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RESEARCH PAPERS

Control of *Phytophthora capsici* and *Phytophthora parasitica* on pepper (*Capsicum annuum* L.) with compost teas from different sources, and their effects on plant growth promotion

Francisco MARÍN[1], Fernando DIÁNEZ[1], Mila SANTOS[1], Francisco CARRETERO[1], Francisco J. GEA[2], Carlos CASTAÑEDA[1], María Jesús NAVARRO[2] and José A. YAU[3]

[1] Departamento de Agronomía, Escuela Superior de Ingeniería, Universidad de Almería, 04120 Almería, Spain
[2] Centro de Investigación, Experimentación y Servicios del Champiñón (CIES), Quintanar del Rey, 16220 Cuenca, Spain
[3] Instituto de Investigación Agropecuaria de Panamá. Edificio 161, 162, Ciudad del Saber, Clayton. Calle Carlos R. Lara, Republica Panamá

Summary. Suppressive effects of different compost teas were evaluated against the phytopathogens *P. capsici* and *P. parasitica*, isolated from diseased plants from commercial sweet pepper farms in Almería (Spain), during 2011. Aerated compost tea and non-aerated compost tea were prepared from spent mushroom compost, grape marc compost, crop residues compost and vermicompost. *In vitro* inhibition of mycelial growth of the two tested pathogens was assessed, and *in vivo* effects of compost teas on disease severity, caused by *P. capsici* and *P. parasitica* were evaluated on pepper plants, in greenhouse experiments. Different morphological parameters were also measured for plants treated with compost teas, to determine growth promotion effects on pepper plants. The compost teas controlled the two tested pathogens *in vitro* and *in vivo*. Non-aerated compost teas (NCT) were more beneficial in increasing growth of pepper plants than aerated compost teas. This study demonstrates the clear effect of compost tea on disease suppression and plant growth promotion. These compost extracts may be used as alternatives to inorganic fertilizers/fungicides to enhance plant growth, reduce disease incidence and increase crop yields.

Key words: Biological control, disease suppression.

Introduction

Chili and sweet pepper are important vegetable crops worldwide, cultivated in approximately 1.9 million ha, and the harvested crops produce draws approximately 30M tons annually. This represent 2.75% of the global horticultural crop production and 3.35% of global horticultural crop area (FAO, 2011). By 2011, approximately 63% of the global area of pepper crops was in Asia, and 14% (263,000 ha) was in Mediterranean countries (FAO, 2011).

Approximately 59% (10,600 ha) of the Spanish pepper area is currently grown as a greenhouse crops. Almeria province is the main pepper-producing area in Spain with 7,475 ha, representing 42% of the national area and 50% of Spanish production. Murcia province is the second largest producer with 1,400 ha, representing 8% of Spanish area and 13% of production (MAGRAMA, 2010).

Pepper production is often hindered by fungal diseases. One of the most important diseases limiting production is Phytophthora blight, caused by either *Phytophthora capsici* or *P. parasitica* Dastur (= *P. nicotianae* Breda de Haan). *Phytophthora capsici* is one of the most destructive pathogens causing disease in pepper worldwide. This pathogen causes the main disease in pepper crops in the Mediterranean area (Palazón and Palazón, 1989; Rodríguez-Molina *et al.*, 2010), and an important disease worldwide (Erwin and Ribeiro, 1996). *Phytophthora parasitica* has been

Corresponding author: M. Santos
Fax: +34 950 01 45939
E-mail: msantos@ual.es

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reported as a pathogen of pepper plants in United States, Puerto Rico, Japan, Italy, Mauritius and India (Erwin and Ribeiro, 1996 and references therein), and this is the unique species causing the disease in Tunisia (Allagui *et al.*, 1995). In Spain *P. parasitica* causes root and crown rot in pepper in Ciudad Real and Toledo provinces (Castilla-La Mancha) (Bartual *et al.*, 1991); in Cáceres province it has been reported as the principal causal agent of Phytophthora blight (Rodríguez-Molina *et al*., 2010); and in the Andalucía (Larregla, 2003) and Galicia (Pomar *et al.*, 2001; Andrés-Ares *et al*., 2003) regions, this pathogen has been found in association with *P. capsici*.

