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Growth Stimulation of *Panax ginseng* C.A. Meyer (Araliaceae) Arising from AMF-Isolate Inoculation

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Abstract

Seedlings of Asian ginseng (*Panax ginseng* C.A. Meyer) were studied to examine the growth stimulation effects arising from different arbuscular mycorrhizal fungi (AMF). Nine AMF-isolates were used for inoculation treatment. As soil factors can favour specific endophytes and modulate their symbiotic effectiveness, three soil types with different mineral nutrient regimes were considered in the experiments. Seeds were germinated in clay pots and, after inoculation with AMF, cultivated in growth chambers under controlled environmental conditions (experiment 1), or under natural conditions (experiments 2 and 3). After the primary leaves emerged, endophyte establishment was examined weekly. Mycorrhizal plants were harvested and subjected to several measurement criteria to ascertain growth rates and variation. Considerable differences were found between the plants inoculated with different AMF-isolates. These effects were also influenced by the soil type employed. Statistical analysis shows significant differences within the mean results of the growth characteristics, except for the "number of lateral roots" criterion. Noteworthy, AMF can promote or inhibit shoot and root growth of *P. ginseng* in a distinct manner, and the rate and variation is dependent on the AMF-isolate and the available soil nutrients. Hence, practical application of AMF in the agricultural production of *P. ginseng* is suggested. However, it is very important to clarify the suitability of the AMF-isolates employed in connection with the field soil type and/or the soil fertilization regime.

Keywords: Arbuscular mycorrhizal fungi, growth stimulation, *Panax*

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1. Introduction

Panax ginseng C.A. Meyer is one of the oldest medicinal herbs and the benefits of its underground organs have been known for thousands of years by the peoples of Asia. From time immemorial, ginseng roots were collected in quantities in wilderness sites without regard to the reduction in natural populations. Today, the plant is an endangered species and it is now proposed for inclusion in Appendix II of CITES by the Russian Federation. Efforts to cultivate ginseng in large plantations have been undertaken. While there was good success of growing ginseng in China, Japan and Korea for hundreds of years, efforts at commercial cultivation in Europe often failed (Weber et al., 1998a, b). Recent scientific studies on ginseng mostly refer to improvement of the ginseng production, cultivation treatments and medicinal aspects or on chemical components of the root. However, information of morphology, anatomy or mycorrhizal status of this exciting plant is rare (Zeuske and Weber, 1998; Zeuske et al., 1999).

In conformity with ecologically beneficial and responsible plant production, innovative mycorrhiza-technology may offer an opportunity for agricultural improvement. Developing the so-called "arbuscular mycorrhiza" (AM, former VAM, see Walker, 1995), the arbuscular mycorrhizal fungi are known as one of the most common symbiotic partners in angiosperms (Nicolson, 1967). They support most flowering plants by stimulating nutrient uptake and increasing resistance to soil-borne pathogens. As a result of these enhancements, most mycorrhizal plants are more vigorous and show increased growth compared to non-mycorrhizal plants.

Ueda et al. (1992) investigated several medicinal plants in Japan at natural sites and found that ginseng was associated with AMF. Mycorrhizal structures developed in the root cortex of *P. ginseng* and *P. quinquefolius* have been investigated (Whitbread et al., 1995; Zeuske et al., 1999), and the given description corresponds to the "Paris-type" of AM. Investigation of several ginseng plants taken from plantations in Germany reveal that these roots are free of mycorrhizal structures in most cases (Zeuske, unpublished data). This could be due to the intensive cultivation of land which damages AMF associations (Kough et al., 1987; Menge, 1983; Trappe et al., 1984; McGonigle et al., 1990; Allen and Boosalis, 1983). On the other hand, it has become increasingly apparent that some plants require mycorrhizal association to a much greater extent than do others. This leads to another explanation, especially for *P. ginseng*, proposed by Weber (1998). According to the low spore densities in ginseng monocultures and the development of the AM-Paris-type, Weber (1998) suggests that the ginseng plant is highly dependent on AM-endophytes and therefore depletes the mycorrhizal potential of the soil. Fungus control by the ginseng plant may be so severe, that the mycorrhizal

fungus has no chance to develop propagules, and spore density in the soil diminishes after a short time.

There is little information of successful inoculations of *P. ginseng* with AMF. Also, little is known about the stimulation effects of endomycorrhizal fungi colonizing ginseng roots. For that reason, experiments were designed to assess whether: 1. AMF generally stimulates the growth of *P. ginseng*, 2. specific AMF are more suitable in promoting growth-effects of root and/or shoot, and 3. they can be used for application in ginseng commercial production.

