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Selection for the Effective Species of Vesicular-Arbuscular Mycorrhizal Fungi on Soybean Root Infection and Growth Enhancement

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ABSTRACT

The selection for the effective species of vesicular-arbuscular mycorrhizal fungi (VAMF) was conducted in the greenhouse of Soil Science Department, Kasetsart University at Kamphaengsaen Campus. Nine VAMF species, from pot production in Yangtalard soil, consisted of *Acaulospora dilatata, Acaulospora scrobiculata, Entrophospora colombiana, Gigaspora* sp. No 2, *Glomus aggregatum, G. claroideum, G. geosporium, G. tenuis* and *Scutellospora* sp. were inoculated to SJ5 soybeans grown in a 6–litre clay pots with sterilized sand medium. The results revealed that various VAMF had different abilities to infect soybean roots. The VAMF species having fast infection rate and high intensities of root colonization were *E. colombiana, A. scrobiculata, G. aggregatum, G. geosporium* and *Scutellospora* sp. The intensities of root colonization were 96.75, 95.25, 93.75, 90.50 and 89.25 %, respectively. The ability of VAMF on hyphal development in soil were differed among species. *G. aggregatum, G. geosporium, Scutellospora* sp. and *E. colombiana* had greater hyphal development than the rest while their lengths of extraradical hyphae at harvest period were 168.33, 137.37, 134.85 and 128.90 cm, respectively. Finally, high yield and high mycorrhizal dependency were found in plants inoculated with *Scutellospora* sp., *E. colombiana, G. aggregatum* and *G. geosporium*. These VAMF species showed high potential to enhance soybean growth and should be further examined with different levels and kinds of phosphorus fertilizer in various conditions.

Key words: extraradical hyphae, root infection, soybean, vesicular-arbuscular mycorrhizal fungi.

INTRODUCTION

Vesicular-arbuscular mycorrhizal fungi (VAMF) is one of the most interesting soil microorganisms which can solubilize fixed phosphate and retentive phosphate in soil. Through observation, it was found that VAMF enhanced plant growth and P uptake particularly in the soil with low to moderate P level (Schenck, 1982; Bolan, 1991). In certain soils with high level of P, positive relations between VAMF and plant growth were also found (Kiernan *et al*; 1984., Mala *et al*., 1997). However, many species of VAMF can not enhance plant growth and P uptake of plant even in low fertile soils, mainly due to some limiting conditions appearing in the soils. The quantity of available P is one of the important factors which limits the efficiency of VAMF. The mechanisms for acquisition of P and other mineral nutrients in their deficient soils, drought tolerance and protection

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of plant root from destruction by pathogen of mycorrhizal plants are described (Bolan, 1991). Therefore, the compatibility among certain soil environment, plants and VAMF species must be realized in order to acquire appropriate benefit from VAMF-plant association. VAMF are differed in their responses to phosphate application, produce different amounts of hyphae in the soil even at the same phosphate treatment (De Miranda and Harris, 1994). Most of VAMF species decrease their abilities on infecting plant roots with increasing phosphate application but some species can tolerate and show high activity even in high phosphate conditions (Marschner and Dell, 1994). The study on various VAMF species and levels of rock phosphate which are suitable for the application to some soils in order to obtain maximum return from individual plant cultivation is highly recommended. The objective of this experiment is to compare the effectiveness of selected VAMF species on soybean growth enhancement.

MATERIALS AND METHODS

The experiment was conducted in the greenhouse of Soil Science Department, Kasetsart University at Kamphaengsaen Campus using completely randomized design with 4 replications. Treatments consisted of soybean plants grown in six-litre clay pots without VAMF(control) and nine other species of VAMF; *Acaulospora dilatata*, *Acaulospora scrobiculata*, *Entrophospora colombiana*, *Gigaspora* sp. No 2., *Glomus aggregatum*, *G. clariodeum*, *G. geosporium*, *G. tenuis* and *Scutellospora* sp. Before starting the experiment, the surface of every 6-litre clay pot was cleaned and sterilized using 70 % ethyl alcohol. Seven kilograms of sterilized sand for individual pot was prepared. Inoculums of VAMF were prepared in sterilized Yangtalard soil as described by Mala *et al*.(1997). Individual species of mycorrhiza was inoculated into the soil by mixing 1,000 ml of soil with 200 ml of inoculum. The mixture of inoculum (inoculum layer) was spreaded and pressed down into the pot, then, 600 ml of the remaining soil was topped over the inoculum layer, leveled and pressed down. Sterilized inoculum was used in the control treatment.

