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AGRICULTURE

ARBUSCULAR MYCORRHIZAL FUNGI ON GROWTH, FRUIT YIELD, AND QUALITY OF CHERRY TOMATO UNDER GLASSHOUSE CONDITIONS

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Abstract

The effects of arbuscular mycorrhizal fungi (AMF) on growth, flower, fruit production, and fruit quality on Cherry tomato plants (*Solanum lycopersicum* L.) were studied under glasshouse conditions. This is to find out the most promising AMF that could promote the growth and yield of Cherry tomatoes. The inoculation of 7 AMF indigenous species; *Glomus* sp.1, *Glomus* sp.2, *Glomus* sp.3, *Glomus mosseae*, *Acaulospora* sp.1, *Entrophospora schenckii*, *Scutellospora fulgida*, and distilled water as a control were performed on Cherry tomatoes. The single spores of mycorrhizal fungi were collected using the pot maize technique. Results showed that all AMF species were able to colonize on tomato roots. The *Glomus mosseae* gave the highest growth and fruit quality compared with all other treatments. *G. mosseae* could increase the height up to 79.04 cm on the 66th day after planting and the flowers numbered 67.5 flowers per plant. Finally it gave fruits numbered at 24.0 fruit per plant on the 87th day after planting. Furthermore, *G. mosseae* gave a significantly higher fruit weight and fruit diameter at 21.36 g per fruit and 31.53 mm per fruit, respectively. In addition, the quality of fruit and total soluble solid and ascorbic acid were 5.75 % brix and 272 mg per 100 g, respectively, which were also significantly higher than other species.

Keywords: Arbuscular mycorrhizal fungi, *Glomus mosseae*, Cherry tomato, growth, yield

Introduction

AMF have an important role in plant communities. They can promote crop yield by improving soil aggregation and modifying the rhizosphere of adverse soil conditions (Na Bhadalung, 2005). Plants with AMF can increase the uptake of macronutrients, such as N, P, K, and Mg (Smith and Read, 1997: Clark and Zeto, 2000; Hodge *et al*., 2001). The tomato which is known to be a mycorrhizal crop can benefit f rom mycorrhizal association. AMF can promote plant growth, shoot dry weight, and better root morphology (Berta *et al*., 1993; Manian *et al*., 1995; Sylvia

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et al., 2001). *Glomus mosseae* significantly increased shoot dry weight, flower numbers, and root growth of sweet corn and tomato (Tahat *et al*., 2008; Mustafa *et al*., 2010). Furthermore, a higher significance of plant growth of the tomato was found seven weeks after planting (Tahat *et al*., 2008). Although many AMF species can colonize the roots of the tomato plant, the ones that best promote growth and yield should be studied. AMF such as *G. aggregatum*, *G. mosseae*, and *G. versiforme* can improve yield as well as N, P, and K uptake of *Solanum* cultivars. Knowledge of the best symbiotic partner could be a very promising solution toward the sustainability of *Solanum* cultivars (Diop *et al*., 2003).

In Thailand the Cherry tomato (*Solanum lycopersicum* L.) is an economic crop for papaya salad. Unfortunately, this tomato is mainly grown in dry areas. Hence, the objectives of this research were to evaluate the effect of different AMF species on growth, fruit yield, and fruit quality of the Cherry tomato as grown under glasshouse conditions. The purpose is to select the best AMF that can improve the water situation and can also increase the drought resistance of the Cherry tomato that will be grown in the field.

Material and Methods

AMF Production

This study was conducted during September 2009 to January 2010 at Suranaree University of Technology Farm, Nakhon Ratchasima, Thailand. Single spores of 7 species of mycorrhizal fungi were collected using the pot maize technique, then the reculturing of *Glomus* sp.1, *Glomus* sp.2, *Glomus* sp.3, *G. mosseae*, *Acaulospora* sp.1, *Entrophospora schenckii*, and *Scutellospora fulgida* was carried out (Na Bhadalung, 2005). Distilled water was added daily to the soil surface and nutrient solution for 2 weeks. The inoculums of each AMF species were separated from the soil by using sieves and decanting techniques. One hundred grams of soil were collected and mixed with water. The mixture was poured through 250, 125, and 45 μm sieves followed by adding modified sucrose. Then the mixture was centrifuged (Daniels and Skipper, 1982). After that the spores were washed on a sieve several times and then the spores were transferred to a Petri dish. Then the spores were counted under a binocular-microscope (Gerdemann and Nicolson, 1963). The spores were tested for mycorrhizal colonization at the end of 3 weeks after inoculation and the spores were collected 3 months later.

