Chapter

Plant Microbiome and Mycorrhizal Fungi

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Abstract

In this paper, the research results on the synergy between mycorrhizal fungi and plant microorganisms in China and abroad were summarized. The purpose of this paper was to elaborate the effects of the synergy mechanism between mycorrhizal fungi and plant microorganisms on crop growth and stress resistance, soil physical and chemical properties, and soil microbial diversity and to analyze the contribution of the interaction between mycorrhizal fungi and plant microorganisms in agriculture and forestry, so as to provide theoretical basis for the further preparation of composite microbial agents, the healthy and green improvement of crop yield, and the ecological restoration of forestry stress resistance. The main directions of future research in this field were also analyzed.

Keywords: symbiosis, endophytic microbe, rhizosphere microorganism, interaction

1. Introduction

Mycorrhizal fungi can infect plant roots to form mycorrhiza [1, 2]. In recent years, there have been many studies on the symbiotic relationship between mycorrhizal fungi and plants [3, 4]. The dynamic interaction between plants and mycorrhizal fungi can promote the effective absorption of minerals by plants from soil and provide protection for various environmental stresses [5, 6]. However, some studies have found that this interaction is closely related to mycorrhizal helper bacteria (MHB). Mycorrhizal helper microorganism is a kind of special rhizosphere and endophyte that can specifically bind to mycorrhizal fungi, promote mycorrhizal fungi infection to the host, and promote plant growth and development [7, 8]. The interaction of mycorrhizal fungi and auxiliary microorganisms can promote plant growth, reduce the occurrence of soil-borne diseases, and improve the availability of nutrients in soil and plant absorption rate [9–11]. However, there are still insufficient studies on the synergistic effect of mycorrhizal fungi and auxiliary microorganisms on agricultural crops and forests.

The purpose was to elaborate the effects of the synergy mechanism between mycorrhizal fungi and mycorrhizal fungi, plant microflora, rhizosphere microorganisms and mycorrhizal relationships, and the relationship between endophytic bacteria and mycorrhizal fungi.

2. Mycorrhiza and mycorrhizal fungi

Mycorrhiza refers to the reciprocal symbiosis formed by fungi and plant roots, according to different morphological structures. Mycorrhiza is divided into seven types: arbuscular mycorrhiza, ecto mycorrhiza, endo mycorrhiza, orchid mycorrhiza, arbutoid mycorrhiza, monotropoid mycorrhiza, and ericoid mycorrhiza. Among them, arbuscular mycorrhiza, ecto mycorrhiza, orchid mycorrhiza, and ericoid mycorrhiza are four common types [12]. The characteristic is that fungi do not invade the inner cortex and can form a typical structure of hyphal ring in root cortex cells. Aging hyphal rings are eventually digested and absorbed by plant cells. Studies have shown that the biological binding force of orchid mycorrhiza (OM) symbionts to each other is not symmetrical, and plants are the beneficiaries of symbiotic relationships [13]; some OM fungi are not specifically associated with orchids [14]; fungal heterotrophic orchids have more diverse mycorrhizal fungal lineages than autotrophic orchids [15].

Mycorrhizal fungi are fungi that can infect plant roots to form mycorrhiza [16]. Mycorrhizal fungi and terrestrial plants have formed mutually beneficial, mutually conditional physiological wholes and symbionts with different morphological characteristics 500 million years ago. The core of symbiosis is the bidirectional exchange of plant carbon sequestration and nutrients obtained by fungi. Mycorrhizal fungi mycelium can interact directly or indirectly with other beneficial organisms in soil interior and surface and participate in nutrient transformation, absorption, and recycling processes in soil ecosystems [17]; it plays a role in maintaining the balance of atmospheric composition, regulating ecosystems, increasing biodiversity, and stabilizing and maintaining sustainable productivity of ecosystems [18]. It can also improve the absorption of nutrients and water and salt resistance and disease resistance of plants by combining with the roots of host plants, releasing plant hormones and enzymes to promote plant growth [19].

