Research Article

Suppressiveness of Late Blight and Fusarium Wilt of Tomato with Trichoderma Fortified Composts

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Abstract | *Trichoderma* is widely distributed and ubiquitous in almost all type of soils and their species promote growth of the plants and commercially used as bio-fungicide against soil borne plant pathogens. The present study was conducted with the aim to determine the efficacy of *Trichoderma* species using dual culture and pot assays against *Phytophthora infestans* (late blight) and *Fusarium oxysporum* (wilt) of tomato on different compost including carbon rich compost, nitrogen rich compost and nutrient enriched compost. The species of *Trichoderma* includes *T. harzianum* and *T. asperellum* isolated from rhizosphere of tomato from different localities of district Sargodha, Punjab, Pakistan which were recognized morphologically. Three isolates of *T. harzianum* HM, HK, HC and one isolate of *T. asperellum* TH were evaluated in dual culture assays and in pots amended with different composts against *P. infestans* and *F. oxysporum*. Mycelial growth reduction and inhibition percentage of *P. infestans* and *F. oxysporum* in dual culture assay significantly higher by *T. harzianum* HK as compared to all other isolates. Furthermore, pot experiments conducted with carbon rich compost inoculated with *Trichoderma* strains with pathogens inoculums provided most effective control as compared with nitrogen rich compost and nutrient enriched compost. These results suggested the potential of *Trichoderma* spp. for affective control of plant pathogens by considering the growth, environmental conditions favoring the disease suppression.

Received | June 02, 2018; **Accepted** | May 30, 2019; **Published** | Jult 27, 2019
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Citation | Ghazanfar, M.U., M.I. Hamid, M. Raza, W. Raza, M.I. Qamar. 2019. Suppressiveness of late blight and fusarium wilt of tomato with trichoderma fortified composts. *Sarhad Journal of Agriculture,* 35(3): 823-833.
DOI | http://dx.doi.org/10.17582/journal.sja/2019/35.3.823.833
Keywords | *Trichoderma* species, Morphological characterization, *Phytophthora*, *Fusarium,* Compost

Introduction

Tomato (*Solanum lycopersicum* Mill.) belongs to solanaceae family and extensively cultivated vegetable that grows in almost every country of the world (Peralta and Spooner, 2007; Bashir et al., 2014). It has high nutritional value and contains vitamin B, C, phosphorus and iron (Beecher, 1998) and being consumed as fresh salad, pickle ketchup (Panthee and Chen, 2010) in different regions of the world. It is affected by many foliar, seed and soil borne pathogens (Oladiran and Lwu, 1993; Panthee and Chen, 2010). Among these, *Phytophthora infestans* (Mont.) de Bary (Olanya et al., 2015) and *Fusarium oxysporum* f. sp. *lycopersici* (FOL) (Li et al., 2017) are most destructive diseases causing agents worldwide. Both pathogens under favorable environmental conditions cause severe financial losses up to 100% (Chaerani and Voorrips, 2006; Nowicki et al., 2012; Ayukawa et al., 2016). Both the pathogens enter through the roots resulted in yellowing of leaves (Ayukawa et al., 2016) by clogging the vascular tissues while, late blight causes damage

to leaves and fruit (Soylu et al., 2006; Majeed et al., 2017). Currently, management strategies through protective copper based fungicides are being used frequently for the control these diseases (Yao et al., 2016). This result in enhanced cost of production (Yao et al., 2016), residual toxicity problems, development of fungicide resistant strains, environmental pollution (Abo-Elyousr et al., 2014). Moreover, pesticides and other environmental disturbing chemicals have been banned and forbidden in Europe (Okkerman and van der Putte, 2002). Therefore, bio-control of plant diseases through the use of biocontrol agents can be the best alternative strategy compared with fungicides (Gavrilescu and Chisti, 2005; El-Komy et al., 2015; Yao et al., 2016; Li et al., 2017).