Soil Preparation

The experimental soil was a loam soil with the pH of 7.45. It had an electrical conductivity of 503 μSm/cm and a high organic carbon status (11.02%). It contained N, P, K, and Ca of 27.6, 0.1532, 2.02, and 3.88 g kg^{-1}, respectively. Plastic pots (12 inch in diameter) were filled with experimental soil and cattle manure 1:1 (v:v). The soil mixture was sterilized for 15 days by using Dazomet (tetrahydro-3,5-dimethyl-1, 3, 5-thai diazed-2-thione) at the rate of 60 g per 100 kg^{-1} of soil and left for 15 days before planting.

Experimental Design

A pot experiment using a randomized complete block design (RCBD) with 8 treatments and 4 replications (5 plants per replication) was conducted on the Cherry tomato. The treatments were performed through the inoculation of *Glomus* sp.1 (GS1), *Glomus* sp.2 (GS2), *Glomus* sp.3 (GS3), *G. mosseae* (GM), *Acaulospora* sp1. (AS), *E. schenckii* (ES), and *S. fulgida* (SF), and distilled water as a control was sprayed.

Tomato Plant

Commercial Cherry tomato seeds were surface sterilized by immersion in 70% alcohol for 5 min, and rinsed 4 times with distilled water before being germinated on sterilized tissue paper in the Petri dishes. After 1-2 weeks, seedlings were transferred with 1 seedling per pot, 5 seedlings per replication. The pots contained mycorrhizal fungi spores which were obtained from maize culture pots. Fifty spores

per 100 g of dry soil were collected from the maize pots. The Cherry tomato roots were tested for mycorrhizal colonization at the end of 4 weeks after inoculation (28 days after sowing).

Root Colonization (%)

The roots of the sample plants were washed and cut into lengths of 1 cm. Then 30 root cuttings were sub-sampled and put in 10% KOH. Then 0.05% trypan blue in lactophenol was used to stain the samples (Phillips and Hayman, 1970). The percentage of root colonization was evaluated by counting the mycorrhizal infection under a microscope. The percentage of AMF root colonized was calculated by the following formula:

$$\% \text{ colonization (M)} = \frac{95(n_5)+70(n_4)+30(n_3)+5(n_2)+n_1}{n}$$

where n is the number of observed roots, n_1 is the number of roots that showed <1% of infection, n_2 is the number of roots that showed <10% of infection, n_3 is the number of roots that showed 11-50% of infection, n_4 is the number of roots that showed 51-90% of infection, and n_5 is the number of roots that showed >90% of infection (Trouvelot *et al.*, 1986).

Growth Attributes and Reproductive Behavior

The plant height, the number of flowers per plant, the number of fruits per plant, and the fruit yield were examined. The plant heights were recorded 4 times during the growing season, starting from 45-50 days after planting (DAP). Flowers were counted when 50% of the tomato plants flowered. Fruit yields were recorded after harvesting.

Biomass Production

When the plants were 120 days old, their shoots and roots were separated and dried in the oven for 2 days at 60°C. Then the dry weight of the shoots and roots was measured.

Determination of Ascorbic Acid and Total Soluble Solid

Ten g fresh weight of Cherry tomato was homogenized in 20 ml of meta-phosphoric acid (MPA) with a mortar. The juice was made up to 100 ml using MPA and then the juice was filtered through paper. Five ml of juice was pipetted and 10 ml of 2, 6 dichloroindophenol dye (0.02%) was added to the juice until it turned to a permanent pink. Then the juice was measured for 15-20 sec at the absorbance of 518 nm by using a Genesys TM 5 spectrophotometer. A similar method was used on a standard ascorbic acid solution (100 mg ascorbic acid in 100 ml of MPA). This was to compare with the ascorbic acid content in the sample juice. The total amount of soluble solid was measured using a hand refractometer. The % brix of the samples was recorded.