In recent years, there have been many studies on the symbiotic relationship between mycorrhizal fungi and plants. The dynamic interaction between plants and mycorrhizal fungi can promote the effective absorption of minerals by plants from soil and provide protection for various environmental stresses [20]. However, some studies have found that this phenomenon is also closely related to the mycorrhizal helper bacteria (MHB) [21], which is less studied. MHB is a kind of special rhizosphere bacteria that can specifically bind to mycorrhizal fungi, promote the infection of mycorrhizal fungi to the host, and promote the growth and development of plants [22]. Studies have shown that MHB not only promotes mycorrhizal symbiosis by triggering plant growth factors but also promotes spore germination, root colonization, metabolic diversity, and biological control of soil-borne diseases [23]. The interaction of mycorrhizal fungi and MHB can promote plant growth, reduce the occurrence of soil-borne diseases, and improve the availability of nutrients in soil and plant absorption rate [24, 25]. However, there are still insufficient studies on the synergistic effect of mycorrhizal fungi and MHB on crops in China and abroad.

3. Plant microbiome

Plant microbial groups include microbial communities that generally interact with plants. They can survive within or outside plant tissues and carry out various beneficial activities, including inhibiting potential plant pathogens and promoting plant growth. Plant microflora mainly includes rhizosphere microbial community, leaf microbial community, and endogenous microbial community. The microbial community composition of different flora is complex, and its diversity, preference, and abundance are affected by host plants and environment, which is the medium of plant-soil-atmosphere interaction. They communicate material and energy through plant body and have formed a highly close symbiotic relationship in the long-term co-evolution [26]. During plant growth, microorganisms are actively recruited from the surrounding microbial pool. In soil, plant roots provide a unique niche for soil microbial communities in addition to fixing plants and as organs for absorbing water and nutrients, attracting various microbial communities to distribute in rhizosphere, root, and to a certain extent above ground parts [27].

Rhizosphere microbial communities can promote plant phenotypic plasticity, such as the flowering time of plants may be affected by them. Studies have found a molecular interaction network linking nitrogen cycle, tryptophan (Trp) synthesis of plant hormone IAA and flowering time, which is of great significance to the study of plant phenotype in climate change and the improvement of crop yield [28].

Endophytes and above-ground microbial communities are known for their potential to promote plant growth, improve disease resistance, and alleviate stress tolerance. Endophytes include fungi and bacteria, archaea, and the rarely explored viral world, among which there are abundant studies on endophytic fungi and their metabolites.

4. Relationship between rhizosphere microorganism and mycorrhiza

4.1 Mycorrhiza and auxiliary bacteria

Garbaye first proposed the concept of MHB by analyzing the isolation, identification, and symbiosis of bacteria in mycorrhiza [24]. MHB acts on mycorrhiza through root sensitivity to fungi, rhizosphere soil improvement, and fungal reproductive germination. At present, in the study of exogenous mycorrhizal, MHB can promote spore germination and mycelial growth by producing growth factors, detoxification antagonistic substances, and inhibiting competitors. The change of mycelium growth represents the adaptability of MHB to fungi and the close relationship between fungi and host plants [29]. MHB can improve the infection rate of exogenous mycorrhizal fungi on plant seedlings, enhance their colonization, and then promote plant growth two categories [30, 31]: the first category is through the production of enzymes that break down the spore wall and other volatile substances such as terpenoids, thereby promoting spore germination and bacterial formation [32]. The second category is by changing the absorption of inorganic salt by mycorrhizal fungi to affect spore germination, the establishment of symbiotic system [33, 34]. The MHB isolated and identified mainly includes *Agrobacterium*, *Burkholderia*, *Pseudomonas*, *Bacillus*, *Paenibacilus*, and *Streptomyces* [35].