Trichoderma species are more frequently used as antagonist against different foliar, seed borne and soil-borne pathogens (Harman et al., 2004; Nawrocka and Małolepsza, 2013). Most of the published literature reported the biocontrol efficacy of *Trichoderma* against various soils as well as foliar pathogens (Martínez-Medina et al., 2013; Kushwaha et al., 2014). Many isolates have proved effective against tomato wilt (Srivastava et al., 2010; Chowdappa et al., 2013; Marzano et al., 2013) and late blight pathogen (Yao et al., 2016). Trichoderma spp. has different mode of action to combat with the plant pathogens by producing lytic enzymes which alter the various morphological and biochemical changes in pathogens and induce systemic resistance in the host against adverse conditions (Harman, 2006; Ranasingh et al., 2006; Charoenporn et al., 2010; Segarra et al., 2010). A successful ecological feature of this genus *Trichoderma* is mycoparasitism and efficient defensive approach induced in plant (Rosado et al., 2007).

Non-chemical approaches such as organic amendment and suppressive compost having long term benefits against the management of plant diseases are available but need to be commercialized (Lazarovits, 2001; Abbasi et al., 2004; Abbasi and Lazarovits, 2005; Abbasi and Lazarovits, 2006). The efficacy of Trichoderma amended compost in reducing the plant pathogens is well documented as this results in altering the physio-chemical properties of compost (Saxena et al., 2015). Organic matter amendment improves the soil productivity by nutrient and water retention (Weil and Magdoff, 2004). Hence, organic matter amendment can enhance the natural biocontrol efficacy against soil-borne plant pathogens (Davis et al., 2001; Mader et al., 2002).

The objective of this study was to check the efficacy of composts such as carbon, nitrogen and nutrient enriched compost inoculated with *Trichoderma* species against *P. infestans* and *F. oxysporum*.

Materials and Methods

The research work was conducted in laboratory of Plant Pathology, College of Agriculture, University of Sargodha, Punjab, Pakistan during 2013-14 to assess the efficacy of different composts inoculated with different spp. of *Trichoderma* against *P. infestans* and *F. oxysporum*.

Isolation of Trichoderma and pathogens

Infected samples were collected from various localities of district Sargodha (32°5′1″N 72°40′16″E). Isolation of *P. infestans* performed on Rye agar A medium containing antibiotics (ampicillin 0.25g/lit, rifampicin 0.01g/lit, pimaricin 0.4ml/lit, PCNB 5ml/lit) and isolation of *F. oxysporum* was performed on antibiotic emended potato dextrose agar (potato starch 4gm, glucose 20 gm, agar 15gm, distilled water 1L, penicillin 0.25mg/lit) from the infected samples showing typical symptoms of blight and wilt while, the *Trichoderma* spp. from different soil samples of tomato rhizosphere of the same location by soil dilution method on Potato dextrose medium and King's B consisting of ingredients K_2HPO4-4.0 g/L; MgSO4-0.4 g/L; protease peptone-20.0 g/L; glycerol-8.0 ml/L; agar-20.0 g/L (The pH was attuned to 7.0 ± 0.2 before autoclave), later on the plates were placed in incubator (Rodriguez-Kabana, 1967).

Dual culture antagonism assay

The isolates of *Trichoderma* (*T. harzianum* HM, HK, HC and *T. asperellum* TH) were evaluated *in vitro* against *P. infestans* and *F. oxysporum* by using dual culture assay in two different ways on 90 mm PDA petri plates by inoculating the 5mm agar plug of antagonist and pathogen from seven day old culture.

Dual Culture technique 1: Each plug from seven days pure colony of antagonistic and pathogenic fungi was placed at equivalent distance from periphery.

Dual Culture technique 2: One plug from seven days pure colony was placed at the centre of Petri plate and

3 plugs of antagonistic fungi placed in a triangle form by placing at equal distance of pathogen. Inoculated PDA plates were incubated in an incubator at 25±2°C and percentage inhibition was calculated at 14dpi by formula;

$$\text{Percentage Inhibition} = \frac{R_1 - R_2}{R_1} \times 100$$

Where;
R_1 is the linear growth of pathogen in check plate, R_2 is the linear growth of pathogen in *Trichoderma* inoculated plate. Complete randomized design was followed against both techniques and the experiment were repeated twice.

