Trichoderma-mediated enhancement of nutrient uptake and reduction in incidence of Rhizoctonia solani in tomato

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Abstract

Trichoderma harzianum is a naturally occurring filamentous fungus which solubilizes mineral nutrients and inorganic fertilizers, increasing availability and uptake of nutrients to the plant. Rhizoctonia solani is a major problem for seedlings, causing damping-off and in mature plants causing foot and root rot in the tomato crop, reducing nutrient uptake. The aim of this study is to evaluate the effect of Trichoderma harzianum (BHU-51), Trichoderma harzianum (BHU-105) and their consortium Trichoderma harzianum (BHU-51+BHU-105) on management of R. solani and nutrient levels in the plants.

The application of Trichoderma as a seed treatment significantly decreased the incidence of damping-off and increased the vigour index of the plants. The maximum reduction in disease incidence was recorded for the consortium (BHU-51+BHU-105) treatments. The mineral content in treated plants was also higher than untreated pathogen-inoculated controls. Field trials also showed that the consortium produced better results in terms of shoot length, chlorophyll content and yield than the control.

The application of Trichoderma in consortium form increased mineral nutrient uptake, reduced disease incidence and obtained a greater yield with reduced chemical pesticide loads, benefitting farmers and consumers.

Keywords: Trichoderma, Rhizoctonia solani, nutrient uptake, damping-off, disease management.

Introduction

Natural agricultural soil harbours lots of agriculturally important beneficial microorganisms, such as Trichoderma, Pseudomonas, Bacillus spp., arbuscular mycorrhizal fungi, etc., which are responsible for sustaining plant health and the fertility of the soil. They affect plant growth either by reducing the deleterious effects of phytopathogenic organisms, increasing nutrient uptake, nutrient cycling, the synthesis and release of growth-promoting hormones (increasing plant vigour) or by preventing pathogen attack and thus acting as biocontrol agents (Jeffries et al. 2003, Glic 1995). The high and indiscriminate use of agrochemical inputs reduces the useful role and populations of rhizosphere microorganisms (Mader et al. 2002), since their efficiency depends mainly upon the physical and chemical properties of the soil. Among beneficial microorganisms, the filamentous fungus Trichoderma is one of the most important and widely used in agriculture as a biocontrol agent against many plant pathogens, and it may also increase plant growth (Shoresh et al. 2010), enhance the vigour of poor-quality seeds (Mastouri et al. 2010; Shoresh et al. 2010), improve the nitrogen-use efficiency of plants (Shoresh et al. 2010, Harman 2011) and solubilize micronutrients (Altomare et al. 1999). Chemical communication is established between the plant and Trichoderma when the most efficient strains infect and colonize the outer epidermal layers of the roots. Beneficial effects can occur for at least the first growing season: because the fungus grows and continues to colonize the roots, in turn the plant also shows increased growth. By this colonization and chemical communication, the physiology of the plant is strongly affected via changes in plant...
gene expression (Samolski et al. 2012; Bae et al. 2011; Shoresh et al. 2010). Thus, the fungus reprogrammes plant gene expression, resulting in an alteration of plant responses to their environment.

Tomato is one of most important vegetable crops in India, cultivated round the year with an acreage of 3.5 million ha producing 10.3 million tons. *Rhizoctonia solani* causes seedling damping-off and foot/root rot in the mature plants, and is found consistently in the field. Control of this sclerotial pathogen is difficult because of its ecology; it has an extremely broad host range and a high survival rate of sclerotia under diverse environmental conditions. Efficient strategies of control are therefore needed. Chemical control causes many negative consequences including resistance, resurgence and residues which cause indirect effects on human health by accumulating in food or reducing food nutritional quality. Numerous studies have shown that biological control offers an environmentally friendly alternative for the protection of plants from soil-borne pathogens.

*Trichoderma* species are worldwide in occurrence and are present in nearly all soils and diverse habitats (Harman et al. 2004). These versatile fungi act on pathogens via various mechanisms such as mycoparasitism, antibiosis, competition, and nutrient competition by secreting antifungal metabolites. *Trichoderma* spp. also solubilize various plant nutrients such as Fe, Cu, Mn and Zn in soils, and even some natural fertilizers such as rock phosphate and pyrite (Altomare et al. 1999): this ability enhances plant growth and productivity. For improving crop yield and growth, and other beneficial effects of rhizosphere activity, the use of *Trichoderma* appears to be a promising alternative to pesticides and chemical fertilizers. In the present study we used a consortium of two different compatible *Trichoderma* isolates for increasing their overall efficiency. Specifically we tested the application of *Trichoderma harzianum* BHU51 (GenBank accession no. JN 618343.), *Trichoderma harzianum* BHU105 (GenBank accession no. JN 618344) and their consortium (BHU51+BHU105) on tomato seeds and seedlings, measuring nutrient uptake, plant growth and biocontrol under greenhouse and field conditions.