Four-surface sterilized SJ5 soybean seeds were sowed at 2 cm deep under the soil surface. Water and nutrient solution were alternatively applied (Asher, 1975). One plant per pot was left after 2-week emergence in the greenhouse until harvest. Insecticide (monocrotophos) was sprayed twice at 6 and 10 weeks after planting. The percentage of mycorrhizal root infection using Grideline Intersect Method (Shenck, 1982; Giovanetti and Mosse, 1980), length of extraradical hyphae (Bethlenfalvay and Ames, 1987) and plant height were determined both at 6 weeks after planting and at harvest time. Measurement of stem, root dry weight, yield and yield component were also conducted. Mycorrhizal dependency on soybean yield (MDSY) were determined according to Plenchette *et al*. (1983) as follows:

$$MDSY = \frac{Yi - Yo}{Yo}$$

where Yi = yield of VAMF inoculated soybean;
Yo = yield of control soybean.

Data were analyzed using analysis of variance procedure and the significance between average means were compared using Duncan's new multiple range test at 95 % confidence.

RESULTS AND DISCUSSION

Colonization of VAMF on SJ5 soybean root

Colonization of VAMF on the root is the first indication of relationships between the two symbionts. The fungal structures in root and soil of various VAMF were illustrated in Figure 1. In

contrast, there was not any structure of VAMF infected to plant root in control plant (Figure 1-a). There were many types of structures such as intraradical hyphae, arbuscules, vesicles, resting spores and extraradical hyphae when plants were inoculated with *A. dilatata*, *A. scrobiculata*, *E. colombiana*, *G. aggregatum*, *G. claroideum*, *G. geosporium* and *G. tenuis* (Figure 1-b, c, d, f, g, h, and i). In plant inoculated with *Gigaspora* sp. No. 2 and *Scutellospora* sp., vesicle in plant roots were not found. However, extraradical and intraradical resting spores were found together with similar fungal structures as found in other species (Figure 1-e and j).

The main structures of various VAMF found at harvest period were different (Table 1). Vesicles were main structures found in roots inoculated with *E. colombiana* and *G. aggregatum*, meanwhile, arbuscules were prominent in *Scutellospora* sp. inoculation but hyphae were prominent in the remaining species.

The intensity of colonization showed the tendency of VAMF ability on enhancing plant growth. In this experiment, the abilities of various VAMF on soybean root colonization were illustrated in Table 2. Root infection percentages of soybean caused by various VAMF at both stages, such as 6-week and harvest periods, were found to be highly significant. Four species of VAMF, *E. colombiana*, *G. geosporium*, *Scutellospora* sp. and *G. aggregatum* showed very high potential of soybean root infection, meanwhile the rest of the species showed rather low potential at 6 week-period. The most rapidly effective species at 6 weeks was *E. colombiana* (89.75 %) and the lowest infection was found in soybean inoculated with *A. dilatata* (7.75 %).

At harvest, the intensity of root infection of various VAMF species were examined. High potential species (group a) which showed a very high percentage of root infection were *E. colombiana*, *A. scrobiculata*, *G. aggregatum*, *G. geosporium* and *Scutellospora* sp. with the range of infection were 89.25-96.75 %. The minimum infection was found in *A. dilatata* inoculation as 24.25 %.

The intensity of root infection of individual VAMF species at harvest period was increased as compared to its intensity at 6 weeks. In Some species whose infections along the plant root developed rapidly in the early stage (*E. colombiana*), the intensity of infection at this stage was further

Table 1 Main structure of VAMF found in the root of SJ5 soybean.

VAMF	Main structure	Quantity(%) (compared to the whole VAMF structures)
A. dilatata	Hyphae	95.95
A. scrobiculata	Hyphae	69.14
E. colombiana	Vesicle	56.58
Gigaspora sp. No 2	Hyphae	87.39
G. aggregatum	Vesicle	46.15
G. claroideum	Hyphae	68.00
G. geosporium	Hyphae	55.96
G. tenuis	Hyphae	59.35
Scutellospora sp.	Arbuscule	43.00

progressed continuously and finally reached the peak at 96.75 %. Certain species showed moderate potential of infection at 6 weeks, such as *G. geosporium*, *Scutellospora* sp. (71.00 and 69. 25 %); however, the development of infection was quite fast at harvest stage for these species up to 90.50 and 89.25 %, respectively. The species which showed high ability for increasing infection from 6 weeks to harvest period of plant growth was *A. scrobiculata*. The root infection at 6 weeks was 31. 25 % and increased up 64 % to 95.25 % at harvest .

