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Review Article

Beneficial Effects of Mycorrhizal Association for Crop Production in the Tropics - A Review

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Abstract

Mycorrhiza plays a significant role in sustainable agriculture and has mutualistic symbiotic association with plant roots. There are several species of mycorrhiza and among the species studied *Glomus mosseae* is well known to colonize several vegetables, fruits, cereals and industrial crops. This paper highlighted the symbioses and beneficial effects of arbuscular mycorrhiza fungi (AMF) with tomato (*Solanum lycopersicum*), brinjal (*S. melongena*), potato (*S. tuberosum*), lady's finger (*Abelmoschus esculentus*), cucumber (*Cucumis sativus*), bean (*Phaseolus vulgaris*), pepper (*Capsicum annuum*), wheat (*Triticum aestivum*), aerobic rice (*Oryza sativa*), corn (*Zea mays*), durian (*Durio zibethinus*), rambutan (*Nephelium lappaceum*), pineapple (*Ananas comosus*), citrus (*Citrus sinensis*), banana (*Musa acuminata*), oil palm (*Elaeis guineensis*) and kenaf (*Hibiscus cannabinus*). Application of AMF increased nutrient uptake, water relations and perform as bio-protectants against pathogens and toxic stresses. In order to further improve their benefits, it is necessary to ensure the management practices comprising low tillage, abridged use of chemical fertilizers, especially the phosphatic fertilizers.

Keywords: Mycorrhizae association; Growth; Infection; Inoculation; Symbiotic
Abbreviations: Arbuscular mycorrhizal fungi (AMF); beach ridges interspersed with swales (BRIS); ground magnesium limestone (GML); plant growth promoting rhizobacteria (PGPR); vesicular-arbuscular mycorrhiza (VAM)

Introduction

Most of the plants form symbiotic relationship with a group of fungi called mycorrhiza, which function as a bridge for the flow of energy and matter between plants and soils (Cardon and Whitbeck, 2007). The symbiotic association involves most plant species and certain fungal species which has great relevance to soil ecosystem functions, especially nutrient dynamics, microbial processes, plant ecology and agriculture. The mycorrhiza performs beneficial functions for crops, like other microorganisms such as; phosphate-solubilizing bacteria (Panhwar *et al*., 2009) and N_2 fixing bacteria (Naher *et al.,* 2009). The fungus colonizes the host plant's roots inside the cortical tissues. The association may be either intracellular like AMF, or extracellularly as in ectomycorrhizal fungi. The root infection by the mycorrhiza increases active absorptive surface area and stimulate nutrient and water up take even in water stress condition.

Mycorrhizal colonization increases disease suppression capability of the host plant. AMF occur naturally and are the important component of tropical soil system (Cardoso and Kuyper, 2006). The biomass of AMF accounted for 54-900 kg ha^{-1} (Zhu and Miller, 2003). It forms natural association with several crops including annuals, vegetables, fruit trees and also industrial crops like oil palm. Mycorrhizal colonization on various crops and their beneficial effects are well documented in many countries all over the world. Currently in Malaysia, much work has been done on selection of effective indigenous mycorrhizae and exploiting their beneficial effects for enhancing crop production. This paper briefly discusses the scope and benefits of mycorrhizal association on several vegetables, field and industrial crops.

Effect of Mycorrhizal Inoculation on Growth and Yield of Vegetables

Mycorrhizal colonization is common in tomato plants and well documented as a mycotrophic plant (Kubota *et al.*, 2005). Many studies were conducted to assess the response on seedlings of tomato with the inoculation of AMF. The inoculated seedlings showed better performance due to its higher shoot fresh weight (11.28 g $plant^{-1}$), high shoot/root ratio (0.236), higher root biomass(2.17 g $plant^{-1}$) higher relative growth rate (7.34 mg $g^{-1}day^{-1}$) and unitleafrate 1.28 mg cm^{-1} day^{-1} (Oseni *et al.*, 2010).