Statistical Analysis

The analysis of variance (ANOVA) was performed using SPSS 14.0 software and

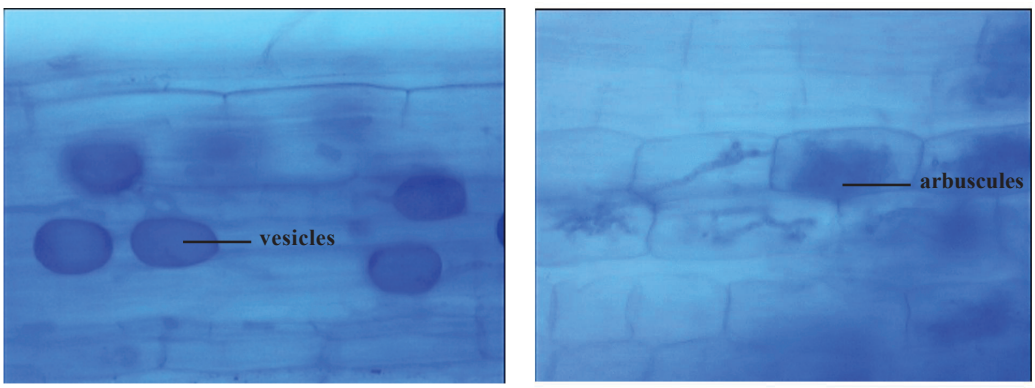

Figure 1. Root colonized by *Glomus mosseae* mycorrhizal fungi species in tomato root

Duncan's Multiple Rang Test (DMRT) was used to compare the differences between means (Levesque and SPSS Inc., 2006).

Results and Discussion

Effects on Growth and Reproductive Behavior:

Mycorrhizal Colonization

All of the AMF species studied were able to colonize Cherry tomato roots. This may due to the root of Cherry tomatoes exudating nutrient solutions such as carbohydrates, amino acids, and glucose that enhance spore germination and spore density in such low nutrient soils as Serdang series soil (Tahat *et al.*, 2008). The AMF showed significant differences in colonizing the Cherry tomato roots (Figure 1). The highest percentage of colonization was *Glomus* sp.3 (68.86%) followed by *E. schenckii* (68.16%), *Glomus* sp.2 (62.80%), *Glomus* sp.1 (61.48%), *Acaulospora* sp.1 (60.26%), *S. fulgida* (59.46%), and *G. mosseae* (58.65%), respectively, while the control showed no colonization (Table 1).

Plant Height

Growth showed statistically significant differences at 45, 52, and 59 DAP. However, at 66 DAP, all plants accelerated in growth. Therefore, at the end there were no significant differences among treatments with regard to the mean height of the Cherry tomatoes. Although the tomato inoculated with *G. mosseae* showed no statistically significant difference to the tomatoes inoculated with *Glomus* sp.1, the *G. mosseae* treated plants gave the highest plant height of 30.75, 43.17, 62.08, and 79.04 cm at 45, 52, 59, and 66 DAP, respectively (Table 1). The *G. mosseae* inoculated plants gave higher growth, yield, and fruit quality than the other species treated. These plants had a high photosynthetic rate (Tahat *et al*., 2008) which leads to an increase in fresh weight. The results were confirmed by the report of Rahman *et al*. (2006) that *G. mosseae* with P (120 kg P/ha) increased plant height, root dry weight, shoot dry weight, and Nand P contents in maize plants.