2. Materials and Methods

Determination of inoculum spore density

Spore density of each AMF-isolate was determined (see Table 1). For spore extraction, 10 g of inoculum were washed through 1000 µm, 160 µm, and 50 µm pore sieves with running water. The contents of the 160 µm and 50 µm pore sieves was backwashed in a beaker with minimum volume. Tubes (10 ml) were filled halfway up the tubes with 60% (w/v) sucrose solution. Then, the beaker contents was carefully filled in the tube. After centrifugation at 1500 rpm for 5 min, the supernatend was washed over a filter paper with water. The spores on the filter were counted under a stereomicroscope. The number of spores determined corresponds to spore density, given as spore number/10 g inoculum.

Planting and inoculation

Seeds of *Panax ginseng* were obtained from Wischmann FloraFarm (Walsrode, Germany) in 1998. These were harvested in September 1997. The seeds were embedded in slightly wet sand and kept under cold conditions (1–4°C) until sowing. In February and March 1999, the seeds were sown in clay pots and three experiments were conducted. In experiment 1, the potted seeds were kept in controlled environment growth chambers (temperature: 17°C, light intensity: 2500 lux, 12 h/d). The substrate (soil 1) was sand (river sand, grain size 500–1500 µm) which was heated before using (4 h at 140°C) to inactivate and destroy any existing pathogens or AMF-spores. No nutrient amendments were applied. Experiments 2 and 3 were carried out under natural conditions (Botanical Garden of Marburg, Germany, temperature: 1–26°C (seasonal fluctuations), light intensity: 1000–12000 lux). The substrate applied in experiment 2 (soil 2) was sowing soil (Fruhstorfer Erde, Typ Aussaat, Industrie-Erdenwerk Archut GmbH and Co. KG, 36341 Lauterbach-Wallenrod) with a low nutritive level (N: 80–120 mg/l, P: 80–120 mg/l, K: 100–150 mg/l). For experiment 3, a third substrate (soil 3) was collected from the production fields

Table 1. Origin, amounts and spore density (number of spores /10 g substrate) of the applied inocula

Inoculum	Origin	Inoculum amount per pot in g	Spore density
Acaulospora longula Spain and Schenck	BEG 8*	3.5	230
Gigaspora margarita Becker and Hall	BEG 34	10	75
Glomus albidum Walker and Rhodes	Prof. Weber, Marburg**	16	50
Glomus etunicatum Becker and Gerdemann	Isolate 139, Dr. v. Alten, Hannover***	3	220
Glomus fasciculatum (Thaxt.) Gerd. and Trappe emend. Walker and Rhodes	BEG 53	9	90
Glomus intraradices H 11/3 Schenck and Smith	Kultur H 11/3, Dr. v. Alten, Hannover	8	120
Glomus intraradices H 49 Schenck and Smith	Isolate H 49, Dr. v. Alten, Hannover	4	180
Glomus intraradices T 510 Schenck and Smith	Isolate T 510, Dr. v. Alten, Hannover	5	150
Glomus mosseae (Nicol. and Gerd.) Gerd. and Trappe	BEG 12	16	50

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of Wischmann FloraFarm, and it had a typical heathland character. This soil was sandy and nutrient-amended and, therefore, at a high mineral nutrient regime (N: not determined, but the soil was amended with 70–100 t/ha stable manure before sowing, P: 350–380 mg/l, K: 600–630 mg/l). Soil 2 and soil 3 were

not sterilized. All pots were filled three quarters with the corresponding soil. Then, one of the inocula denoted in Table 1 was added, to such an extent, that the inoculum amount per pot corresponded to 80 spores. The inoculum was distributed evenly on the soil surface. About 50 mm of soil in depth was distributed over the inocula layers to avoid immediately contacting of the growing primary roots with AMF-propagules. Then, four seeds were sown per pot and covered with a thin soil layer. Control plants were treated identically, but instead of inoculum, pure sand was added.

Harvest and measurements

At the end of March 1999, the primary leaves of the ginseng seedlings emerged. From that time, samples of lateral roots from three randomly selected plants were taken weekly and stained with Trypan-Blue (Philips and Hayman, 1970) to detect AM-structures. After endophyte establishment, which occurred between 8 and 15 weeks after the primary leaves emerged (see Table 2), the seedlings were harvested. Immediately, the harvested plants were weighed and measured to determine growth criteria. These criteria were: (a) germination rate, i. e. the percentage value of germinated seeds/sown seeds, (b) primary leaf length, (c) tap root length, (d) fresh weight of the whole seedling, (e) fresh weight of the primary leaf, (f) fresh weight of the tap root, (g) root/shoot ratio, and (h) number of lateral roots. Dry weights have not been determined, because the roots were intended for further investigations.

