Vesicular arbuscular mycorrhizae: A promising trend for biocontrolling plant parasitic nematodes. A review

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ABSTRACT

Arbuscular mycorrhiza fungi (AMF) are obligate symbionts that colonize the roots of the most cultivated plant species. Mycorrhizal symbiosis can be found in nearly all types of ecological situations and the most plant species are able to form this symbiosis naturally. Plant-parasitic nematodes, including endoparasitic nematodes and arbuscular mycorrhizal fungi, often occur together colonizing the same area of the rhizosphere roots of host plants interacting with each other. VAM fungi and root knot nematodes are members of the microbial populations of the plant rhizosphere competing with each other for the same site in the rhizosphere. Therefore, AM fungi may be used as biocontrol agents to reduce infestation by root-knot nematodes. Numerous studies have reported that AMF can increase host tolerance or resistance in many plant/nematode systems. Recently, it is demonstrated that AMF induced systemic resistance against plant-parasitic nematodes in the roots. However, most of the studies did not ensure whether the improved host response was a result of improved host nutrition, antagonism or competition between the nematode and mycorrhizal fungus. In VAM associations, the plant partner provides carbohydrates and space to the fungus which supplies nutrients, especially phosphorus to plants. Effects of inoculation time, phosphorus, some microorganisms and certain factors on AMF and certain plant parasitic nematodes were discussed in this review.

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Introduction

Plant-parasitic nematodes, including endoparasitic nematodes and arbuscular mycorrhizal fungi (AMF) often survive together in the rhizosphere colonizing the same area of roots of host plants and, therefore, interacting with each other. The interaction between AMF and nematodes has been studied by several workers (Hussey and Roncadori, 1982; Elsen et al., 2003; de la Peña et al., 2006) and it has caused nematode reduction (Sankaranarayanan and Sundarababu, 1994; John and Bai, 2004; Kantharaju et al., 2005; Siddiqui and Akhtar, 2007), no effect (Hasan and Jain, 1987) or an increase in numbers of nematodes (Atilano et al., 1981). Numerous studies have reported that AMF can increase host tolerance or resistance in many plant/nematode systems. Recently, Elsen et al. (2008) showed that AMF induce systemic resistance against plant-parasitic nematodes in the roots. However, most of the studies did not ensure whether the improved host growth was a result of improved host nutrition, antagonism or competition between the nematode and mycorrhizal fungus. Thus, there is a necessity to study the interaction effects between these two groups of organisms regarding effects on plant growth or yield and in terms of their reciprocal influences besides studying some factors influencing this interaction.

Arbuscular Mycorrhizae as biocontrol agents of plant parasitic nematodes

The AM fungi and plant parasitic nematodes are members of the microbial population of the plant rhizosphere competing with each other for the same site. Therefore, AM fungi may be used as biocontrol agents to reduce infestation by root-knot nematodes. In that trend, Pandey et al. (2004) showed that the dose of VAM fungus of 500 chlamydospores per tree was found the most effective for the reduction of the maximum population of Tylenchulus semipenetrans infesting citrus. As reported by Rodriguez Romero and Jaiizme-Vega (2005), micro-propagated plants of banana (Musa acuminate) cv. Grand Naine were inoculated with Glomus manihotis at the beginning of the hardening phase. Then, plants were inoculated with Meloidogyne javanica. Number of galls and the population of M. javanica were reduced 120,160 and 200 days after inoculation with no negative effect on root colonization by the mycorrhizal fungus. Shreenivasa et al. (2007) studied the interactive effect of mycorrhizal fungus, Glomus fasciculatum with root knot nematode, Meloidogyne incognita and their effect on tomato. G. fasciculatum significantly reduced nematode population, number of galls and root
knot index and increased the growth, plant biomass, phosphorous uptake and yield of tomato compared to plants inoculated with nematode alone. Hajra et al. (2013) studied the biocontrol of nematodes by arbuscular mycorrhizal (AM) fungi and compared their effects and interaction on physical and biochemical parameters, especially carbon profile of sponge gourd (Luffa cylindrica (L.) Roem). They clearly indicate the significant variations in all parameters. Leaf area and plant height were increased in mycorrhizal plants than non-mycorrhizal, but mycorrhizal plants showed a sharp decrease in nematode-infected plants with less water content due to xylem vessels damage. On the other hand, in mycorrhizal plants, roots had large amount of carbohydrates indicating transfer of photosynthates to fungal partner. Nematode infected roots have the least amount of carbohydrates showing a great sink of carbon to rhizosphere. Omolara Olaniji (2014) investigated the ability of mycorrhizal fungi, oil palm bunch refuse and sawdust mulches on banana growth and nematode infection. Twenty four suckers of cooking banana cultivar ‘Fougamo’ were used for the experiment. The tested materials improved aerial and underground plant growth. Sawdust mulch increased area of youngest leaf by 215%, mycorrhizal fungi by 234% and oil palm bunch refuse much by 267%. Mycorrhizal inoculants supported more vigorous plants and inhibited root invasion by Pratylenchus coffeae and Radopholus similis.