The difference of root infection between two stages of plant growth explained how VAMF

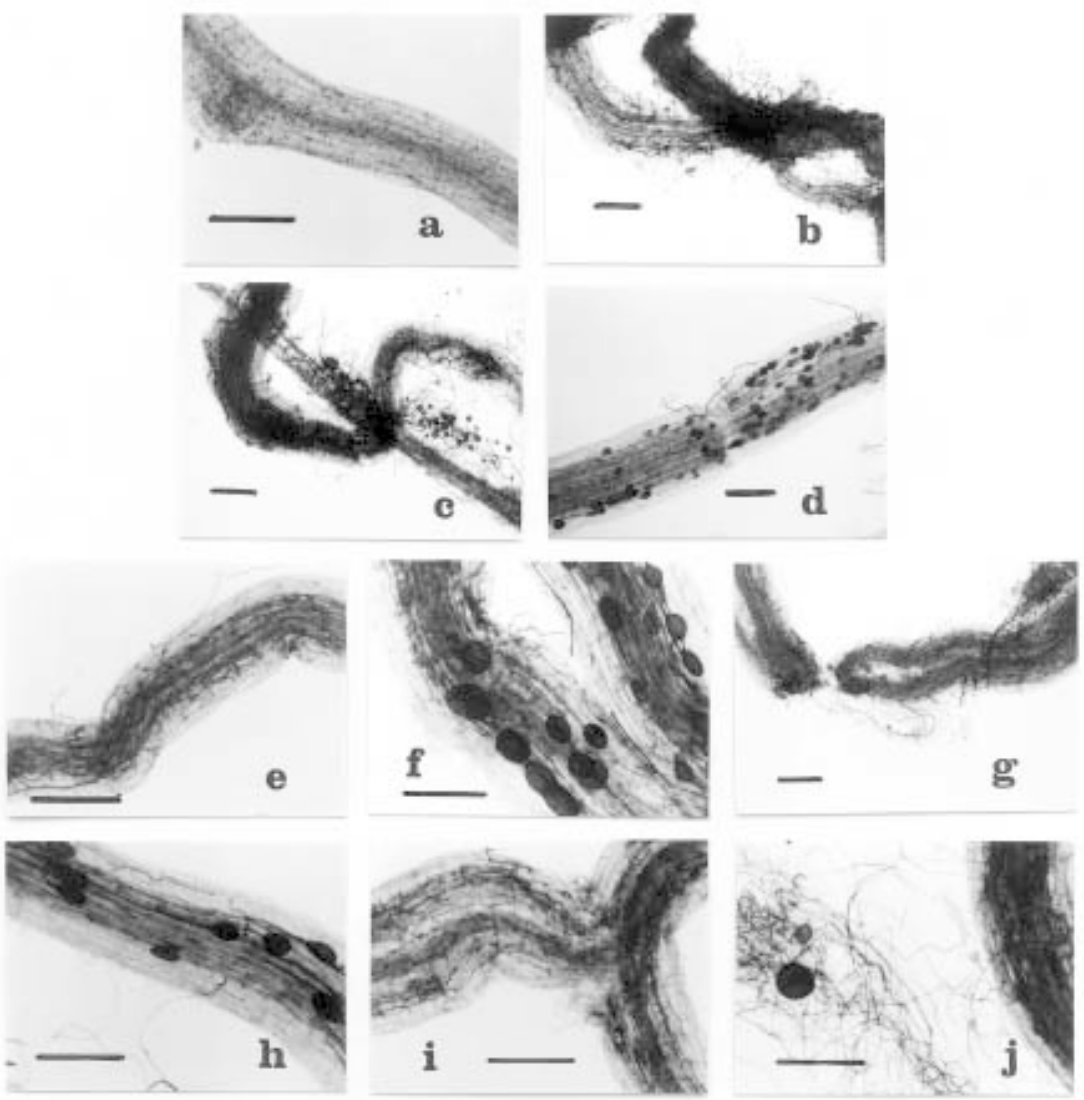

Figure 1 Characteristics of VAMF root colonization on SJ5 soybean root (a = non-inoculation, b = *A. dilatata*, c = *A. scrobiculata*, d = *E. colombiana*, e = *Gigaspora* sp. No. 2, f = *G. aggregatam*, g = *G. claroideum*, h = *G. geosporium*, i = *G. tenuis* and j = *Scutellospora* sp., bar = 0.2 mm).