Evaluation and statistical analysis

The recorded data represent the mean for three (experiment 1) or five (experiments 2 and 3) replicates within each treatment. Data were subjected to a statistical analysis (Student's test), the significance level was at $\alpha \leq 0.1$ (significant difference, *), $\alpha \leq 0.05$ (very significant difference, **), and $\alpha \leq 0.01$ (most significant difference, ***). To compare the results obtained from inoculated plants with the non-mycorrhizal plants, means were transformed to percentage values:

$$\frac{(X_I - X_C)}{X_C} * 100$$

where X_I is the mean of a growth criterion obtained from inoculated plants and X_C is the mean of a growth criterion obtained from control plants. These results were the basis for Figs. 1–3 with positive values representing beneficial effects and negative values for inhibiting effects in relation to non-mycorrhizal plants (control).

Table 2. Mycorrhiza treatment and percentage of growth stimulation effect in relation to control. Means of inoculated plants are given in relation to means of non-inoculated control plants (see formula in Materials and Methods): a – germination rate, b – primary leaf length, c – tap root length, d – fresh weight whole seedling, e – fresh weight primary leaf, f – fresh weight tap root, g – root/shoot ratio, h – number of lateral roots. Significance level was at $\alpha \leq 0.1$ (significant difference, *), $\alpha \leq 0.05$ (very significant difference, **), and $\alpha \leq 0.01$ (most significant difference, ***). ns – not significant. # – statistic analysis unreasonable, since only one plant was available; – – seedling died before measurements were carried out. Soil types: 1: sand without nutrient amendments, 2: low nutrient amended soil, 3: high nutrient amended soil (see text for further explanation).

Mycorrhiza-treatment	Soil type	First record of established AMF (in weeks)	Growth stimulation in relation to control (%) / level of significance							
			a	b	c	d	e	f	g	h
A. longula	1	8	0	112/***	362/**	182/***	114/***	325/***	124/***	142/***
	2	–	50	–	–	–	–	–	–	–
	3	–	125	–	–	–	–	–	–	–
G. margarita	1	8	0	50/#	62/#	118/#	86/#	175/#	67/#	68/#
	2	15	78	7/ns	40/***	44/**	100/***	28/*	–11/ns	
	3	13	142	27/***	39/***	105/***	33/**	178/***	111/***	74/***
G. albidum	1	8	0	115/***	127/*	91/***	71/**	125/***	55/***	79/*
	2	14	50	12/ns	16/ns	48/*	33/ns	52/*	10/ns	–7/ns
	3	12	58	42/***	49/***	90/***	67/***	100/***	25/ns	62/***
G. etunicatum	1	8	0	101/***	185/**	100/***	57/*	150/***	88/***	5/ns
	2	14	78	32/***	17/ns	48/***	67/***	33/*	–23/***	–1/ns
	3	12	67	46/***	37/ns	85/***	75/***	78/*	0/ns	2/ns
G. fasciculatum	1	8	0	82/***	277/***	82/**	43/ns	150/***	98/***	121/**
	2	–	–	–	–	–	–	–	–	–
	3	13	75	51/***	145/***	135/***	83/***	89/***	–3/ns	87/***

Table 2. Continued

Mycorrhiza-treatment	Soil type	First record of established AMF (in weeks)	Growth stimulation in relation to control (%) / level of significance							
			a	b	c	d	e	f	g	h
G. mosseae	1	8	0	101/***	242/***	118/***	57/*	225/***	133/***	163/**
	2	15	−93	15/#	41/#	59/#	50/#	59/#	2/#	−17/#
	3	13	−25	25/*	33/ns	65/*	33/ns	78/*	38/**	3/ns
G. intraradices H 11/3	1	8	0	61/***	350/***	91/***	71/**	125/***	55/***	111/*
	2	12	63	17/*	12/ns	9/ns	28/ns	96/ns	−30/**	−42/*
	3	12	117	38/***	59/***	125/***	75/***	167/***	53/***	100/***
G. intraradices H 49	1	8	0	89/***	128/***	64/**	57/**	100/*	35/***	47/ns
	2	14	71	24/***	16/ns	64/***	61/***	59/***	−3/ns	−5/ns
	3	12	25	38/***	40/***	135/***	92/***	167/***	45/***	79/***
G. intraradices T 510	1	8	0	118/***	421/***	100/***	71/**	150/***	73/***	47/ns
	2	14	56	25/***	5/ns	50/*	50/**	44/*	−8/ns	−17/ns
	3	12	8	36/***	61/*	50/*	33/*	44/ns	12/ns	21/ns

3. Results

Success of inoculation

The present investigation of seedlings of *P. ginseng* reveal that inoculation with the AMF species *Acaulospora longula, Gigaspora margarita, Glomus albidum, G. etunicatum, G. fasciculatum* and *G. mosseae* were successful when sand was used for substrate, as well as inoculations with the isolates H 49, T 510 and H 11/3 of *G. intraradices*. When low nutrient amended soil was employed, seedlings inoculated with *A. longula* and *G. fasciculatum* died before establishment of mycorrhizal structures could be assessed. Application of *A. longula* to seedlings cultivated in substrate 3 (high nutrient level) also resulted in early death of the recently germinated seedlings. All other soil/fungus combinations in experiments 2 and 3 resulted in successful mycorrhization.

