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INVESTIGATION OF THE EFFECTS OF MYCORRHIZAL FUNGI ON CADMIUM ACCUMULATION IN CACAO

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ABSTRACT: Currently, increasing emphasis is being placed on the contamination of cacao beans by heavy metals, particularly cadmium (Cd). Since the primary source of Cd contamination in cacao has been attributed to metal-contaminated soils, it is becoming crucial to develop strategies to minimize its uptake. Recent studies have shown that mycorrhiza could contribute to the immobilization of Cd in soils, thereby decreasing Cd toxicity to plants. A preliminary pot trial study was designed to determine whether mycorrhizal fungi in the form of bio-fertilizers could be used as a method of soil remediation, to inhibit Cd uptake by cacao plants. Roots of cuttings of a single variety and age of cacao were grown with and without a commercial bio-fertilizer, in a Cd-spiked, sterilized soil in pots, in randomized blocks in a greenhouse. The experiment was conducted over a period of four months, with replicates of plants being sacrificed and analyzed monthly, to determine the Cd contents of leaf and stem samples. Microscopic examinations were also done to detect mycorrhizal infection of roots of bio-fertilizer treated and control plants. Paired data analysis demonstrated that cacao plants treated with the mycorrhizal bio-fertilizer accumulated significantly higher ($p < 0.05$) levels of Cd in both leaves and stems than non-mycorrhizal-treated plants for the period of the study. The higher Cd concentrations found for the mycorrhizal treatment may have resulted from an increase of Cd absorption into the plants by soil mycelia, known to spread several centimeters around the plant roots. This investigation, while preliminary, indicates that the variety of cacao plant used with the commercial mycorrhiza used accumulates significantly higher levels of Cd in their leaves and stems than non-mycorrhizal plants.

Keywords: Mycorrhiza, bio-fertilizer, cadmium, cacao

INTRODUCTION

There are increasing concerns over the intake of excessive Cd in contaminated food crops, which may be toxic to animals, including humans (Welch and Norvell, 1999). It can cause abdominal cramps, headaches, vomiting and diarrhea (ATSDR, 1993) and in severe cases, kidney tubule damage, anemia and severe loss of bone minerals (Reilly, 2002). The levels of heavy metals, particularly Cd in cacao beans, have been of concern for many years (BCCCA, 1996). Concentrations of Cd in cocoa powders and liquors made from cacao beans and used in chocolate production are gaining public significance (Mounicou et al., 2002, 2003; Dahiya et al., 2005; Jalbani et al., 2009). International legislative bodies, as well as chocolate manufacturing countries have introduced new Cd regulations for the protection of the health of their consumers (FSA, 2009; Ducos et al., 2010; ICCO, 2010).

An investigation by Lee and Low (1985) reported high levels of Cd in raw cacao beans. It was speculated that Cd present in cacao beans is due to uptake by cacao plants from Cd contaminated soils (Fauziah et al., 2001; Mounicou et al., 2003; Beckett, 2009). Such soil contamination can be treated using various technologies, including physical (Evanko and Dzombak, 1997) and chemical treatments (Mahabadi et al., 2007). However, low-cost and low-impact biological techniques such as the application of microorganisms and microbial products have been receiving increasing attention for soil remediation (Leyval et al., 2002; Doumett et al., 2008; Karimi et al., 2011). Soil microorganisms such as mycorrhizal fungi have been shown to restrict or enhance heavy metal uptake (Joner et al., 2000; Janoušková et al., 2005; Hildebrandt et al., 2007). Mycorrhizal hyphal mats act as barriers against metal transport across root cell walls, thereby reducing metal uptake by plants (Gaur and Adholeya, 2004; Andrade and Silveira, 2008). In addition to sequestration of heavy metals in the vacuole of the fungal cells, extracellular heavy metal chelation by secreted mycorrhizal exudates appear to provide barriers to heavy metal absorption by plant roots (Göhre and Paszkowski, 2006; Muthukumar and Bagyaraj, 2010). Recent studies have shown that mycorrhiza could also contribute to the immobilization of Cd in soils, thereby decreasing Cd toxicity to plants (Janoušková et al., 2005; 2006). As a result, it is possible that this approach can also apply to cacao plants, minimizing or preventing Cd uptake throughout its tissues.

Thus the main objective of this research is to determine whether mycorrhizal fungi could be used as an alternative method of soil remediation to inhibit Cd uptake in cacao.

MATERIALS AND METHODS

For this study a pot trial was designed to assess the effectiveness of mycorrhizal fungi in the form of bio-fertilizers on the minimization of Cd uptake in cocoa.