Control methods such as selection of genetically resistant cultivars and planting in well-drained soil are of great importance. Although some fungicides, such as metalaxyl, fosetyl-Al and terrazole propamocarb-hydrochloride can be effective, fungicide applications may not be sufficient for controlling the collar blight, if conditions are favourable for disease development. Using fungicides also brings certain environmental hazards (Erwin and Ribeiro, 1996; Akgül and Mirik, 2008). Genetic resistance is the most effective and economical way for plant disease management. Resistance to *P. capsici* has been introduced into commercially grown pepper cultivars through traditional breeding. However, the resistance has not been entirely successful due to the large number of pathogen physiological races (Monroy-Barbosa and Bosland, 2011). Biocontrol using antagonists represents a potentially attractive disease management approach to reduce the side effects of fungicides as environmental pollutants.

Compost and its aqueous extracts, commonly called as compost teas, are described as having suppressive properties, essentially due to their biotic components which have antagonistic activity against phytopathogens (Noble and Coventry, 2005; Pane *et al*., 2011), and/or incite systemic resistance responses in treated plants (Zhang *et al*., 1996). For these reasons, compost tea production techniques are based on the regulation of some parameters, such as ratios of compost to water, oxygenation levels, duration and temperature of fermentation, to generate conditions favorable to the presence and development of beneficial organisms in the final products (Pane *et al*., 2012). A number of studies have indicated that the microbial communities of compost teas are necessary for disease suppression (Hoitink *et al*., 1997; Santos et al., 2008; Siddiqui *et al*., 2009). Compost teas have been shown to suppress soil-borne diseases, including damping-off and root rots caused by *Pythium ultimum*, *Rhizoctonia solani* (Scheuerell and Mahaffee, 2004; Dionné *et al*., 2012) and wilts produced by *Fusarium oxysporum* and *Verticillium dahliae* (Alfano *et al*., 2011), among many others. In these cases, compost aqueous extracts were used either to irrigate newly transplanted seedlings or to keep the seeds or seedlings in contact with them for some time prior to use. Hibar *et al*. (2005) demonstrated that transplanting inoculated tomato seedlings in compost extract-treated peat inhibited *Fusarium oxysporum*. There is also evidence of the effective use of these extracts in the ornamental plant industry. For instance, ornamental flower bulbs are commercially treated in order to reduce root rot by washing them in compost solution. This has reduced the number of root rot-affected roots in cyclamen-producing nurseries (Scheuerell and Mahaffee, 2002).

Residues derived from agricultural activity in Spain became a serious environmental and economic problem. Composting and vermicomposting of these residues are currently seen as proper and effective solutions. The composts and vermicomposts used in the present research were processed from the very large amounts of wastes generated from three cultures, in which Spain is an important European producer country: mushroom, vineyard for winemaking and intensive greenhouse horticultural cropping. In the present work, aerated (ACT) and non-aerated compost teas (NCT) prepared from four compost types were tested for their effects on the mycelial growth of the phytopathogens *P. parasitica* and *P. capsici*, for their capacity to protect pepper plants against the diseases caused by these pathogens, and for promotion of growth of pepper seedlings.

Materials and methods

Phytopathogenic fungi

Two pepper pathogens, *P. capsici* Leonian and *P. parasitica* Dastur (=*P. nicotianae* Breda de Haan) were used to assess the suppressive effect of the prepared ACT and NCT in *in vitro* and *in vivo* assays. Plants infected with *P. capsici* and *P. parasitica* were collected from pepper fields in the province of Almeria (Spain), during 2011. Selected stem sections with active lesions were cut and tissue pieces from the boundaries between healthy and discolored areas were planted on

P10ARP CMA medium (Kannwischer and Mitchell, 1978) after surface sterilization with 2% NaOCl for 2 min. The plates were incubated for 3–4 d at 25°C and *Phytophthora* colonies were transferred on potato dextrose agar (PDA). Pathogenicity tests were carried out on pepper plants (*Capsicum annuum* L. cv. Acorde RZ F1), using the methods of Sunwoo *et al*. (1996). The pathogens were maintained on PDA at 25°C.