Mycorrhizal fungi were established in roots of *P. ginseng* at different times after inoculation (see Table 2), dependent on soil, fungus and environmental conditions. In experiment 1, AMF structures were identified after eight weeks, after the primary leaves emerged the substrate surface. Under natural conditions (experiments 2 and 3), the endophytes were established 12 to 15 weeks after the primary leaves were observed aboveground (Table 2). The level of colonization of every individual plant differed widely from one another (data not illustrated herein). Regardless of which AMF-isolate was applied, the Paris-type was developed in the roots of *P. ginseng*. There are negligible morphological differences amongst the fungal structures of different isolates (Zeuske, in preparation).

Despite the employment of non-sterilized soil in experiments 2 and 3, lateral roots of the non-inoculated control plants were free of AMF, even 18 weeks after the primary leaves of the seedlings were seen aboveground.

Germination rate

The germination rate was highly modified by application of the different AMF-isolates. This was obviously related to the soil type, the available nutrients and the environmental conditions (Table 2 and Figs. 1–3).
In experiment 1, the germination rate was equal for every AMF-isolate and is 100%. Moreover, there was no stimulation effect of the germination rate compared to the control plants. However, sowing and cultivation of *P. ginseng* in soil at low mineral nutrition regime (experiment 2) resulted in a depression of the germination rate up to –93% when *G. mosseae* was applied (see Table 2 and Fig. 2). Inoculations with *G. fasciculatum* suppressed germination completely. Other tested inocula, i.e. *A. longula, G. margarita, G. intraradices H 11/3, G. intraradices H 49, G. intraradices T 510, G. etunicatum* and *G. albidum* enhanced

