Review Article

Mycorrhizal Associations in Orchids: A Review

Paras Chauhan, L.K. Attri*

Department of Biosciences, Chandigarh University, Gharuan, Punjab, INDIA.

Submission Date: 22-06-2024; Revision Date: 27-07-2024; Accepted Date: 18-08-2024.

Correspondence:
Prof. Dr L.K. Attri
Department of Biosciences, Chandigarh University, Gharuan, Punjab, INDIA.

Email: hod.biosciences@cumail.in, attril@rediffmail.com

ABSTRACT

Aim/Background: Orchids, known for their exquisite beauty of flowers and ecological diversities, invariably depend on mycorrhizal fungi partner to obtain the essential nutrients and growth factors at the time of their seed germination and further growth and development. This paper will explore the multifaceted roles including importance of mycorrhizal associations in orchids, mechanisms, specificity, and ecological implications. Therefore, the specificity in orchid mycorrhizal associations, including the high selectivity level of the fungus by different orchid species, signals co-evolutionary dynamics in orchids and their fungal partners. Besides, fungal partners are recorded to have indispensable roles including nutrient acquisition, water uptake and resistance to the stresses of the environment, improvement of orchid fitness etc. **Materials and Methods:** An extensive literature study was done to understand and explore the basis and mechanism of orchid mimicry using variety of genuine search engines including google, Wikipedia, online libraries, books and monographs available online and offline. **Results and Conclusion:** This review highlights intimate and intricate symbiosis of orchid plants with fungal partner. The mycorrhizal associations in orchids are not only shaped by the specificity of interactions (molecular recognition) between different fungal partners and among different orchid species but also by the co-evolutionary mosaic that has contributed to the current diversity and distribution of orchids around the globe. It also sheds light on the intricate plant-fungal encounters that support the biology and ecology of the charismatic orchids and opens tantalizing research opportunities to conserve these captivating plant-fungal unions in their natural habitats. Further investigation into the mechanisms underlying orchid mycorrhizal interactions is pivotal in the quest to reveal the beneficial significance of these symbiotic relations.

Keywords: Fungal partner, Orchids, Mycorrhizal Association, symbiosis, pelotons, *Rhizoctonia* spp.

INTRODUCTION

Mycorrhizal Associations

Mycorrhizal association is a mutualistic association involving one or more kinds of fungi and the roots of plants, including those of orchids.[1,2] Generally, most of the mechanisms are important for the growth and survival of many plant species growing on sites where conditions are not conducive for their life.[1] In a mycorrhizal interaction, the fungal partner colonizes the root system of the plant and forms specialized structures, called mycorrhizae, whose function is mainly to facilitate the exchange of nutrients between the fungus and the plant.[2] It is recorded that the orchid propagation from seed is difficult due to their micro size of seeds (0.1-6 mm), therefore dependence on fungi as mycorrhizal associations for germination and nutritional requirements.[3] Further, the orchid embryo has no endosperm and it gets nourishment from the endophytic fungi requirements.[3,4] Therefore, the mycorrhizal association as Orchid Mycorrhiza (OM) is imperative and therefore exists.[4] The importance of fungi lies in the supply varied nutrients including nitrogen, phosphorous, and carbon, very essential at the time of the establishment of the developing orchid seedlings and hence able to grow in harsher habitats.[4,5] Orchids depict a wide diversity of mycorrhizal associations,

SCAN QR CODE TO VIEW ONLINE

www.ajbls.com

DOI: 10.5530/ajbls.2024.13.36

with different orchids forming a certain symbiotic association with a certain type of fungi. Relationships may be highly specialized to only a few partners, for instance, certain orchid species when their seeds may have a narrow range of fungal associates required for germination and growth.[6] Specialized interactions have a great contribution to forming the unique ecological niches occupied by orchids and their adaptation to diverse habitats.[7] In mycorrhizal associations, the orchid absorption capacity in relation to water and nutrients from the soil is bigger and thus promotes its overall fitness and competitiveness in natural ecosystems.[8] Additionally, mycorrhizal fungi can protect orchids from pathogens and other damaging factors therefore, promote their survival and success [9]. It is recorded that numerous orchid species face endangered due to habitat loss, climate change, and many other anthropogenic activities. Therefore, the fungi that make a mutualistic relationship with orchids has a contribution to securing orchid populations and their surrounding ecosystems. [10] Plant-linked microbiota also confer survival rewards to the plant host, including growth promotion, nutrient uptake, stress tolerance and resistance to pathogens.[10] In general, mycorrhizal associations in orchids are of basic importance to biology and ecology, since they do affect nutrient acquisition, growth, and survival. therefore, it is critically important to know the mycorrhizal associations in orchids as this is important for the conservation and restoration of orchids. Further study of the biological aspects of such symbiotic relationships is thus an important way towards the unveiling of more about the biology and new strategies for conservation and restoration of orchids.

MATERIALS AND METHODS

For the present studies related to "Mycorrhizal Associations in Orchids: A Review", genuine search engines including PubMed, Google, Research gate, Wikipedia, Google scholar, Science direct database, shodganga, online libraries, books and other authentic data available online and offline are considered across countries