Several species of AMF species had positive effect on growth of tomato plant. Studies were conducted by Tahat *et al.* (2008a) using three AMF species *Glomus mosseae*,

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Scutellospora sp. and *Gigaspora margarita* on tomato plants grown on alluvial soil in Malaysia. Higher root colonization (80%), shoot (2.8 g plant^{-1}), root growth (18.56 cm^3) and spores (455/100 g soil) were obtained in *G. mosseae* inoculated plants. The plant growth improvement of tomato inoculated with mycorrhizal fungi might be associated with higher nutrient uptake, which was also reported earlier by Perner *et al.* (2007) and Aboul-Nassar (1996).

Mycorrhizal inoculation was also beneficial for lady's finger (*Abelmoschus esculentus*). Several greenhouse and field studies showed growth and yield improvement of lady's finger with mycorrhizal inoculation. The study showed that *G. mosseae* was able to colonize lady's finger and showed a synergistic effect with plant growth promoting rhizobacterial (PGPR) isolate UPMB10 (Radziah *et al.,* 2007). A significant increase in plant biomass, yield and zinc uptake of lady's finger was observed with microbial inoculation (Table 1).

AMF have been observed to improve growth of brinjal (*Solanum melongena*) (Matsubara *et al.,* 1995). Studies using multistrain biofertilizer (consisting of *G. mosseae,* P-solubilizing and N-fixing bacteria) along with reduced doses of N (75%) and P(67%) fertilizers of the recommended rate showed comparable growth and fruit yield as that of full fertilized treatment (Table 2). Similar findings were reported by Sen (2008) that a application *G. intraradices* on brinjal seedling, significantly affected the shoot length, shoot diameter, number of leaves, shoot fresh weight, shoot dry weight, root fresh weight and root dry weight. The inoculation of *Gigaspora margarita*- and *G. intraradices* on cucumber seedlings showed higher Fe concentrations in the shoots. However, both the mycorrhizae had significant effect on seedling stem diameter, leaf number, shoot height and root length and micronutrients in the leaf tissue (Tufenkci *et al.,* 2012; Rouphael *et al.,* 2010).

Gaurav *et al.* (2010) conducted a study in India, to find the effect of mycorrhiza on water stress tolerance in 34 varieties of potatoes. They found that leaf area index was increased by 60-88% and yield 32-39% with mycorrhizae application under water stress condition. Tuber deformity was decreased from 33 to 100% . In another study, Douds *et al.* (2007) found a 35-45% increase in the fresh potato tuber yield. There was a positive correlation between mycorrhizal colonization and nodule trehalose content in bean (Ballesteros-Almanza *et al.,* 2010). Inoculation of pepper (*Capsicum annuum*) with two AMF (*G. mosseae* and *G. intraradices*) species enhanced the relative water content, P, chlorophyll and carotenoid contents of (Çekic *et al.,* 2012). Aguilera-Gomez *et al.* (1999) also reported profound effect of mycorrhizal inoculation in pepper.

Table 1: Effect of AMF and PGPR inoculation on dry weights of shoot, root, fruits and Zn uptake of lady's finger

Treatment	Shoot dry weight (g plant^{-1})	Root dry weight (g plant^{-1})	Fruit (g plant^{-1})	Zn uptake (Fruit plant^{-1})
Control	47.55 b*	8.28 b	1.88 b	1.51 b
AMF	53.72 ab	12.66 a	4.27 ab	3.20 ab
UPMB10	53.33 ab	9.02 b	2.76 b	1.94 b
AMF + UPMB10	61.86 a	13.08 a	6.75 a	4.96 a

*Means in column followed by different letter(s) are significantly different at ($p \leq 0.05$) Source: Adopted from Azizul Hafiz *et al.* (2007)

Table 2: Effect of multistrain biofertilizer on the growth of brinjal in Malaysia

