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Review Article

A friendly-environmental strategy: application of arbuscular mycorrhizal fungi to ornamental plants for plant growth and garden landscape

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Abstract

The demand for ornamental plants is increasing due to urban greening and rural construction, while the growing environment of plants, especially the soil environment, is deteriorating. Hence, sustainable methods of ornamental plant cultivation need to be developed quickly. The application of arbuscular mycorrhizal fungi (AMF) to ornamental plants can be one of the eco-friendly ways to achieve the objective. Soil AMF establish mycorrhizal symbiosis with roots of ornamental plants, which can develop a marvelous mycorrhizal mycelium network in the rhizosphere to stimulate nutrient and water acquisition of host plants. Numerous researches have proven that AMF improved the quality of ornamental plants, like fruit yield, height, biomass, seed quality, the size and number of flowers, leaf, and root. In addition, mycorrhizal fungi also improve nutrient uptake and endogenous hormone balance of host plants. Another important function of AMF is to regulate the physiological, biochemical, and molecular responses of host plants to adversity, including drought stress, temperature stress, heavy-metal stress, and insect and disease stress. From the perspective of the ecological garden landscape, AMF richness would maintain plant abundance, nutrient and energy balance, and higher productivity in normal and soil environment stress, thus, establishing a friendly-environmental ecosystem. This review also provides the basis to exploit and improve the commercial application of AMF in ornamental plants in the future.

Keywords: endophytic fungi; ecological reconstruction; garden plants; stress; symbiosis

Introduction

As far as 19 centuries, arbuscular mycorrhizal fungi (AMF) were found to be symbiotic with roots of terrestrial plants in nature for establishing arbuscular mycorrhiza (AM) (Zhang *et al.*, 2020). AM symbiosis can enhance the photosynthetic efficiency of the host to improve shoot and root biomass, roots number and size, flowering, and other morphological indexes (Xie *et al.*, 2018; Li *et al.*, 2020). AMF are important for increasing the uptake of water and nutrients for plant growth and development by a mycorrhizal hyphal network that can

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be expanded the absorptive area by 40 times and explore deeper water and nutrients (Giovannetti *et al.*, 2001; Hayashi *et al.*, 2018; Zhang *et al.*, 2019a). Similarly, AMF regulate endogenous hormone levels to affect plant growth and flowering (Bi *et al.*, 2019). So far, earlier studies have indicated that AMF play one of the most important regulators in plant development in adversity stress. In drought stress, AMF regulate osmotic substances, increase antioxidant enzyme activities, and promote water absorption to enhance drought resistance (Khalvait and Ruth, 2005; Wu et al., 2013; Li *et al.*, 2019). In addition, the presence of AMF alters plant-type, activates the antioxidant defense system, and regulates temperature-related gene expression to alleviate damage by extreme weather (Chen *et al.*, 2013; Zou *et al.*, 2020).

In ornamental plants, according to the variety of mycorrhizal fungi and the characteristics of symbiosis with plants, there are AM, ectotrophic mycorrhiza, orchid mycorrhiza, arbutiod mycorrhiza, ericoid mycorrhiza, and monotropoid mycorrhiza. Hereinto, most of woody and herbaceous plants form AM type. Wood ornamental plants that belong to AM plants include *Michelia alba* DC., *Idesia polycarpa* (Figure 1a), *Davidia involucrata* Baill., *Acacia farnesiana* (Linn.) Willd., *Chimonanthus praecox* (Linn.) Link, *Osmanthus* sp., etc.; Shrub oranmental plants include *Cercis chinensis* Bunge, *Nerium indicum Mill.*, *Camellia japonica* L., *Hibiscus rosa-sinensis* Linn., and so on; and herbaceous ornamental plants include *Cymbidium ensifolium* Sw.., *Rosa chinenses* Jacq., *Trifolium repens* (Figure 1b), *Dendranthema morifolium* Ram, etc. (Wang *et al.*, 2008). Ornamental plants have different dependence on AMF: *Trifolium repens*, *Rosa chinenses* Jacq., and *Dendranthema morifolium* Ram are the high-dependent on AMF; *Matthiola incana* (L.) R. Br. and *Petunia hybrida* Vilm. are the moderate dependent type; *Nicotiana tabacum* L. and *Solanum lycopersicum* L. are the low dependent type (Urcelay *et al.*, 2003). It is documented that AMF are widely distributed in various habitats, e.g., meadows, forests, tropical regions, and frigid regions (Yang *et al.*, 2011). These AMF are varied, dependent on environments, and give different effects on ornamental plants (Brundrett, 2004). For example, A part of ornamental plants are also growing in arid and semi-arid areas for soil remediation, where they usually grow poor soil with a small amount of AMF species (Zhang *et al.*, 2018b). The present review outlined the effects of AMF on ornamental quality, nutrient absorption, endogenous hormone levels, and stress resistance of ornamental plants. And the review conferred the function of AMF on the landscape ecosystem of ornamental plants.