RESULTS

Orchid Mycorrhiza

Orchid Mycorrhiza (OM) is a highly important symbiotic relation of plant and fungal partner because it is needed for the successful germination, growth, and development of orchids.[11] Unlike in most plants, orchid seeds lack endosperm.[11,12] the food-rich tissue to aid in the normal growth of seedlings in conventional plants.[12] Orchid seeds, in turn, do not germinate or grow without their establishment by mycorrhizal fungi. In orchid mycorrhizal symbiosis, the fungal partner colonizes an orchid seed and forms within the seed tissue, a specialized structure named a peloton.[13,14] The peloton acts as the exchange point of nutrients via the fungus, which in turn supplies to the young orchid seedling essentials such as carbon and nitrogen. In exchange, once mature, the orchid supplies the fungus with carbohydrates produced during photosynthesis.[15] Orchid mycorrhizal association is often specific, with different species associated specifically with certain groups of mycorrhizal fungi. These fungi associations sometimes supply essential nutrients for the seed germination because they provide nutrients and growth factors do not present in the seed.[5] Secondly, the fungal partner associated with the orchid's roots has the ability to uptake water and nutrients from the soil even in nutrient poor habitats.[13] The importance of orchid mycorrhiza does not end with the germination of the seeds, since the mycorrhizal associations might happen at different periods during the life history of an orchid.[14] Mycorrhizal fungi help in nutrient acquisition, disease resistance, and environmental adaptations of the orchids that contribute to fitness and survival in different ecosystems.[14,15] Besides, the knowledge of the orchid mycorrhizal association is indispensable to orchid conservation, as its disturbances can be adverse on the orchid populations and habitats involved in them. The involved relationship is one of the plants, the fungus, and the mycorrhizal partner, and a balance with the preservation of all three is important in maintaining this unique and ecologically important balance.

Symbiotic Relationship

Symbiotic relationships between orchids and fungal partners, referred to as orchid mycorrhiza, play fundamental roles in the survival, growth and ecological success of orchids from a wide range of habitats.[16] Orchids are renowned for their diversity and widespread habitat dominance and even nutrient-poor soils, where access to essential nutrients limits growth and reproductive processes.[17] In order to overcome these important constraints, orchids have evolved nutritional symbiosis with fungi that are essential for mediating nutrient acquisition processes and facilitating ecological adaptation.[17,18] The fungal partner colonizes the roots of orchid plants in web intimate connections that facilitate the flow of nutrients between the partners.[18] Orchids supply their partner with carbohydrates synthesized through photosynthesis, acting as the fungi's carbon

source.[19] It is observed that the mycorrhizal fungi take up nutrients like nitrogen, phosphorus, potassium, and micronutrients, from the soil and transport them to orchid roots. The specificity of these symbiotic relationships is a hallmark of orchid mycorrhiza.[18-20] Different orchid species are in symbiotic association with varied groups of fungi, forming partnerships so specialized that they can be exquisitely adjusted to each species particular ecological requirements. The specificity of the orchid-fungus partnership reflects the orchids specificity for specific nutrients, provided in the right qualities and at the right time during its life cycle," Dearnaley writes for The Plant Press.[20] This specificity ensures that orchids receive the appropriate nutrients tailored to their physiological needs, enabling growth, development and reproductive success in diverse habitats.[21] The associations in orchid mycorrhiza go beyond nutrients as they cover ecological interactions and adaptations. Mycorrhizal fungi can help in a variety of ecological functions such as protection against pathogens, tolerance of drought, and colonization of new habitats. Noteworthy, the mycorrhizal fungal association affects the diversity, distribution and abundance of orchid species in natural systems.[20,21]

The ecological significance and evolutionary implications of these associations is the possibility to unravel the dynamics of symbiotic interactions between fungal partners and orchids. This information provides important information about the factors contributing to the large number of orchid species in the tropics and adaptation to diverse habitats, by allowing us to understand the symbiotic relationships that have been a requisite step in the evolutionary history to this diversity.[20,22] In addition, an understanding of the symbiotic relationships that exist in orchid mycorrhiza may further bring to light the possibilities for conservation and restoration of these plants, as well as their fungal associates, in times when these communities are under environmental stress.[13]

Fungal Partnership

Fungal partnerships are keys to the mycotrophic nature of orchid mycorrhizas, which, in turn, underpin nutrient acquisition strategies and ecological adaptations of orchids to diverse habitats.[23] These symbiotic associations involve intricate interactions between orchid plants and unique assemblages of mycorrhizal fungi, with both parties playing essential roles in resource exchange and nutrient uptake. It is the specificity of fungal partnerships that is most characteristic of orchid mycorrhizas.[23,24] Different orchid species exhibit strong preferences for particular lineages of fungal taxa. They form highly specialized associations that are finely tuned to their ecological requirements.[24] As, orchids depends on these fungi for access to nutrients like carbon, nitrogen, and phosphorus and growth factors especially during germination and early establishment when orchid seeds are effectively devoid of endosperm.[26] While the orchids benefit from nitrogen uptake from their mycorrhizal fungi, the fungi receive carbohydrates synthesized by the orchids through photosynthesis. These relations of reciprocal resource transfer between the two mutualistic partners also sustain both the beneficiary. Plant-fungal interactions are primarily localized, where orchid roots release chemical attractants, such as sugars and organic acids, that stimulate fungal hyphae proliferation towards the roots and physical contact.[25,26] Mycorrhizal fungi on meeting orchid roots, form highly specialized structures, such as pelotons or coils, within root cells, which serve as sites of nutrient exchange, facilitating the bidirectional flow of carbon compounds from the orchid to the fungus and essential nutrients, including nitrogen, phosphorus, and micronutrients, from the fungus to the orchid.[27,28] Finally, plant-fungal interactions in orchid mycorrhizae are characterized by a sophisticated web of signaling pathways and molecular dialogues between partners. Chemical signals released by orchids and mycorrhizal fungi control the development of mycorrhizal structures within the roots of orchids and they regulate the transport of nutrients in fungal hyphae, thereby ensuring effective exchange of resources and their prolonged association.[29,30]