Growth room pot experiment

Pot experiments were conducted with three replicates to compare three different composts viz, carbon rich compost, nitrogen rich compost and nutrient enriched compost comprising of sulphur and zinc mixed at the ratio of 1:10 (1kg compost: 10kg soil) with soil for performance evaluation of most competent isolates of *T. harzianum* and *T. asperellum* against *P.infestans* and *F. oxysporum* causing under growth room conditions. The fifteen days old seedlings of tomato variety (Early boy) were sown in surface sterilized plastic pots treated with *Trichoderma* and pathogens filled with different composts according to the description of Mwangi et al. (2011).

Inoculation of the inoculum

The antagonist and both the pathogens were isolated from infected tissue using standard laboratory techniques as described earlier. After the seven days of the colony growth, the colony grown on petri plates was wet-scraped using distilled sterile water and then the inoculum was observed at the microscope and the spores counted. The total spore suspension (1×10^7 spores/ml) of *Trichoderma* isolates counted by using haemocytometer were applied with pathogen inoculums while control treatments were treated only with pathogen *P. infestans* and *F. oxysporum* separately. The plant parameters such as, plant height, number of leaves, fresh weight of shoot, dry weight of shoot, and fresh weight of root as well as dry weight of root were recorded at 15 days of inoculation on carbon rich compost, nitrogen rich compost and nutrient enriched compost respectively.

Statistical analysis

The collected data were analyzed with the help of statistical software R by using least significant difference test (LSD). The results which have $P<0.05$ were considered as significant.

Results

Isolation and identification of Trichoderma spp and pathogens

The four isolates of *Trichoderma* were selected among 15 isolates based on their morphological characteristics as *T. asperellum* (TH) and *T. harzianum* (HM, HK and HC) as described by Castle et al. (1998) for further biological assays. The pathogens, *Phytophthora infestans* and *Fusarium oxysporum* was identified under the light microscope on the basis of morphological characteristics such as length, width of spores and colonies patterns according to the description of (Abad, 2008) and Leslie et al. (2006) respectively.

Pathogen suppression in dual culture antagonism test

The experimental findings in dual culture techniques showed the significant inhibition of *P. infestans* and *F. oxysporum* by *Trichoderma* species (Figure 1). It was also observed that both dual culture techniques were significantly effective against both plant pathogens (Figure 2).

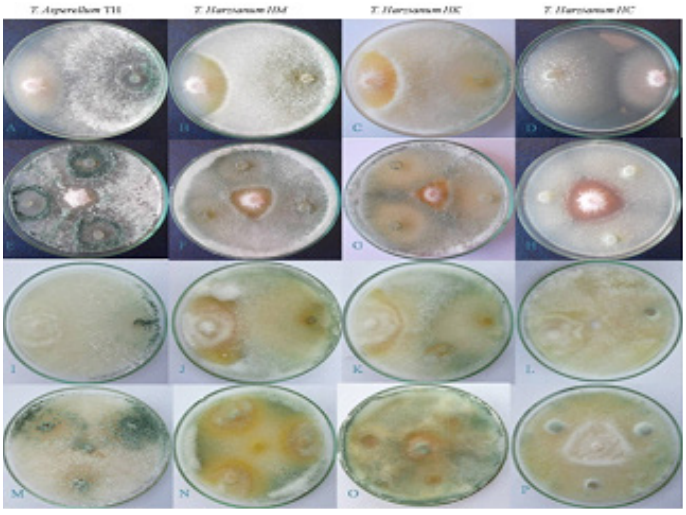

Figure 1: *Dual culture test of Trichoderma spices against Fusarium oxysporum (A-H) and Phytophthora infestans (I-P). Dual culture technique 1 against Fusarium oxysporum (A-D), Dual culture technique 2 against Fusarium oxysporum (E-H). Dual culture technique 1 against Phytophthora infestans (I-L), Dual culture technique 2 against Phytophthora infestans (M-P).*