can enhance soybean successfully at different growth stage. The species which infected plant root intensively in early stage was also showed the signal of high potential to enhance plant growth. The species which infected the plant root with slower rate will be losing this advantage. Generally, the infection rates of various VAMF are different.

By determining the interval of root infection intensity between two periods of plant growth, it was found that the root infection of some VAMF species increased in a very high intensity, meanwhile those of root infection caused by other species increased in negligible amount. These roles may suggest the categories that, the colonization on plant root of those VAMF in early stage (6 weeks) were highly intensive depending upon individual VAMF ability to infect and developing their colonization through host root. VAMF in this group were *E. colombiana*, *G. geosporium* and *Scutellospora* sp. which initially infected host root at a very fast rate and the intensity increased abruptly to reach above 70 % within 6 weeks. These VAMF, however, still further developed colonies actively and spreading their infection continuously to other parts of plant root and reached their peak at harvest as shown in Table 2. The another category is that, the intensity of root infection in early stage was low due to the slowly development of VAMF on the host root. This group of VAMF such as *Gigaspora* sp. and *A. dilatata*, showed low root infectious intensity at both stages of plant growth. Due to the low efficiency on root infection at both stages, root infectious intensity of both species were 21.50 and 7. 75 % at 6 weeks, and the development of root infection in the second stage was slowly occurred. Their intensities of infection were 41.50 and 24.25 % which increased to 20.00 and 16.50 %, respectively.

In case of other species, the intensity of root infection was at moderate level. But the development of VAMF occurred very fast in the second stage which caused high intensity of root

Table 2 Colonization of various VAMF species on the root of soybean.

VAMF	Root infection(%)		Increased infection after 6 weeks
	At 6 weeks	At harvest	
Non inoculation(control)	0^{f}	0^{f}	0
A. dilatata	7.75^{f}	24.25^{e}	16.50
A. scrobiculata	31.25^{d-e}	95.25^{a}	64.00
E. colombiana	89.75^{a}	96.75^{a}	7.00
Gigaspora sp. No 2	21.50^{e}	41.50^{d}	20.00
G. aggregatum	54.50^{c}	93.75^{a}	39.25
G. claroideum	46.75^{c}	79.25^{b}	32.50
G. geosporium	71.00^{b}	90.50^{a-b}	19.50
G. tenuis	33.75^{d}	62.25^{c}	28.50
Scutellospora sp.	69.25^{b}	89.25^{a-b}	20.00
CV.(%)	18.93	11.39	
F-test	**	**	

Note: Means in each column followed by the same letter are not significant by DMRT at 95 % of confidence.

infection at harvest. The VAMF in this group including *A. scrobiculata*, *G. aggregatum*, *G. claroideum* and *G. tenuis* showed the increasing of colonization as 64.00, 39.25, 32.50 and 28.50 %, respectively.

The differences of VAMF manner, extent and their abilities on infecting plant root were attributed (Bolan, 1991; Abbott and Gazey, 1994). Factors affecting VAMF infection may come from the differences in inoculum quantity, types of VAMF species, concentration of VAMF propagules in inoculum, kinds of plant and concerned environments. This experiment was carried out in the same environment with the same amount of inoculum. The quantity of spore of each VAMF was above 40 spores/g. Various inoculums were produced and stored in the same condition. Therefore, the difference in ability of VAMF on infecting soybean root may be due to the compatibility of individual VAMF on soybean plant.

Extraradical hyphae of VAMF

The length of extraradical hyphae of different VAMF species inoculated to SJ5 soybean was illustrated in Table 3. The results of statistical analysis of the extraradical hyphae of various VAMF at both periods of plant growth were highly significant. Three species of VAMF, *G. aggregatum*, *Scutellospora* sp. and *G. geosporium*, showed prominent ability to produce extraradical hyphae at 6 weeks as much as 47.65, 61.73 and 65.15 cm $g^{-1}$of soil. Meanwhile, the other species had shorter extraradical hyphae.