**Materials & Methods**

The experiments were conducted under greenhouse and field conditions at the experimental farm of Banaras Hindu University, Varanasi, India. The soil type of the experimental field was sandy loam (Udico Ustochrept) with the following physicochemical and electrochemical properties: bulk density 1.41 Mg m$^{-3}$, particle density 2.47 Mg m$^{-3}$, water-holding capacity 44.38%, sand 512.6 g kg$^{-1}$, silt 284.8 g kg$^{-1}$, clay 202.6 g kg$^{-1}$, pH$_w$ (1 : 2.5 in distilled water) 7.3, electrical conductivity 0.454 dSm$^{-1}$, free CaCO$_3$ 0.32%, organic carbon 4.2 g kg$^{-1}$, cation exchange capacity 11.8 {Cmol (p+) kg$^{-1}$}, available nitrogen 252 kg ha$^{-1}$, available phosphorus 21.3 kg ha$^{-1}$, available potassium 158.3 kg ha$^{-1}$.

*Trichoderma* isolates were isolated from different regions of Uttar Pradesh (India), characterized for their antagonistic and plant growth-promotion activity, and sequenced (data not shown). The two most efficient and compatible *Trichoderma* isolates were *Trichoderma harzianum* BHU51 (GenBank accession no. JN 618343) and *Trichoderma harzianum* BHU105 (GenBank accession no. JN 618344): they and their consortium (BHU51+ BHU105) were used in this study. The pathogen *Rhizoctonia solani* was isolated from infected tomato plants from the vegetable farm of Banaras Hindu University. The pathogen inoculum was prepared in sand maize meal media (Blestos et al. 1997).

Experiments were performed with four treatments and three replicates each. The plot size was 2×2 m$^2$ and the seedling distance was kept at 60 × 60 cm. The analysis used Anova implemented by SPSS-16. Four treatments combinations were arranged as in Table 1.
Table 1: Treatment combinations

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td><em>Rhizoctonia solani</em></td>
</tr>
<tr>
<td>T2</td>
<td><em>Trichoderma harzianum (BHU-51) + T. harzianum (BHU-105) + R. solani</em></td>
</tr>
<tr>
<td>T3</td>
<td><em>T. harzianum (BHU-51) + R. solani</em></td>
</tr>
<tr>
<td>T4</td>
<td><em>T. harzianum (BHU-105) + R. solani</em></td>
</tr>
</tbody>
</table>

Seeds of ‘Navodya’ tomato (*Lycopersicum esculentum* Mill.) were obtained from a local market. Seedlings were raised in pots filled with sterilized soil (121 °C and 15 lbs pressure for 1 h for two consecutive days) and transplanted into the field after 30 days of sowing.

*Trichoderma* formulations containing approximately $10^8$ spores/g were used for treating seeds and seedlings. For the combined inoculation (consortium), formulations were prepared separately and mixed in equal amount (1:1) before treatment. A slurry of the formulations was made and then seeds added to the slurry, mixed and allowed to soak for 30 min. The treated seeds were placed in sterile Petri dishes and air-dried on a laminar flow bench overnight at room temperature. Control seeds were treated with mixtures of CMC suspension and talcum powder only. Thirty-day-old seedlings were used for field trials. Seedlings were treated by being dipped into the *Trichoderma* suspensions prepared as above and left for half an hour before transplanting. Surface-disinfected seeds were first inoculated with mycelial suspension of pathogens followed by talc preparations of *Trichoderma* isolates separately. The pathogen was grown in liquid culture medium for a week and homogenized before being used as an inoculum. *Trichoderma* isolates were tested for their plant growth promotion activity using the standard roll-towel method (ISTA 1993). The germination percentage of seeds was recorded and the vigour index calculated as described by Baki & Anderson (1973).