Treatments	Plant height (cm)	Fruit weight (g plant^{-1})
T_1) Organic (2t ha^{-1}) + (NPK@ 200-75-75) kg ha^{-1}	61.0	109.8
T_2) Biofertilizer + (NPK @150 -75-75) kg ha^{-1}	64.3	122.0
T_3) Biofertilizer + (NPK @150 -50-75) kg ha^{-1}	65.0	142.2
T_4) Organic (2t ha^{-1}) +(NPK @150 -50-75) kg ha^{-1}	61.0	134.3
T_5) Fertilizer (NPK @ 200-75-75 kg ha^{-1})	61.3	128.3

Effect of Mycorrhizal Inoculation on Growth and Yield of Field Crops

The beneficial effect of mycorrhizal colonization on many field crops has been proven. In wheat crop the mycorrhizal colonization was higher in well watered plants while lower in water-stressed plants. The AMF had a positive effect on many field crops. Mycorrhizal colonization was higher in well drained plants compared with stressed plants. Higher wheat plant biomass, grain yields with higher shoot P and Fe concentrations were recorded with mycorrhizal inoculation (Al-Karaki, 1998; 2004). The application of insoluble P was applied to rice plants inoculated with either *G. mosseae* or *G. intraradices*, showed increased P uptake. The root colonization by AMF inoculation increased (117%) in flooded condition. However, in the absence of P, shoot and root dry weight increased by 86-206%. Mycorrhizal colonization had also a major contribution in the uptake of P and K in the plants (Hajiboland *et al.,* 2009).

Aerobic rice genotypes inoculated with mycorrhizal inoculums showed high root colonization (28-57%) (Gao *et al.,* 2007). The colonization of mycorrhizal inocula with upland rice seedlings proved beneficial to achieve higher yields at optimum fertilizer dosage. Hence, it decreased the costs and environmental pollution (Rajeshkannan *et al.,* 2009). Sweet corn inoculated with AMF (*G. mosseae*) showed an increased plant biomass and plant tissue N (24.2%), P (8.4%) and K (18.2%), content (Fig. 1).

AM fungus (*G. mosseae*) grows well in acid sulfate soil. Corn plants grown on acid sulfate soil applied with different levels of ground magnesium limestone (GML) at 2, 4, 6 and 8 ton ha^{-1} with AM enhanced growth and uptake of nutrients (Fig. 2). Application of 8 ton ha^{-1} GML with mycorrhiza inoculation produced higher plant height, biomass, and N and P uptake compared to treatment without mycorrhiza. The ability of AMF in regulating the low P availability together with the high Al activity of acid sulfate soil demonstrated crucial role of AMF symbiosis in nutrient cycling especially the P.