After 6 weeks, the extraradical hyphae of certain VAMF associating with SJ5 soybean developed intensively through soil volume. Since the rate of hyphal development of various VAMF from the early stage to 6 weeks was different, the extraradical hyphae of 4 species, *E. colombiana*, *Scutellospora* sp., *G. geo*sporium and *G. aggregatum* at harvest period were longer than 1 m g^{-1} meanwhile those of the remaining species were

Table 3 Length of extraradical hyphae of various VAMF associated with soybean(cm g^{-1}).

VAMF	At 6 weeks	At harvest	Increasing after 6 week
Non inoculation(control)	0^{d}	0^{d}	0
A. dilatata	37.53^{b-c}	45.83^{c}	8.30
A. scrobiculata	27.38^{b-c}	62.38^{c}	35
E. colombiana	36.95^{b-c}	128.90^{b}	91.95
Gigaspora sp. No 2	20.58^{c-d}	41.95^{c}	21.37
G. aggregatum	47.65^{a-b}	168.33^{a}	120.68
G. claroideum	26.98^{b-c}	58.73^{c}	31.75
G. geosporium	65.15^{a}	137.37^{a-b}	72.23
G. tenuis	24.73^{b-c}	28.75^{c-d}	4.02
Scutellospora sp.	61.73^{a}	134.85^{a-b}	73.12
C.V.(%)	41.04	27.68	
F-test	**	**	

Note: Means in each column followed by the same letter are not significant by DMRT at 95 % of confidence.

shorter.

Extraradical hyphae of *G. geosporium*, *Scutellospora* sp. *and G. aggregatum* developed thoroughly to the soil. The hyphal length of three species in soil at harvest was conspicuous which increased more than 72 cm g^{-1}. Markedly, the hyphal length of *E. colombiana* at the first stage of plant growth was moderate at 36.95 cm g^{-1}, then, the hyphae developed rapidly afterward and the length was increased up to 91.95 cm at harvest period. This result revealed that 4 species of VAMF are conspicuous having high potential on the development of extraradical hyphae and enhancing plant growth through these special structures. The result was coincided with the suggestion of De Miranda and Harris (1994), who examined 3 species of VAMF using sorghum plant and found that *Scutellospora heterogama* produced extraradical hyphae more profusely than others. In contrast, Abbott and Robson (1985) found that *Glomus calospora* and *Acaulospora laevis* were prominent on producing more hyphae in soil when associated with subterranean clover. Finally, Abbott and Robson (1985) suggested that extraradical hyphae are the important device for enhancing plant growth. Normally, nutrients are taken up through extraradical hyphae and then translocated to plant root. Longer hyphae will have more advantages of absorbing nutrients beyond the depletion zone of normal root.

The effects of VAMF on growth of SJ5 soybean

The height of SJ5 soybean inoculated with different VAMF at 6 weeks was significant at both periods of measurement as shown in Table 4. The group "a" of VAMF species, *G. aggregatum, E. colombiana* and *Scutellospora* sp., exposed high potential to stimulate the growth of soybean

Table 4 The effects of VAMF on growth of SJ5 soybean.

VAMF	Plant height(cm)			Dry weight(g $plant^{-1}$)	
	At 6 weeks	At harvest	Increased height	Shoot	Root
Non inoculation(control)	25.9^{c}	37.0^{b}	11.1	0.58^{c}	0.50^{d}
A. dilatata	35.1^{b-c}	37.3^{b}	2.2	0.53^{c}	0.58^{d}
A. scrobiculata	31.6^{b-c}	34.7^{b}	3.1	0.67^{b-c}	0.84^{c-d}
E. colombiana	43.1^{a-b}	52.7^{a-b}	9.6	1.68^{a}	2.04^{a}
Gigaspora sp. No 2	36.1^{b-c}	38.0^{b}	1.9	0.67^{b-c}	0.96^{c-d}
G. aggregatum	42.6^{a-b}	58.5^{a}	15.9	1.77^{a}	1.68^{a-b}
G. claroideum	34.9^{b-c}	41.4^{a-b}	6.5	0.82^{b-c}	1.34^{b-c}
G. geosporium	38.1^{b-c}	42.5^{a-b}	4.4	1.08^{b}	1.54^{a-b}
G. tenuis	35.3^{b-c}	36.5^{b}	1.2	0.59^{c}	0.65^{d}
Scutellospora sp.	52.5^{a}	57.3^{a}	4.8	1.90^{a}	1.89^{a-b}
C.V.(%)	20.81	27.24	–	29.23	29.45
F-test	**	*	–	**	**