4.2 Mycorrhizal and rhizosphere microorganisms

Mycorrhiza fungi treatment can significantly increase the species of beneficial fungi and reduce the species of pathogenic bacteria. Mycorrhizal fungi and some rhizosphere beneficial microorganisms have synergistic promotion relationship [36], which can significantly improve plant resistance [37–39]. Arbuscular mycorrhizal (AM) fungi have effects on rhizosphere microbial community structure and activity under atrazine stress, but there are few reports on the composition and diversity of rhizosphere bacterial community. Arbuscular mycorrhizal fungi (AMF) increased the phospholipid fatty acid analysis (PLFA) biomass of AM fungi but decreased the phospholipid fatty acid analysis (PLFA) biomass of microbial bacteria and fungi in rhizosphere soil.

Under the same site conditions, the number of fungi in rhizosphere soil of larch mycorrhizal fungi was significantly different from that in non-rhizosphere soil, and the species composition and dominant population were also significantly different. Since the relationship between tree roots, mycorrhizal fungi, and soil is very complex, many studies have been reported. However, the research field of mycorrhizal rhizosphere fungi has just started, and there are still many contents to be further studied. At the same time, mycorrhizal fungi have direct or indirect effects on plant growth and development. Enzymes, hormones, and toxins produced by mycorrhizal fungi affect the mineral nutrition, water absorption, and root development of plant roots in soil environment.

5. Relationship between endophytic bacteria and mycorrhizal fungi in plants

Endophytic bacteria, as a unique form of arbuscular mycorrhizal fungi (AMF), exist in the host AMF. At present, studies have shown that endophytic bacteria can enhance the ecological adaptability of the host AMF and improve its environmental stress resistance [40]. At present, it can only be preliminarily proved that the growth promotion effect and defense ability are related to endophytic bacteria. However, AMF without endophytic bacteria symbiosis, such as *R. intraradices*, can still produce the effect of disease resistance and injury stress on host plants without endophytic bacteria symbiosis. The interaction mechanism and disease resistance of this kind of AMF with host plants are different from those of the above endophytic bacteria. There are few studies on the interaction mechanism between symbiotic endophytic bacteria and host AMF. Strengthening the research in this direction has important innovative value and scientific significance for further exploration and evaluation of AMF fungal resources.

The unique arbuscular mycorrhizal structure of AMF and its diverse ecological functions formed by its interaction with host plants play a positive role and influence in the restoration of ecological environment vegetation, the restoration of ecological areas with moderate to strong alkaline effects [41], the restoration of wasteland containing metal mines [42], the phytoremediation of heavy metals in sewage-contaminated soil [43], and the rapid restoration of soil vegetation after interference [40]. The interaction between improving crop growth and mineral nutrition [44], plant productivity, and nutrient absorption is still an important research direction at present and in the future [45].

Ectomycorrhizal fungi (ECMF) usually selects bacterial communities from the surrounding soil according to symbiotic function or habitat requirements, and the short-term contact between soil bacteria and their fruiting bodies can also directly or indirectly promote the endobacteria (EB) community composition of fruiting bodies [46, 47]. According to the ecological function or habitat requirements, ECMF selects specific bacteria to colonize its body, which lays the foundation for the establishment and maintenance of symbiotic relationship. However, at present, it is still necessary to further explore the extent to which these specific species affect ECMF microbial communities and how they interact. Bacteria colonize selectively in ECMFs suitable for their own growth and form a new symbiotic relationship under severe environmental stresses [48].

It has been proved that whether ECMF selects specific bacterial groups according to symbiotic function or habitat requirements, or bacteria colonize in ECMF due to their own nutrient needs or niche expansion, the symbiotic mode formed between the two is more excellent in adapting to environmental changes.

In the symbiotic interaction between bacteria and ECMF, bacteria can loosely interact with the mycelium surface; it can also colonize mycelia and fruiting bodies, or show some symbiotic species specificity, as well as some potential metabolic complementation and ecological functions, thereby promoting mycelial growth, biomass increase, fruiting body formation of host fungi, and providing nitrogen sources for host fungi through nitrogen fixation [40, 46, 49]. At the same time, the mycelia and fruiting bodies of fungi create a suitable habitat for EB by providing different carbon sources for EB and protecting it from environmental stresses [50].