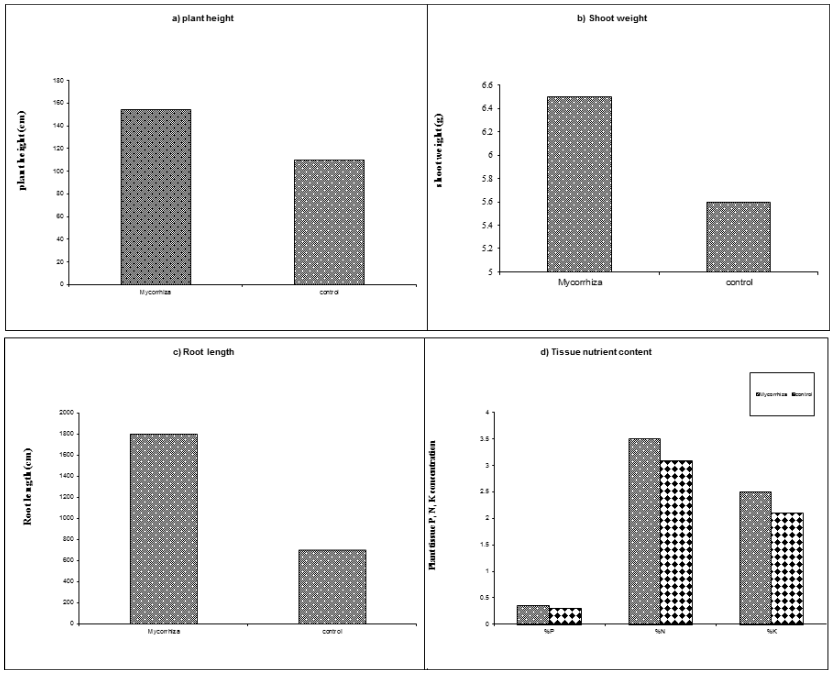

Fig. 1: Effects of *Glomus mosseae* colonization on sweet corn: (a) plant height, (b) shoot weight, (c) root length, (d) tissue nutrient concentrations. Sweet corn was grown in alluvial soil for 10 weeks

Source: Modified from Mustafa *et al.* (2010)

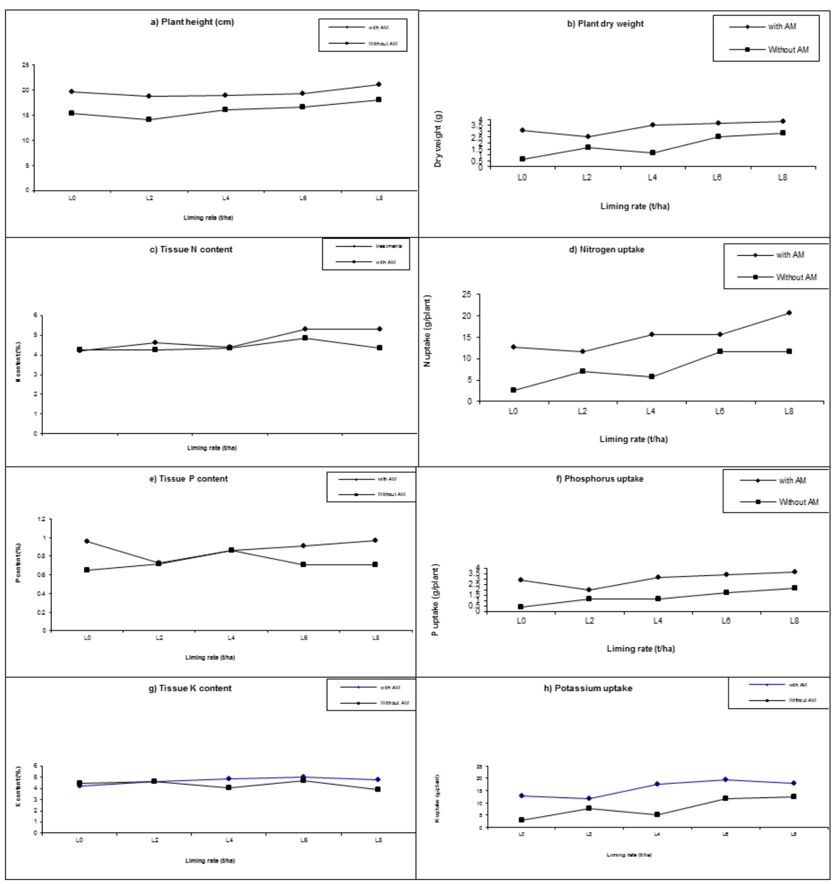

Fig. 2: Effect of different rate of liming and mycorrhiza inoculation on growth and nutrient uptake of corn: (a) plant height; (b) shoot weight, (c) tissue N, (d) N uptake, (e) tissue P, (f) P uptake, (g) tissue K, (h) K uptake

Mycorrhizal inoculation is generally accepted as substitute for the chemical fertilizers (especially phosphorus) to continuously enhance the productivity of maize crop. Mycorrhizal fungi trials perform better in terms of plant height (Shrestha *et al.,* 2009).