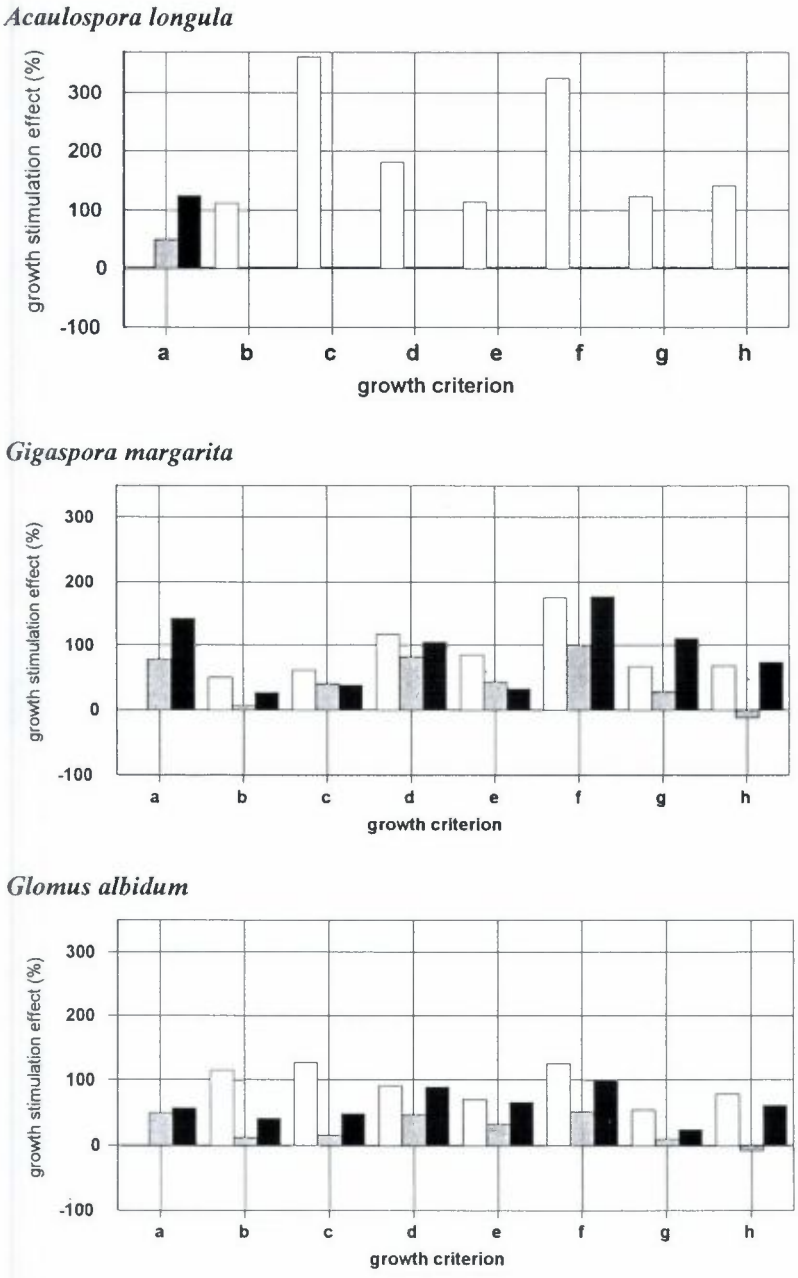

Figure 1. Growth stimulation effects of inoculation on *Panax ginseng* by *Acaulospora longula*, *Gigaspora margarita* and *Glomus albidum* and concurrent applications of soil 1 (white bars), soil 2 (gray bars) and soil 3 (black bars). Growth criteria are: a – germination rate, b – primary leaf length, c – tap root length, d – fresh weight of the whole seedling, e – fresh weight of the primary leaf, f – fresh weight of the tap root, g – root/shoot ratio, h – number of lateral roots.

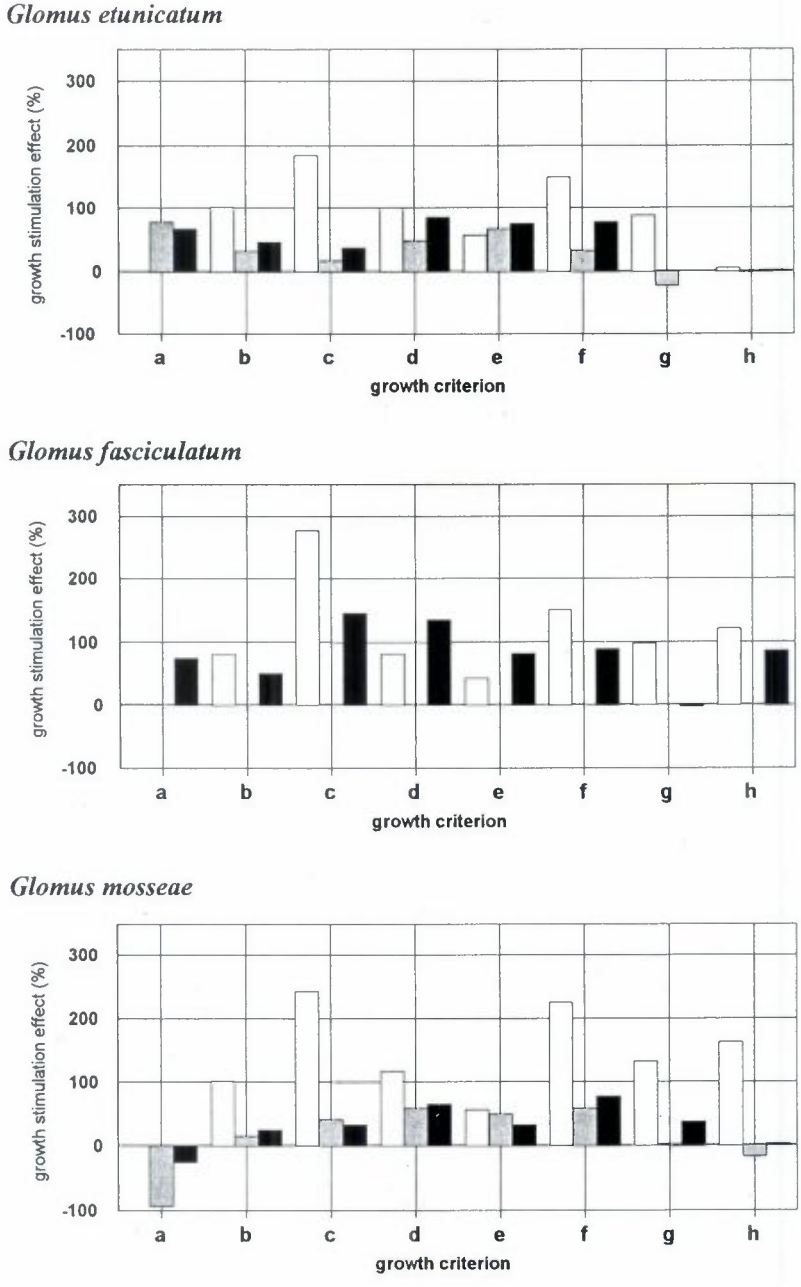

Figure 2. Growth stimulation effects of inoculation on *Panax ginseng* by *Glomus etunicatum*, *Glomus fasciculatum* and *Glomus mosseae*. Further explanation see legend Fig. 1 and text.

