cross-talk. The bacteria then reply by releasing signals that encourage colonization (Berg, 2009; Nihorimbere, 2011). Plants can alter their rhizosphere microbiome, and different plant species thrive in soils with varied microbial communities, according to recent research on plant-microbe interactions (Berendsen *et al.,* 2012). Successful root colonization and the capacity to endure, proliferate, and establish on plant roots over an extended period of time are prerequisites for biocontrol agents in the presence of the native microflora (Weller, 1988; Lugtenberg *et al.,* 1999; Nihorimbere *et al.*, 2011).

Isolated bacterial microflora from rhizosphere soil

The rhizosphere is frequently home to bacteria, which have a big effect on plants. *Pseudomonas*, *Bacillus,* Arthrobacter, *Rhizobium, Agrobacterium, Alcaligenes, Azotobacter, Mycobacterium, Flavobacterium*, *Cellulomonas*, and *Micrococcus* are among the most common genera of bacteria that are found in the rhizosphere. Gram-negative, rod-shaped, non-sporulating bacteria belonging to the actinobacteria and proteobacteria families predominate in the rhizosphere soil (Atlas and Bartha, 1993; Teixeira *et al.*, 2010). The population of aerobic bacteria is smaller than that of anaerobic bacteria in the rhizosphere because of reduced oxygen levels brought on by root respiration (Garbeva *et al.,* 2004). This explains why, accounting for up to 95% of all gram-positive soil *Bacilli, Bacillus* strains are the most prevalent gram-positive rhizosphere dwellers, followed by*Arthrobacter* and *Frankia* (Barriuso *et al.*, 2008). Gram-positive bacterial strains, particularly

Bacillus, have been found to have a larger population than gram-negative bacteria in a number of crops, including oilseed rape, potatoes, wheat, and strawberries (Smalla *et al.,* 2001; Joshi and Bhatt, 2011). As saprophytic soil dwellers, actinomycetes, or G+ bacteria, are the most widely distributed group of microorganisms in nature (Takizawa *et al.*, 1993). Most actinomycetes that are discovered in soil belong to the genus Streptomyces (Good fellow and Simpson, 1987; Suzuki *et al.,* 2000; Khamna *et al.,* 2010). Enzymes that degrade halo-tolerant materials, such as lipase and cellulase, can be found in mangrove-associated actinomycetes (Reyad, 2013). The majority of endophytic actinomycetes that were recovered from roots had antibacterial and plant growth-promoting properties (representing 70% of all isolates). Stems and leaves came in second and third, respectively, at 17.5% and 12.5%. In 2014, Gangwar and co-workers proposed that actinomycetes aid in the healthy growth of medicinal plants by shielding them from harmful fungus such as *Fusarium oxysporum* and *Colletotrichum capsici* (Ashokvardhan *et al.,* 2014).

Physico-chemical parameters of rhizosphere soil

Significant physico-chemical factors for the colonization of rhizosphere micro-flora and plant health include soil texture, pH, moisture, electrical conductivity (EC), water holding capacity (WHC), organic carbon (OC), inorganic phosphate, accessible nitrogen, potassium, and salt. The physico-chemical parameters of bulk soil, including pH, moisture, EC, WHC, organic matter, available phosphorus, inorganic phosphate, nitrate, and sodium, have been analyzed in bulk soil (Hinsinger, 2001; Wemedo and Onolleka, 2012; Suebrasri *et al.,* 2013; Bera and Ghosh, 2014). These factors increase the rhizosphere microbial population (Kennedy, 1998; Barea *et al.,* 2005). Moreover, the microbial population increased as a result of organic additions improving the physico-chemical characteristics of rhizospheric soil. Rhizospheric soil is more conducive to microorganisms than bulk soil (Das and Dkhar, 2011). These microbes break down organic matter, detoxify toxic substances, fix nitrogen, and alter the phosphate and potassium levels in soil (Bhattarai *et al.,* 2015). Nonetheless, plants vary greatly in these physico-chemical traits (Shekh *et al.,* 2012). Natural soil is often rich in nitrogen, phosphate, potassium, and organic matter after the wet season (Saravanakumar and Kaviyarasan, 2010; Shekh *et al.,* 2012).

The therapeutic qualities of medicinal plants

In many regions of the world, medicinal plants have been utilized as traditional remedies for a wide range of human ailments. In rural parts of developing nations, they serve as the primary supply of medication (Chitme *et al.,* 2004; Palombo, 2006). Over 80% of people in developing countries use traditional medicines to keep themselves healthy (Kim, 2005). Numerous physiologically active secondary metabolites present in these therapeutic plants have been used to create innovative lead molecules for pharmaceutical applications. Just 1% of the world's 5 million plant species have been researched for potential use in medicine (Palombo, 2006). The World Conservation Monitoring Center of the United Nations Environment Programs reports that because of the rapid loss of plants and animals, one important medication is lost globally every two years (Palombo, 2006).