Rhizosphere

The numerical account of fungi occupies in orchid roots are reported to belongs to at least 150 families contained in 28 orders of Basidiomycota and Ascomycota. These fungi were determined to diverse ecological station belongs to typical orchid fungal partner ('rhizoctonia'), ectomycorrhizal, wood- or litter-decaying saprotrophic fungi, and other endophytes/pathogens/saprotrophs and among the four different mycorrhizal types. Microbiologists have long been intrigued by the complexities of orchid mycorrhizal associations, in the rhizosphere, the vital microenvironment that flanks plant roots.[33,34] Typically, orchid exquisite flowers boasting remarkable ecological diversity reside in ecosystems defined by extremely nutrient-poor soils, where the ability to efficiently access nutrients is critical to survival and success.[31,32] Mycorrhizal fungi emerge as key allies in this context, establishing symbiotic relationships with orchids that markedly enhance nutrient uptake and overall plant fitness.[33] In the rhizosphere, a suite of compounds that includes organic acids, sugars and

amino acids actively released by orchid roots attracts mycorrhizal fungi to their host[35] and specialized fungal hyphae navigate toward orchid roots and form intimate associations that enable bidirectional nutrient exchange.[34] The fungal partner have an impressive capacity for nutrient acquisition including the ability to solubilize organic and inorganic forms of nutrients, as well as transport nutrients over large distances through their hyphal networks. This nutrient scavenging ability is a real boon for orchids which are often found in nutrient poor environments.[35] By bartering these scavenged nutrients, the orchids can draw down a constant supply of vital resources,[31] very essential as orchids normally be otherwise in hostile habitats, allowing the orchids to easily outcompete neighboring plant species.[36] Similarly, the rhizosphere is also a hub for the complex signaling pathways and crosstalk between orchids and mycorrhizal fungi. The chemical release that takes place between provides the cues for distinct physiological engagements that engender mutualistic alliances, such as the establishment of mycorrhizal structures within orchid roots and the trigger of nutrient transport processes in fungal hyphae.[30] The hitchhiker's guide such intimate mycorrhizal alliances, furthermore, are also bound by the element of specificity that further complicates them. That is, different orchid species have affinities for different assemblages of mycorrhizal fungi, producing highly specialized partnerships the proliferation of which contribute to the broad ecological niche differentiation and diversity of orchids in varied habitats. And thus underscores the co-evolutionary dance of the inner realm that has led to the global prevalence of orchid species.[33] Beyond their ecological significance, orchid mycorrhizal associations have profound implications for orchid conservation and restoration efforts. By gaining a in depth knowledge of the complexities of these symbiotic relationships, and the ecological and genetic factors that influence their stability and functioning, conservation biologists can develop highly targeted strategies for conserving both orchids and their associated fungal communities, helping to safeguard the delicate dance of plant-fungal interactions in natural ecosystems.[36]

Plant Fungal Interactions

Plant-fungal interactions in orchid mycorrhizae are critical for nutrient exchange, plant growth, and ecological adaptation of orchids. The rhizosphere is a primary location of plant-fungal interactions in orchid mycorrhizae. Chemical signaling from orchid roots to attract fungal hyphae to the roots (e.g., sugars, organic acids are released from orchid roots) and facilitate hyphal contact by reducing physical distance between the fungal hyphae and orchid roots species is best known.[38] In the rhizosphere, physical contact promotes the colonization within roots by mycorrhizal fungi by formation of specialized structures (e.g., pelotons, coils) within the root cells and thus, intimate association with host orchid.[39] These structures serve as the sites for nutrient exchange, which facilitate the movement of resources between the orchid and the fungus.[40] Orchids are dependent on mycorrhizal fungi for the essential nutrients including nitrogen, phosphorus and micronutrients especially in the early stages of seed germination and seedling establishment.[41] The fungi, in turn, are supplied with the carbon compounds that the orchids produce through photosynthesis. This affords the partners a balanced, reciprocal symbiotic association. Moreover, the plant-fungal interactions that underpin orchid mycorrhizae involve complex signaling pathways and molecular crosstalk.[42] Chemical signals that are traded between orchids and mycorrhizal fungi guide the construction of mycorrhizal structures within orchid roots and regulate the nutrient transport processes that unfold their fungal hyphae, thereby guaranteeing efficient nutrient exchange and the perpetuation of the mutualistic partnership [42]. Plant-fungal interactions in orchid mycorrhizae exhibit high inner specificity that is essential in orchestrating symbiotic relationships. Different orchid species demonstrate preferences for narrow taxonomic groups of mycorrhizal fungi, leading to associations that evolved under fine ecological tuning to their ecological requirements and to the diversity and adaptation of orchids to a large variety of habitats, which underlie their wide distribution and the diversity of ecological niches they occupy.[43] The understanding of plant-fungal interactions in orchid mycorrhizae is essential to reveal the ecological significance and evolutionary consequences of these symbiotic relationships, ultimately providing critical information to understand the processes underlying the diversification and adaptation of orchids in natural ecosystems.[44]

Furthermore, understanding these interactions can inform conservation and restoration efforts aimed at preserving orchid populations and their associated fungal communities in the face of environmental challenges.

Nutrient Uptake

Orchid mycorrhizae represent an intriguing evolutionary development that involves the intricate relation between orchids and their fungal partners that enables them to acquire essential nutrients from their surroundings, particularly in nutrient-poor soils[45] (Table 1). Orchids are widely known for their astounding diversity of

often highly specialized ecological niches. One shared attribute among even the yet-unknown orchids awaiting discovery is their masterful ability to create and inhabit environments of limited nutrient availability.[46] To overcome this universal environmental condition, orchids have evolved mycorrhizal associations with fungi. Mycorrhizal fungi, with their vast hyphal networks extending throughout the soil, can exploit nutrients in soil that are unavailable to plant roots. Nutrient uptake within orchid mycorrhizae is dominated by the fungal hyphae. Mycorrhizal fungi scavenge for nutrients, such as nitrogen, phosphorus, potassium, and micronutrients, within the soil matrix and carry them, via their hyphal networks, to the orchid roots.[47] This nutrient transfer is facilitated by specialized structures (e.g., pelotons or coils) formed within the orchid root cells, which allows the fungal hyphae to directly interface with plant cells. Nutrient uptake by the orchid mycorrhiza is so efficient that orchids can thrive in nutrient-poor soils where other plant species may struggle. Mycorrhizal associations vastly increase the surface area that is available for nutrient absorption, thus enabling the orchid to acquire essential resources. But this is not the only way mycorrhizal fungi help. They also have mechanisms for solubilizing organic and inorganic forms of nutrients. This increases the nutrient pool available to the orchid even further.[47] The specificity of orchid mycorrhizal associations is critical for nutrient uptake. Different orchid species have preferences for certain groups of mycorrhizal fungi. These highly specialized partnerships are finely tuned to the orchid's ecological requirements. This specificity allows orchid to obtain the right nutrient tailored to their physiological need, which contributes to their growth, development and ecological success in a wide range of habitats.[48]