Preparation of compost teas

Four commercially-available composts were used for the production of aerated (ACT) and non-aerated compost tea (NCT): grape marc compost (GMC), spent mushroom substrate compost (SMS), vegetable crop residues compost (CRC) and vegetable crop residues vermicompost (CRV). To prepare ACT from different composts, 100 g of compost was added to 1 L Erlenmeyer flasks, with 300 or 400 mL of sterile distilled water, obtaining ratios 1:3 and 1:4 weight:volume (w:v), respectively. The mixtures were homogenized in an orbital shaker at 150 rpm and 25ºC for 14 d in the dark. To obtain NCT at the same ratios, the mixtures were loosely covered and stored in the same conditions (25ºC for 14 d in the dark). Later, the solid fractions were removed and extracts were stored at 4°C until used (Koné *et al.*, 2010).

Effects of ACT and NCT on pathogen mycelial growth

ACT and NCT obtained as described above were filtered through six layers of cheesecloth to eliminate the excess of largest materials (filtrates or extracts F). After filtering, a volume of each type of filtrate was centrifuged at 10,000 rpm for 10 min to eliminate the excess of organic matter, and the sterilized by microfiltration through sterilized membranes of 0.22 mm pore size (Millipore®) (extracts C). They were previously subjected to preparation filtering through pre-filters with a larger pore size (0.45 mm Millipore®). Another type of extract was obtained by sterilizing the filtrates in an autoclave at 120ºC for 30 min to deactivate the live components (extracts E) (Diánez *et al.*, 2006). To prepare the ACT- and NCT-containing media, PDA was sterilized and cooled to 45°C. Extracts were then incorporated and mixed with the cooled PDA at 5, 10 or 15% v:v and immediately poured into Petri dishes (Diánez *et al.*, 2006). Controls consisted of adding sterile distilled water instead of compost teas. Agar plugs (0.5 cm diameter) covered with actively growing mycelia of the respective pathogens were individually inoculated on the media and incubated for 6–7 d in the dark at 25°C. The mycelial growth was measured as the average of two perpendicular diameters of the colony on each plate, and results were expressed in terms of inhibition percentage in comparison with the experimental control. The experiment was of a completely randomized design, with five replications per treatment.

Effects of ACT and NCT on severity of Phytophthora blight in pepper

ACT and NCT, ratio 1:4 (w:v) from the four different sources, were tested for control of Phytophthora blight (*P. capsici* and *P. parasitica*) in pepper plants (*Capsicum annuum* L., cv. Velero). Two complete and independent experiments were carried out in greenhouse conditions during the late autumn of 2011 and the winter of 2012.

Seeds were sown into commercial peat mix in nursery polystyrene planting trays and covered with vermiculite. Forty-eight h later compost tea treatments were carried out by applying a volume of each tea (5 mL/plant) diluted at 1:5 v:v in water, swapping composts tea for water as the control. After 50 d of culture at the commercial nursery, 96 plants per treatment and 96 control plants were transferred into pots (one plant/1 L capacity pot) containing peat and grown for another 48 h. Then, 100 mL of compost tea diluted at 1:5 v:v in water were again applied to 48 plants of each treatment ("retreated plants (R)", and 100 mL of tap water were applied both to 48 remaining non-retreated plants (T) and the control plants. After 2 d, all plants were inoculated with 5 mL of inoculum suspension.