Colonization of AMF in roots of ornamental plants

As mentioned earlier, many ornamental plants have the root mycorrhizal fungal colonization (Figure 1a, 1b), and the degree of mycorrhizal colonization in ornamental plants is varied, dependent on AMF species and plant species. In Solan district, Himachal Pradesh, India, 15 ornamental flower plants showed the different AMF colonization rate, among the highest colonization rate of *Senecio cineraria* was 100%, and the lowest in *Jacobinea carnea* was 14.28% (Kumar *et al.*, 2012). Possibly, some secondary metabolites contents of host plants, such as flavonoid, can affect spore's germination, and mycelium elongation and branching (Fall *et al.*, 2015). The percentage of AMF colonization in roots is increased with the increase of plant-age. For example, *Cryptomeria japonica* plants had higher colonization rate in first-order roots of older plants than in younger plants, which is related to P content and C/N ratio, thus, conferring more nutrient acquisition (Hishi *et al.*, 2016). Even in the same plant, the percent of AMF infection shows a dynamic change due to the change of season and soil environment (Kumar *et al.*, 2012). AMF colonization in black locust seedlings was decreased, due to the decline of carbon supplication (Yang *et al.*, 2014a). The illumination intensity affected the AMF colonization rate in *Syzygium* seedlings, whilst the higher photosynthesis results in more carbohydrates into the fungal partner for fungal growth (Gamage *et al.*, 2004). Therefore, the inoculating time, ornamental plant types, and soil environment are critical factors to ensure the success to faster and better form mycorrhizal symbiosis between AMF and ornamental plants.

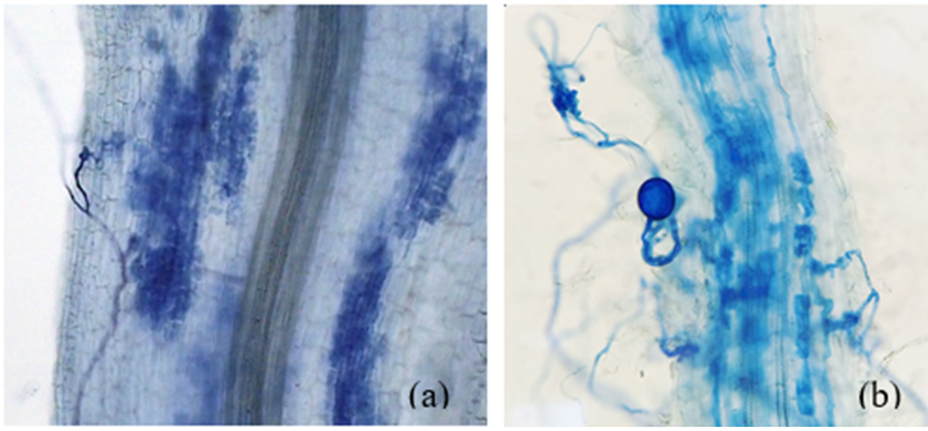

Figure 1. Colonization of arbuscular mycorrhizal fungi in roots of ornamental plants. a: *Idesia polycarpa*; b: *Trifolium repens*