Table 1: Nutrient Uptake in Orchid Mycorrhiza: Comparative Analysis of Direct Root Absorption and Fungal Facilitation.

Nutrient	Direct Uptake by Orchid Roots	Facilitated by Mycorrhizal Fungi	Source
Nitrogen (N)	Yes	Yes	46
Phosphorus (P)	Yes	Yes	46
Potassium (K)	Yes	Yes	40
Calcium (Ca)	Yes	Yes	49
Magnesium (Mg)	Yes	Yes	59
Sulfur (S)	Yes	Yes	49
Iron (Fe)	No	Yes	59
Zinc (Zn)	No	Yes	50
Manganese (Mn)	No	Yes	59
Boron (B)	No	Yes	46
Copper (Cu)	No	Yes	50

Broader significance the findings from this work furthers our ability to elucidate the ecological significance and evolutionary implications of the mutual relationships between orchids and their fungal partner by providing a means by which to understand the dynamics of nutrient exchange between the partners, the mechanisms generating and maintaining diversity in how these orchids are adapted to diverse habitat conditions, including some of the most nutrient challenged environments known, and the means by which we can leverage this knowledge to guide orchid conservation and restoration efforts aimed at maintaining orchid populations and their fungal communities in the face of the powerful anthropogenic forces now driving orchids toward global endangerment and extinction.

Mycorrhizal Diversity

Mycorrhizal diversity in orchid mycorrhiza refers to the wide range of mycorrhizal fungi species that form symbiotic relationships with orchid plants, contributing to the ecological success and adaptability of orchids in various habitats. Orchids, with their remarkable diversity and ecological versatility, exhibit a broad spectrum of mycorrhizal associations with different groups of mycorrhizal fungi.[49] These associations vary in specificity, with different orchid species forming partnerships with fungal taxa are finely tuned to their ecological requirements. The diversity of mycorrhizal fungi associated with orchids reflects their complex interactions with fungal partners. These interactions are shaped by a number of factors including soil conditions, environmental gradients, and the ecological niches of orchid species. Orchid mycorrhizal partners include diverse fungal taxa such as *Rhizoctonia,* Tulasnellaceae, Ceratobasidiaceae, Sebacinales, and others.[55,51] Each orchid species may have preferences for specific groups of mycorrhizal fungi, which result in highly specialized associations. These associations contribute to orchid adaptation and ecological success in different habitats and can play crucial roles in nutrient acquisition and the growth and reproductive success of orchids, particularly in nutrient-poor soils where orchids often occur.[52] Moreover, mycorrhizal diversity in orchid mycorrhiza has important implications for orchid conservation and restoration efforts. Preserving the diversity of mycorrhizal fungi associated with orchids is essential for maintaining the ecological integrity and resilience of orchid populations in the face of environmental changes and habitat disturbances.

Orchid Conservation

Orchid conservation is an important endeavor expected to save the notable diversity and ecological importance

of orchid species around the world. Orchids confront countless dangers, including habitat destruction, overharvesting, climate change and the escalation of the illegal trade in the highlights of an impressive series of review papers. These pressures have resulted in the decline of populations of many species of orchids and the elimination of genomes of value.[53] In order to work, orchid conservation must be multifaceted, employing a mix of scientific research and technical advances, habitat restoration, community involvement and policy advocacy. Habitats require conservation, specific sites need to be identified, conservancies must be created, and regulations on collection and trading must be enforced.[54] Seed banking, tissue culture, and captive breeding are other important ex situ conservation measures that help to safeguard orchid species at risk of extinction. Conservation of orchid species and their associated ecosystems requires global collaborations among scientists, conservationists, governments, and local communities. Only through proactive conservation efforts that are informed by scientific research and consultation with stakeholders can the current threats to orchids be reduced and the conservation of global biodiversity enhanced.[54]

Orchid species and their habitats, efforts to conserve orchids should also include raising awareness and promoting education about the value of these plants and their habitats. Public outreach programs, school curricula, ecotourism opportunities, and information sharing can help build an appreciation among local communities and the public.[55] Conservation planning and a conservation decision-making process that engage all stakeholders including landowners, indigenous and local communities, and relevant government agencies are also necessary to ensure the sustainability and effectiveness of orchid conservation initiatives.[56] Other important steps include the establishment of monitoring and research programs that would provide information on the status of orchid populations, emerging threats and the effectiveness of conservation action over time.[57] Orchids also need to be developed as key indicators of the health of ecosystems and the natural systems that underpin biodiversity around the planet, highlighting their potential value as iconic symbols of the natural world and not just scarce commodities. Securing their future will take science to develop practical ways of conserving species that can be used by conservationists and land managers;[58] and site support ensuring at-risk species and habitats are owned and managed by people with the incentive and skills to protect them; and policy support ensuring proper governance of the environmental impacts of land use and development, and the protection of vulnerable species like orchids.[57,58] There is neither time nor money to take individual orchids in their delicate, critically endangered habitats and grow them up to be photographed, name-checked in papers and then die. The knowledge and power centers of the world must now come together and tackle this thing.