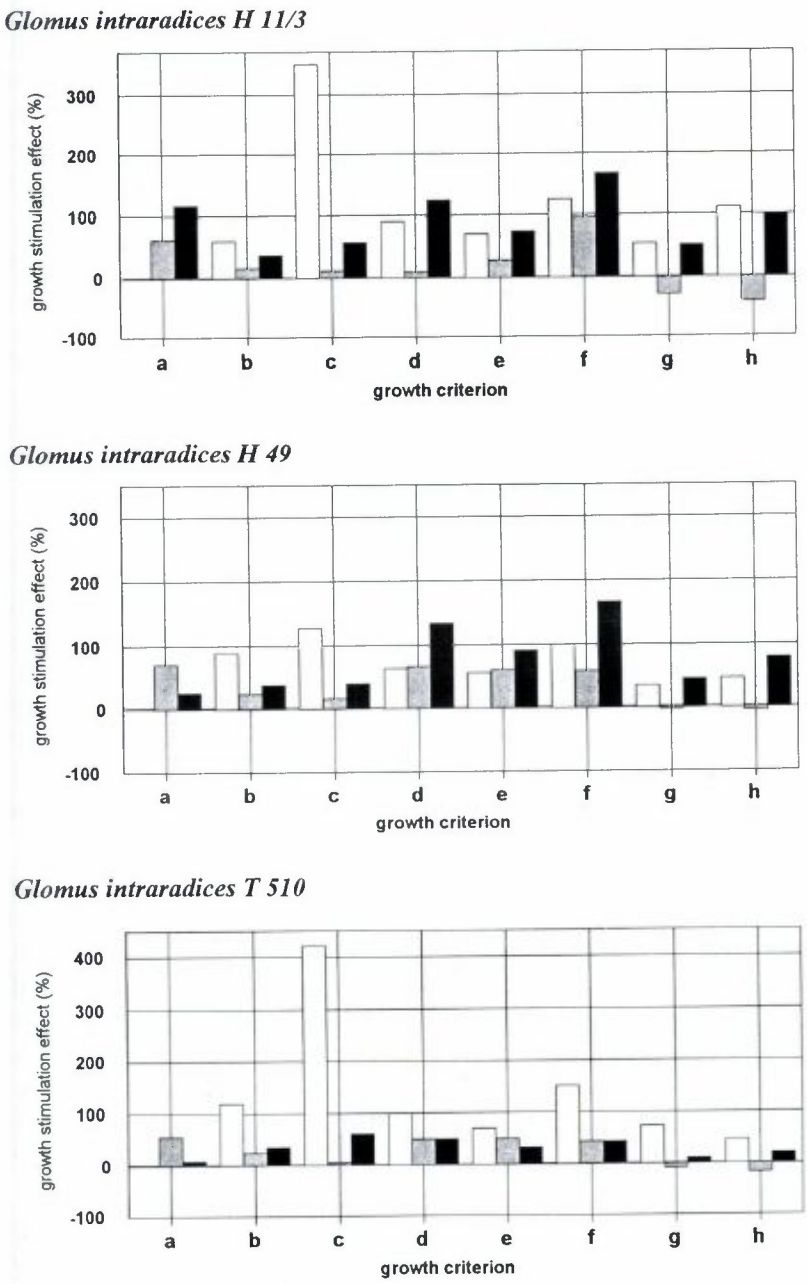

Figure 3. Growth stimulation effects of inoculation on *Panax ginseng* by *Glomus intraradices H 11/3*, *Glomus intraradices H 49* and *Glomus intraradices T 510*. Further explanation see legend Fig. 1 and text.

germination of *P. ginseng* between 50% and 78% as compared to the non-inoculated control plants (see Figs. 1–3). Use of nutrient-amended soil within experiment 3 lead to both inhibition and increase of germination, with fluctuating values between –25% and 142%. The depression mentioned was registered by applying *G. mosseae*, whereas inoculation treatments with *G. margarita*, *A. longula* and *G. intraradices H11/3* produced increased germination.

Effects of different AMF-species on growth criteria

The great variability in effectiveness of the different AMF-isolates was evidenced by significantly different mean results of the various growth criteria. In the following description, only results at significant levels not under $\alpha \leq 0.1$ were taken into account. To elucidate stimulation effects, means were transformed in percentage values as mentioned above.