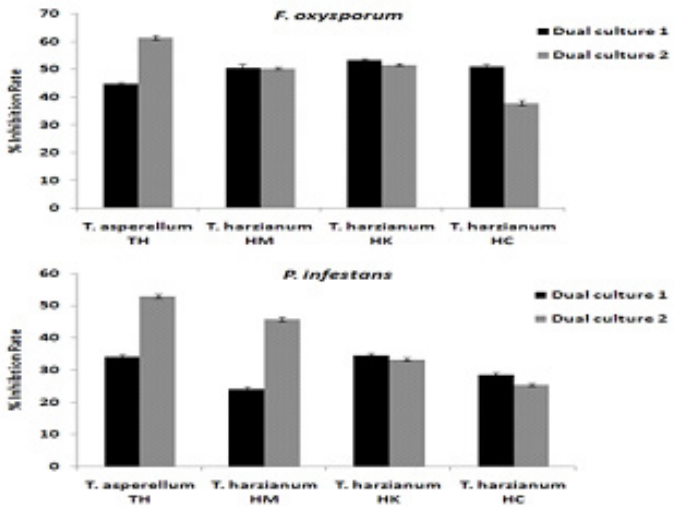

Figure 2: *Activity of Trichodsrma spp. against tamato pathogens in dual culture assays.*

Pot experiment

The effects of *Trichoderma* species with carbon, nitrogen and nutrient enriched (Phosphorous and zinc) compost was observed on plant height, number of leaves, shoot fresh weight, shoot dry weight, root fresh weight and root dry weight after 15 days of seed potting. The results revealed that comparing different composts, carbon rich compost was found to be the best rather than nitrogen rich and nutrient enriched compost when compared with control. Carbon rich compost inoculated with *T. harzianum* HK was found to be most successful for root and shoot development followed by *T. harzianum* HM, *T. asperellum* and *T. harzianum* HC against both pathogens. Carbon rich compost when used after inoculation with *T. harzianum* against *F. oxysporum* resulted in increase of plant height (9.95cm), number of leaves (62.0), shoot fresh weight (22.2 wt.), shoot dry weight (2.54g), root fresh weight (3.53g) and dry weight (2.4g) in all tested treatments as compared to control while *T. harzianum* compost when used against *P. infestans* resulted in increase of plant height (8.64cm), number of leaves (49.66), shoot fresh weight (19.67 wt.), shoot dry weight (1.96 g), root fresh weight (2.86g) and dry weight (1.7 g) (Table 3). The soil amended with different compost materials and *Trichoderma* species lead to increase in area and numbers of leaves of plant according to results and evidence shown in statistical analyzed data (Table 1, 2).

Discussion

The antagonistic ability of *Trichoderma* spp. varies from different regions of the world and may be inconsistent i.e. it may act poorly against pathogen for which it proved efficient in other regions (Hajieghrari et al., 2008; Otadoh et al., 2011). Therefore, it is imperative to use indigenous isolates for efficient products development which are compatible with environment and other related factors of the region where they will be used (Rabeendran et al., 2006). Furthermore, by molecular characterization, the chances of duplication of microbial control agents can be minimized (Stocco et al., 2016).

F. oxysporum and *P. infestans* cause wilt and late blight of tomato is yield limiting factors of tomato plant. Chemical control is not successful to control these diseases due to soil borne nature of the plant pathogens. Some limitations are common of all bio-control agents in varying environmental conditions related to their inconsistency. A large number of *Trichoderma* spp. isolated from soil were analyzed against *F. oxysporum* and *P. infestans* (Rai et al., 2016; Yao et al., 2016). Our results also demonstrated that there is clear inhibition zone created by the antimicrobial activity of the Trichoderma and formation of zone of inhibition and its size may be due to the production of antibiotics like glucanases, chitinases, trichodermol, trichodermin, peptaibols (Harman et al., 2004; Idris et al., 2007; Shoresh et al., 2010; Chowdappa et al., 2013).