Numbers of Flowers and Fruits

The numbers of the flowers and fruits were recorded at the end of the experiment. There were highly significant differences in the number of flowers and the number of fruits per plant. Although the tomato inoculated with *G. mosseae* showed no statistically significant difference between the tomatoes inoculated with *Glomus* sp.2, *Glomus* sp.3, *Acaulospora* sp.1, *S. fulgida*, and the control, the tomato inoculated with *G. mosseae* gave the highest numbers of flowers and fruits per plant at 66, 73, 80, and 87 DAP, while *Glomus* sp.1 and *E. schenckii* gave the lowest numbers of flowers and fruits per plant when compared with all other treatments at 66,

Table 1. The effects of different mycorrhizal species on AMF colonization (%) and plant height at 45, 52, 59, and 66 days after planting

Treatments	AM colonization (%)	Plant height (cm)*			
		45	52	59	66
		.....(DAP).....			
Control	0 ^{e}	27.0 ^{bc}	39.83 ^{abc}	57.95 ^{b}	73.08
Glomus sp.1	61.48 ^{bc}	28.5 ^{ab}	40.50 ^{ab}	53.79 ^{cd}	68.08
Glomus sp.2	62.80 ^{b}	20.75 ^{e}	34.42 ^{c}	57.75 ^{bc}	74.92
Glomus sp.3	68.86 ^{a}	22.08 ^{de}	36.08 ^{bc}	57.08 ^{bc}	73.59
Glomus mosseae	58.65 ^{d}	30.75 ^{a}	43.17 ^{a}	62.08 ^{a}	79.04
Acaulospora sp.1	60.26 ^{cd}	25.25 ^{cd}	36.92 ^{bc}	56.77 ^{bc}	73.42
Entrophosapora schenckii	68.16 ^{a}	27.00 ^{bc}	38.84 ^{abc}	52.87 ^{d}	69.17
Scutellospora fulgida	59.46 ^{cd}	22.33 ^{de}	37.17 ^{bc}	60.25 ^{ab}	75.00
CV (%)	2.74	6.11	6.54	3.25	6.89

* Means within a followed by the same letter are not significantly different at $P < 0.01$ according to DMRT.

73, 80, and 87 DAP (Tables 2 and 3). The numbers of flowers and fruits per plant of tomatoes inoculated by *G. mosseae* were related to each other. These results were confirmed by the study of Tahat *et al*. (2008) which reported that *G. mosseae* significantly increased the flowers numbered at 23.75 flowers per plant, shoot dry weight at 2.82 g, and the root growth of tomatoes. In addition, the mycorrhizal infected plants can increase flower production such as in pepper (Dodd *et al*., 1983), in soybean (*Glycine max*), and in pelargonium (Schenck and Smith, 1982 and Perner *et al*., 2007). In the experiment, *E. schenckii* and *Glomus* sp.1 were not effective to promote growth of Cherry tomato. The results were confirmed by Na Bhadalung (2005) who found that *Acaulospora* sp.1, *E. schenckii*, *S. fulgida*, and *Glomus* sp.1 tended to decrease plant growth in all measurement periods. Klironomos (2003) indicated that plant growth responses to mycorrhizal inoculation within an ecosystem could be from its being highly parasitic to highly mutualistic.

Root Dry Weight

Root dry weight showed statistically significant differences between treatments while there were no significant differences in shoot dry weight. This may be because of the high nutrient of the soil and high soil moisture used in this experiment. In general, AMF promote plant growth and nutrient uptake in soil

Table 2. The effects of different AMF species on the number of flowers per plant at 66, 73, 80, and 87 days after planting

Treatments	The number of flowers per plant*			
	66	73	80	87
	.....(DAP).....			
Control	39.95 ^{bcd}	52.35 ^{a}	57.95 ^{b}	56.00 ^{ab}
Glomus sp.1	30.08 ^{d}	34.08 ^{b}	53.79 ^{cd}	38.12 ^{b}
Glomus sp.2	45.54 ^{ab}	59.17 ^{a}	57.75 ^{b}	62.08 ^{ab}
Glomus sp.3	42.04 ^{abc}	60.37 ^{a}	57.08 ^{bc}	64.75 ^{ab}
Glomus mosseae	51.95 ^{a}	68.62 ^{a}	62.08 ^{a}	67.50 ^{ab}
Acaulospora sp.1	42.66 ^{abc}	64.79 ^{a}	56.77 ^{bc}	68.83 ^{a}
Entrophosapora schenckii	34.16 ^{cd}	35.41 ^{b}	52.87 ^{d}	44.16 ^{ab}
Scutellospora fulgida	49.12 ^{ab}	64.54 ^{a}	60.25 ^{ab}	67.87 ^{ab}
CV (%)	11.48	13.76	16.18	18.21

* Means within a followed by the same letter are not significantly different at $P < 0.01$according to DMRT.