Under glasshouse and field conditions we tested the ability of *Trichoderma* isolates to reduce damping-off of seedlings, induce and increase the emergence of seedlings, increase plant height, and fresh and dry weight. Trials of the two *Trichoderma* isolates and their consortium were carried out in pots kept under glasshouse conditions. Pots were filled with sterilized soil and mixed with pathogen inoculates at a rate of 5g per kg of soil. The pots containing inoculum were incubated for seven days at room temperature. Treated dry tomato seeds were planted into pots according to treatment. One hundred seeds were planted per pot and evaluated for percent germination and damping-off of seedlings. Seedling emergence was counted at regular intervals. The germination and cumulative damping-off of seedlings were recorded 30 days after sowing. The incidence of damping off in seedlings was expressed as a percentage of the total number of plants. The number of seedlings which had survived, and the shoot length, root length and fresh and dry weight of shoot and root of surviving plants were recorded from each replicate. To measure fresh and dry weights, plants were washed under running tap water to remove all soil from the roots and then dried at 80 °C in a drying oven after recording their fresh weight. After 72 hr, plant dry weights were recorded. For the field study, inoculates of *R. solani* comprising 100g per m² (grown on sand maize media) were inoculated in the field seven days before transplanting.

Plant samples for study of minerals in seedlings were taken 30 days after sowing. The plant material was dried at 65 °C for 48 hr. The dried samples were separately ground, and passed through a 0.5 mm sieve for analysis of mineral components. The micro-Kjeldahl procedure (IITA 1982) used for analysis of total Nitrogen. Total phosphorus content was determined by the Vanadomolybdate method using a spectrophotometer; flame photometry was carried out for the analysis of K and Ca, while Zn, Mn, Mg, Cu and Fe were determined by atomic absorption spectrophotometry.

In the field, transplanted seedlings were observed at regular intervals for the symptoms of wilting, foot rot or damping off, and for signs of *R. solani*. Disease severity was estimated by
scoring individual plants. The severity of stem lesions was scored on the 0-5 scale described by Sneh et al. (1966) and Ferry & Dukes (2002). The mean disease rating and Percent disease reduction were calculated by the formula given by Pal et al. (2001).

The measurement of shoot length was carried out at 60 days after transplanting. The yield was measured at regular intervals, and the cumulative yield was expressed in kg/plot. The analysis of chlorophyll content was done by harvesting fresh leaves at 60 days after transplanting and weighed to determine fresh weight. The leaves were crushed in 80% acetone, centrifuged, and the amount of chlorophyll determined by taking the absorbance at 645 and 663 nm using a spectrophotometer (Arnon 1949). The result was expressed as mg chlorophyll per gram fresh weight.

Results

Plant growth promotion activity

Seeds treated with *Trichoderma* BHU-51, BHU-105 and their consortium (BHU-51+BHU-105) significantly increased seed germination compared to the pathogen-inoculated control (Fig. 1), with the consortium the highest value. The incidence of damping-off was maximal in the untreated control, and lowest in seeds treated with the consortium (Fig 1).

![Graph showing germination and damping-off](image)

**Fig. 1:** Effects of *Trichoderma harzianum* (BHU-51), *Trichoderma harzianum* (BHU-105) and their consortium (BHU-51+BHU-105) on the germination and incidence of damping-off of tomato caused by *Rhizoctonia solani*. Bars with different letters indicate statistically significant differences among treatments using Duncan’s multiple range test (p<0.05).

Treated seeds had significantly increased shoot and root lengths compared to control plants, and treatment also had beneficial effects on fresh and dry shoot and root weights (Table 2). The vigour index was maximal in the consortium treatment and lowest in the untreated pathogen-inoculated seeds (Table 2).
Singh et al.: Effects of Trichoderma on tomato growth and disease resistance

Table 2: Efficacy of Trichoderma isolates on growth attributes and incidence of tomato inoculated by Rhizoctonia solani

