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INTERACTION BETWEEN A VESICULAR–ARBUSCULAR MYCORRHIZAL FUNGUS AND *STREPTOMYCES CINNAMOMEOUS* AND THEIR EFFECTS ON FINGER MILLET

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SUMMARY

Growth and phosphorus nutrition of finger millet (*Eleusine coracana*) on a sterile, phosphorus-deficient soil was improved by inoculation with either the vesicular–arbuscular mycorrhizal fungus *Glomus fasciculatus* or with the streptomycete *Streptomyces cinnamomeous*. These micro-organisms interacted antagonistically when added simultaneously or with one 2 weeks after the other: *Streptomyces* reduced spore production and development of infection by *Glomus*, while *Glomus* reduced the multiplication of *Streptomyces*. Because of this antagonism, dual inoculations stimulated plant growth less than individual inoculations.

INTRODUCTION

Interactions between vesicular–arbuscular (VA) mycorrhizal fungi and other soil organisms may occur widely. The root pathogen, *Thielaviopsis basicola* is known to be inhibited by VA mycorrhiza (Baltruschat and Schönbeck, 1972). On the other hand *Phytophthora* root rot was increased by VA mycorrhiza in soybean (Ross, 1972) and avocado (Davis, Menge and Zentmyer, 1978). Azcon, Barea and Hayman (1975) found that phosphate-solubilizing bacteria inoculated on to seeds or seedlings maintained high populations longer in the rhizosphere of mycorrhizal roots. *Azotobacter chroococcum* decreased in number around tomato roots more slowly if they were mycorrhizal (Bagyaraj and Menge, 1978). Inoculation of crops with mycorrhizal fungi and *Rhizobium* was found to have a synergistic beneficial effect on nodulation, nitrogen fixation, mineral uptake and plant growth (Daft and El-Giahmi, 1976; Bagyaraj, Manjunath and Patil, 1978).

Streptomyces species form a major component of soil actinomycetes. Beneficial effects of *Streptomyces* on plant growth (Koaze, Sakai and Arima, 1957; Balakrishna, 1979) and stimulatory effects on the nitrogen-fixing rhizosphere bacteria *Azotobacter chroococcum* and *Beijerinckia mobilis* (Balakrishna, 1979) have been observed. Inhibition of the growth of plant pathogenic fungi by *Streptomyces cinnamomeous* has also been reported (Pridham *et al.*, 1956a, b). However, there is no information on the interaction between any soil actinomycete with VA mycorrhizal fungi. The present study reports the effects of interactions between the VA mycorrhizal fungus, *Glomus fasciculatus* and the actinomycete *S. cinnamomeous* on the growth of finger millet.

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MATERIALS AND METHODS

Red sandy loam soil (pH 5·5) deficient in phosphorus (3·0 mg kg^{-1} soil extracted with $NH_4F + HCl$) was autoclaved at 1·1 kg cm^{-2} pressure and 121 °C for 1 h then put into 15 cm pots. One surface-sterilized seed of finger millet (*Eleusine coracana* Gaertn. cv Indaf 5) was placed 1 cm below the soil surface. Mycorrhizal inoculum contained approximately 300 spores of *G. fasciculatus* (Thaxt.) Gerd. and Trappe. To inoculate with *S. cinnamomeous*, 1-week-old cultures on Strezelczyk's agar (Strezelczyk, 1961) were scraped into sterile saline to give a suspension of 10^5 cells ml^{-1} and 10 ml of this was added per pot. The six treatments in the study were (1) uninoculated control; (2) inoculated with *G. fasciculatus* at sowing; (3) inoculated with *S. cinnamomeous* at sowing; (4) inoculated with *G. fasciculatus* and *S. cinnamomeous* simultaneously; (5) inoculated with *G. fasciculatus* first and *S. cinnamomeous* 2 weeks later; (6) inoculated with *S. cinnamomeous* first and *G. fasciculatus* 2 weeks later. There were three replications for each treatment. Plants were grown in a glass house with a mean temperature range of 26 °C to 31 °C and harvested after 7 weeks.

Percentage mycorrhizal infection was assessed by staining 1 cm root segments with trypan blue (Phillips and Hayman, 1970). Mycorrhizal spores in the soil were counted by the wet sieving and decanting technique (Gerdemann and Nicolson, 1963). The population of *Streptomyces* in the soil at the time of harvest was measured by dilution counts on Kustar's agar (Kustar and Williams, 1964). Root and shoot weights of the plants were recorded. Phosphorus in the root and shoot was determined using the vanadomolybdate method as described by Jackson (1970).

RESULTS

Streptomyces cinnamomeous was found to reduce sporulation by the mycorrhizal fungus (Table 1). This reduction was most prominent when *S. cinnamomeous* was added earlier than *G. fasciculatus*. Addition of *S. cinnamomeous* also reduced mycorrhizal infection. Again the reduction was most marked when *S. cinnamomeous* was added before *G. fasciculatus*, giving an infection of only 24% at harvest.