Table 3. The effects of different AMF species on the number of fruits per plant at 66, 73, 80, and 87 days after planting

Treatments	The number of flowers per plant*			
	66	73	80	87
	.....(DAP).....			
Control	8.12 ^{bc}	16.00 ^{ab}	21.87 ^{a}	20.25 ^{ab}
Glomus sp.1	5.87 ^{d}	12.00 ^{bc}	14.50 ^{b}	14.75 ^{b}
Glomus sp.2	7.95 ^{bc}	16.00 ^{ab}	23.18 ^{a}	22.60 ^{a}
Glomus sp.3	7.41 ^{bcd}	16.87 ^{ab}	21.75 ^{a}	21.25 ^{ab}
Glomus mosseae	10.58 ^{a}	21.83 ^{a}	24.62 ^{a}	24.00 ^{a}
Acaulospora sp.1	7.00 ^{cd}	18.41 ^{a}	23.20 ^{a}	22.75 ^{a}
Entrophosapora schenckii	7.00 ^{cd}	9.45 ^{c}	15.33 ^{b}	17.00 ^{ab}
Scutellospora fulgida	9.12 ^{ab}	18.50 ^{a}	23.20 ^{a}	22.25 ^{a}
CV (%)	10.69	16.62	13.94	16.50

* Means within a followed by the same letter are not significantly different at $P < 0.01$according to DMRT.

of low fertility (Smith and Gianinazzi-Pearson, 1988; Marschner, 1995). Although the tomatoes inoculated with *Glomus* sp.2 showed no statistically significant differences compared with tomatoes inoculated with *Glomus* sp.3, *G. mosseae*, *Acaulospora* sp.1, *E. schenckii*, and *S. fulgida*, the plants inoculated with *Glomus* sp.2 gave the highest root dry weight by 46.53% when compared with the plants inoculated with *Glomus* sp.1 and the control (Table 4).

Fruit Yield

Fruit yield showed highly significant differences between treatments. Although the tomato inoculated with *G. mosseae* showed no statistically significant differences to the tomatoes inoculated with *Glomus* sp.2, *Glomus* sp.3, *Acaulospora* sp.1, *E. schenckii*, *S. fulgida*, and the control, the *G. mosseae* gave the highest fruit yield of 248 g plant^{-1} when compared with all other treatments (Table 4). AMF are known to increase the supply of available P and other immobile nutrients by translocating them from the soil through their hyphae to the plants (Hatting *et al*., 1973; Plenchette *et al.*, 2005).

Quality of Tomato Fruits:

Fruit Weight and Diameter

Inoculated tomatoes showed highly significant differences in fruit weight and fruit diameter. Although tomatoes inoculated with *G. mosseae* showed no statistically significant differences to tomatoes inoculated with *Glomus* sp.2, *Glomus* sp.3, *Acaulospora* sp.1, *E. schenckii*, and *S. fulgida*, the *G. mosseae* treated plants gave the highest fruit weight and fruit diameter of 21.36 g fruit^{-1} and 31.53 mm fruit^{-1}, respectively (Table 4).

Total Soluble Solid

Percent brix showed highly significant differences between the treatments. Although tomatos inoculated with *G. mosseae* showed no statistically significant differences to tomatoes inoculated with *Glomus* sp.1, *Glomus* sp.2, *Glomus* sp.3, *Acaulospora* sp.1, *E. schenckii*, and *S. fulgida*, the *G. mosseae* treated plants gave the highest %brix at an average of 88.69% when compared with the control (Table 4).

