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RESEARCH ARTICLE

Antioxidant compounds and minerals in tomatoes by *Trichoderma*-enriched biofertilizer and their relationship with the soil environments

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Abstract

The experiment was conducted to evaluate the efficacy of *Trichoderma*-enriched biofertilizer (BioF/compost) on antioxidants and minerals in ripe tomatoes and soil health improvements in terms of nutrient availability and microbial populations. The study was comprised of six treatments: control (zero input); recommended doses of NPK (135.5, 45.6 and 22.9 kg ha^{-1}, respectively); 100% BioF/compost; 75% BioF/compost+25% N; 50% BioF/compost+50% N; and 25% BioF/compost+75% N. The recommended doses of P and K were used in the last three treatments. It was found that the application of 100% BioF/compost enhanced plant growth, leaf greenness, and produced 12.9% higher yield compared to the recommended doses of NPK and other treatments. Mineral contents (P, K, Ca, Mg, Cu, Fe, Mn and Zn) in tomato roots, shoots and fruits and antioxidant compounds, i.e., ascorbic acid, β-carotine, and lycopene were increased significantly in fruits fertilized with 100% BioF/compost. The high efficiency of *Trichoderma* compost might be the result of its potential of nutrient solubilization and harboring soil microorganisms. Collectively, BioF/compost increased soil fertility and favored growth of microbes in the rhizosphere which ultimately contributed to higher yield, antioxidant, and mineral concentrations in tomatoes. Thus, *Trichoderma*-enriched biofertilizer may reduce application of chemical fertilizers and therefore, can be considered as a noble practice in sustainable agriculture.

Keywords: *Trichoderma harzianum* T22, minerals, antioxidants, nutrient availability, microbial populations

1. Introduction

The application of chemical fertilizer is the accepted method of intensive agriculture despite the apprehension of environmental pollution. Movement of nitrogen (N) and phosphorus (P) from agricultural fields to surface water may cause eutrophication of aquatic ecosystems, leading to anoxic areas called dead zones (Simpson *et al.* 2011). Application of P fertilizers can also introduce cadmium into the soil and, thereby, to the crops (Rembiałkowska 2007).

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N is linked to leaching of nitrates into ground water. In the digestive system of human, nitrate is readily converted into nitrites, which can further react with amines and amides to produce N-nitroso compounds that are often associated with fatal methemoglobinemia (Chan 2011). Microbial denitrification of nitrate nitrogen contributes to ozone layer depletion, global warming, and acid rain production (Galloway *et al.* 2003; Ma *et al.* 2007; Burger and Ventera 2011). Furthermore, N fertilizers favor microbial decomposition of organic matter. This causes depletion of soil organic carbon (Khan *et al.* 2007) and results in poor quality of products (Dumas *et al.* 2003). Organic farming, which strictly limits the use of chemical fertilizers, provides an alternative that minimizes the negative effects of chemical fertilization (Aguilera *et al.* 2013; Aires *et al.* 2013). Unfortunately, organic farming almost always means a lower yield and increasing cost of production. Integrated nutrient management systems do not aim to entirely remove chemical fertilizers but suggest the use of microbial inoculants or "biofertilizers" (products containing living cells of microorganisms), or plant growth promoting microbes (PGPM), to reduce the amount of the chemical fertilizers applied (Adesemoye and Kloepper 2009).

Among PGPM, *Trichoderma* species are filamentous fungus widely used as biopesticides (Harman 2006). In recent years, they have become popular as a plant growth promoter (Haque *et al.* 2010; Kaveh *et al.* 2011; Hermosa *et al.* 2012; Cai *et al.* 2015). *Trichoderma hazianum* strain T203 was shown to increase the concentrations of P, Fe, Mn, Cu, Zn, and Na in cucumber roots grown in hydroponic system (Yedidia *et al.* 2001), whereas *Trichoderma asperellum* strain T34 was shown to decrease the concentrations of Cu, Zn and Mn in aerial part of wheat plants grown in a ferrihydrite-enriched calcareous medium (Santiago *et al.* 2011). Recently, Li *et al.* (2015) inoculated tomato seedlings with a *T*. *harzianum* strain SQR-T037 using hydroponic system with a nutrient solution deficient in P, Fe, Cu or Zn and supplemented with their corresponding solid minerals. In Cu-deficient condition, both dry matter production and Cu uptake were increased, whereas in Fe, Zn and P-deficient conditions, the produced biomass was decreased. However, macro- and micro-elements in tomato plants by inoculation with *Trichoderma* yet to be quantified under field condition.

Trichoderma spp. was also shown to increase the yield of various crops under field condition (Srivastava *et al.* 2006; Haque *et al.* 2010; Banayo *et al.* 2012; Molla *et al.* 2012; Sharma *et al.* 2012; Abudulai *et al.* 2014). Bio-organic fertilizer (enriched with *T. harzianum* strain SQR-T037) coupled with 75% chemical fertilizer was shown to have produced tomato yields equivalent to those obtained using the 100% chemical fertilizers (Cai *et al.* 2015). However, impacts of 100% bio-organic fertilizer on yield was not reported in the literature (Cai *et al.* 2015). We previously demonstrated that 50% *Trichoderma*-enriched biofertilizer (BioF/compost, press mud of sugar mills, poultry liter, cowdung and household/kitchen wastes composted with *T*. *harzianum* T22) coupled with 50% NPK had produced 11.87% higher yield than the recommended dose of NPK in tomato (*cv*. BARI tomato 14). However, sole application of BioF/compost produced 30.08% lower yield than that under the recommended dose of NPK although BioF/compost was used as recommended by the manufacturer (Molla *et al.* 2012). It is therefore important for this area research to be investigated in detail based on the integrated plant nutrition system (IPNS). This paper reports the results of an experiment carried out to quantify the appropriate rate of application of BioF/compost. The research question therefore, is what doses of BioF/compost (*Trichoderma*-enriched) should be used, exclusively or in combination with NPK, so that the yield and quality of tomato are not jeopardized.

Tomatoes are excellent source of micronutrients, certain minerals (notably potassium), carboxylic acids (Caputo *et al.* 2004), antioxidants such as lycopene, β-carotene, lutein, phytoene, phytofluene, vitamin C and E (Hernández-Suárez *et al.* 2007; Nour *et al.* 2013), phenolic compounds (Hernández-Suárez *et al.* 2007; Ray *et al.* 2011), vitamins, and trace elements (Luthria *et al.* 2010; Molla *et al.* 2012) but low in fat and calories, as well as being cholesterol-free. Consumption of tomato and tomato products has been shown to reduce the risk of cardiovascular disease and certain types of cancer (Canene-Adams *et al.* 2005). However, minerals and phytochemical contents in tomato fruits are dramatically affected by the environmental factors such as temperature, light, and agronomic options such as variety, water availability, mineral nutrients, growth and development regulators, harvesting time and etc. (Dumas *et al.* 2003; Hernández-Suárez *et al.* 2007; Nour *et al.* 2013). Therefore, the objectives of the study were to evaluate the effect of *Trichoderma*-enriched biofertilizer (BioF/compost) on the antioxidant and mineral contents of tomato fruits. This research also aims to quantify and establish relationship amongst the plant growth attributes and the biochemical contents of fruits, roots and shoots. In addition, the effect of BioF/compost on the soil health, i.e., nutrient availability and microbial populations were also examined so as to understand if the biofertilizers could partially substitute the need of N fertilizers.

2. Materials and methods

2.1. Description of the experimental site

The experiment was conducted during October 2014 to March 2015 at the research field of the Department of Envi-