6. Contribution of mycorrhizal fungi to agriculture

The effect of AM fungi inoculation combined with appropriate agronomic measures on improving soil fertility, promoting plant growth, and increasing plant yield is greater than any single effect. For example, rotation, intercropping, or grass orchard inoculation of AM fungi are more obvious. At present some countries in the world are not rich in land resources, continuous cropping cultivation, especially the protection land contact for many years, resulting in soil fertility, soil quality, and ecological comprehensive service function decline, it is difficult to meet the needs of production. Therefore, it is worthy of systematic research and development to establish a new system of soil and seedling management dominated by mycorrhizal fungi inoculation to overcome continuous cropping obstacles under the combined cropping pattern of multiple crops mixed planting structure and rotation and intercropping. It is foreseeable that the implementation of AM fungi inoculation combined with appropriate agricultural measures will continue to develop and become an important emerging agricultural technology.

6.1 Application of AMF technology in agriculture

Most crops show some mycorrhizal dependence on AMF. AMF can promote crop uptake of soil nutrients, promote crop growth, improve crop yield, improve fertilizer use efficiency, and reduce fertilizer consumption, which is conducive to maintaining sustainable agricultural development. At present, there are research institutions and companies in the world that can produce AMF fungicides on a large scale [51]. In practical application, selecting crops with strong mycorrhizal dependence and high economic value to promote the application of mycorrhizal biotechnology has great ecological and economic benefits.

Many studies have shown that AMF inoculation can increase the yield of maize, wheat, soybean, and other major grain crops, improve crop nutritional status, and enhance crop resistance to drought, salinity, and other stresses [52, 53]. The commercial fungicide MYKEPROSG2 (Canada) was used to inoculated maize, and it was found that the P content of host plants could still be increased in the presence of indigenous AMF [54]. AMF combined with chemical fertilizer can improve the quality of rice and increase the contents of Fe and Zn in rice [55]. Ceballos inoculated cassava (Manihot esculenta), an important food crop in tropical regions, with *Rhizophagus irregularis*, which greatly increased its yield [56]. The effectiveness and economy of AMF inoculation could be taken into account when 2500 spores were inoculated per cassava.

6.2 Application of AMF technology in horticulture

Most horticultural crops can form symbiotic systems with AMF, such as Solanaceae, Onionaceae, most fruit trees, herbs, herbs, and ornamental flowers. Horticultural crops have high economic value and are used to nursery and container seedling, which provides convenient conditions for mycorrhizal plants at seedling stage. After mycorrhizal inoculation, it can shorten the nursery period of seedlings, improve the survival rate of transplanting, promote seedling growth, enhance disease resistance, ultimately improve product yield and quality, increase the economic added value of horticultural crops, and obtain greater benefits with less investment.

Under the premise of halving fertilizer application rate, Ziane (2020) inoculated tomatoes with commercial fungicide Symbivit, indigenous fungicide *Aspergillus moxicanus*, and *Septoglomus constrictum*, which could improve plant biomass and achieve the effect of 100% fertilizer application rate without inoculation [57]. The inoculation of horticultural crops such as fruit trees and vegetables can improve the yield and quality of fruits and vegetables. For example, the inoculation of *Glomus trufemii* on cucumber improved the quality of single fruit and the total yield per plant, while the contents of soluble protein and Vc in fruit were significantly increased [58]. AMF can also promote the formation of secondary metabolites and active substances in herb spices and medicinal plants, such as *Salvia japonica* inoculated with commercial bacteria and *Septoglomus viscosum*, the content and quality of essential oil in plants were significantly improved, and the proportion of taxol increased [59]. Xie (2018) found that the content of glycyrrhizic acid and liquiritin in roots of *Glycyrrhiza uralensis* increased significantly after inoculation with AMF [60]. Mycorrhizal plants have stronger adaptability under adverse conditions such as drought and salinity. The activities of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and guaiacol peroxidase (GPOX) in vivo are significantly increased, which can slow down the oxidative damage of plants and make plants have stronger resistance to water deficit [61, 62]. Selecting appropriate AMF for inoculation of plants can not only promote the absorption of phosphorus (P) by plants but also increase the contents of Zn, Cu, Mn, and other trace elements in plants [63, 64]. Therefore, mycorrhizal biotechnology can substantially reduce the use of fertilizers and pesticides, avoid pesticide residues in fruit and vegetable products, and improve the quality of fruits and vegetables. In the international production of fruit trees and flowers, AMF has been widely used as biological protective agent, biological accelerator, and biological fertilizer.