Furthermore, high impact of mycorrhizal inoculation on 100 seed weight and seed number per ear and grain yield of maize proved the successful symbiosis (Mobasser *et al.*, 2012). Khalil *et al.* (1992) observed marked differences in root infection of soybean by VAM fungi with a spore count of 66 to 998/100g soil. Generally, root colonization ranges from 60-100% from most soils except with very high soil P levels. The effect of AMF on plant mostly was positively related to the inoculation percentage (Sheng *et al.*, 2004). On the other hand, an increase was found in *S. viarum* medicinal plants inoculated with mycorrhiza (Hemashenpagam and Selvaraj, 2011).

Many other crops have been proven for positive growth response to AMF, however there have been genetic variation observed within plant species. The response of AMF also varied among the different cultivars of crops including *Zea mays* (Kaeppler *et al.*, 2000), *Avena sativa* (Koide *et al.*, 1988), *Hordeum vulgare* (Zhu *et al.*, 2003), *Triticum aestivum* (Zhu *et al*., 2001; Li *et al.*, 2006), tomato (Bryla and Koide, 1990a, b), soya (Bethlenfalvay *et al.*, 1989) etc.

Effect of Mycorrhizal Inoculation on Growth and Yield of Industrial Crops

Oil palm is the main industrial crop in Malaysia. Application of AMF inoculum either as single species (*Glomus* sp.) or mixed species (*Acaulospora* sp., *Gigaspora* sp., *Glomus* sp., *Scutellospora* sp.) showed better growth performance compared to that of chemical fertilizers (Fig. 3). Single AM species produced longer frond length while, significantly high pinnae number was obtained from mixed mycorrhizal inoculums. Both AM inoculums showed almost similar overall vegetative growth performance.

Even though AMF are of significance to the crops, comparatively few published reports on the interaction of AMF and oil palms were reported. Blal *et al.* (1990) showed that the coefficient of fertilizer use in micropropagated oil palms was increased 4–5-folds after inoculation with mycorrhiza, mainly when using rock phosphate. Similar findings were reported by Motta and Munévar (2005) that the inoculation of oil palm seedlings in the nursery resulted in a 3-fold growth enhance over non- inoculated plants after 570 days in natural soil substrate with no fertilizer addition.

In South East Asia, a survey on oil palm soil first of all explained a beneficial effect of mycorrhizal inoculation on oil palm (Nadarajah, 1980). The inoculation of oil palm seedlings with AMF increased plant growth and nutrient uptake of oil palm particularly P uptake enhanced by 37–44% (Widiastuti and Tahardi, 1993).

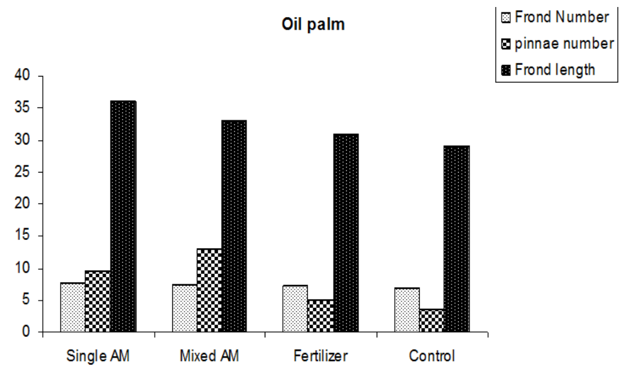

Fig. 3: Effects of AM inoculums on growth of oil palm
Source: Modified from Mohd Nazif Saifuddin *et al.* (2010)

Table 3: Effect of AM and PGPR inoculation on growth of pineapple

Treatments	Dry weight (g plant^{-1})	Number of leaves plant^{-1}	Leaf length (cm)	No of spores 10 g soil^{-1}
Control	2.08	19	16.15	0
AM	4.12	22	19.05	10
PGPR	4.95	20	22.0	0
AM + PGPR	5	20	17.02	9

AM= arbuscular mycorrhiza, PGPR = Plant growth

Kenaf is usually grown in beach ridges interspersed with swales (BRIS) marine deposit soil. This type of soil is considered a poor soil in terms of nutrient and has very low water holding capacity. Nutrient leaching is common as it is sandy. AMF play a vital role in nutrient and water deficiency management of plants grown in this soil. The AMF colonization significantly improved plant height (76.7%) and root length (40.9%) of kenaf (Fig. 4).