The fungal mycelia had lysed with abnormal morphology and mycoparasitism clearly evident in Figure 2. Our results are almost comparable with the findings of (Rai et al., 2016) who reported that among twenty Trichoderma isolates obtained from tomato rhizosphere, nine considerably reduced the linear growth of fungal pathogens including *F. Oxysporum* (Trillas et al., 2006; Tondje et al., 2007; de los Santos-Villalobos et al., 2013). The results of the laboratory bioassays (Yao et al., 2016) showed that Trichoderma isolate NHA 14 significantly retarded the growth of the *P. infestans* (Barari, 2016) reported that the inhibition efficacy of twenty eight isolates obtained from healthy tomatoes rhizosphere of Trichoderma against *F. oxysporum*L-6 under dual culture bioassays, the isolate *T. harzianum* isolate N-8 proved most effective.

The practice of using organic amendment for the management of soil borne pathogen is an alternate strategy however; inconsistent results hinder its application in modern agriculture

Table 1: *Response of different plant parameters on nutrient enriched (P and Zn) compost emended with Trichoderma spp.*

Trichoderma species	Nutrient enriched compost											
	Fusarium oxysporum						*Phytophthora infestans*					
	Plant height (cm)	No. of leaves	Shoot fresh wt. (g)	Shoot dry wt. (g)	Root fresh wt. (g)	Roots dry wt. (g)	Plant height (cm)	No. of leaves	Shoot fresh wt. (g)	Shoot dry wt. (g)	Root fresh wt. (g)	Roots dry wt. (g)
Control	4.2± 1.07 ^{d}	11.1± 1.6^{e}	1.3± 1.7 ^{d}	0.7± 0.78^{d}	0.69± 0.04 ^{d}	0.38± 0.05^{d}	3.97± 1.17^{d}	10.01± 1.05 ^{e}	0.98± 0.13 ^{d}	0.30± 0.05 ^{d}	0.38± 0.04 ^{e}	0.20± 0.06^{d}
T. asperellum TH	6.1± 0.05 ^{b}	25.3± 1.77 ^{c}	9.9± 0.26 ^{b}	1.2± 0.09 ^{c}	2.10± 0.04 ^{c}	1.58± 0.05^{b}	6.24± 0.04^{b}	22.54± 0.04 ^{c}	8.76± 0.05 ^{c}	1.29± 0.03^{a}	1.75± 0.04^{c}	0.81± 0.07^{b}
T. harzianum HM	7.4± 0.04 ^{a}	32.5± 1.66 ^{b}	11.4± 0.17^{a}	1.5± 0.12 ^{b}	2.71± 0.76 ^{b}	1.81± 0.03^{a}	6.89± 0.06 ^{a}	29.4± 0.04 ^{b}	9.88± 0.02 ^{b}	1.43± 0.03 ^{a}	2.1± 0.03 ^{b}	0.91± 0.03^{a}
T. harzianum HK	7.6± 0.76 ^{a}	36.0± 1.04 ^{a}	12.3± 0.24^{a}	1.9± 0.2 ^{a}	2.98± 0.24 ^{a}	1.7± 0.04 ^{a}	7.14± 0.05 ^{a}	33.87± 1.52 ^{a}	10.69± 0.06 ^{a}	1.56± 0.05 ^{a}	2.64± 0.03 ^{a}	0.97± 0.02^{a}
T. harzianum HC	5.4± 0.06 ^{c}	21.5± 0.04 ^{d}	8.7± 0.14 ^{c}	1.1± 0.08^{c}	1.57± 0.04 ^{c}	0.94± 0.09 ^{c}	5.23± 0.03 ^{c}	19.43± 0.06 ^{c}	8.11± 0.05 ^{c}	0.95± 0.04 ^{c}	1.51± 0.04 ^{d}	0.61± 0.03 ^{c}