AMF effects on ornamental quality of ornamental plants

There are many paths to improve flowering, growth, and field of ornamental plants, such as temperature, light, and plant growth regulator. However, these paths would be too costly in terms of capital and energy consumption, and long-term use of plant growth regulators harms the soil environment. AMF can be a friendly environmental approach to promote the quality of ornamental plants. Studies indicated that AMF significantly affected flowering, such as the size, the number of flowers, and the phenological stage of flowering (Shamshiri *et al.*, 2012). Comparing with non-AMF plants, AMF-inoculated plants had relatively higher flower number in ornamental plants, such as marigold, geranium, and harlequin (Engel *et al.*, 2016; Varga and Kytöviita, 2010; Scagel, 2004), and also increased size and color in carnation and hyacinth (Navarro *et al.*, 2012; Xie and Wu, 2015; Xie *et al.*, 2018). Similarly, the flowering time of *Medicago truncatula* was earlier by inoculation with AMF (Liu *et al.*, 2018). The total flowering stage was significantly prolonged in tomato after mycorrhization (Banla *et al.*, 2015), but was shortened in *Chrysanthemum morifolium* by AMF colonization (Sohn *et al.*, 2003). Garmendia and Manga (2012) reported that inoculation with *Glomus mosseae* in *Rosa hybrida* was not significantly affected on early flowering and the number of flowers. The species of AMF have different effects on the flower of host plants and depend on how AMF regulate the nutrient element content in host plants and a certain amount of carbohydrates accumulated in plants (Liu *et al.*, 2018). Similarly, AMF also can directly or indirectly affect the balance of endogenous hormones in plants, thus affecting the growth and flowering of mycorhizal plants. Endogenous hormones, such as indoleacetic acid (IAA), gibberellin (GA), and cytokinin (CTK), are growth-promoting hormones, and are affected by AMF (Perner *et al.*, 2007). And Song et al. (2012) has also proved that inoculation with *G. intraradices* and *G. mosseae* can significantly enhance the level of IAA, GA and zeatin (ZR) in *Amorpha fruticosa*. During seed germination, leaf growth, stem elongation, pollen tube elongation, flower and fruit development, and flower transformation, endogenous hormone levels are regulated by AMF for better plant growth responses (Swain and Singh, 2005; Razem *et al.*, 2006). In addition, the hyphae of AMF can produce CTK and GA to effect growth and flowering of ornamental plants (Barea and Azconaguilar, 1982).

AMF do not just change morphological of flower, but also affect inclusion of flower. polyphenol, as an important component of flowering ornament plants, has been affected by AMF in *Calendula officinalis*, *Melissa officinalis*, and *Origanum majorana* (Engel *et al.*, 2016). Not only that, AMF also can influence the quality of ornamental plant progeny by indirectly affecting ornamental plant pollination, AMF alter the seed quality of some *Rosaceae* by indirectly affecting plant pollination (Barber and Gorden, 2006). AMF increased nectar yield and the male or hermaphrodite flower number and size, to attract pollinators more easily to ensure the formation and quality of progeny seed (Asikainen and Mutikainen, 2005; Kiers *et al.*, 2010; Varga and

Kytöviita, 2010). At the same time, AMF cause transgenerational effects on the offspring of plants through increasing the proportion of methylated DNA in seed (Varga and Soulsbury, 2017).

Inoculation with *G. intraradices* or *Gigaspora albida* significantly increased collar diameter and root length in *Eucalyptus hybrid* (Sastry *et al.*, 2000). In the urban garden, inoculation with AMF had positive effects on total shoot length, trunk diameter, shoot and root biomass, and shoot to root ratio in *Acacia smallii* and *Fraxinus uhdei* (Stabler *et al.*, 2001). In addition, root structure was greatly improved by AMF to delay the senescence of *Cryptomeria japonica* (Hishi *et al.*, 2016). Similarly, the most significant effect of AMF on ornamental grasses is to increase the biomass of shoot and root and the root activity for promoting density and coverage of lawn (Watts-Williams *et al.*, 2019). However, there was no effect on plant height in mycorrhizal tall fescue, while plant height of both eastern gamagrass and big bluestem was positively increased in mycorrhizal plants (Thorne *et al.*, 2013), suggesting that the AMF effect is dependent on host and AMF species. Therefore, when AMF are applied to any ornamental plant, efficient screening of mycorrhizal fungi is required.

Improvement of mineral nutrition in mycorrhizal ornamental plants

Ornamental plants need adequate industrial chemical fertilizer, which would pollute the soil environment. AMF, a natural biological fertilizer, could not result in environmental pollution. Studies have proven that AMF significantly improved the absorption of nutrient elements, like N, P, and K in mycorrhizal *Chrysanthemum morifolium*, *Petunia hybrida, Tegetes erecta, Callistephus chinensis, Papaver rhoeas,* and *Dianthus caryophyllus*, as well Fe, Mn, Cu, and Zn (Table 1) (Sohn *et al.*, 2003; Gaur and Adholeya, 2005). The nutritional improvement under mycorrhizal is closely related to hyphae of AMF that increases the absorption of nutrient elements. The mycorrhizal hyphae expand the area of absorption of nutrient element, but also increase the ability to absorb nutrient elements (Mathur *et al.*, 2018). The content of N, P, and K was significantly increased in *Hyacinthus orientalis* L. by inoculation with *Funneliformis mosseae*, but not *Diversispora spurca* and *D. versiformis* (Xie and Wu, 2015). In pelargonium, inoculation with AMF significantly increased P and K content, not N concentration (Perner *et al.*, 2007). Huang *et al.* (2020) reported that in walnut (*Juglans regia*), inoculation with AMF (*Acaulospora scrobiculata*, *D. spurca*, *G. etunicatum*, *G. mosseae* and *G. versiforme*), to some extent, increased root nutrient contents, dependent on AMF species and mineral types. The above results fully indicate that AMF inoculation has a positive effect on nutrient uptake of ornamental plants, which depends on mineral elements, host plants, and AMF species.