Effect of Mycorrhizal Inoculation on Fruit Crops

Beneficial effect of mycorrhizal inoculation found in fruit crops. The occurrence of AM fungi studied in Malaysia in two perennial fruits namely, durian (*Durio zibethinus*) and rambutan (*Nephelium lappaceum*). Higher spores were found in rambutan orchard. It is well known that AM inoculation at early stages of plant development performed better. The micropropagated banana plant inoculated at the beginning of the weaning phase showed significant growth response (Declerck *et al.,* 1994; Grant *et al.*, 2005). A glasshouse experiment was conducted to determine the effect of AMF and plant growth promoting rhizobacteria on growth and nutrient uptake of tissue cultured pineapple seedlings (Table 3). There was no significant difference for N uptake, however, significant difference for P uptake. A high P uptake was found in mycorrhizal inoculated treatments. Various glasshouse and field experiments proved that inoculation with AMF enhanced the growth and ion uptake in citrus plants, and improved tolerance to drought and salt stress and also the quality of fruit (Wu and Zou, 2009; Wu *et al.,* 2010a, b). Moreover, it is reported

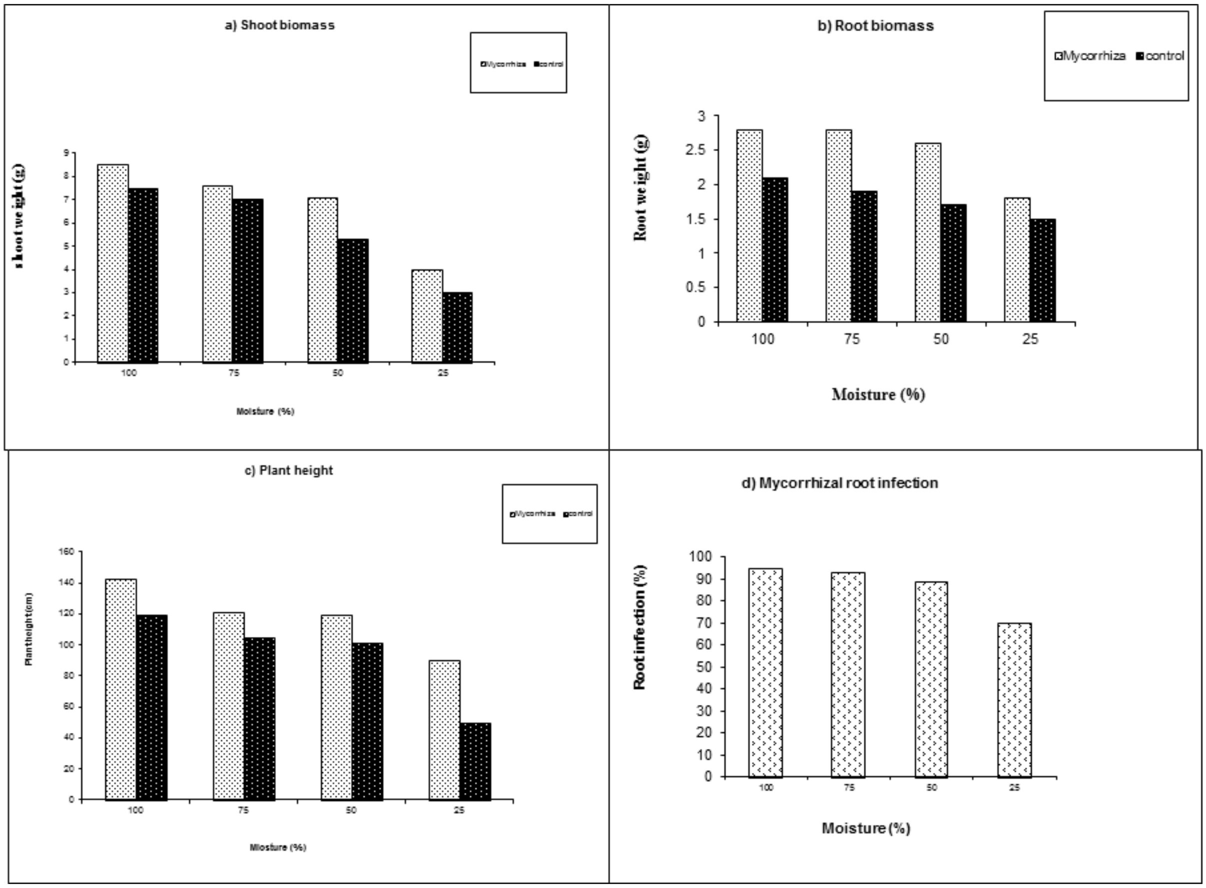

Fig. 4: Effect of mycorrhizal colonization in kenaf plant with different moisture levels grown on BRIS soil: (a) shoot biomass, (b) root biomass, (c) plant height, (d) mycorrhizal root infection

that the symbiosis of AMF in trifoliate orange enhanced the soluble sugar and leaf chlorophyll content. However, one-layer mycorrhizal inoculation was the best for mycorrhization of trifoliate orange (Wu and Zou, 2012).

Potential of Mycorrhiza as Biocontrol Agent

The biocontrol system in plants can be described as the management of frequent components to protect plants against pathogens. A number of findings showed that mycorrhizal inoculation directly or indirectly increased plant defense against pathogen. AMF inoculation improved plant nutrition; compensated the root damage and changed mycorrhizosphere microbial populations and augmented activation of plant defense mechanisms (Hooker *et al.,* 1994; Linderman, 1994). AM inoculated