7. Application of mycorrhizal fungi in forestry

Once a plant enters a new growth environment, the introduction fails due to lack of symbiotic mycorrhizal fungi or suitable mycorrhizal fungi. This phenomenon is common in all continents. For example, Puerto Rico introduced foreign pine, and annual introduction failed repeatedly until the introduction of mycorrhiza fungi from the origin of the successful introduction. The survival rate of imported pine reached above by mycorrhizal fungi inoculation and afforestation with mycorrhizal seedlings in China. Mycorrhizal seedling afforestation can not only improve the ability of trees to absorb and utilize nutrients but also improve the survival rate of afforestation and timber yield. Moreover, inoculation at seedling stage can also greatly reduce the amount of fungicides. To this end, the United States also established mycorrhizal technology companies. Mycorrhizal biological agents were specially provided for mycorrhizal forest trees. The mycorrhizal research and development center of Chinese Academy of Forestry has also carried out research on the production and application technology of mycorrhizal biological agents, has been popularized in various provinces and regions throughout the country, and achieved remarkable results. A large number of studies have shown that mycorrhizal fungi not only prevent the invasion of pathogenic bacteria in structure but also secrete antibiotics to inhibit the growth and development of pathogenic bacteria, which can improve the disease resistance of forest trees and play an important role in the biological control of forest root diseases. At present, the inoculation of *Larix gmelinii* with Boletus has been successfully used to prevent and control root rot caused by *Pythium fulvus*.

7.1 Application of mycorrhizal fungi in tree breeding

When introducing new tree species, corresponding mycorrhizal species should be introduced, especially pine and other specialized mycorrhizal species. As early as in the early 1950s, after the failure of introducing eucalyptus, Iraq introduced undisinfected soil and finally introduced it successfully and significantly promoted seedling growth [65]. In 2001, Hua et al. put forward the concept of forest mycorrhizal bioengineering or forest mycorrhizal biotechnology [66], that mycorrhizal trees and the whole forest ecosystem is of great significance, that not only can improve forestry productivity but also provide a sustainable development path for forestry development.

In the current study on the effects of mycorrhizal fungi on forest growth, most of the experiments inoculated mycorrhizal fungi on forest seedlings to observe the changes in growth indicators, namely mycorrhizal forest. Zhang et al. test showed that the survival rate of mycorrhizal fungi in *Pinus elliottii* was above 90% [67]. The ground diameter and height of mycorrhizal *P. sylvestris* seedlings were 37% and 39% higher, respectively, and the survival rate of seedlings under drought conditions was improved [68]. Zhang found that inoculation with mycorrhizal fungi could promote seedling height growth, ground diameter growth, and biomass growth of poplar through experiments [69]. Some studies also inoculated seven mycorrhizal fungi of Russula on *Pinus massoniana* seedlings [70], which could not only form mycorrhizal fungi with *P. massoniana* seedlings but also promote the growth of seedlings to varying degrees. He et al. treated the rhizosphere of *P. massoniana* seedlings with mycorrhizal fungi by non-sterile inoculation method [71]. The height, ground diameter, and crown width of mycorrhizal *P. massoniana* seedlings were 29%, 51.7%, and 46.6% higher than those of the control group, respectively. Wu et al. conducted pot experiments after soil sterilization, and the results showed that exogenous mycorrhizal fungi could promote the growth and development of *P. tabulaeformis* seedlings and the accumulation of phosphorus *in vivo* and could significantly increase the basal diameter and leaf length of plants [72]. At the same time, it was concluded that the difference between natural forest and artificial forest in the natural regeneration of seedlings was due to the composition and diversity of exogenous mycorrhizal communities. Therefore, mycorrhizal fungi played an important role in the natural regeneration and growth of *P. tabulaeformis*.