It was proved that extraradical mycelium of AMF contribute P requirements for up to 80% plants (Marschner and Dell, 1994) because the network of hyphae expands the volume of P absorption, but also secretes phosphatases to catalyze organic compounds into phosphate (Hayashi *et al.*, 2018). The gene of P transporters is up-regulated by AMF to associate P uptake in many plants (Fellbaum *et al.*, 2014). The expression of *MtPT4* was induced by AMF in the root of *Medocago truncatula*. AMF promote organic and inorganic N absorption and transportation for host plants by extratradical mycelium, and NH_4^+ is the major form to be absorbed (Leigh *et al.*, 2009). Wang *et al.* (2020) proved that about 42% of total N was obtained via mycorrhizal rice roots under NO_3^- supply condition, and putative nitrate transporter gene *OsNPF4.5* had been strongly induced in rice roots. Especially, the increase of N nutrient was more obviously in leguminous by AMF, contributed to the nodule number and N metabolism-related enzyme activity (Xie *et al.*, 2020). A higher K^+/Na^+ ratio in mycorrhizal *Zelkova serrata* seedling subjected to salt stress protected protein synthesis and cellular enzymatic processes (Wang *et al.*, 2019a). Paying attention to other nutrients in ornamental plants should be involved.

Table 1. Effects of inoculation with AMF on the quality performance of ornamental plants

Ornamental plant species	AMF species	Mycorrhizal effects on ornamental plants	Reference
Kinnow	*Glomus manihotis*, *G. mosseae*, and *Gigaspora gigantia*	Improving growth parameters like plant height, canopy volume, mean leaf area, and number of new shoots per plant, and altering flowering phenology	Shamshiri *et al.*, 2012
Calendula officinalis, *Melissa officinalis*, and *Origanum majorana*	*Claroideoglomus etunicatum*, *C. claroideum* and *Rhizophagus intraradices*	Increasing biomass and polyphenol content	Engel *et al.*, 2016
Geranium sylvaticum	*Glomus claroideum* and *G. hoi*	Improvement of floral diameter, functional stamens, and pollen grains	Varga and Kytöviita, 2010
Sparaxis tricolor	*Glomus intraradices*	AMF-inoculated plants blossom 7-9 days earlier and produced more flowers, croms and biomass per plant	Scagel, 2004
D. caryophyllus	*Glomus intraradices*	Improvemeng in growth, quality and mineral concentrations	Navarro *et al.*, 2012
Hyacinth	*Diversispora spurca, D. versiformis*, and *Funneliformis mosseae*	Only *Funneliformis mosseae* increased morphology, color, and lasting time of flowers, which is related with enhanced IAA levels and N, P and K concentrations	Xie and Wu, 2015
Trifolium repens	*Funneliformis mosseae, Paraglomus occultum, and Rhizophagus intraradices*	Dual inoculation of *Rhizobium trifolii* and *P. occultum* or *R. intraradices* further magnified the positive effect. Leaf and root N content, root total soluble protein content, root nitrogenase activity, and amino acid	Xie *et al.*, 2018
Rosa hybrida	*Glomus intraradices* and *G. mosseae*	No change in plant biomass, leaf nutritional status and flower quality of rose after inoculation with AMF, due to low symbiosis establishment	Garmendia and Manga, 2012
Pelargonium peltatum L'Her.	Three different commercially available inocula	Mycorrhizal colonization increased the number of buds and flowers, as well as shoot P and potassium (K) concentrations, but did not significantly affect shoot dry matter or shoot N concentration	Perner *et al.*, 2007
Amorpha fruticosa	*Glomus intraradices* and *G. mosseae*	the seedlings' growth indexes, dynamic characteristics of plant endogenous hormone levels, soluble sugar contents in roots and in leaves respectively, and nitrogen (N), phosphorous (P) were significantly increased by AMF	Song *et al.*, 2012
Calendula officinalis, *Melissa officinalis*, *Origanum majorana*	*Claroideoglomus etunicatum*, *C. claroideum*, and *Rhizophagus intraradices*	AMF inoculation significantly increased the biomass of marjoram, the number of marigold's flowers and the yield of rosmarinic acid and lithospermic acid isomers of marjoram and lemon balm.	Engel *et al.*, 2016
Medicago truncatula	*Acaulospora scrobiculata, Gigaspora margarita, Funneliformis geosporum, Rhizophagus intraradices, F. mosseae,* and *Glomus tortuosum,*	Inoculation with *Funneliformis geosporum*, *Glomus tortuosum*, or *Acaulospora scrobiculata* had two periods of rapid flower production	Liu *et al.*, 2018
Geranium sylvaticum	*Claroideoglomus claroideum* and *Glomus hoi*	Higher DNA methylation	Varga and Soulsbury, 2017
Eucalyptus hybrid	*Acaulospora scrobiculata, Gigaspora albida,* and *Glomus intraradices*	*Glomus intraradices* or *Gigaspora albida* significantly increased collar diameter, root length and shoot length.	Sastry *et al.*, 2000
Acacia smalii, Fraxinus uhdei, and *Parkinsonia microph*	*Acaulospor morrowiae, Glomus ebumeum, G. facisculatum, G. miaoaggmgatum,* and *G. mosseae*	Increase in total shoot length, trunk caliper, total dry weight, shoot dry weight, root dry weight, shoot to root ratio, and phosphorus concentration in *Acacia smallii* and *Fraxinus uhdei*	Stabler *et al.*, 2001
Cryptomeria japonica	Various mycorrhizal fungi in foreste	Improvement in root structure, especially fine roots, and delaying of plant senescence	Hishi *et al.*, 2016
Medicago truncatula	*Funneliformis mosseae*	Increase in biomass, shoot nutrient concentrations, and root activity and inducation of *MtAQP1 MtPIP1, MtPIP2, MtNIP1,* and *MtNIP4* expression under drought stress	Watts-Williams *et al.*, 2019
Tall fescue, Big bluestem, and *Eastern gamagrass*	Sources of AMF from Claridon and Wilds	Tall fescue was not affected by AMF, while plant growth of big bluestem and eastern gamagrass was enhanced	Thorne *et al.*, 2013