According to several research (Cowan, 1999; Kalemba and Kunicka, 2003), diarrheal disorders can be treated with traditional plants and plant products that have antibacterial qualities. With a 3000-year history, traditional Chinese medicine is a prime example of a comprehensive approach to healthcare (Xutian *et al.,* 2009). The world's oldest herbal treatise is The Devine Farmer's Classic of Herbalism, which was authored in China some 2000 years ago. It has painstakingly gathered information on therapeutic plants. People have been looking for natural remedies to heal their illnesses since the beginning of time. Personal experience was used because there was a lack of information regarding the plants that may be used as a cure and the causes of the illness. Prior to the introduction of iatrochemistry in the 16th century, plants served as the foundation for both prophylaxis and therapy (Petrovska, 2012). Natural medications are growing in popularity inspite of the diminishing efficacy of synthetic pharmaceuticals and the increasing number of contraindications to their usage.

In India, people have been using medicinal herbs to heal illnesses at least since 1900 BC (Aggarwal *et al.,* 2007). The Ayurvedic method is based on the enormous medical information found in two ancient books called the Rig Veda and the Atharva Veda (Aggarwal *et al.,* 2007). Around the first millennium BC, early Indian herbalists like Charaka and Sushruta used a wide variety of different herbs and minerals in Ayurveda. A lot of people used herbal medicines in the fifteenth, sixteenth, and seventeenth centuries.

The range of phytochemical substances found in medicinal plants gives them their therapeutic properties. Contemporary medical researchers have been pursuing these plant-derived bioactive compounds. These compounds differ from plant to plant and even within the same plant organs due to their diversity. Bioactive compounds in plants are secondary metabolites that has pharmacological or toxicological effects on both humans and animals. According to Sharma *et al.* (2011), biologically active medicinal substances are used to treat a variety of illnesses. They include phenolic compounds (such as phenolic acids, flavonoids, tannins, coumarins, lignans, stilbenes), alkaloids, vitamins A, C, E, and K, nitrogen compounds (betalains, amines), terpenoids (including carotenoids), minerals, enzymes, saponins, endogenous metabolites, etc.

Effects of rhizospheric soil physico-chemical and biological components on the development of medicinal plants

Rhizobacteria are beneficial bacteria that live in plant roots and stimulate the growth of plants. Two hundred and nineteen bacterial strains were discovered from rhizosphere soil samples of different medicinal plants (Malleswari and Bagyanarayana, 2013). It was discovered that *Azospirillum*, *Azotobacter*, *Bacillus,* and *Pseudomonas* were helpful in enhancing *W. somnifera* and nutrient intake of ashwagandha (Gopal and Natrajan, 2009). By producing iron siderophores, particularly in neutral and alkaline soils, these bacterial strains promote medicinal plant growth in the rhizosphere and hence reduce the amount of iron available for pathogen growth (Alexander and Zuberer, 1991; Husen, 2003). Because *Pseudomonas* and *Bacillus* can cause systemic resistance (ISR), their hostile effects are well-documented. The agricultural system is improved by the application of biocontrol techniques (Beneduzi *et al.,* 2012). Certain strains of PGPR emit volatile organic compounds (VOCs) that accelerate the growth of Arabidopsis seedlings and provide resistance against *Erwinia carotovora* subsp. *carotovora* (Ryu *et al.,* 2005).

Auxins or gibberellins, which stimulate plant growth, are produced by Streptomyces in the rhizosphere soil (Kaunat, 1969; Merckx *et al.*, 1987; Khamna *et al.,* 2010). The study conducted by Kamara and Gangwar (2015) examined the antifungal activity of actinomycete isolates against various phytopathogenic fungi, including *Alternaria alternata*, *Fusarium oxysporum*, *Helminthosporium oryzae, Macrophomina phaseolina*, *Penicillium* sp., *Rhizoctonia solani*, and *Sclerotium rolfsii.*

The plant-growing fungus *Pythium oligandrum* participates in complex antagonistic interactions in the rhizosphere, where it exhibits direct plant-induced resistance and indirectly suppresses pathogens (Floch *et al.,* 2003). By solubilizing and making available the phosphorus in the soil, phosphate-solubilizing fungi (PSF) benefit plants. According to Malviya *et al.* (2011), *Penicillium notatum* and *Aspergillus niger* have the ability to solubilize tricalcium phosphate (TCP) and hasten the growth of ground nut (*Arachis hypogaea*) plants.

Rhizospheric soil physico-chemical characteristics and microbial diversity are altered by plants. Plant-to-plant variations exist in the rhizosphere microbiome, which is made up of *Mesorhizobium*, *Rhizobium* (pea), *Bradyrhizobium, Rhizobium* (lentil), *Pseudomonas, Bacillus, Enterobacter*, and *Klebsiella* (mustard). It has been found that certain Rhizobium species exhibit host specificity towards certain plant species (Ahmed and Khan, 2011). The two most important variables that affect the overall bacterial structure are the types of soil and the collection sites. *Bacillus* and *pseudomonas* (Garbeva *et al.,* 2008). The rhizosphere soils of *Bt* and non-*Bt* cotton fields, which were gathered from four separate locations in Mahabubnagar District, Andhra Pradesh, India, varied in terms of bacterial diversity as well (Pindi and Sultana, 2013). The majority of fungal genera and species were isolated in the winter and summer, respectively, due to seasonal variations in the physical characteristics and distribution of fungus (Guleri *et al.,* 2010). Rhizosphere soils have higher levels of K, Ca, Mg, and Na than bulk soil (particularly in the spring). The rhizosphere soils in the spring had significantly higher Ca, Mg, and Na concentrations than in the fall and winter (Calvaruso *et al.,* 2014).