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Shoot length (cm)</th>
<th>Shoot fresh weight (mg)</th>
<th>Shoot dry weight (mg)</th>
<th>Root length (cm)</th>
<th>Root fresh weight (mg)</th>
<th>Root dry weight (mg)</th>
<th>Vigor index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (R. solani)</td>
<td>9.44 ± 0.38c</td>
<td>290.67 ± 12.58c</td>
<td>19.47 ± 1.00c</td>
<td>2.05 ± 0.19c</td>
<td>11.93 ± 1.80c</td>
<td>2.33 ± 0.32c</td>
<td>345.74 ± 58.72d</td>
</tr>
<tr>
<td>BHU-051+BHU-105+R. solani</td>
<td>12.83 ± 0.47a</td>
<td>583.27 ± 7.13a</td>
<td>44.40 ± 3.14a</td>
<td>3.18 ± 0.39a</td>
<td>33.83 ± 2.08a</td>
<td>4.02 ± 0.25a</td>
<td>1393.17 ± 55.20a</td>
</tr>
<tr>
<td>BHU-051+R. solani</td>
<td>11.56 ± 0.10b</td>
<td>562.03 ± 10.75ab</td>
<td>37.63 ± 2.65b</td>
<td>2.62 ± 0.11b</td>
<td>25.70 ± 1.77b</td>
<td>3.04 ± 0.21b</td>
<td>1246.50 ± 57.47b</td>
</tr>
<tr>
<td>BHU-105+R. solani</td>
<td>11.44 ± 0.21 b</td>
<td>543.33 ± 15.50b</td>
<td>36.67 ± 4.51b</td>
<td>2.60 ± 0.17b</td>
<td>24.03 ± 1.86b</td>
<td>2.94 ± 0.36b</td>
<td>1127.08 ± 51.40c</td>
</tr>
<tr>
<td>LSD (p= 0.05)</td>
<td>0.72</td>
<td>25.62</td>
<td>4.46</td>
<td>0.45</td>
<td>4.33</td>
<td>0.56</td>
<td>120.04</td>
</tr>
</tbody>
</table>

All the values represent the mean of three replicates ± standard deviation. Different letters denote a statistically significant difference according to Duncan’s Multiple Range Test; we give also the Least Significant Difference (LSD) at p=0.05.

Table 3: Effect of Trichoderma and Rhizoctonia solani on nutrient uptake in tomato seedlings, measured 30 days after sowing

<table>
<thead>
<tr>
<th>Treatments</th>
<th>N (%)</th>
<th>P (%)</th>
<th>K (%)</th>
<th>Mg (%)</th>
<th>Ca (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (R. solani)</td>
<td>1.31 ± 0.13c</td>
<td>0.13 ± 0.01c</td>
<td>1.61 ± 0.08c</td>
<td>0.40 ± 0.02d</td>
<td>1.19 ± 0.09c</td>
</tr>
<tr>
<td>BHU-051+BHU-105+R. solani</td>
<td>2.27 ± 0.12a</td>
<td>0.28 ± 0.02a</td>
<td>2.14 ± 0.09a</td>
<td>0.76 ± 0.05a</td>
<td>1.75 ± 0.07a</td>
</tr>
<tr>
<td>BHU-051+R. solani</td>
<td>1.76 ± 0.19b</td>
<td>0.22 ± 0.01b</td>
<td>1.93 ± 0.07b</td>
<td>0.67 ± 0.04b</td>
<td>1.47 ± 0.08b</td>
</tr>
<tr>
<td>BHU-105+R. solani</td>
<td>1.99 ± 0.24ab</td>
<td>0.20 ± 0.02b</td>
<td>1.86 ± 0.08b</td>
<td>0.51 ± 0.04c</td>
<td>1.35 ± 0.04b</td>
</tr>
<tr>
<td>LSD (P= 0.05)</td>
<td>0.26</td>
<td>0.03</td>
<td>0.11</td>
<td>0.08</td>
<td>0.11</td>
</tr>
</tbody>
</table>

as Table 1

Table 4: Effect of Trichoderma and Rhizoctonia solani on micro-nutrient uptake in tomato seedlings

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Zn (ppm)</th>
<th>Mn (ppm)</th>
<th>Cu (ppm)</th>
<th>Fe(ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (R. solani)</td>
<td>26.10 ± 2.10c</td>
<td>29.00 ± 1.73d</td>
<td>5.83 ± 0.87b</td>
<td>76.13 ± 4.90c</td>
</tr>
<tr>
<td>BHU-051+BHU-105+R. solani</td>
<td>36.93 ± 1.97a</td>
<td>42.87 ± 1.40a</td>
<td>10.37 ± 0.91a</td>
<td>100.47 ± 3.97a</td>
</tr>
<tr>
<td>BHU-051+R. solani</td>
<td>31.33 ± 1.63b</td>
<td>39.00 ± 1.37b</td>
<td>9.07 ± 0.45a</td>
<td>91.20 ± 6.68ab</td>
</tr>
<tr>
<td>BHU-105+R. solani</td>
<td>30.33 ± 1.80b</td>
<td>32.60 ± 1.35c</td>
<td>6.00 ± 0.44b</td>
<td>87.73 ± 3.59b</td>
</tr>
<tr>
<td>LSD (P= 0.05)</td>
<td>4.23</td>
<td>3.27</td>
<td>1.42</td>
<td>9.03</td>
</tr>
</tbody>
</table>