Changes in plant water use efficiency, stomatal conductance, and CO_2 absorption efficiency can also affect the distribution of nitrogen content. Mycorrhiza can change the photosynthetic efficiency and thus affect the growth of trees through the above methods [73]. Experiments show that mycorrhizal *P. elliottii* can increase chlorophyll content, thereby increasing photosynthesis [67]. Zhu et al. found that the net photosynthetic rate, intercellular CO_2 concentration, stomatal conductance, seedling height, and ground diameter of *Zelkova schneideriana* were significantly improved after inoculation with mycorrhizal fungi [74].

Mycorrhiza promoted root growth of seedlings. Wang (2013) inoculated exogenous mycorrhiza on *P. massoniana* seedlings [75]. The results showed that the main root length, lateral root length, and lateral root number of mycorrhizal seedlings were higher than those of control group. Song et al. found that the establishment of symbiotic relationship between *P. cathayana* seedlings and VA mycorrhizal fungi could promote the development of seedling roots, increase the root surface absorption area, increase the ratio of active root absorption area, and enhance the activity of polyphenol oxidase in roots [76]. Mycorrhiza can indirectly promote forest growth by promoting root absorption of nutrients in soil. Lu found that after AM fungi infected roots, the growth of host plants changed significantly, and seedling height and root length changed significantly in the early stage of seedlings [77]. Jin (2019) inoculated different strains of *Quercus* spp., and the inoculated mycorrhizal fungi showed different degrees of growth-promoting effects on the host and the ability to significantly regulate root architecture [78]. Ditengou et al. found that *C. bicolor* could secrete sesquiterpenoid small-molecule substances, which had a significant regulatory effect on poplar roots, resulting in an increase in the number of secondary roots, expanding the root area of poplar, thus making poplar absorb nutrients [79]. Wu inoculated *R. irregularis* in arbuscular mycorrhizal fungi on *Populus deltoides* and found that inoculation with mycorrhizal fungi could increase the contents of iron, copper, manganese, and phosphorus in roots at high nitrogen levels [80]. It was speculated that *R. irregularis* could alleviate the nutritional imbalance caused by high nitrogen stress by promoting the absorption of nutrients and the content of elements in roots of *P. deltoides*. At the same time, this experiment found that mycorrhizal poplars might absorb nitrogen through mycorrhizal pathways and downregulate the expression of nitrogen transport-related genes in roots.

7.2 Application of mycorrhiza in forestry nursery

With the continuous understanding and in-depth study of mycorrhiza, mycorrhiza seedling technology is more and more widely used in forestry. From introduction, mycorrhizal seedling to afforestation in ecologically fragile areas, the application of mycorrhizal has achieved initial results. For mycorrhizal plants, countries or regions should introduce corresponding mycorrhizal fungi while introducing a new plant. There are many examples of failed introduction due to the lack of mycorrhizal fungi. For example, Puerto Rico in South America introduced pine tree species from all countries in the world in the 1930s, which failed. It was not until the introduction of mycorrhizal fungi from the origin that the afforestation was successful in 1955. Iraq's migration to different tree species was also unsuccessful. In the early 20th century, Iraq 's move to different eucalyptus species was also unsuccessful. Later, the unsterilized soil in the introduced eucalyptus forest was introduced and applied to the roots of the seedlings. Finally, it was successful and significantly promoted seedling growth. Finally, it succeeded and significantly promoted the growth of seedlings. Three kinds of pine trees, *P. elliottii*, *P. caribbeanensis*, and *Pinus taeda*, were introduced by Guangdong Forestry Research Institute in China. However, due to the lack of sufficient mycorrhizal fungi, afforestation was declared to be unsuccessful. Subsequently, the seedlings inoculated with mycorrhizal fungi were used for afforestation so that the survival rates of these three pines reached, and a large number of *P. yunnanensis* trees were introduced into Hainan Island in China. Due to the adoption of mycorrhizal fungi inoculation measures, the seedlings grew vigorously, and the introduction and afforestation were also successful. Chen (2013) reported the role of Australian and domestic exogenous mycorrhizal fungi in the introduction of Australian tail leaves, and the results showed that the inoculation of exogenous mycorrhizal fungi could improve the plant growth [81].