Rooted cacao cuttings of a single variety and stage of maturity (approx. one month) were obtained. At the start of the trial, five samples of cuttings were taken for analysis to determine their initial levels of Cd, in addition to the mycorrhizal colonization of roots of plants. A commercial mycorrhizal preparation (MycoApply® Micronized Endo bio-fertilizer, Oregon, USA) was used to supply mycorrhiza to the roots of cacao cuttings. Mycorrhizal non-inoculated (Control, Treatment A) and inoculated (Treatment B) rooted cacao cuttings were then planted in sterilized Cd-spiked soil (10 µg/g) in polyethylene bags.

The experiment was set up in a completely randomized design, with five replications per treatment for a period of four months in a naturally illuminated greenhouse, where plants were watered periodically. Each plant was placed on a heavy-duty polystyrene plate, to minimize cross-contamination from excess irrigation water on the floor. Each month, plants were sacrificed for analysis, where leaf and stem Cd levels were determined by flame atomic absorption spectrometry (FAAS) on a Varian SpectrAA 880 (Australia), and the mycorrhizal infection of bio-fertilizer-treated roots through a clearing and staining procedure, as outlined by Koske and Gemma (1989).

The differences in Cd levels between the non-inoculated and inoculated mycorrhizal treatments were evaluated using pair data analysis ($p < 0.05$). Statistical software Minitab (version 16), 2010 was applied.

RESULTS AND DISCUSSION

Cadmium Accumulation in Mycorrhizal vs Non-Mycorrhizal-Treated Cacao Plants

Tables 1 and 2 illustrate the mean Cd concentration of leaves and stems per gram of plant dry weight (DW), respectively, for treatments A and B, during each month of the experimental period.

Table 1. Mean Leaf Cd Concentrations per gram of Plant DW for Treatments A and B over four months.

Treatment	Mean Cd ($\mu\text{g/g}$)/g in leaves (DW) \pm SD for each month			
	1	2	3	4
A	0.86 \pm 0.13	5.45 \pm 0.62	12.15 \pm 0.65	13.16 \pm 1.20
B	1.43 \pm 0.32	8.92 \pm 1.49	15.40 \pm 0.82	16.41 \pm 1.72

Table 2. Mean Stem Cd Concentrations per gram of Plant DW for Treatments A and B over four months.

Treatment	Mean Cd ($\mu\text{g/g}$)/g Stem DW \pm SD for each Month			
	1	2	3	4
A	2.06 \pm 0.39	6.73 \pm 0.19	9.36 \pm 0.54	7.37 \pm 0.56
B	3.77 \pm 0.86	12.29 \pm 0.25	12.30 \pm 2.34	9.57 \pm 0.41

Paired data analysis demonstrated that cacao plants treated with the mycorrhizal bio-fertilizer accumulated significantly higher ($p < 0.05$) levels of Cd in both leaves and stems than non-mycorrhizal plants for the period of the investigation. These results are contrary to those reported to show decreases in Cd uptake by mycorrhiza (Janoušková et al., 2005; Janoušková et al., 2006). However, plants grown with mycorrhiza may show enhanced Cd uptake and root-to-shoot transport (Vogel-Mikus et al., 2005; Göhre and Paszkowski, 2006), as found in our preliminary study.

Even though this difference in Cd uptake can be attributed to the presence of mycorrhiza in the commercial mycorrhizal preparation, results from mycological analyses over the four-month study period showed that none of the roots sampled were infected. It is possible that low infection rates of the roots by the mycorrhiza may not have allowed their true effects to be realized within the four months of our trial. However, intra-radical mycorrhizal colonization may be reduced by high heavy metal levels in soils (Liao et al., 2003), and high soil Cd can reduce the mycorrhizal infections of roots in such soils (Tullio et al., 2003; Andrade and Silveira, 2008). It is thus possible that the soil Cd concentration used in this experiment may have had a similar affect on colonization of mycorrhiza in the roots of the cacao plant.

It must also be noted that the mycelia of mycorrhiza do not propagate only in the root cortex of the host plant, but also in the soil around the root (Neumann and George, 2009). Thus, the significantly higher Cd concentrations found for the mycorrhizal treatment may have resulted from

an increase of Cd absorption into the plants by soil mycelia, known to spread several centimeters around the plant roots (Gowariker et al., 2009).

CONCLUSION

This investigation, while preliminary, indicates that the variety of cacao plants treated with the commercial mycorrhiza accumulated significantly higher levels of Cd in the leaves and stems than non-treated plants. Consequently, mycorrhiza in the form of bio-fertilizers may not be effective treatment to minimize Cd accumulation in cacao plants. However, it is possible that other mycorrhiza and cacao plants may behave differently, as found in other plants and should be further investigated.

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