as Table 1
The mineral content of treated seedlings showed significantly higher N, P, K, Ca and Mg levels in comparison with the untreated pathogen-inoculated control (Table 3). Seed treated with the consortium exhibited maximal N, P, K, Mg and Ca content. There was no significant difference in N content between BHU-51+BHU-105 and BHU-105 treatments, whereas significantly higher contents of P, K, Ca, and Mg were usually recorded in consortium versus either or both singly treated seeds (Table 3). The micronutrient contents of Zn, Mn, Cu and Fe were also recorded as significantly higher in the Trichoderma-treated plants in comparison with the controls (Table 4). Again the maximum contents of Zn, Mn, Cu and Fe were recorded in the consortium treatment, followed by single Trichoderma-treated treatments, with the lowest contents in the untreated pathogen-inoculated control.

Table 5: Effect of Trichoderma isolates on chlorophyll content, disease incidence and yield of tomato against Rhizoctonia solani

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Shoot length (cm)</th>
<th>Chlorophyll content, (mg g⁻¹fw)</th>
<th>Mean disease rating</th>
<th>Disease reduction (%)</th>
<th>Yield (kg/plot)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2008-09</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control (R. solani)</td>
<td>55.0 ± 3.6c</td>
<td>0.75 ± 0.05b</td>
<td>3.13 ± 0.15a</td>
<td>-</td>
<td>6.6 ± 0.5c</td>
</tr>
<tr>
<td>BHU -051+BHU-105+R. solani</td>
<td>79.7 ± 2.5a</td>
<td>1.07 ± 0.01a</td>
<td>1.57 ± 0.12c</td>
<td>45.1 ± 0.9a</td>
<td>11.9 ± 0.9a</td>
</tr>
<tr>
<td>BHU- 051+R. solani</td>
<td>70.0 ± 3.6b</td>
<td>0.99 ± 0.05a</td>
<td>1.88 ± 0.07b</td>
<td>39.1 ± 2.0b</td>
<td>9.6 ± 0.5b</td>
</tr>
<tr>
<td>BHU-105+R. solani</td>
<td>73.0 ± 3.6ab</td>
<td>0.99 ± 0.04a</td>
<td>1.85 ± 0.09b</td>
<td>39.9 ± 1.9b</td>
<td>9.1 ± 0.5b</td>
</tr>
<tr>
<td>LSD (P= 0.05)</td>
<td>6.7</td>
<td>0.08</td>
<td>0.20</td>
<td>3.2</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>2009-10</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control (R. solani)</td>
<td>50.7 ± 3.2c</td>
<td>0.79 ± 0.10c</td>
<td>3.42 ± 0.17a</td>
<td>-</td>
<td>6.9 ± 0.5c</td>
</tr>
<tr>
<td>BHU -051+BHU-105+R. solani</td>
<td>76.0 ± 2.0a</td>
<td>1.02 ± 0.07a</td>
<td>1.58 ± 0.07c</td>
<td>47.1 ± 2.7a</td>
<td>12.3 ± 0.9a</td>
</tr>
<tr>
<td>BHU- 051+R. solani</td>
<td>69.7 ± 2.1b</td>
<td>0.99 ± 0.03a</td>
<td>2.00 ± 0.09b</td>
<td>40.1 ± 1.4b</td>
<td>9.2 ± 0.7b</td>
</tr>
<tr>
<td>BHU-105+R. solani</td>
<td>66.7 ± 3.1b</td>
<td>0.99 ± 0.04a</td>
<td>1.88 ± 0.14b</td>
<td>41.8 ± 2.2b</td>
<td>8.3 ± 1.0b</td>
</tr>
<tr>
<td>LSD (P= 0.05)</td>
<td>5.7</td>
<td>0.14</td>
<td>0.26</td>
<td>4.2</td>
<td>1.6</td>
</tr>
</tbody>
</table>