plant generated various compounds such as phytoalexins, enzymes of the phenylpropanoid pathway, chitinases, β-1,3-glucanases, peroxidases, pathogenesis-related (PR) proteins, callose, hydroxyproline-rich glycoproteins (HRGP) and phenolics (Bowles, 1990; Gianinazzi-Pearson *et al.,* 1994). These compounds are related to plant defense mechanisms. AMF initiated host defense responses which were subsequently suppressed disease infestations. A report by Gianinazzi and Gianinazzi-Pearson (1992) showed that there was a minor change in the accumulation of defense-related transcriptions in *G. intraradices* colonized roots compared to un-inoculated controls. However, peroxidase activity concerned with epidermal and hypodermal cells was enhanced in mycorrhizal roots, which could be a mechanism for higher resistance to root pathogens. The enhanced lignification of root endodermal cells by AMF colonization has been recorded (Dehne, 1979). Nevertheless, AMF symbiosis-specific genes control the expression of the genes concerned to plant defense during the establishment of AMF (Gianinazzi-Pearson *et al.,* 1994; 1995; 1996).

AMF are the main components of many plant rhizosphere and play an important role in decreasing plant disease (Akhtar and Siddiqui, 2008). The application of AMF as a biocontrol agent performed a vital role in plant resistance and display greater potential to protect bean plants against the infection with *F. solani* (Al-Askar and Rashad, 2010). *Ralstonia solanacerum* is a causal agent of bacterial wilt disease in many vegetable crops including tomato (Vailleau *et al.,* 2007). Tomato plants inoculated with *G. mosseae* reduced infestation of *R. Solanacerum.* Moreover, the positive results of *G. etinicatunium* and *G.*

margarita spores were found against the *Verticillilum* disease in brinjal (Matsubara *et al.,* 1995).

AMF are able to grow with *Trichoderma harzianum*, which is known as a bio-enhancer and have potential to suppress many diseases of oil palm. Results showed that, although, *T. harzianum* infused-compost (TC) gave highest yield, these mixed inoculum (TC and AMF) produced higher yield than AMF alone (Table 4).