Measurements of seedlings from experiment 1, inoculated with *A. longula* (Fig, 1), show increases in length and fresh weight of the tap roots (length: 362%, fresh weight: 325%, see Fig. 1 and Table 2). At the same time, there was more than 100% increase in the other criteria. When low and high mineral nutrient amended soil was used (experiments 2 and 3), plants inoculated with *A. longula* survived only for a short time. In spite of the recognized germination boost in the beginning, the seedlings died before the establishment of any endophyte could be detected. Within all of the soil/inoculum combinations assessed, the combination of soil 1/*A. longula* resulted in the highest increases in the criterion d (182%), e (114%) and f (325%).

However, inoculations with *G. margarita* (Fig. 1) clearly promote seedling growth for whatever soil quality was applied. Moreover, only one seedling survived under the experimental conditions of experiment 1; but measurements and comparisons to the control plants show that growth of this mycorrhizal seedling was positively effected. On the contrary, applying nutrient amended soil (soil 3) obviously gave rise to lower growth increases, but produced the highest germination rate (142%) within all soil/inoculum combinations. At the same time, the lowest values amongst all results of the criterion c (39%) and e (33%) were obtained. Results from experiment 2 represent the lowest stimulation effects observed.

Additions of the AMF-isolate *G. albidum* (Fig. 1) show increases about 100% in the determined criterion when the seeds are planted in soil 1. In experiment 2, where available nutrients were low, growth promotion was modest compared to results obtained from experiment 3. The criterion "fresh weight whole seedling" showed the lowest result of all experiments (48%) when *G. albidum* and soil 2 was applied. Enhancement of the tap root is given in experiments 1

and 3, whilst the root/shoot ratio in experiment 2 reveals a negative value. This is interpreted as shoot growth furtherance. The criterion "freshweight of the tap root" was the most promoted criterion within these experiments.

When seedlings were inoculated with *G. etunicatum* (Fig. 2), maximal growth promotion was achieved in experiment 1, with the exception of the criterion "fresh weight primary leaf". However, the lowest growth increases were obtained within experiment 2, and the criterion f showed the lowest value (33%) of all soil/inoculum combinations.

Effects of the inoculum *G. fasciculatum* (Fig. 2) were obtained from the following. Within experiment 1, high increases of the criteria b, c, f, g and h were observed. The root/shoot ratio value reveals high growth promotion of the root. When the low amended soil 2 was used, no germination could be observed. In contrast to this, the germination rate was 75% when applying soil 3 (high nutritive level). Nevertheless, growth criteria in this experiment show values between 83% and 145%.

When *G. mosseae* (Fig. 2) was added, the best results were achieved using soil 1. Additionally, both criteria g and h had obtained the highest values of all experiments conducted. Besides the low germination rate of seeds planted in soil 2, which was the poorest result of all determined germination rates, only one seedling survived. But measurements of this seedling seem to reveal, because of the low values when compared to the other experiments, that the low amended soil is not suitable for ginseng and inoculations with *G. mosseae*. In addition to the germination depression by application of soil 3, low increases of growth were also observed in experiment 3.

Within the three isolates of *G. intraradices* (Fig. 3), there are also modifications in growth stimulation effects on *P. ginseng*. In experiment 1, the length of the tap root was enhanced enormously by inoculations with *G. intraradices H 11/3* (350%) and *G. intraradices T 510* (421%), while stimulation effects caused by *G. intraradices H 49* were less (128%). While inoculations with *G. intraradices H 11/3* effected the results of the growth criterion strongly with the application of soil at high nutritive levels (soil 3), *G. intraradices T 510* creates more growth increase in seedlings when sand without fertilizer (soil 1) was used. Moreover, the highest values within the criteria b and c were obtained with combination of soil/inoculum. When the AMF-isolate *G. intraradices H 11/3* was applied in experiment 2, the root/shoot ratio showed the most negative value of all inoculum/soil combinations and also the lowest results in the criteria h and b. It is remarkable, that the majority of values within the criteria "number of lateral roots" were not significant. In summary, the different inoculation treatments of *P. ginseng* roots can result in: 1. different successes for AMF colonization within the root cortex, 2. different germination rates of ginseng seeds, 3. highly varying length and fresh weight of ginseng roots and shoots. Additionally, there were distinct variations in the data when

different mineral nutrient amended soils were applied, 4. the best combination for ginseng growth, based on the presented experiments, is *A. longula*/soil 1. For high germination rates, the combination *G. margarita*/soil 3 is recommended. 5. "Worst" combination for ginseng growth is *G. fasciculatum*/soil 2, where no seedling germinated and *G. intraradices H 49*/soil 2 where the lowest stimulation effects were observed.