As Table 1

In the field trials, seedlings treated with the consortium exhibited maximal shoot lengths, significantly longer than singly treated seedlings, which were significantly longer than the untreated pathogen-inoculated control (Table 5), a pattern repeated in both trials. Chlorophyll content also showed the same pattern (Table 5). Mean disease rating (Table 5) was highest in the untreated pathogen-inoculated control and lowest in the consortium treatment, with intermediate values for the singly treated plants, all significantly different from one another. The disease reduction was significantly higher in the consortium than single treatments, again repeated across years (Table 5). The beneficial effect of Trichoderma was also observed in the yield parameter, which were higher in the treatments than in the control (Table 5). Again the yield was significantly greater in the consortium treatment than singly treated plants, which were significantly greater than the controls.

Discussion

The use of Trichoderma species as biocontrol agents of different soil-borne plant pathogenic fungi is well documented, as is their influence on seed germination and seedling vigour (Clear & Valic, 2005). The growth promotion activity in plants is usually determined by their shoot length, fresh weight and dry weight (Chang et al., 1986, Kleifeld & Chet, 1992, Azarmi et al., 2011), and Trichoderma spp. are known to do this (Samolski et al. 2012, Harman et al. 2012, Hermosa et al. 2012).
In this study two Trichoderma isolates were applied individually and together as a consortium in talc-based formulations for seed and seedling treatments. Our results indicated that the consortium of compatible isolates enhanced the growth and vigour of the plants compared with single isolates. Srivastava et al. (2010) also reported that the use of combinations of bioagents are more effective than when used singly, and also that biopriming of seeds with Trichoderma and fluorescent Pseudomonas increased seed germination and reduced the incidence of disease. Pandey & Maheshwari (2006) and Abeyasinghe (2009) also reported that use of consortia of beneficial microbes can lead greater plant protection and growth promotion activity. Our results are similar to those of other authors (Hajieghrari, 2010; Ousley et al., 1994) and may be due to the ability of Trichoderma isolates to survive and colonize in the root and rhizosphere (Harman, 2006; Harman et al. 2004). Root colonization by Trichoderma is affected by many factors, such as root exudates, soil conditions, and the species or isolate involved, and their source populations: all these factors influence the Trichoderma – plant interaction. Many researchers report that rhizosphere-competent isolates produce a number of metabolites in the rhizosphere which influence Trichoderma colonization and plant growth promotion (Vinale et al. 2008a, b). Under glasshouse conditions, it has been reported that without the addition of fertilizers, Trichoderma significantly increased the phosphorus and potassium content in the leaves of tomato (Inbar et al. 1994). In our experiments the plants were also not fertilized, and we also found significantly increased levels of nitrogen, phosphorus and potassium, especially in the consortium treatment. We conclude that the growth response and development of plants is probably caused by compounds of Trichoderma and increased uptake of mineral nutrients by treated seeds and seedlings.

Solubilization of mineral nutrients of soil by beneficial microbes enhances soil fertility. The production of organic acids such as gluconic, citric and fumaric acid by fungi such as Trichoderma sequester cations and acidify the microenvironment in the rhizosphere and decrease soil pH, which leads to increased solubility of mineral nutrients and plant nutrient uptake (Azarmi et al., 2011, Cunningham & Kuiack, 1992), and ultimately photosynthetic rate and plant vigour. Increased concentrations of Ca, Mg, P, Na and K in the shoot and root following the application of Trichoderma harzianum T447 to the soil were reported by Azarmi et al. (2011). In our study not only macronutrients but also micronutrients were increased following Trichoderma treatment. Nzanza et al. (2011) also reported that the application of Trichoderma increased nitrogen; the combination of Trichoderma and mycorrhiza increased Mn and Zn content, whereas mycorrhiza alone increased the uptake of P and S in tomato plants. Samolski et al. (2012) reported that the qid-74 gene induced modification in root architecture that increased total absorptive surface area in response to increased nutrient uptake, ultimately increasing plant biomass. It has also been reported that it is possible to reduce nitrogen application rates by 30–50% with no reduction in yield by the use of Trichoderma (Harman 2011; Shoresh et al. 2010) in several crops. Kaya et al. (2009) also reported that observed increases in plant growth might be due to increased solubility of relatively insoluble plant nutrients caused by Trichoderma species. Altomare et al. (1999) and Yedidia et al. (2001) reported that T. harzianum has the ability to solubilize plant nutrients (rock phosphate, MnO2, Fe2O3, Cu and metallic Zinc) from their solid phase. T. harzianum T-22 reduced oxidized metallic ions which increased their solubility, and also produced siderophores that chelated iron (Altomare et al. 1999).