Ecological Significance

In recent years, the study of the ecological significance (Table 2) of orchid mycorrhiza has led to a burgeoning appreciation of the complex roles that these symbiotic associations play in the generation of ecosystems.[59] Several review papers have been written indicating how the interactions between orchids and mycorrhizal fungi are critical for the maintenance of biodiversity and ecosystem function. Orchid mycorrhiza plays a significant ecological role within ecosystems by mediating nutrient flows and redistributions. Since orchids, especially those adapted to nutrient-poor soils, are dependent on mycorrhizal fungi to obtain essential nutrients, such as nitrogen, phosphorus and micronutrients, these symbiotic relationships enhance nutrient cycling by more effectively utilizing limited resources and redistributing nutrients within ecosystems. Thus, this nutrient cycling not only benefits orchids but influences the availability of nutrients to other plant species and ultimately, the composition and diversity of plant communities.[60] Orchid mycorrhizal associations function in a variety of ways that contribute to ecosystem functioning. In the context of soil health and microbial diversity, orchid research shows that they rely upon these and other poorly understood mycorrhizal processes. Mycorrhizal fungi play pivotal roles in soil aggregation, organic matter decomposition and nutrient mineralization, thereby increasing soil structural and fertility; by increasing microbial diversity and activity in the rhizosphere, orchid mycorrhizal associations contribute to soil biodiversity and ecosystem resilience, which in turn supports the productivity and stability of ecosystems. These consequences permeate ecosystems as they flow into changes in species diversity, abundance, and ecosystem functioning. Not only that, but also orchid mycorrhizal associations play the critical roles in ecosystem resilience and adaptation to environmental change. Orchids, together with their mycorrhizal partner, show extraordinary abilities to grow in a wide variety of environments, many challenging including disturbed habitats, very nutrient-poor soils and highly variable climatic conditions. Mycorrhizal associations may confer numerous advantages to orchids such improved drought tolerance, disease resistance, and

seedling establishment, thus enhancing their capacity to persist and adapt in changing ecosystems.[40,60]

In short, "they're not all the same" Orchid mycorrhizal fungi have ecological importance extending beyond the individual species level, to broader ecosystem processes and dynamics. They have the potential to affect nutrient cycling, soil health, plant community dynamics and ecosystem resilience, shaping the functioning and stability of ecosystems across the globe.[61]

Mycorrhizal fungi are reported as sources of both positive and negative neighbor effects mediated by orchids, in some cases acting as mycorrhizal bridges facilitating establishment and growth, and in other cases transmitting inhibitory signals.[62]

Table 2: Ecological Significance of Orchid Mycorrhiza.

Ecological Role	References
Nutrient Acquisition	
Orchids rely heavily on mycorrhizal fungi to obtain nutrients, especially nitrogen and phosphorus, from the soil. Mycorrhizal associations enhance nutrient uptake efficiency, particularly in nutrient-poor environments.	45
Mycorrhizal fungi facilitate the absorption of mineral nutrients from the soil, aiding in the growth and development of orchids.	39
Orchids may exhibit high specificity in their mycorrhizal associations, forming symbiotic relationships with particular fungal species.	1
Habitat Adaptation	
Mycorrhizal associations contribute to orchids' ability to colonize diverse habitats, including forests, grasslands, and even disturbed or degraded ecosystems.	39
Orchid mycorrhizal fungi can help orchids adapt to environmental stressors such as drought, salinity, and heavy metal contamination.	61
Mycorrhizal networks may provide orchids with increased resilience to changing environmental conditions, including climate change.	39
Conservation	
Understanding the role of mycorrhizal fungi in orchid ecology is crucial for conservation efforts, as many orchid species are endangered or threatened due to habitat loss and other human activities.	61
Conservation strategies for orchids often involve preserving their associated mycorrhizal fungi and restoring suitable habitats to support their growth and reproduction.	61
Conservation strategies for orchids often involve preserving their associated mycorrhizal fungi and restoring suitable habitats to support their growth and reproduction.	62

Understanding and conserving these delicate plant-fungal interactions is crucial to maintaining biodiversity and ecosystem function in the face of human disturbance and environmental change.

SUMMARY AND CONCLUSION

The review of mycorrhizal associations in orchids highlights the pivotal role of these underground partnerships in ecological and evolutionary strategies of orchid species. Their intimate and intricate symbioses with mycorrhizal fungi are exemplified in their soil nutrient acquisition growth and adaptation to a variety of habitats. Their mycorrhizal associations are not only shaped by the specificity of interactions (molecular recognition) between different mycorrhizal fungal partners and among different orchid species that show a high degree of fungal selectivity but also by the co-evolutionary mosaic that has contributed to the current diversity and distribution of orchids around the globe. More generally, mycorrhizal associations contribute to the stability and preservation of orchid populations, especially when faced with deforestation, climate change, and other human perturbations. Moving forward, further investigation into the mechanisms underlying orchid mycorrhizal interactions is pivotal in the quest to reveal the ecological and evolutionary implications of these symbiosis unions. By opening the black box of the subterranean dialogues between orchids and their mycorrhizal fungi, the present review sheds light on the intricate plant-fungal encounters that underpin the biology and ecology of the charismatic orchids and opens tantalizing research opportunities to conserve these captivating plant-fungal unions in their natural habitats.