**Arbuscular Mycorrhizae as resistance inducers against plant parasitic nematodes**

As shown by Masadeh et al.(2004), mycorrhizal infection in one part of the split root system did not cause a systemic induced biocontrol of root-knot in the opposite, non-mycorrhizal part. This suggests that the lowering of M. hapla development by G. intraradices is controlled by a mainly local systemic mechanism in the susceptible tomato cv. ‘Hildares’. Therefore, a critical threshold of mycorrhizal infection density is needed for biocontrol. However, Glomus intraradices was able to trigger systemic resistance in banana plants towards two plant parasitic nematodes, *Radopholus similis* and *Pratylenchus coffeae*, using a split-root technique. The AMF reduced both nematode species by more than 50%, when they were spatially separated. The results obtained clarified that AMF have the ability to induce systemic resistance against plant parasitic nematodes in a root system (Elsen et al., 2008). Another trend that plants stressed by pathogens activate a variety of defense mechanisms to survive such as the osmoprotector amino acids, of which proline. On this basis, the effects of arbuscular mycorrhizal fungi on plants infested by *M. incognita* were evaluated by Bañuelos et al. (2012) with regard to the accumulation of the osmoprotectant proline. They that the arbuscular mycorrhizal fungi significantly reduced the proline content compared with the non-inoculated mycorrhizal plants which exhibited a higher proline concentration. Both the infestation of the nematodes and the addition of fertilizer significantly did not affect the proline content. The presence of the arbuscular mycorrhizal fungi significantly improved Plant parameters.

**Effect of VAM on certain plant parasitic nematodes as influenced by inoculation time, phosphorus, certain microorganisms alone or in combination with other factors**