In this study the increase in chlorophyll content of the leaves validated the advantage of Trichoderma-treated seedlings over the controls, increasing photosynthetic efficiency (Vargas et al. 2009). Our data on the vigor index and yield showed that the consortium was far better than the single treatments. Treated seedlings were more resistant to damping-off caused by R. solani, again maximal in the consortium treatment. The relative contributions of Trichoderma spp. to the suppression of Rhizoctonia damping-off have been discussed by many researchers.
(Kwok et al., 1987; Lumsden & Locke, 1989; Lewis & Papavizas, 1985) in species such as cotton, sugarbeet and radish seedlings in the greenhouse.

*Trichoderma* was clearly beneficial in biocontrol, with the mean disease rating greatest in the untreated control and lowest in the consortium treatment, mirrored in the data for the maximum percent disease reduction. The second field trial used the same fields and hence there were successive crops from the same soil; there were therefore increased inocula of soil-borne pathogens in the control plots, which thereby increased the mean disease rating in the growing season. Elad et al. (1980) reported that incorporation of *Trichoderma harzianum* in pathogen-infested soil significantly reduced bean disease caused by *R. solani* and *Sclerotium rolfsii*. Similar results for disease reduction were recorded by Pal et al. (2001) using plant growth promoting rhizobacteria against *Macrophomina phaseolina*, *Fusarium moniliforme* and *Fusarium graminearum*. The ability of *Trichoderma* species to reduce the incidence of fungal diseases is well known, and is mainly due to mycoparasitism, antibiotic and competition for nutrients in the rhizosphere (Harman & Lumsden, 1990; Sivan & Chet, 1986, 1992). *Trichoderma* penetrate the root cortex, increasing lignification and inducing resistance in treated plants against pathogen attack (Kleifeld & Chet, 1992). *Trichoderma* also increase activities of the hydrolytic enzyme chitinase and β-1, 3-glucanase, and also stimulate the plant defense mechanism (Shoresh et al. 2010, Lorito et al. 2010, Singh et al. 2011, Druzhinina et al. 2011). Being an endophytic plant symbiont, *Trichoderma* induces gene expression in plants, which probably changes the physiology of plant in such a way as to improve resistance to abiotic and biotic factors, increase uptake of nitrogen fertilizer and photosynthetic efficiency and ultimately increase plant growth and productivity (Harman 2012, Hermosa et al. 2012).

We conclude that the application of beneficial microorganisms such as *Trichoderma* in combinations of strains (as in the consortium here) are more useful than as individual strains because two or more compatible isolates of same or different species work synergistically to give enhanced impact. The production of vigorous seedlings with more resistance to soil-borne plant pathogenic fungi is advantageous to the producers as well as to the farmers. Increased uptake of mineral nutrients reduces the quantity of inorganic fertilizer used, and reductions in the incidence of diseases reduce the burden of chemical pesticides on the crop, both of which benefit farmers and consumers alike.

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الملخص العربي

يعد اللاذكوري Trichoderma نوع من تrypto caracteres البكتيريا التي تساهم بشكل كبير في التهوية. تعزز هذه المضادات البكتيرية نمو النباتات ومقاومة الأمراض. هذا النمو والمقاومة يمكن أن يكون ناتجاً عن العديد من العوامل، بما في ذلك قدرة اللاذكوري على إحداث التغييرات الوظيفية في الأوراق الطبيعية. المضادات البكتيرية اللاذكوري تلعب دوراً مهماً في الحفاظ على صحة النباتات ونموها بشكل صحي. يتم استخدام هذه المضادات في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساهم اللاذكوري في نمو النباتات ومقاومة الأمراض عن طريق إحداث التغييرات المرضية في الأوراق الطبيعية والاضطرابات الجينية. المضادات البكتيرية اللاذكوري يمكن أن تكون ناجحة في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلفة وظروف مختلفة. يتم استخدام هذه المضادات البكتيرية اللاذكوري في العديد من الصناعات الزراعية لتحسين نمو النباتات ومقاومة الأمراض. يساعد اللاذكوري في الحفاظ على صحة النباتات ونموها بشكل صحي في بيئات مختلف