**Small letters are for comparison for within column.*

Table 2: *Response of different plant parameters on nitrogen rich compost emended with Trichoderma spp.*

Trichoderma species	Nitrogen compost											
	Fusarium oxysporum						*Phytophthora infestans*					
	Plant height (cm)	No. of leaves	Shoot fresh wt. (g)	Shoot dry wt. (g)	Root fresh wt. (g)	Roots dry wt. (g)	Plant height (cm)	No. of leaves	Shoot fresh wt. (g)	Shoot dry wt. (g)	Root fresh wt. (g)	Roots dry wt. (g)
Control	4.23± 0.04^{d}	12.10± 1.6 ^{e}	1.38± 1.3 ^{d}	0.74± 0.12^{d}	0.79± 0.06 ^{d}	0.47± 0.06 ^{d}	3.99± 0.06 ^{d}	10.66± 0.08 ^{e}	1.12± 0.14 ^{e}	0.33± 0.06 ^{c}	0.44± 0.06^{c}	0.23± 0.05^{d}
T. asperellum TH	6.73± 0.06^{b}	37.32± 1.77^{c}	12.4± 0.29^{b}	1.64± 0.13^{b}	2.46± 0.05 ^{c}	1.11± 0.04 ^{b}	6.33± 0.06 ^{b}	25.31± 0.05 ^{c}	10.13± 0.06 ^{c}	1.21± 0.04 ^{b}	1.88± 0.03^{b}	0.89± 0.07^{b}
T. harzianum HM	7.56± 0.05^{a}	43.43± 1.70^{b}	13.1± 0.20^{b}	1.78± 0.13^{a}	2.38± 0.84 ^{b}	1.92± 0.04 ^{a}	7.00± 0.04 ^{a}	30.5± 0.05 ^{b}	11.36± 0.03 ^{b}	1.58± 0.04 ^{a}	2.02± 0.05^{a}	1.21± 0.04^{a}
T. harzianum HK	8.02± 0.08^{a}	46.0± 1.06^{a}	15.6± 0.21^{a}	2.11± 0.23^{a}	3.26± 0.12 ^{a}	2.1± 0.05 ^{a}	7.36± 0.03 ^{a}	36.54± 0.04 ^{a}	13.44± 0.0 ^{a}	1.73± 0.04 ^{a}	2.72± 0.04^{a}	1.3± 0.03^{a}
T. harzianum HC	5.88± 0.07^{c}	31.77± 0.07^{d}	10.5± 0.17^{c}	1.44± 0.07^{c}	2.12± 0.05 ^{c}	0.83± 0.03 ^{c}	5.32± 0.02 ^{c}	25.55± 0.03 ^{c}	9.43± 0.04 ^{d}	1.37± 0.02 ^{b}	1.54± 0.03^{b}	0.67± 0.03^{c}

**Small letters are for comparison for within column.*

Table 3: *Response of different plant parameters on carbon rich compost emended with Trichoderma spp.*