There are many advantages of mycorrhizal seedlings compared with ordinary afforestation technology, which can greatly improve the survival rate of tree afforestation, promote the growth of seedlings, increase the absorption capacity of plants to equal greenhouse gases, improve the carbon fixation ability of plants, improve the ability of seedlings to absorb nutrients such as nitrogen, phosphorus, and potassium, and secrete a variety of enzymes to activate soil components to form soil aggregates and improve soil rhizosphere microenvironment. At present, many countries and regions in the world stipulate that afforestation in some ecologically fragile areas must adopt mycorrhizal seedling technology.

American mycorrhizal development has been in the forefront of the world and set up a special mycorrhizal technology company to provide special mycorrhizal agents for forest mycorrhizal. The relevant departments of the United States have stipulated that seedling cultivation and afforestation in wet grassland areas must be inoculated before the Soviet Union stipulated in the forest steppe zone, and the mycorrhizal inoculation technology must be used to establish nursery for the seedlings. Mycorrhizal inoculation of roots at the early stage of seedlings was not only beneficial to mycorrhizal formation but also had less usage and obvious effect.

Forestry scientists in China have been working on mycorrhizal seedling technology in recent years. Mycorrhizal agent developed by China Academy of Forestry is mainly used for seedling cultivation of *P. massoniana*, which can increase seedling height, ground diameter, biomass, lateral root number, yield of qualified seedlings, and survival growth rate of afforestation. Therefore, it can solve the problems of low survival rate and slow growth in the early stage of *P. massoniana* and has been popularized in various provinces, cities, and regions nationwide, and remarkable results have been achieved. Using mycorrhizal technology to develop *P. elliottii*, studies on seedling cultivation and seedling ectomycorrhizal rate up to the above indicated that mycorrhizal treatment of seedlings of *P. massoniana* and *P. elliottii* could promote root growth of seedlings, increase seedling growth, increase ground diameter by one, and grow vigorously.

In areas where conventional afforestation is difficult, selecting suitable mycorrhizal fungi and adopting mycorrhizal technology according to the principle of suitable land and tree can greatly improve the survival rate of seedlings and afforestation effect, accelerate the recovery ability of vegetation, prevent further deterioration of the environment, and promote ecological balance. Mycorrhizal technology will play an important role in the restoration and reconstruction of ecological environment in China and other countries.

In summary, mycorrhizal technology has been applied in a variety of tree species, and pine mycorrhizal research has also been widely concerned. Many scientists have done some statistical analysis on the mycorrhizal formation of a tree species or a mycorrhizal fungi, described the mycorrhizal fungi of American pine seedlings, and described the necessary species of ectomycorrhizal roots for radiation pine seedlings. The exophytic mycorrhizas of P. radiata were divided into subclasses and subsubclasses. A series of morphological, histological, and cytological studies on the mycorrhiza were carried out. A key to the mycorrhiza of *Platycladus erinaceus*, *Picea norwayensis*, and Pine New Year's Eve was developed, from which the 10 genera of Boletus, such as Russula, Lactarius, Bacteroides, Boletus, Cephalophyllum, Chlamydomonas, and so on, which formed mycorrhiza, can be retrieved. It is a comprehensive reference for the identification of mycorrhiza. *P. tabulaeformis* is the second largest species of pine in planting area and quantity. The application value and prospect of fine mycorrhizal fungi breeding and propagation technology for *P. tabulaeformis* are quite extensive.