ACKNOWLEGEMENT

We are thankful to the Department of Biosciences, Chandigarh University to provide necessary access to complete this paper.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Smith SE, Read DJ. Mycorrhizal symbiosis. Academic Press; 2010.
2. Bucking H, Liepold E, Ambilwade P. The Role of the Mycorrhizal Symbiosis in Nutrient Uptake of Plants and the Regulatory Mechanisms Underlying These Transport Processes. InTech; 2012. Available from: https://doi.org/10.5772/52570
3. Jolman D, Batalla MI, Hungerford A, Norwood P, Tait N, Wallace LE. The challenges of growing orchids from seeds for conservation: An assessment

of asymbiotic techniques. Appl Plant Sci. 2022;10(5). Available from: https://doi.org/10.1002/aps3.11496
4. Sathiyadash K, Karthikeyan V, Rajendran K, Thangavelu M, Sathiyadash K, Muthukumar T, *et al*. Orchid Mycorrhizal Fungi: Structure, Function, and Diversity. 2020. Available from: https://doi.org/10.1007/978-981-32-9456-1_13
5. Naranjo-Ortiz MA, Gabaldón T. Fungal evolution: Major ecological adaptations and evolutionary transitions. Biol Rev Camb Philos Soc. 2019;94(4):1443-76. Available from: https://doi.org/10.1111/brv.12510
6. Reiter N, Lawrie AC, Linde CC. Matching symbiotic associations of an endangered orchid to habitat to improve conservation outcomes. Ann Bot. 2018;122(6):947-59. Available from: https://doi.org/10.1093/aob/mcy094
7. Martín-Forés I, Bywaters SL, Sparrow B, Guerin GR. Simultaneous effect of habitat remnancy, exotic species, and anthropogenic disturbance on orchid diversity in South Australia. Conserv Sci Pract. 2022;4(4). Available from: https://doi.org/10.1111/csp2.12652
8. Delavaux CS, Weigelt P, Dawson W, Duchicela J, Essl F, van Kleunen M, *et al*. Mycorrhizal fungi influence global plant biogeography. Nat Ecol Evol. 2019;3:424-29. Available from: https://doi.org/10.1038/s41559-019-0823-4
9. Chen YH, Gao Y, Song LL, Zhao ZY, Guo SX, Xing XK. Mycorrhizal fungal community composition in seven orchid species inhabiting Song Mountain, Beijing, China. Sci China Life Sci. 2019;62:838-47. Available from: https://doi.org/10.1007/s11427-018-9471-x
10. Trivedi P, Leach JE, Tringe SG, Sa T, Singh BK. Plant-microbiome interactions: From community assembly to plant health. Nat Rev Microbiol. 2020;18:607-21. Available from: https://doi.org/10.1038/s41579-020-0412-1
11. Dearnaley J, Perotto S, Selosse MA. Structure and development of orchid mycorrhizas. In: Martin F, editor. Molecular mycorrhizal symbiosis. John Wiley and Sons; 2016. p. 63-86.
12. Chen XG, Wu YH, Li NQ, Gao JY. What role does the seed coat play during symbiotic seed germination in orchids: an experimental approach with *Dendrobium officinale*. BMC Plant Biol. 2022;22(1):375. Available from: https://doi.org/10.1186/s12870-022-03760-0
13. Li T, Yang W, Wu S, Selosse MA, Gao J. Progress and Prospects of Mycorrhizal Fungal Diversity in Orchids. Front Plant Sci. 2021;12:646325. Available from: https://doi.org/10.3389/fpls.2021.646325
14. Yeh CM, Chung K, Liang CK, Tsai WC. New Insights into the Symbiotic Relationship between Orchids and Fungi. Appl Sci. 2019;9(3):585.: Available from: https://doi.org/10.3390/app9030585
15. Cameron D, Leake J, Read D. Mutualistic mycorrhiza in orchids: Evidence from plant-fungus carbon and nitrogen transfers in the green-leaved terrestrial orchid Goodyera repens. New Phytol. 2006;171:405-16. Available from: https://doi.org/10.1111/j.1469-8137.2006.01767.x
16. Sathiyadash K, Karthikeyan V, Rajendran K, Thangavelu M, Sathiyadash K, Muthukumar T, *et al*. Orchid Mycorrhizal Fungi: Structure, Function, and Diversity. 2020. Available from: https://doi.org/10.1007/978-981-32-9456-1_13
17. Swarts ND, Dixon KW. Terrestrial orchid conservation in the age of extinction. Ann Bot. 2009;104(3):543-56. Available from: https://doi.org/10.1093/aob/mcp025
18. Dearnaley J, Martos F, Selosse M. Orchid mycorrhizas: Molecular ecology, physiology, evolution and conservation aspects. In: Hock B, editor. Fungal Associations. Berlin, Heidelberg: Springer; 2012. p. 207-30.
19. Selosse MA, Petrolli R, Mujica MI, Laurent L, Perez-Lamarque B, Figura T, *et al*. The Waiting Room Hypothesis revisited by orchids: Were orchid mycorrhizal fungi recruited among root endophytes? Ann Bot. 2022;129(3):259-70. Available from: https://doi.org/10.1093/aob/mcab134
20. Dearnaley J, Martos F, Selosse M. Orchid mycorrhizas: Molecular ecology, physiology, evolution and conservation aspects. In: Hock B, editor. Fungal Associations. Berlin, Heidelberg: Springer; 2012. p. 207-30.
21. Smith S, Read D. Mycorrhizal Symbiosis. 2008. Available from: https://doi.org/10.1016/B978-0-12-370526-6.X5001-6