Trichoderma species	Carbon compost											
	Fusarium oxysporum						*Phytophthora infestans*					
	Plant height (cm)	No. of leaves	Shoot fresh wt. (g)	Shoot dry wt. (g)	Root fresh wt. (g)	Roots dry wt. (g)	Plant height (cm)	No. of leaves	Shoot fresh wt. (g)	Shoot dry wt. (g)	Root fresh wt. (g)	Roots dry wt. (g)
Control	6.10± 0.05 ^{d}	16.04± 0.72^{e}	1.44± 0.11 ^{e}	0.83± 0.05 ^{d}	0.79± 0.07^{c}	0.47± 0.05^{e}	5.59± 0.04^{d}	14.66± 0.07^{e}	1.18± 0.12^{d}	0.63± 0.07^{d}	0.62± 0.08^{c}	0.31± 0.07^{c}
T. asperellum TH	7.80± 0.13 ^{b}	43.55± 1.47^{c}	16.3± 0.42^{c}	1.92± 0.18^{b}	2.77± 0.08^{b}	1.26± 0.05^{c}	6.62± 0.07^{b}	33.43± 0.04^{c}	14.16± 0.05^{c}	1.33± 0.03^{b}	1.99± 0.05^{b}	1.11± 0.04^{a}
T. harzianum HM	9.91± 0.014^{a}	58.43± 1.90^{b}	18.0± 0.27^{b}	2.37± 0.19^{a}	3.14± 0.94^{a}	2.09± 0.06^{b}	8.00± 0.05^{a}	45.5± 0.03^{b}	16.34± 0.02^{b}	1.67± 0.02^{a}	2.44± 0.04^{a}	1.33± 0.05^{a}
T. harzianum HK	9.95± 0.36^{a}	62.0± 0.07^{a}	22.2± 0.34^{a}	2.54± 0.21^{a}	3.53± 0.15^{a}	2.4± 0.08^{a}	8.64± 0.04^{a}	49.66± 0.04^{a}	19.67± 0.03^{a}	1.96± 0.04^{a}	2.86± 0.06^{a}	1.7± 0.8^{a}
T. harzianum HC	6.97± 0.09^{c}	38.77± 0.09^{d}	15.1± 0.18^{d}	1.54± 0.06^{c}	2.52± 0.06^{b}	0.98± 0.04^{d}	5.54± 0.03^{c}	28.64± 0.02^{d}	13.56± 0.03^{c}	1.10± 0.03^{c}	1.77± 0.04^{b}	0.78± 0.04^{b}

**Small letters are for comparison for within column.*

(Bonanomi et al., 2010). It is valuable that, composts which rich in carbon, nitrogen and zinc as well as phosphorous used as raw material emended with *Trichoderma* in this work was suppressive to *F. oxysporum* and *P. infestans* pathogens of tomato and promote the plant growth. The present results suggested that carbon rich compost with *Trichoderma* is most effective than the nitrogen rich and nutrient enriched compost against *F. oxysporum* and *P. infestans*. The maximum disease suppression can be achieved using optimum ratio of C: N in the compost and that compost emended with *Trichoderma* can give efficient control as well as promote the growth of the plant. In addition, compost characterized by mixture of different substrates authorized an equal large diversity of microorganism to establish in which some are contributing in disease suppression (Pascual et al., 2002).