**Effect of Inoculation Time**

Osman et al. (1990) reported that a significant increase in fresh weight of common bean plants occurred when vesicular arbuscular mycorrhizal fungus (VAMF) was inoculated 15 and 30 days before *M. incognita* inoculation. When AMF was inoculated, 15 days and at the same time of nematode inoculation, there were no significant differences in total nitrogen between plants received both nematode and VAMF and plants inoculated by nematode only. Inoculation of VAMF, 30 days before nematode inoculation caused significant increase in total nitrogen. Also, the inoculation with VAMF only had a significant increase in phosphorus content. Whereas in those inoculated with nematode and VAFM at the same time or inoculated with nematode only, phosphorus content significantly decreased. On the other hand, final nematode population significantly increased when both VAMF and nematode inoculated at the same time, but colonization by fungus decreased. When inoculation by fungus occurred 15 and 30 days before nematode inoculation, there were significant decrease in nematode final population and gall index. Mirghani and Elsheik (1996) reported that *mycorrhizae* significantly decreased the gall number on roots of tomato when the mycorrhizal infection preceded the nematode infection. Also, Sankaranarayanan and Sundarababu (2009) studied the reciprocal influence of the (AMF) Glomus fasciculatum and the root-knot nematode Meloidogyne incognita and their interaction effects on the growth of blackgram. Inoculation of AMF, 20 days before nematode inoculation, increased significantly shoot and root growth and pod yield of blackgram and suppressed root gall index and the nematode population in the soil. Vice versa, inoculation of the nematode before AMF, especially 20 days affected negatively root mycorrhizal colonization and spores in the soil. AMF treatments increased phosphorus content of shoots and roots of blackgram. In Addition, Hjara et al. (2015) clarified histopathological changes in roots of *Luffa cylindrica* as affected by VAM fungi mediated root knot nematode suppression as follows: In roots inoculated with VAM only, the amount of vascular tissue and number of vessels increased. Roots inoculated with nematode and VAM simultaneously exhibited numerous giant cells having dense and granular cytoplasm. Fungal spores were found in the cortical layer. In roots inoculated with VAM before nematode, giant cells were detected in endodermis and stele regions. Amount of phloem increased due to presence of VAM which help root to draw more nutrients and overcome the damage caused by nematodes. After roots were inoculated with nematode before VAM, endodermis and pericycle appeared as distorted layer. Partial destruction of phloem was seen in the roots of early stages of nematode infection.
Effect of Phosphorus

Thompson Cason et al. (1983) reported that inoculation with two mycorrhizal fungi, Glomus mosseae or Gigaspora margarita on tomato cv. Walter, 2 weeks before nematode inoculation did not alter infection by M. incognita compared to noninoculated plants regardless P- level although other investigators (Schonbeck, 1979 and Sikora, 1979) reported that AMF protected plants from plant parasitic nematodes. For AMF to be effective in reducing nematodes on plants, either plant tolerance or pre-post inflectional nematode-host relationship must be influenced. In high P level, plants had greater root weights, increased nematode penetration and egg production per plant and decreased colonization by mycorrhizal fungi compared to low P level. In another experiment, the rate of nematode development was not affected by G. margarita or high level of P- content compared to low P -level. Smith and Kaplan (1988) studied the influence of mycorrhizal fungus, phosphorus and burrowing nematode, Radopholus citriphilus on growth of rough lemon plants. The results showed that mycorrhizal and nonmycorrhizal plants with high P-plants, had lower densities of burrowing nematode, Radopholus citriphilus and greater phosphorus content in leaf tissue than did non-mycorrhizal with low-P plants. Improved plant growth and root colonization associated with improved P nutrition. Heald et al. (1989) showed that the interaction among Glomus intraradices, Meloidogyne incognita and cantaloupe (Cucumis melo) under three soil phosphorus levels (0.50 and 100µg P). All plants grew poorly in soil not amended with P, regardless of mycorrhizal or nematode status. In soil amended with 50 µg P/g soil, M. incognita suppressed the growth of nonmycorrhizal plants by 84%. In contrast, growth of mycorrhizal plants inoculated with M. incognita was inhibited with only 21%. The same trend was noticed regarding plants received 100 µg P/g soil. Minerals in plant shoots declined as P- levels increased and were not significantly influenced by G. intraradices or M. incognita. Santhe and Sundarababu (1995) studied the effect of different levels of phosphorus 0, 50 and 100 µg /g soil) on root knot nematode, Meloidogyne incognita, VAM fungi and interaction between them. When cowpea plants were inoculated with VAM, they became more resistant to nematode compared with those without VAM. When plants were treated with phosphorus, content of total phosphorus increased with positive correlation between phosphorus levels and the nematode population and negative correlation between phosphorus levels and fungi spore population and colonization. Mirghani and ELsheikh (1996) studied the effect of phosphorus (P) compared to nematicide, nemacur on the interaction between VAM fungi, Glomus sp, and root-knot nematode, Meloidogyne incognita, on tomato (Lycopersicon esculentum) growth. The results indicated that addition of P or Glomus sp. significantly increased the shoot and root dry weight and P content. However, the addition of P, nemacur or Glomus sp. significantly decreased the gall number in plants infected with M. incognita. Also, P significantly decreased the mycorrhizal infection percentage, but nemacur did not affect it.