22. Rasmussen H, Rasmussen F. Trophic relationships in orchid mycorrhiza-diversity and implications for conservation. Lankesteriana. 2015;7. Available from: https://doi.org/10.15517/lank.v7i1-2.19560
23. De Rose S, Kuga Y, Sillo F, Fochi V, Sakamoto N, Calevo J, *et al*. Plant and fungal gene expression coupled with stable isotope labeling provide novel information on sulfur uptake and metabolism in orchid mycorrhizal protocorms. Plant J. 2023;116(2):416-31. Available from: https://doi.org/10.1111/tpj.16381
24. Zahn FE, Söll E, Chapin TK, Wang D, Gomes SIF, Hynson NA, *et al*. Novel insights into orchid mycorrhiza functioning from stable isotope signatures of fungal pelotons. New Phytol. 2023;239(4):1449-63. Available from: https://doi.org/10.1111/nph.18991
25. Xu Z, Zhu X, Yin H, Li B, Chen X, Fan X, *et al*. Symbiosis between *Dendrobium catenatum* protocorms and *Serendipita indica* involves the plant hypoxia response pathway. Plant Physiol. 2023;192(3):2554-68. Available from: https://doi.org/10.1093/plphys/kiad198
26. Leroy C. Fungi in ant-plant interactions: A key to enhancing plant nutrient-acquisition strategies. New Phytol. 2023;238(5):1752-4. Available from: https://doi.org/10.1111/nph.18830
27. Wang D, Lerou J, Nuytinck J, Gomes SIF, Jacquemyn H, Merckx V. Root-associated fungi in Orchidaceae: Diversity, phylogeny, ecology, and outstanding questions. bioRxiv. 2022. Available from: https://doi.org/10.1101/2022.12.16.519622
28. Petrolli R, Zinger L, Perez-Lamarque B, Collobert G, Griveau C, Pailler T, *et al*. Spatial turnover of fungi and partner choice shape mycorrhizal networks in epiphytic orchids. J Ecol. 2022;110(11):2568-84. Available from: https://doi.org/10.1111/1365-2745.13986
29. De Rose S, Perotto S, Balestrini R, Sillo F. Gene Expression Profiling in Orchid Mycorrhizae to Decipher the Molecular Mechanisms of Plant-Fungus Interactions. In: Advances in Orchid Biology, Biotechnology and Omics. 2023. p. 145-62. Available from: https://doi.org/10.1007/978-981-99-1079-3_4
30. Zahn FE, Söll E, Chapin TK, Wang D, Gomes SIF, Hynson NA, *et al*. Novel insights into orchid mycorrhiza functioning from stable isotope signatures of fungal pelotons. New Phytol. 2023;239(4):1449-63. Available from: https://doi.org/10.1111/nph.18991
31. Mennicken S, Vogt-Schilb H, Těšitelová T, Kotilínek M, Alomía YA, Schatz B, *et al*. Orchid-mycorrhizal fungi interactions reveal a duality in their network structure in two European regions differing in climate. Mol Ecol. 2023;32(12):3308-21. Available from: https://doi.org/10.1111/mec.16918
32. Wang D, Lerou J, Nuytinck J, Gomes SIF, Jacquemyn H, Merckx V. Root-associated fungi in Orchidaceae: Diversity, phylogeny, ecology, and outstanding questions. bioRxiv. 2022. Available from: https://doi.org/10.1101/2022.12.16.519622
33. Tanwir K, Abbas S, Shahid M, Chaudhary HJ, Javed MT. Mycorrhizal symbiosis and nutrients uptake in plants. In: Plant Ionomics: Sensing, Signaling, and Regulation. 2023. p. 73-95. Available from: https://doi.org/10.1002/9781119803041.ch5
34. Fazeli-Nasab B, Piri R, Rahmani AF. Assessment of the role of rhizosphere in soil and its relationship with microorganisms and element absorption. In: De Gruyter eBooks. 2022. p. 225-52. Available from: https://doi.org/10.1515/9783110771558-010
35. Leroy C. Fungi in ant-plant interactions: A key to enhancing plant nutrient-acquisition strategies. New Phytol. 2023;238(5):1752-4. Available from: https://doi.org/10.1111/nph.18830
36. Mennicken S, Vogt-Schilb H, Těšitelová T, Kotilínek M, Alomía YA, Schatz B, *et al*. Orchid-mycorrhizal fungi interactions reveal a duality in their network structure in two European regions differing in climate. Mol Ecol. 2023;32(12):3308-21. Available from: https://doi.org/10.1111/mec.16918
37. De Rose S, Kuga Y, Sillo F, Fochi V, Sakamoto N, Calevo J, *et al*. Plant and fungal gene expression coupled with stable isotope labeling provide novel information on sulfur uptake and metabolism in orchid mycorrhizal protocorms. Plant J. 2023;116(2):416-31. Available from: https://doi.org/10.1111/tpj.16381
38. Wernet V, Kriegler M, Kumpošt V, Mikut R, Hilbert L, Fischer R. Synchronization of oscillatory growth prepares fungal hyphae for fusion. eLife. 2023;12. Available from: https://doi.org/10.7554/elife.83310
39. Mennicken S, Vogt-Schilb H, Těšitelová T, Kotilínek M, Alomía YA, Schatz B, *et al*. Orchid-mycorrhizal fungi interactions reveal a duality in their network structure in two European regions differing in climate. Mol Ecol. 2023;32(12):3308-21. Available from: https://doi.org/10.1111/mec.16918
40. Shah S, Shah B, Sharma R, *et al*. Colonization with non-mycorrhizal culturable endophytic fungi enhances orchid growth and indole acetic acid production. BMC Microbiol. 2022;22(1):101. Available from: https://doi.org/10.1186/s12866-022-02507-z