Table 4: Effect of mycorrhiza and *Trichoderma harzianum* inoculation on oil palm growth

Treatments	Girth (cm)	Frond number	Frond length (cm)	Pinnae number
Control	28.4d	12.5b	154.2	58d
T. harzianum	80.2a	20.3a	193.5	112.3a
Glomus sp.)	60 c	15.99c	148.2	83.9c
T. harzianum + Glomus sp.)	72.3b	19b	173.2	98b

Means in column followed by different letter(s) are significantly different at (p≤ 0.05) Source: Adopted from Mohd Nazif Saifuddin *et al.* (2010)

Effect of P Nutrition on Mycorrhizal Infection

The possible factor that can affect AMF root colonization with plant is the P status. Increased P concentration in soil solution decreased mycorrhizal association, spore production and formation of secondary external hyphae (Menge *et al.,* 1978; Bruce *et al.,* 1994; De Miranda and Harris, 1994; Lu *et al.,* 1994; Valentine *et al.,* 2001). There are many evidences that mycorrhizal plants can absorb more P if lower P concentration exists in the soil solution. The AMF hyphae diameter may be a possible mechanism in this process. Barber (1984) explained that the radius of hyphae was much smaller than that of roots hairs and capable to absorb in low soil solution P.

High phosphorus status in the plant root tissue also reduced secretion of signal molecules that are responsible for hyphal branching and mycorrhizal association (Nagahashi and Douds, 2000). Moreover, cell phospholipids influencing membrane permeability and release of carbon compound that is essential for mycorrhizal colonization (Graham *et al.,* 1981; Schwab *et al.,* 1991). Muthukumar and Udaiyan (2000) reported that soluble carbon in cowpea root was increased with decreasing tissue P levels. However, increased P concentration reduced extra-radical mycelium less than colonization (Olsson *et al.,* 1999). Miller *et al.* (1995) found that application of P fertilizer does not always reduce mycorrhizal colonization. Factors reduced soil solution P influenced mycorrhizal association and noticeably high mycorrhizal association was found in soils with high P fixing capacity (Fardeau, 1998).

It is well understood that application of higher P levels hampers mycorrhizal formation (Bolan *et al.,* 1984) and in some plants the mycorrhizal benefits can be annulled. Wood (1992) recorded some limitations of P and suggested 5 ppm Olsen P as a common lowest amount generally promoted mycorrhizal colonization. However, mycorrhizal colonization of roots declined quickly as P levels rose from 5 to 10 ppm. Though, Stribley *et al.* (1980) proposed the mycorrhizal effect in the highly mycorrhizal dependent leek plant was not negated at 200 ppm Olsen P in the soil solution. In general, higher rates of the P fertilizer application to the crops showed reverse effect of mycorrhiza (Phosri *et al.,* 2010); e.g., barley at 83 kg Clarke and Mosse (1981), maize at 50 kg (McGonigle *et al.,* 1990) and soyabean 176 kg (Ross, 1971) of P ha^{-1}, respectively.

AMF Inoculums Production

There are still several problems faced in the production of AMF inoculum on the commercial scale. Selection of suitable host is important in ensuring high propagule production in a short period of time. *G. mosseae* is the most common mycorrhiza adapted in tropical soil and it can form mutual association with different crops. A number of plant species were selected for the multiplication of *G. mosseae*. At 75 days of growth the highest number of AMF spores was found in corn as the host plant (Tahat *et al.,* 2008b). Nadarajah and Nawawi (1990) observed a significant correlation between root colonization and spore density. A high spore density of 400-4000 100 g^{-1} in dried rubber soil was found in Srilanka (Jayaratne and Waidyanatha, 1982).

Conclusion

AMF colonized with several cereal, vegetables, fruits and industrial crops. Among the species studied, *G. mosseae* showed better colonization and improved plant growth, yield, nutrient uptake, water use efficiency and disease resistance. However, mycorrhizae exhibited better performance in low P added soil.

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