Note: Means in each column followed by the same letter are not significant by DMRT at 95 % of confidence.

presented as measured by plant height at 6 weeks. The height of soybean inoculated with those three species were 42.6, 43.1 and 52.3 cm, respectively. Plants inoculated with other VAMF species were shorter, while the height of non-inoculated plant in control treatment was shortest.

The tallest group of soybeans at harvest period were those inoculated with *G. aggregatum*, *Scutellospora* sp. and *E. colombiana*, while the shortest plants were those inoculated with *A. scrobiculata* at 34.7 cm. In soybeans inoculated with *G. aggregatum*, plant height was up to 15.8 cm at 6 weeks, reaching the peak of growth at harvest period at 58.5 cm. Some VAMF species exposed rather low efficiency in stimulating plant height during the period from 6 weeks to harvest. These groups were *A. scrobiculata*, *G. tenuis*, *A. dilatata* and *Gigaspora* sp. No. 2. Plant height inoculated with those species was in the range of 34.7 to 38.0 cm.

Although the height of soybean in every treatment increased after 6 weeks, plant-height of most treatments increased negligibly.

Interestingly, the plant inoculated with individual species of VAMF included *Scutellospora* sp., *E. colombiana* and *G. aggregatum* grew very fast and produced over 40 cm of plant height at 6 weeks. Consequently, plant height was increased rather distinctively in most of the treatments except those inoculated with *Scutellospora* sp. which the increased height was only 4.75 cm. This result suggested that VAMF enhanced plant growth at 6 weeks stage and when the enhancement of VAMF was prominent, the growth of soybean was further enhanced through harvest period by that particular VAMF.

On the contrary, other group of VAMF caused soybean plant height to develop slowly at the first stage of growth. Later, plant height still developed in the same manner excepted for non-inoculation treatment. The difference of plant height between two stages of plant growth of this group were lower than 6.45 cm. These plants were those inoculated by *G. tenuis*, *G. claroideum*, *Gigaspora* sp. No. 2, *G. geosporium, A. scrobiculata* and *A. dilatata*.

The dry weight of soybean was determined in term of shoot and root dry weight as shown in Table 4. Different species of VAMF influenced the shoot dry weight. The shoot dry weight of soybean in treatments inoculated with *Scutellospora* sp., *G. aggregatum* and *E. colombiana* were 1.90, 1.77 and 1.68 g plant^{-1}, accomplished in the higher quantity than the ability of the other species. The minimal dry weight was found in soybean inoculated with *A. dilatata* and in non-inoculated soybean as 0.53 and 0.58 g plant^{-1}, respectively.

Root dry weight of soybean inoculated with different species of VAMF was highly significant. The maximum root dry weight was found in soybean inoculated with *E. colombiana*. In this treatment, the root of plant developed intensively through the volume of soil which was determined as root dry weight at 2.04 g plant^{-1}, but the root distribution declined sequentially to 1.89, 1.68, 1.54 and 1.34 g plant^{-1} of soybeans inoculated with *Scutellospora* sp., *G. aggregatum*, *G. geosporium* and *G. claroideum*, respectively. The minimal root dry weight was found in non-inoculated treatment at 0.50 g plant^{-1}.

Effects of VAMF on soybean yield

The number of pod, seed and yield of soybean inoculated with different VAMF species were highly significant. But the size of seed presented as 100-seed weight was significant (Table 5). VAMF-inoculated soybean had more quantities of pod, number of seed and seed size than those of non-inoculated plant. The group of soybean inoculated with *Scutellospora* sp., *G. aggregatum*, *E. colombiana and G. geosporium* had more quantities of pod than those of plant inoculated

with the other species. The maximum quantity of pod was found in soybean inoculated with *Scutellospora* sp. at 28.28 pod plant $^{-1}$.