The inoculation of *P. tabulaeformis* with mycorrhizal technology can not only provide excellent nursery stocks but also improve the ecological environment in ecologically fragile areas, control soil erosion, and improve soil fertility. In landscaping, it can increase the absorption capacity of equivalent greenhouse gases, that is carbon sequestration capacity is very strong, and can slow down the heat island effect in the city. In today's global warming, without sacrificing the premise of economic development, this technology makes a certain contribution to the social energy conservation and emission reduction. Using mycorrhizal inoculation technology to cultivate fine *P. tabulaeformis* seedlings, carrying out industrial production, establishing nursery, and applying it to afforestation under difficult site conditions will greatly improve the survival rate of seedlings and forest growth, accelerate the pace of afforestation in obstacle areas, and promote a new step in afforestation in China. It plays an important role in improving the ecological environment, improving the productivity of forest land, controlling desertification land, and preventing soil erosion.

8. Future perspectives

With the continuous strengthening of people's awareness of forest resource protection, the ecological value of forestry has attracted more and more attention. Mycorrhizal fungi, as an important role in forestry, play a positive role in the growth and development of trees and the whole forestry ecological environment. It is mainly manifested in the introduction of new species of trees, breeding and afforestation, promoting the growth and development of trees, affecting the photosynthesis of trees, strengthening the absorption of soil nutrients by tree roots and the resistance to adverse environments, and improving the soil and the whole forestry ecology.

Although the research on mycorrhizal science is deepening, there are still shortcomings. In order to better apply mycorrhizal science to forestry development and provide a theoretical basis for the sustainable development of forestry economy, it is suggested to carry out research from the following aspects. At present, there are few statistical studies on the influence of geographical environment on mycorrhizal fungi. By analyzing the distribution characteristics of mycorrhizal fungi in various mountainous areas and forest areas under the influence of environmental factors, the dominant mycorrhizal fungi in various forest areas can be selected for investigation, analysis and in-depth study. The classification of mycorrhizal fungi needs to be further refined, which can be associated with peripheral factors such as symbiotic trees, surrounding undergrowth vegetation, and other microorganisms in soil and soil element content, to more comprehensively analyze the role of mycorrhizal fungi in forest land ecology. Molecular biology and omics are rarely used in mycorrhizal fungi, and the study on the dynamic changes of forest molecular level under the action of mycorrhizal fungi is rare, including omics such as molecules, proteins, and metabolism, which can strengthen the study on molecular level and further reveal the mechanism of symbiosis between mycorrhizal fungi and forest.

9. Conclusion

The interaction of mycorrhizal fungi and MHB can promote plant growth, reduce the occurrence of soil-borne diseases, and improve the availability of nutrients in soil and plant absorption rate. Plant microorganisms encode more genes than the host plant itself and affect the growth, development, and health of plants through the cooperation and competition between microorganisms and plants. The number of fungi in mycorrhizal rhizosphere is large, indicating that the rhizosphere microenvironment is conducive to the growth and development of fungi. The differences in species composition reflected that mycorrhiza and its metabolites changed the growth environment of soil fungi. The differences in dominant species indicated that some fungi in mycorrhizal rhizosphere adapted to the environment of mycorrhizal rhizosphere and survived. Endophytic bacteria symbiotic AMF significantly promoted the increase of chlorophyll content and promoted the utilization of photosynthesis in host plants. Endophytic bacteria symbiotic AMF significantly increased chitinase activity and activity of phenylalanine ammonia-lyase (PAL) and promoted host plant resistance to disease stress. These endophytic fungi are host plant mycorrhizal fungi. The effect of AM fungi inoculation combined with appropriate agronomic measures on improving soil fertility, promoting plant growth, and increasing plant yield is greater than any single effect.

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