Ascorbic Acid

Ascorbic acid showed highly significant differences between treatments. Although tomatoes inoculated with *G. mosseae* showed no statistically significant differences to tomatoes inoculated with *Glomus* sp.2, *Acaulospora* sp.1, and *S. fulgida*, plants inoculation with *G. mosseae* showed the highest ascorbic acid at a rate of 81.88% when compared with *Glomus* sp.1 and *Glomus* sp.3 treated tomatoes (Table 4). The *G. mosseae* improved yield and quality of Cherry tomato fruit by increasing fruit weight, fruit diameter, ascorbic acid, and total soluble solids

Table 4. The effects of AMF on root and shoot dry weight, fruit yields, the number of spores, fruit weight, fruit diameter, total soluble solids, and ascorbic acid on tomatoes at 120 days after planting

Treatments	Dry weight (g plant^{-1})		Fruits yield (g plant^{-1})	No. spores	Fruits weight (g fruit^{-1})	Fruits diameter (mm fruit^{-1})	Total soluble (%brix)	Ascorbic acid (mg 100 g^{-1})
	Shoot	Root						
Control	7.737	0.805 ^{b}	196.8 ^{ab}	0.0 ^{f}	16.17 ^{bc}	27.47 ^{bc}	5.10 ^{b}	241.6 ^{bc}
Glomus sp.1	8.428	0.720 ^{b}	124.9 ^{b}	15.0 ^{e}	13.03 ^{c}	26.04 ^{c}	5.35 ^{ab}	222.7 ^{cd}
Glomus sp.2	12.880	1.730 ^{a}	233.8 ^{a}	214.0 ^{a}	15.71 ^{bc}	28.21 ^{abc}	5.70 ^{a}	263.7 ^{a}
Glomus sp.3	11.405	1.212 ^{ab}	227.5 ^{ab}	39.0 ^{d}	17.01 ^{abc}	29.96 ^{ab}	5.65 ^{a}	220.5 ^{d}
Glomus mosseae	12.608	1.408 ^{ab}	248.0 ^{a}	14.5 ^{e}	21.36 ^{a}	31.53 ^{a}	5.75 ^{a}	272.0 ^{a}
Acaulospora sp.1	11.508	1.322 ^{ab}	213.6 ^{ab}	211.75 ^{a}	18.80 ^{ab}	30.43 ^{ab}	5.72 ^{a}	268.0 ^{a}
Entrophosapora schenckii	10.117	1.135 ^{ab}	169.3 ^{ab}	129.75 ^{c}	17.97 ^{ab}	30.12 ^{ab}	5.42 ^{ab}	214.2 ^{d}
Scutellospora fulgida	10.704	1.398 ^{ab}	197.5 ^{ab}	171.75 ^{b}	20.33 ^{ab}	30.69 ^{ab}	5.67 ^{a}	257.0 ^{ab}
C.V.(%)	16.10	16.25	11.92	13.06	12.76	6.08	3.37	4.09

* Means with in a followed by the same letter are not significantly different at $P < 0.01$ according to DMRT.

in the fruit. Mycorrhizal plants can translocate considerable amounts of monocalcium phosphate and P uptake to the fruits (Subramanian *et al*., 2006).

The results suggested that there should be benefits of improved growth, yield, and quality of Cherry tomato fruit by using specific AMF. In addition, AMF can improve the plant-water relationship thus increasing the drought resistance of the host plants. Ruiz-Lozano *et al*. (1995) showed that AMF species could induce drought tolerance as follows: *G. deserticola* > *G. fasciculatum* > *G. mosseae* > *G. etunicatum* > *G. intraradices* > *G. caledonium* > *G. occultum*, respectively. The ability of AMF to induce drought tolerance in plants is of great interest. In this experiment, *G.mosseae* gave higher growth, more flowers, greater fruit production, and fruit quality than the other species studied. Thus, *G. mosseae* is very promising and it will be worth trying it in our next drought tolerance experiment under field conditions.

Conclusions

All of the AMF studied were able to colonize Cherry tomato roots. AMF colonization improved growth and yield of Cherry tomatoes. The endogenous species, *G. mosseae* gave the higher growth, number of flowers, fruit production, and fruit quality than the other species studied. Furthermore *G. mosseae* gave positive effects of AM symbiosis with Cherry tomatoes grown in glasshouse conditions.

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