Enhancement of stress resistance in ornamental plants by AMF

Drought stress

Researches have confirmed that AMF significantly enhanced drought resistance in ornamental plants (Wu *et al.*, 2013, 2019; Zhang *et al.*, 2020). AMF usually improved the root structure of ornamental plants, such as root number, length, surface area, and diameter (Wu *et al.*, 2013). The great root system obtains more water in wider and deeper soil, but also allow more abundant extraradical hyphae of AMF, which are much thinner than fine roots, to expand beyond depletion zone and penetrate smaller pores to absorb water and nutrient (Allen, 2011; Smith and Smith, 2011; Zhang *et al.*, 2018a; Zou *et al.*, 2020). Meanwhile, Khalvait and Ruth (2005) indicated that 4% of water was transported to the roots of host plants by hyphae. And the hyphae increase the total water absorption rate by 20% (Ruth *et al.*, 2011). Therefore, mycorrhizal ornamental plants improve drought tolerance, which attributes to the increase of hydraulic conductivity (Robert *et al.*, 2008). Mycorrhizal ornamental plants can maintain higher water-use efficiency and relative water content than non-AMF plants (Yang *et al.*, 2014b), providing favorable condition for accumulation of carbohydrates and gas exchange (Zhu *et al.*, 2012). Under soil water deficit, mycorrhizal plants remarkably increase the accumulation of carbon compounds to respond to oxidative burst (Barros *et al.*, 2018). In addition, AMF induce antioxidant defense systems to mitigate the accumulation of reactive oxygen species in mycorrhizal plants (Zou *et al.*, 2020). Li *et al.* (2019) showed that AMF reduced malondialdehyde content, increased catalase and superoxide dismutase activity in *Leymus chinensis* under water stress. Furthermore, AMF can AMF regulate the expression of drought-related genes in plants (Cheng *et al.*, 2020a). Two functional aquaporin genes from *G. intraradices*, *GintAQPF1* and *GintAQPF2*, were expressed strongly in cortical cells with rich intraradical mycelia and extraradical mycelia of roots under drought stress (Li *et al.*, 2013). However, host *AQPs* were down-regulated or unchanged by AMF inoculation under drought stress (Zou et al., 2019). Hence, Cheng et al. (2020a) proposed the synergistic effect of host and fungal *AQPs* on water status of hosts. AMF are involved in the induced expression of *P5CS* genes encoding a rate-limiting enzyme in proline synthesis (Porcel *et al.*, 2004) and *NCED* genes encoding a key enzyme in ABA synthesis during drought stress and recovery (Aroca *et al.*, 2008). Hence, mycorrhizal ornamental plants have a greater capacity to tolerate drought stress by a series of physiological and molecular mechanisms.