4. Discussion

In the present work, the majority of AMF isolates applied for the inoculation of *P. ginseng* established successfully and resulted in mycorrhizal ginseng. However, the failure for the successful establishment of *A. longula* in experiments 2 and 3 is contradictory to the previous findings by Han et al. (1996) who established this endophyte in ginseng roots when they used "pot soil". Unfortunately, there is a lack of detailed information concerning the soil nutrient contents and fertilization procedures. Ueda et al. (1992), who found ginseng associated with AMF at natural sites, gave neither precise information of the AMF species colonizing ginseng roots nor did they specify the soil type. Successful inoculations of *P. ginseng* with *G. albidum*, *G. mosseae* and *G. intraradices* were obtained by Zeuske et al. (1999), who used a low nutrient amended soil (corresponding to soil 2 in this study). Obviously, *P. ginseng* presents the potential for a wide range of possible AMF symbiotic partners and endophyte establishment depends on soil quality, especially on alterations of soil mineral nutrients.

The influence of AM is still unknown in the lifecycle of a plant (Grubb, 1977). Since varying plant growth responses are connected with the fungal genotype of AMF (Plenchette et al., 1982; Haas and Krikun, 1985), the effectiveness of the AMF relationship to specified host plants merits discussion. This report is in conformance with Allen et al. (1989), who documented that inoculation with AMF inhibit seedling growth of the normally non-mycorrhizal *Salsola kali*. A similar was obtained for *Arabis hirsuta* by Francis and Read (1995). When *Echium vulgare* was inoculated with VAM, Francis and Read (1995) observed damaged meristem areas and, concluded, that there exists a kind of antagonistic-parasitic type in AM symbiosis. On the basis of the results from the present work, there is good reason to agree with Ravnskov et al. (1995), who hypothesized that plant/fungus interactions differ in functional compatibility related to the associated symbiotic partners. They show that the effectiveness of one fungus is meaningful only in the context of its associated host plant species. Functional or physiological compatibility between both partners, influencing the symbiotic effectiveness was also assumed by Gianinazzi-Pearson (1984) and conform to the present results. Hyphae of

mycorrhizal fungi are able to infect the primary roots of young seedlings, and requirements of root/fungus interactions are met. Varying germination rates of plant species, caused by inoculations with different AMF species, may be interpreted as hints that there exists smooth transitions between mutualistic and parasitic characters of the AM symbiosis, especially in seedling stages. In agreement with Francis and Read (1995), the combination of ginseng seedlings and *G. fasciculatum*, resulting in completely suppressed germination (when soil 2 was applied), can be interpreted as antagonistic, amensalistic or competitive type of the symbiosis. On the other hand, combinations with *A. longula* might be mutualistic, because germination rate increased.

Growth stimulation effects were modified by utilization of soils of different nutrient levels. Since the early endophyte screening trials of Mosse (1972), it has become obvious that symbiotic effectiveness of AMF can be modified by soil type. Jakobsen et al. (1992) assumed that there may be a substantial variation in P transport by different fungi which was not related to levels of colonization or hyphal length densities in soil. The nutrient exchange across the interface between the two partners is considered as the key to functional compatibility (Gianinazzi, 1991). This is in conformity with the results of the present study, since AMF showing enhanced growth in high nutrient amended soil may also inhibit at other soil nutrient levels. Accordingly, AM-associations should be interpreted at least as a three-way-interaction between host, fungus and soil.

The structures of the fungus developed in ginseng roots were of the AM-Paris-type (Gallaud, 1905). As supposed by Barrett (1958), Jacquelinet-Jeanmougin and Gianinazzi-Pearson (1983), Demuth and Weber (1990), and Weber et al. (1995), the morphological AM-type is created by plant influence. However, the Paris-type is – contrary to the Arum-type – assumed to be a hint of decreased fungal vigor and also of "structural incompatibility" between both symbiotic partners (Demuth and Weber, 1990;Weber et al., 1995). Therefore, it is assumed that ginseng is highly dependent on mycorrhiza (Weber et al., 1998a). As mentioned above, *P. ginseng* planted in monocultures were obviously not dependent on the symbiosis. Ginseng plants may grow under cultivation treatments, but field application of functional and physiological compatible AMF may be useful.

The varying symbiotic effectiveness, especially in combination with different soil types, is an important factor for ginseng commercial production. However, it must be noted that the present work was obtained from measurements taken over a short time interval. The results may be different if measurements had been carried out over a longer time interval, at another stage of plant growth or at different environmental conditions. Hence, ginseng compatible endophytes can only be speculated. Therefore, an effective inoculant fungus should be determined by bioassays. As chemical amendments can be counterproductive, they have to be included in these bioassays as well as

the soil type of the designated production environment. Full acknowledgement should be given to the biological diversity of AMF and the wide range of host-fungus-soil specifics. Preliminary results of the present study are most promising and merit further investigation and study.

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