41. Jolman D, Batalla MI, Hungerford A, Norwood P, Tait N, Wallace LE. The challenges of growing orchids from seeds for conservation: An assessment of asymbiotic techniques. Appl Plant Sci. 2022;10(5). Available from: https://doi.org/10.1002/aps3.11496
42. Ma GH, Chen XG, Selosse MA, Gao JY. Compatible and Incompatible Mycorrhizal Fungi with Seeds of Dendrobium Species: The Colonization Process and Effects of Coculture on Germination and Seedling Development. Front Plant Sci. 2022;13:823794. Available from: https://doi.org/10.3389/fpls.2022.823794
43. Genre A, Lanfranco L, Perotto S, Bonfante P. Unique and common traits in mycorrhizal symbioses. Nat Rev Microbiol. 2020;18(11):649-60. Available from: https://doi.org/10.1038/s41579-020-0402-3
44. Zhang S, Yang Y, Li J, Qin J, Zhang W, Huang W, *et al*. Physiological diversity of orchids. Plant Divers. 2018;40(4):196-208. Available from: https://doi.org/10.1016/j.pld.2018.06.003
45. De Rose S, Kuga Y, Sillo F, Fochi V, Sakamoto N, Calevo J, *et al*. Plant and fungal gene expression coupled with stable isotope labeling provide novel information on sulfur uptake and metabolism in orchid mycorrhizal protocorms. Plant J. 2023;116(2):416-31. Available from: https://doi.org/10.1111/tpj.16381
46. Wang D, Gebauer G, Jacquemyn H, Zahn FE, Gomes SIF, Lorenz J, *et al*. Variation in mycorrhizal communities and the level of mycoheterotrophy in grassland and Forest populations of *Neottia ovata* (Orchidaceae). Funct Ecol. 2023;37(7):1948-61. Available from: https://doi.org/10.1111/1365-2435.14354
47. Zhang Y, Huo W, Hou J, Liu L, Yu X, Xu L. Effects and Benefits of Orchid Mycorrhizal Symbionts on *Dendrobium officinale*. Horticulturae. 2022;8(10):861. Available from: https://doi.org/10.3390/horticulturae8100861
48. Novotná A, Mennicken S, De Paula CCP, Vogt-Schilb H, Kotilínek M, Těšitelová T, *et al*. Variability in nutrient use by orchid mycorrhizal fungi in two medium types. J Fungi. 2023;9(1):88. Available from: https://doi.org/10.3390/jof9010088
49. Wang Q, Liu M, Wang Z, Li J, Liu K, Huang D. The role of arbuscular mycorrhizal symbiosis in plant abiotic stress. Front Microbiol. 2024;14:1323881. Available from: https://doi.org/10.3389/fmicb.2023.1323881
50. Chakraborty O, Agrawala DK, Chakraborty AP. Studies on Orchidoid Mycorrhizae and Mycobionts, Associated with Orchid Plants as Plant Growth Promoters and Stimulators in Seed Germination. In: Rhizosphere Biology. 2023. p. 439-63. Available from: https://doi.org/10.1007/978-981-99-0030-5_16
51. Kanchan M, Verma J, Bhatti SK, Thakur K, Kusum S, Sagar A, *et al*. Orchids and mycorrhizal endophytes: a Hand-in-Glove relationship. In: Apple Academic Press eBooks. 2022. p. 295-319. Available from: https://doi.org/10.1201/9781003277262-14
52. Bhuiyan MDH, Hossain MK, Hossain KS, Islam M. Isolation and identification of mycorrhizal fungus from an epiphytic orchid (*Rhynchostylis retusa* L. Bl.). Bangladesh J Bot. 2021;50(1):85-91. Available from: https://doi.org/10.3329/bjb.v50i1.52675
53. Vitt P, Taylor A, Rakosy D, *et al*. Global conservation prioritization for the Orchidaceae. Sci Rep. 2023;13:6718. Available from: https://doi.org/10.1038/s41598-023-30177-y
54. Mutum RD, Chanu NM, Khanganba TN, Thongam B, Das S. In Vitro Conservation and Propagation of Endangered Ethno-Medicinal Orchids from the Northeast Region of India. In: Sustainable Development and Biodiversity. 2023. p. 541-79. Available from: https://doi.org/10.1007/978-981-19-9936-920
55. Droissart V, Verlynde S, Ramandimbisoa B, Andriamahefarivo L, Stévart T. Diversity and distribution of Orchidaceae in one of the world's most threatened plant hotspots (Madagascar). Biodivers Data J. 2023. Available from: https://doi.org/10.3897/arphapreprints.e106248
56. Wang X, Tang Y, Peng X, Wang J, Zhang S, Feng Y, *et al*. Solving the "species bias" to facilitate orchid multi-scenario conservation planning in the south of the Hengduan Mountains. Res Sq. 2023. Available from: https://doi.org/10.21203/rs.3.rs-2663890/v1
57. Rusconi O, Steiner T, Le Bayon C, *et al*. Soil properties and plant species can predict population size and potential introduction sites of the endangered orchid *Cypripedium calceolus*. Plant Soil. 2023;487:467-83. Available from: https://doi.org/10.1007/s11104-023-05945-4
58. Tiwari P, Bose SK, Gautam A, Chen J. Emerging trends and insights into the cultivation strategies, ethnomedicinal uses, and socio-economic attributes of orchids. J Hortic Sci Biotechnol. 2023;98(3):273-98. Available from: https://doi.org/10.1080/14620316.2022.2164524
59. Shao Y, Imran I, Ortaş İ. Impact of mycorrhiza on plant nutrition and food security. J Plant Nutr. 2023;46(13):3247-72. Available from: https://doi.org/10.1080/01904167.2023.2192780
60. Wang D, Gebauer G, Jacquemyn H, Zahn FE, Gomes SIF, Lorenz J, *et al*. Variation in mycorrhizal communities and the level of mycoheterotrophy in grassland and forest populations of *Neottia ovata* (Orchidaceae). Funct Ecol. 2023;37(7):1948-61. Available from: https://doi.org/10.1111/1365-2435.14354
61. Garcia E. Conservation of South Florida orchid mycorrhizal fungi [dissertation on the Internet]. 2023. Available from: https://doi.org/10.25148/etd.fidc010263
62. Liang J, Zhou R, Huang Y, Qin H, Tang J, Xiao W, *et al*. Structure and diversity of mycorrhizal fungi communities of different parts of *Bulbophyllum tianguii* in three terrestrial environments. Front Plant Sci. 2022;13. Available from: https://doi.org/10.3389/fpls.2022.992184

Cite this article: Chauhan P, Attri LK. Mycorrhizal Associations in Orchids: A Review. Asian J Biol Life Sci. 2024;13(2):278-86.