The number of soybean seed affected by VAMF inoculation is similar in effect to the number of pod. Four species of VAMF, *Scutellospora* sp. *G. aggregatum*, *G. geosporium* and *E. colombiana*, had high potential to enhance soybean yield of 47.50, 41.50, 40.75 and 39.75 seed plant^{-1}, respectively. The remaining from the rest species was lower as compared to those one.

The larger seed size were found on plant inoculated with *G. claroideum*, *E. colombiana*, *Scutellospora* sp. and *G. aggregatum*, compared to the rest of the species. They showed the 100 -seed weight of 15.95, 15.18, 13.81 and 13.65 g, respectively, with the smallest seed size found in non-inoculated soybean or control plant.

Similar to the effect on yield component, four species of VAMF accomplished higher soybean yield were *Scutellospora* sp., *E. colombiama*, *G. aggregetum* and *G. geosporium*, gave the yield as much as 6.42, 5.77, 5.37 and 4.34 g plant^{-1}, respectively (Table 5). Since non-inoculated plant gave the yield of 0.44 g plant^{-1}, the yield above this level will come from the encouragement of VAMF affectability. *Scutellospora* sp. had highest ability to accomplish the increased yield as much as 5.98 g plant^{-1}. *E. colombiana*, *G. aggregatum* and *G. geosporium* gave less encouragment to soybean yield and their encouragement were 5.33, 4.97 and 3.90 g plant^{-1}. Meanwhile, *A. dilatata* gave least encouragement at 0.31 g plant^{-1}.

In term of mycorrhizal dependency on soybean yield, five species of VAMF had high potential to enhance soybean growth and raised the level of soybean yield as shown in Table 5. Those species were *Scutellospora* sp., *E. colombiana*, *G. aggregatum*, *G. geosporium* and *G. claroideum*. The mycorrhizal dependency of attributed-VAMF

Table 5 Effects of VAMF on SJ5 soybean yield, yield component and mycorrhizal dependency on soybean yield (MDSY).

VAMF	Number of pod plant^{-1}	Number of seed plant^{-1}	100-seed weight(g)	Yield (g plant^{-1})	MDSY
Non inoculation(control)	3.75^{c}	5.75^{c}	7.63^{d}	0.44^{e}	0
A. dilatata	6.00^{b-c}	8.25^{c}	9.29^{c-d}	0.75^{d-e}	0.71
A. scrobiculata	12.25^{b}	17.25^{b-c}	11.28^{a-d}	1.99^{d}	3.52
E. colombiana	23.75^{a}	39.75^{a}	15.18^{a-b}	5.77^{a}	12.11
Gigaspora sp. No 2	8.00^{b-c}	12.75^{c}	11.72^{a-d}	1.55^{d-e}	2.52
G. aggregatum	26.00^{a}	41.50^{a}	13.65^{a-c}	5.37^{a-b}	11.21
G. claroideum	11.75^{b}	26.75^{b}	15.95^{a}	3.90^{c}	7.86
G. geosporium	22.25^{a}	40.75^{a}	10.83^{a-d}	4.34^{b-c}	8.86
G. tenuis	8.25^{b-c}	15.00^{b-c}	10.11^{b-d}	1.55^{d-e}	2.52
Scutellospora sp.	28.25^{a}	47.50^{a}	13.81^{a-c}	6.42^{a}	13.59
C.V.(%)	27.04	34.07	27.02	26.96	
F-test	**	**	*	**	

Note: Means in each column followed by the same letter are not significant by DMRT at 95 % of confidence.

on plant enhancement to increase the yield over control were 13.59, 12.11, 11.21, 8.86 and 7.86, respectively. These increased yields were obviously encouraged by individual VAMF. The mycorrhizal dependency of the remaining VAMF were lower than those species attributed above.

CONCLUSION

The effectiveness of various VAMF in this experiment is different. Certain species of VAMF showed high potential on infecting soybean root and consequently enhanced plant growth. The yield of SJ5 soybean inoculated with *Scutellospora* sp. was the highest at 6.24 g plant^{-1}. Three species of VAMF, *E. colombiana, G. aggregatum* and *G. geosporium* were also high potential species of high effectiveness on plant stimulation and obtain high yield in the order of 5.77, 5.37 and 4.34 g plant^{-1}, respectively. Therefore, these VAMF should be further examined with soybean in different phosphate conditions.

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