Composts inoculation with antagonists may enhance its effectiveness and consistency to control plant pathogens (Noble and Coventry, 2005). Our results demonstrated that different plant parameters are greatly influenced with the amendments of Trichoderma in different composts while the carbon enriched compost was most effective. Earlier reports reported that compost prepared from swedge sludge with low carbon and nitrogen ratio was not suppressive to *Fusarium* wilt (Hoitink et al., 1987). It has been also reported that be deficient in suppression of biocontrol agent against soil borne pathogens in such low carbon and nitrogen ratio is due to presence of high concentration of ammonia (Hoitink et al., 1987). Numerous studies were done with the application of compost inoculated with bio control agents to control soil-borne diseases (Lumsden et al., 1983; Borrero et al., 2004). Researchers are more focused in formulating correct combination of composts with antagonists for the control of plant pathogens (Abdel-Kardar et al., 2013; Saxena et al., 2015). In this regards, combination of compost with different agriculture waste proved effective in suppressing *R. solani* in cucumber young seedlings (Trillas et al., 2006) and Fusarium wilt of tomato was suppressed by Trichoderma spp. and sewage sludge compost (Cotxarrera et al., 2002). Similarly, the suppressiveness of *R. solani* was enhanced with the addition of Trichoderma T-22 in the compost/peat mix against the soil borne plant pathogens (Pugliese et al., 2011) are also support the present findings. (Li et al., 2017) reported that *T. asperellum* strain CHF 78 increased plant growth i.e. dry weight and plant height and mineral uptake significantly thereby reduced the wilt disease in tomatoes. *T. harzianum* strain notably enhanced seedling growth in tomatoes in reducing the lesion size (Chowdappa et al., 2013). Fusarium wilt of melon was control (Lopez-Mondejar et al., 2010) by the combine application of citrus composed with *T. harzianum* T-78 is another example supports our findings. The addition of *T. asperellum* strain T34 restored suppressive capacity of the compost against Fusarium wilt of carnation as compared with control (Sant et al., 2010). The addition of Trichoderma isolates has direct impact on different plant parameters as in our experiments, *T. harzianum* HK found to be most effective for root and shoot development. The results reported by (Rabeendran et al., 2000) are in conformity with our studies as the authors showed that *T. longipile* and *T. tomentosum* increased leaf, shoot and root dry weight of cabbage seedlings in field trial (58-71%; 91-102%; 100-158% respectively). Tomato plant had 35% less disease intensity when grown in perlite enriched with T34 and also showed increased leaf area, plant height and uptake of nutrient (Fernández et al., 2014) as compared with plants grown in perlite without Trichoderma. The melon wilt can be effectively controlled with the application of *T. polysporum* and liquid compost with 100% increase (Gava and Pinto, 2016) in the production of commercial fruits. (El Khaldi et al., 2016) tested two compost with different nitrogen source against *R. solani* on potato and found highest disease incidence and severity with cattle manure compost than with sheep manure compost. The fortification of vrmi compost with *Trichoderma* greatly influenced the length and weight of plant parts (shoot, root) in mungbean (Saxana et al., 2015) are also in line with the present findings. The disease intensity was significantly lower with low percentage of melon stem infected with *F. oxysporum* f. sp. *melonis* in the compost (Blaya et al., 2013) inoculated with *T. harzianum*. Different Trichoderma isolates have proved effective against *P. infestans* on various host plants, isolate Th-Sks was proved most virulent antagonist against *P. infestans* on tomato and promoted plant height and fruits yield during field trial (Sain and Pandey, 2016) are consistent with our studies. Moreover, six isolates of *T. asperellum* showed higher mycoparasitic activity against *Phytophthora ramorum* under the field conditions (Widmer, 2014). *Trichoderma* strains isolated form Moroccan agro systems and inoculated with composts was proved

effective for the biocontrol of Fusarium wilt of tomato (Taghdi et al., 2015). The reduction in both the diseases in the present study by fortification of compost and biocontrol interaction might be due to mechanisms of antibiosis, competition for substrate, microbiostasis, colonization, propagule destruction and induced systemic resistance (Blaya et al., 2013). Trichoderma isolates have the ability to live as endophyte in plant roots and enhanced the IAA production that might increase the root weight in the said study which was also supported by (López-Bucio et al., 2015) additionally, the siderophores produced by Trichoderma isolates enhanced uptake of nutrients (Rudresh et al., 2005), this may be the reason of increased shoot weight, plant height and number of leaves in amended compost which was more pronounced in *T. harzianum* HK in our experiments.

Conclusions and Recomendations

The present research work demonstrated the integrated management strategies to control diseases of tomato caused by *F oxysporum* and *P. infestans*. The important feature of study was the utilization of antagonist with the carbon, nitrogen and nutrient enriched compost which has potential of controlling tomato diseases as well as promoting the plant growth. Therefore, use of different compost emended with *Trichoderma* spp. may be incorporated with other control strategies to minimize the losses caused by *F. oxysporum* and *P. infestans* of tomato crop under commercial tomato production systems.

Novelty Statement

Trichoderma species are more frequently used as antagonist against different foliar, seed borne and soil-borne pathogens. The study finds out the efficacy of carbon, nitrogen and nutrient enriched compost inoculated with *Trichoderma* species against *P. infestans* and *F. oxysporum*. It proves different compost enriched bio-control agents enhances efficacy against plant pathogens.

Author's Contribution

Muhammad Usman Ghazanfar conceived the idea and facilitated, guided and supervised the experiment. Mr. Mubashar Raza planned and executed the experiment and also noted the results. Imran Hamid did statistical analysis while Waqas Raza wrote and finalized the manuscript.

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