Temperature stress

In recent years, extreme weather is happening with increasing frequency by global climate change. Ornamental plants are always subjected to low- or high-temperature stress. AMF help plant responses to stress by altering plant physiological activities (Duhamel *et al.*, 2013), Thus, inoculation with AMF maybe be an efficient strategy to cope with low and high temperature through promoting nutrient absorption, changing cell membrane structure, activating the antioxidant system, and regulating temperature-related gene expression (Tu *et al.*, 2019). Bunn *et al.* (2009) had proven that AMF showed better heat tolerance than roots, with the increasing temperature. Under high-temperature soil, *Dichanthelium lanuginosm* plants inoculated with AMF significantly increased plant biomass, root length and diameter, and proportion of flowers and promoted early flowering (Bunn *et al.*, 2009). Five AMF species collectively promoted shoot and root biomass, and reduced indices of leaf and root browning in strawberry under high-temperature stress, and *G. mosseae* and *G. aggregatum* had most effective (Matsubara *et al.*, 2004). Additionally, mycorrhizal plants hold higher photosynthetic capacity and avoid the damage to the photosynthetic apparatus under high temperature (Mathur *et al.*, 2020). Under low temperature stress, *Ornithopus compressus* and *Lolium rigidum* inoculated with AMF significantly increased plant growth than non-AMF plants (Carvalho *et al.*, 2015). That could be AMF inoculation stimulated cyclic electron flow process in chloroplasts to reduce damage of stress, but also affected electrons transmission and phosphoric acid production in mitochondria, thus, promoting carbon metabolism under temperature stress (Mathur *et al.*, 2020). Simultaneously, AMF induced the cold-tolerant gene expression of the host, and twenty-four DEGs identified were associated with the metabolism of photosynthesis and respiratory (Li *et al.*, 2020). AMF increased secondary metabolites content and antioxidant enzyme activities, and induced expression of stress-related genes under low temperature (Chen *et al.*, 2013). Therefore, mycorrhizal fungi are an important protocol for ornamental plants to resist temperature stress, which should be paid more attention.

Heavy-metal stress

In cities, a large amount of ornamental plants is planted in soil polluted by heavy metals, which severely limits plant growth and survival. Fortunately, AMF have been considered as a cost-effective and environmentally friendly protocol in phytoremediation and ecological restoration (Yang *et al.*, 2015b). *Elsholtzia splendens* applied to a Cu-contaminated soil that significantly delayed the first-flowering dates and full-bloom stage and shorted flowering duration without AMF, whereas AMF recovered it and even promoted the flowering period (Jin *et al.*, 2015). Generally, mycorrhizal hyphae and spores of AMF combine with heavy metal ions to reduce their mobility in the soil (Janoušková and Pavlíková, 2010). The hyphae also decrease the distribution of heavy metal from root to leaf, protect leaf tissues from injury (Yang *et al.*, 2015a; Kushwaha *et al.*, 2016). Similarly, Zhou *et al.* (2017) adopted a spectrum to analyze Cu content at the cross section of root tip of *Tagetes patula*, and confirmed that intraradical hyphae could selectively sequestrate a great deal of free Cu through sorption and barrier mechanisms. In general, soil nutrients are always low under excessive heavy metals condition, while mycorrhizal ornamental plants usually maintain higher nutrient levels. For example, mycorrhizal *Medicago sativa* had higher biomass and N, P, K and Ca contents than non-mycorrhizal plants under Cd stress (Zhang *et al.*, 2019b). AMF also secrete a special glycoprotein, glomalin, to contribute soil nutrient pools and form protein-metal compounds for reducing the level of heavy metal in soil (Chern *et al.*, 2007; Gonzalez-Chavez *et al.*, 2009; He *et al.*, 2020; Meng *et al.*, 2020). Inoculation with *Funneliformis mosseae* enhanced the levels of *ATP binging cassette* (*ABC*) and *metallothioneins* (*MET*), transcripts in tall fescue roots under Ni stress (Shabani *et al.*, 2016). Thereinto, *GintABC1* isolated from extraradial mycelium of *G. intraradices*, participated in reducing toxicity of Cu and Cd (González-Guerrero *et al.*, 2010). Furthermore, *RintZnT1*, a Zn transporter, participated in isolation of Zn in vacuolar (González-Guerrero *et al.*, 2005). Therefore, an important research hotspot of mycorrhizas in ornamental plants is the mechanism of heavy metal pollution soil adaptive to mycorrhizal fungi in ornamental plants.