Effect of certain microorganisms

Rhizobium

Sankaranarayanan and Sundarababu (1998) showed that bacterium, Rhizobium caused the maximum bacterial nodulation in roots of blackgram plants inoculated with Glomus mosseae. When Rhizobium was combined with G. mosseae and M. incognita, this combination caused similar increased nodules, the least nematode population density and the maximum spores, total nitrogen and phosphorus contents.

Paecilomyces lilacinus

Rao and Eddy (2001) showed a strategy of integrated management of the root knot nematode, M. incognita infesting eggplant by a combination of the Endomycorrhiza G.mosseae, the fungus, Paecilomyces lilacinus compared to neem cake. The results indicated that healthy eggplant seedlings were obtained by using the previous treatments. In other words, transplants obtained from the nursery beds were the least infested by nematode. P. lilacinus significantly parasitized eggs of nematode and the transplants yielded significantly more fruits. Neem cake increased the colonization of VAM before and after transplanting. Udo et al. (2013) used different arbuscular mycorrhizal fungi and bioformulated Paecilomyces lilacinus against M. incognita race1 on tomato. The biofumicide was applied as single and double applications in combination with five species of VAM compared to an uninoculated control. VAM differently affected gall and eggmass numbers, tomato root colonization rate as well as growth and fresh weight of fruits as Glomus etunicatum and G. deserticola were the most efficient species. When biofumicide was applied twice, it significantly reduced galling and egg production more than single application. When individual combinations of two AMF (G. etunicatum and G. deserticola) with a double application of the biofumicide, the greatest gall and egg mass inhibition occurred with consequently the greatest growth and fresh fruit yield.

Azospirillum brasilense, Azotobacter chroococcum, Pseudomonas fluorescens and Bacillus subtilis

Soliman et al. (2011) indicated that AMF was the most effective treatment in decreasing the final nematode population in soil and roots, number of galls and rate of buildup of root knot nematode, M. incognita on Acacia farnesiana and A. saligna. Also, they recorded the maximum plant growth, nodulation parameters and chemical components in the leaves of the two species compared to the least effective bioagents, Azospirillum brasilense, Pseudomonas fluorescens and Azotobacter chroococcum. Hasan et al. (2014) showed that brinjal (Solanum melongena) plants infected by M. incognita and treated with the combination of certain rhizobacteria including Pseudomonas fluorescens, Bacillus subtilis, and Azotobacter sp. and mycorrhizal fungus, Glomus fasciculatum, These rhizobacteria significantly reduced number of galls.
and second stage juveniles and improved plant growth criteria compared to control and single treatments of either microorganism alone. Azotobacter sp. was found to be the least effective compared to the rest microorganisms.

**Trichoderma viride**

As shown by Masadeh et al. (2004), effects of the combination of the arbuscular mycorrhizal fungus (AMF), Glomus intraradices and the fungus Trichoderma viride on the root-knot (RK) nematode, Meloidogyne hapla, were investigated in greenhouse experiments on tomato (Lycopersicon esculentum Mill, cvs. ‘Hildares’ and ‘Tiptop’) cultivars, ‘Hildares’ (as suitable host for RK) and ‘Tiptop’ (less suitable as host for RK). The results showed that the number of galls was reduced and consequently reduced production of egg-sacs when plants were mycorrhized or treated with T. viride. Neither of the two fungi inoculated singly or together, changed general susceptibility of the cultivars. In ‘Hildares’, application of the two fungi reduced the number of galls and egg-sacs with no synergism occur between them in combined inoculation. In ‘Tiptop’, biocontrol of root-knot was not achieved. No negative interactions between the two beneficial fungi with regard to AMF root colonization or population development of T. viride in the rhizosphere.

**References**