Conversely, the population of *S. cinnamomeous* in the rhizosphere was decreased by the mycorrhizal association. Table 1 shows that, regardless of the time of inoculation, *G. fasciculatus* halved the population density attained in the *S. cinnamomeous* only control (17×10^5 g^{-1} soil).

A stimulatory effect on plant growth and phosphorus nutrition was observed in all inoculation treatments (Table 2). Significant increases in root dry wts were found in treatments where *S. cinnamomeous* alone was added and when *G. fasciculatus* was added 2 weeks afterwards. Shoot dry wts were greater in all treatments with added micro-organisms than in uninoculated controls. Effects of addition of *G. fasciculatus* only, *G. fasciculatus* and *S. cinnamomeous* simultaneously, *G. fasciculatus* then *S. cinnamomeous* 2 weeks later, or *S. cinnamomeous* alone on shoot dry wt, were not statistically different.

Percentage phosphorus in the roots and shoots did not change significantly. However, plants infected with *G. fasciculatus* contained consistently higher amounts of phosphorus when compared to the *S. cinnamomeous* only treatment and the control.

Table 1. *Effect of* Glomus fasciculatus *and* Streptomyces cinnamomeous *on each other*

Treatment	Spore count per 25 ml soil	Infection by *G. fasciculatus* (%)	Population of *S. cinnamomeous* (c.f.u. $\times 10^5$ g^{-1} oven dry soil)
G. fasciculatus	53^a	77^a	0
G. fasciculatus + *S. cinnamomeous* simultaneously	51^a	50^b	9^a
G. fasciculatus first followed by *S. cinnamomeous*	49^a	65^{ab}	7^a
S. cinnamomeous first followed by *G. fasciculatus*	47^b	24^c	8^a
S. cinnamomeous	0	0	17^B
Control	0	0	0

Statistical analysis done after $\sqrt{(X+0{\cdot}5)}$ transformation of actual values.

For each variate, any two values without common letters in their superscripts are significantly different (= 0·05).

c.f.u., Colony forming units.

Table 2. *Effect of Glomus fasciculatus and* Streptomyces cinnamomeous *and their interaction on finger millet*

	Dry wt (g)		Phosphorus (dry wt basis) (%)	
Treatment	Root	Shoot	Root	Shoot
G. fasciculatus	$0{\cdot}245^a$	$0{\cdot}621^a$	$0{\cdot}09^a$	$0{\cdot}14^a$
G. fasciculatus + *S. cinnamomeous* simultaneously	$0{\cdot}215^a$	$0{\cdot}568^a$	$0{\cdot}09^a$	$0{\cdot}14^a$
G. fasciculatus first followed by *S. cinnamomeous*	$0{\cdot}291^a$	$0{\cdot}568^a$	$0{\cdot}09^a$	$0{\cdot}12^a$
S. cinnamomeous first followed by *G. fasciculatus*	$0{\cdot}565^b$	$0{\cdot}953^b$	$0{\cdot}11^a$	$0{\cdot}13^a$
S. cinnamomeous	$0{\cdot}603^b$	$0{\cdot}802^{ab}$	$0{\cdot}10^a$	$0{\cdot}09^a$
Control	$0{\cdot}103^c$	$0{\cdot}232^c$	$0{\cdot}07^a$	$0{\cdot}07^a$

For each variate, any two values without common letters in their superscripts are significantly different ($P = 0{\cdot}05$).

Discussion

The results show that *S. cinnamomeous* significantly reduces infection and spore production by *G. fasciculatus*. Conversely, the mycorrhizal association is antagonistic to multiplication of *S. cinnamomeous* in soil. The inhibitory effect of *S. cinnamomeous* on *G. fasciculatus* is possibly due to antibiotics produced by the actinomycete. *Streptomyces cinnamomeous* is known to produce antibiotics such as cinnamycin and duramycin, that are inhibitory to several fungi, including a member of Mucorales (Pridham *et al.*, 1956b) to which order *G. fasciculatus* also belongs.

Antagonism exhibited by *G. fasciculatus* to *S. cinnamomeous* is possibly due to

the presence of inhibitors, unknown as yet, in the exudates of mycorrhizal but not of uninfected roots. The presence of inhibitors in the root exudates have been reported (Schroth and Hildebrande, 1964). Bagyaraj and Menge (1978) have recorded an increase in actinomycete numbers in unsterile soil due to VA mycorrhizal infection. However, their study included all the actinomycetes present in the soil, unlike the present investigation where only *S. cinnamomeous* was involved.

Beneficial effects on plant growth of *S. cinnamomeous* (Koaze *et al.*, 1957) and *G. fasciculatus* (Gerdemann, 1975) individually have been documented. However, it was shown in this study that, because of antagonistic interactions, inoculation with both organisms results in decreased beneficial effects on plant growth compared to individual inoculations.

The present investigation shows that micro-organisms in the rhizosphere may greatly influence the colonization of roots, and hence their effect on plant growth, by the mycorrhizal fungi. This has been the first report and mechanisms responsible for such interactions need further study.

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