Diseases and insect

AMF affect the population of pathogenic microbes and harmful rhizospheric pests (Cheng *et al.*, 2020b). Slezack *et al.* (1999) discovered that inoculation with *Glomus mosseae* significantly reduced the red rot of pea roots by *Aphanomyces euteiches*. The date palm (*Phoenix dactylifera* L.) against inoculated with AMF reduced the index of pathogen occurrence by 8-77% (Jaiti *et al.*, 2007). The mechanisms of AMF on enhancing the tolerance of diseases and insects is due to the competition between AMF and pathogens and insect for rhizospheric microbes, colonization sites, and nutrient substances (Al-Aska *et al.*, 2010). Perhaps AMF compensate the damage of diseases and insect through improvement of plant health, root structure, and nutrient acquisition (Majewska *et al.*, 2017). However, there was no significant difference between *G. intraradices*-colonized plants and non-AMF-colonized plants infected with white rot (Prados-Ligeo., 2002). AMF also inhibited the damage of nematode in menthol mint (Ratti *et al.*, 2000), and reduced the damage of *Pratylenchus coffea* (Elsen *et al.*, 2003). Additionally, many genes (ChtA3, gluB, CEVI16, OSM-8e and PR-1) have been predicted to participate in defense responses to enhance the disease resistance of mycorrhizal plants via transcript profiles (Liu *et al.*, 2007; Ismail and Hijri, 2012).

As a whole, when ornamental plants grow in poor soil, inoculation with AMF not only increases the adaptability of ornamental plants to adversity but also improves the soil environment, which will be beneficial to the further application of ornamental plants in urban greening.

AMF and ecological garden landscape

Ornamental plants are frequently used in the ecological garden that is distributed in urban green space, rural area, and a damaged environment land. A higher richness of community productivity is found in the ecological system with various ornamental plants than in a conventional system (Lacombe *et al.*, 2009). It is well-known that the interaction between plant and microbial communities affects the balance of biodiversity and ecosystem function (Klironomos *et al.*, 2011). AMF are the vital component of the underground biome and widely distributed in various eco-systems with kinds of plants (Lee *et al.*, 2013). In addition, AMF directly affect the performance of host plants and indirectly affect plant communities via the increase of nutrient absorption and availability of soil nutrients by underground mycorrhizal networks (Werner *et al.*, 2015). In contrast, the diversity and richness of host plants also affect AMF communities, which could give priority to providing carbon to beneficial symbionts (Vogelsang *et al.*, 2006). AMF have effect on a variety of ecosystem functions by various pathways. Perhaps AMF are ubiquitous in terrestrial ecosystems and have a greater effect in the ecosystem than other soil microbes, like phosphate-solubilizing bacteria and nitrifiers (Powell *et al.*, 2018). Additionally, AMF have positive effects on soil microorganism population and soil physical and chemical properties, which benefit the ecological restoration (Yang *et al.*, 2016b). Hereinto, AMF reduce water loss of soil and soil hydrophobicity by AMF-released glomalin, resulting in low soil erosion in mycorrhizal soils (Rillig, 2004; Rillig *et al.*, 2010).

Urban ecological landscapes are usually built on developed construction sites, including urban garden, residential landscape, and road afforesting, with a very small number of microbial species. Ornamental plants could be colonized by AMF in urban environments, but the propagule abundance or infectivity is relatively lower than the natural environment (Wisemanand Wells, 2005). Plenty of ornamental plants are applied to the urban ecological garden landscape by tree transplanting, while the plant survival rate is dramatically low under such poor ecological conditions. Dag *et al.* (2009) indicated that AMF promoted olive transplanting with higher height, shoot and root biomass, and leaf and root nutrient levels without fertilization to increase tolerance of transplant shock. The AMF species richness and communities are dependent on ornamental plant species (Wang *et al.*, 2019b). Therefore, the combination with ornamental plants and appropriate AMF community built wonderful garden ecosystems that have less interspecific competition, better water and nutrient levels, and greater tolerance of abiotic and biotic stress (Teste *et al.*, 2017).

Ornamental plants often apply to build beautiful rural, which need to be in line with the local natural conditions. Unlike urban environment, the rural environment has higher species diversity, organisms' number, and total biomass (Bainard *et al.*, 2011). Therefore, exotic ornamental plants are difficult to blend into the local rural ecology without causing a threat by changing native plant species, community composition, and ecological functions (Aerts *et al.*, 2017). The richness and composition of AMF indirectly influence plant survival and establish in an unfamiliar environment (Yang *et al.*, 2014a; Lin *et al.*, 2015). When exotic ornamental plants are introduced into a new environment, the native AMF from rhizosphere of the exotic plants must be introduced to increase the plant survival rate and growth (Egidi *et al.*, 2018; Policelli *et al.*, 2019). Hence, it is necessary to know AMF diversity in the native and new habitat. In some cases, exotic plants and AMF can overcome the lack of AMF group, and the native AMF are crucial for the transplanting of ancient trees (Sulzbacher *et al.*, 2018). However, indigenous AMF may cause ecological risks in the new environment, which needs to be noted (Davison *et al.*, 2015).