The regulation of fungal pathogens by biology

Rhizosphere filamentous fungus of the genus *Trichoderma*, which are a dominant component of numerous soil ecosystem mycobiomes, have the ability to invade plant roots. Knowing everything there is to know about *Trichoderma*, including its metabolic activity and how it interacts with other microorganisms and plants, will help ensure that it is successfully applied in agriculture. There is growing interest in applying *Trichoderma* because of its direct and indirect biocontrol properties against a range of soil phytopathogens. Their many modes of action include inducing plant resistance, dissolving pathogen cell walls, competing with plants for resources and space, and mycoparasitism. The main challenge is creating alternatives to biological protection because plants are frequently exposed to a variety of illnesses, especially filamentous fungus, and these pathogens are becoming increasingly resistant to chemical pesticides. For utilization in green technologies, *Trichoderma* seems to be the best non-pathogenic microbe option due to its wide range of biofertilization and biostimulatory properties. Most *Trichoderma* species belong to a class of fungi that stimulates plant development and produces phytohormones and the enzyme 1-aminocyclopropane-1-carboxylaten (ACC) deaminase. This work reviews the current status of *Trichoderma*, which is crucial for bio-controlling fungal phytopathogens and promoting plant growth (Tyśkiewicz *et al*., 2022).

Utilizing microbiota to control pests

Growing interest has been shown in using microbiota to control pests as an environmentally friendly and sustainable farming practice. The goal is to encourage the growth of natural defensive mechanisms by taking advantage of the intricate relationships that exist between plants, pests, and the bacteria they are associated with. Beneficial microorganisms including bacteria, fungi, and viruses significantly improve plant health and pest resistance. These bacteria can act as biopesticides (Kloepper *et al.*, 2006; Qadri *et al.*, 2020; Zhang *et al.*, 2023) for a variety of pest management, including destructive moths (Mereghetti *et al.*, 2017), by directly opposing pathogenic pests or by creating systemic resistance in plants.

Due to their ability to produce insecticidal proteins, several strains of entomopathogenic bacteria, such *Bacillus thuringiensis* (*Bt*), have found broad usage in the selective targeting of harmful pests while sparing non-target organisms. Similarly, mycorrhizal fungi and plant roots form symbiotic relationships that enhance nutrient uptake and fortify plant defenses. These microbial-plant relationships result in a more robust and resilient agricultural ecosystem (Van Wees *et al.*, 2008).

Beneficial microorganisms and microbiota found in soil

The soil microbiota, a diverse and ever-changing community of microorganisms, influences several ecosystem services and is crucial for maintaining the soil fertility and health. This complex web of life, which is made up of bacteria, fungi, viruses, archaea, and other microorganisms, is what breaks down organic matter, cycles nutrients, and facilitates interactions between microbes and plants. Beneficial microorganisms such as mycorrhizal fungi and nitrogen-fixing bacteria work in symbiotic relationships with plants to enhance nutrient uptake and promote plant growth. A recent study has highlighted the importance of these beneficial relationships in ecologically friendly agriculture and conservation (Hartmann *et al.*, 2008).

Through mycorrhizal interactions, arbuscular mycorrhizal fungi (AMF) in particular are crucial for increasing nutrient exchange between plants and the soil. By enhancing plants resistance to various stresses and enhancing phosphorus uptake, they support the well-being and productivity of plants. Furthermore, by converting atmospheric nitrogen into a form that plants can utilize, nitrogen-fixing bacteria, including those found in the genera *Brady rhizobium* and *Rhizobium*, form symbiotic partnerships with leguminous plants, thereby contributing this essential nutrient to the soil (Van Der *et al.*, 2008).

In addition to its role in the cycling of nutrients, the soil microbiota plays a critical role in mitigating plant diseases through mechanisms like resource competition, antibiosis, and the induction of systemic resistance. As our knowledge of this beneficial microbiota grows, so does the use of soil microbiota for sustainable agricultural practices such biofertilization, soil bioremediation, and the creation of biopesticides (Philippot *et al.*, 2013).

Authors' contributions

Mansoor Ahmad Malik and Nusrat Ahmad contributed to the conception of the study. Mansoor Ahmad malik, M. Y. Bhat, A. H. Wani were involved in preparation and design of this review article. The literature survey was done by the author Mansoor Ahmad malik, I also wrote the first draft. All authors critically read and made their comments on the manuscript. All authors read, revised and approved the final draft of the manuscript.

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Mansoor Ahmad Malik*, Nusrat Ahmad, Mohd Yaqub Bhat, and Abdul Hamid Wani

Section of Mycology and Plant Pathology, Department of Botany, University of Kashmir, India

*Corresponding author

Contact Number: +91 9797381050,

E-mail id: malikmansoor011@gmail.com

https://orcid.org/0000-0001-5400-7601