Possibly, ornamental plants in ecological landscapes cannot be used to remediate the terrible soil environment, such as the soil with heavy metal, pesticide residue, and organic pollutant, but they beautify the polluted environment. AMF as an effective protocol can be considered to apply soil remediation (Joner *et al.*, 2001). Yang *et al.* (2016a) showed that AMF strengthened nutrient complementarities between plants through an underground mycorrhizal hyphal network. Similarly, under hydrocarbon-contaminants soil, AMF colonization promoted the absorption of polycyclic aromatic hydrocarbon, and AMF also degraded organic pollutants in the soil (Singer *et al.*, 2003; Rajtor and Piotrowskaseget, 2016). AMF species and number in the ecosystem having multiple plants are relatively higher than those in the ecosystem with a single plant, and thus an ecosystem of diverse plant species with abundant AMF diversity has more glomalin released from AMF to chelate heavy metals in the soil (Bedini *et al.*, 2010).

Conclusions

At present, the beneficial effects of AMF are confirmed in ornamental plants with better plant growth performance, more nutrient acquisition, and higher resistance to stress (Figure 2). AMF play a vital role in the establishment and maintenance of the ecological landscape in various soil environments. In the future, more applied studies should be carried out as soon as possible to make AMF commercially available. However, there are still many problems to be solved before the AMF can be used:

i) There is no qualitative breakthrough in AMF propagation *in vitro*. Large-area application of AMF on ornamental plants requires a lot of mycorrhizal inoculums. Therefore, the development of economic, reliable, and efficient protocol for AMF propagation still needs to be paid attention;

ii) AMF promote flowering and improve the ornamental quality of ornamental plants, while the underlying mechanism at the molecular level is still unclear and needs to be researched.

iii) When exogenous AMF are applied to the rhizosphere of ornamental plants, the biological risk must be concerned, so as not to destroy the community of indigenous AMF.

iv) The effect of AMF on ornamental plants depends on their compatibility. Therefore, an effective evaluation system of AMF for ornamental plants should be established to screen effective AMF to early apply it in the nursery.

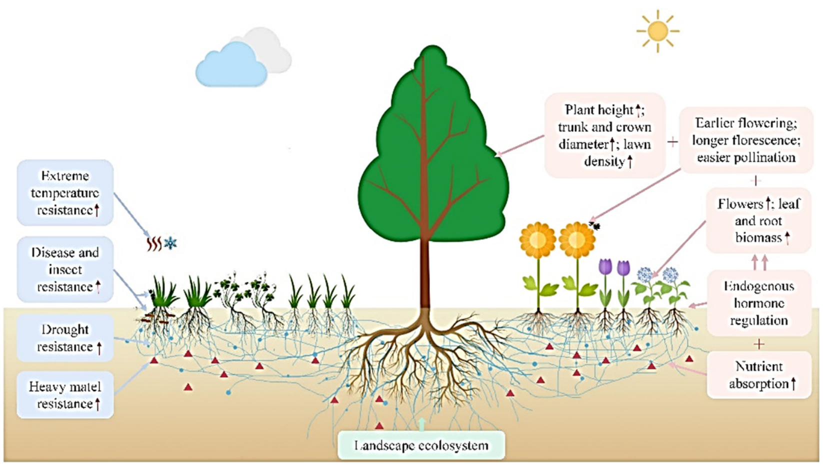

Figure 2. A schematic diagram regarding the effects of arbuscular mycorrhizal fungi (AMF) on ornamental plants and their rhizosphere for establishing and maintaining landscape ecosystem. AMF colonize the root system of an ornamental plant, establish a developed extraradical mycelium network, and further colonize the neighboring plants. Therefore, the developed mycelium network establishes the plants in an ecosystem as an organic whole. These mycorrhizal networks and extracellular mycelium help ornamental plants that grow better and have better nutrients and resistance of abiotic and biotic stress. Therefore, AMF can be used as an environmentally friendly medium to construct garden landscape.
(Insect; Disease; Extraradical hyphae; Spore; Heavy metal pollution)

Authors' Contributions

Conceptualization: MMX and QSW; Data curation: MMX, YW and QSW; Formal analysis: MMX, QSW and KK; Funding acquisition: QSW; Investigation: MMX; Project administration: QSW; Supervision: QSW; Writing - original draft: MMX; Writing -review and editing: QSW and KK. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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