To obtain the inoculum, isolates of *P. capsici* and *P. parasitica* were grown on PDA for 7 d at 25°C. Then, plates were incubated under fluorescent light for 3 d at 25°C to induce sporangium formation (Akgül and Mirik, 2008). Twenty-four h before inoculation, fungal colonies were covered with 20 mL of sterilized tap water and incubated under light overnight. During the inoculation day, Petri dishes were placed at 4°C for 30 min, followed by 60 min at room temperature to enhance zoospore release from sporangia. The flooding water, containing zoospores and mycelium was filtered through two layers of cheesecloth. The concentration of the zoospore suspension was adjusted to approx. 10^4 zoospores mL^{-1} using a hemocytometer. The inoculum was used immediately. Inoculation was performed using a sterile micropipette, by pouring the zoospore suspension uniformly over the surface of the peat in each pot. Symptom severity was rated periodically, and 15 d after inoculation, final disease severity index was estimated according to the following scale (Santos *et al*., 2008, adapted): 0, healthy plant; 1, symptoms beginning; 2, moderate symptoms; 3, severely affected plant and 4, dead plant. The experiments were conducted using completely randomized block designs.

Evaluation of growth promotion effects of ACT and NCT on pepper seedlings

This experiment was performed in nursery polystyrene planting trays, each with 96 cells (70 mL volume), at a commercial nursery (Almería province, Spain). Pepper seeds cv. Velero were sown into commercial peat mix and covered with vermiculite. After 2 d in a germination room (RH = 95%; 25ºC), trays were located in a greenhouse. Compost tea treatments were carried out by applying a volume of each tea (5 mL/plant) diluted at 1:5 v:v ratio in water. Experimental control pots were treated with water. Seedlings were grown using the standard nursery culture conditions. Four trays were used for each treatment, with one tray as a replication. After 50 d of culture, 32 plants per treatment and control were randomly selected from the four replications, and different morphological parameters were determined, including: number of leaves, stem length, stem base diameter, total leaf area, and stem, leaf and root dry weights. Leaf area was measured by using the WINDIAS 3.1. (Delta-T Devices Ltd 2009) leaf area processing program. Four different seedling quality indices were also calculated: Slenderness Index-SR (stem height/stem diameter, Ritchie, 1984), Dickson Quality Index-DQI (Dickson *et al*., 1960), Leaf Area Ratio Index –LAR (total leaf area/ plant dry weight) proposed by Briggs *et al.* (1920), and Specific Leaf Area-SLA (leaf area/leaf weight: Herrera *et al.* (2008, 2009). The experiments were conducted using completely randomized designs.

Statistical analyses

Data were analyzed with analysis of variance (ANOVA), carried out using the STATGRAPHICS CENTURIUM XV (S.G.S., 2009) program. Treatment means were compared using Duncan's test (P<0.05). In the disease severity tests, ANOVA of the experimental data showed no significant differences between the two experiments. The data were therefore combined and analyzed as a single experiment. Data with non-normal distributions were subjected to appropriate transformations prior to analysis. Where these transformations failed to normalize data, nonparametric Kruskal-Wallis one-way analysis of variance was carried out, using chi-Square approximations (P<0.05).

Results

Effects of ACT and NCT on pathogen mycelial growth

Bioassays of mycelial growth showed that only filtered compost teas (Extracts F) suppressed the tested pathogens. Sterilized compost teas (Extracts C and E) completely lost their inhibitory effects (data not shown). Within filtered compost teas, most ACT and NCT almost completely inhibited the mycelial growth of *P. parasitica* and *P. capsici* (Figures 1 and 2). The greatest mycelial growth inhibition for both pathogens was observed in media amended with ACT, with proportional inhibition values ranging from 68% to 100%. In addition, no statistically significant differences were observed between ACT from the different composts (GMC, SMC, CRC and CRV). Inhibition was also observed in media amended with NCT from GMC, with values ranging from 94% to 100%. However, less inhibition was observed in media amended with NCT from the other three composts (SMC, CRC and CRV), with values ranging from 16% to 95%. No significant differences were observed between most treatments, according to One-Way ANOVA test (P=0.05). Only small significant differences were observed in some treatments with NCT from CRC. On the other hand, there was no clear effect of different weight:volume ratios (1:3 and 1:4) of compost used for tea production on the subsequent inhibitory effects, nor for the proportions (5, 10 or 15%) of the teas applied to the culture media.

Effects of ACT and NCT on severity of Phytophthora blight in pepper

Severity of diseases caused by *P. capsici* and *P. parasitica* in pepper plants was reduced by compost tea

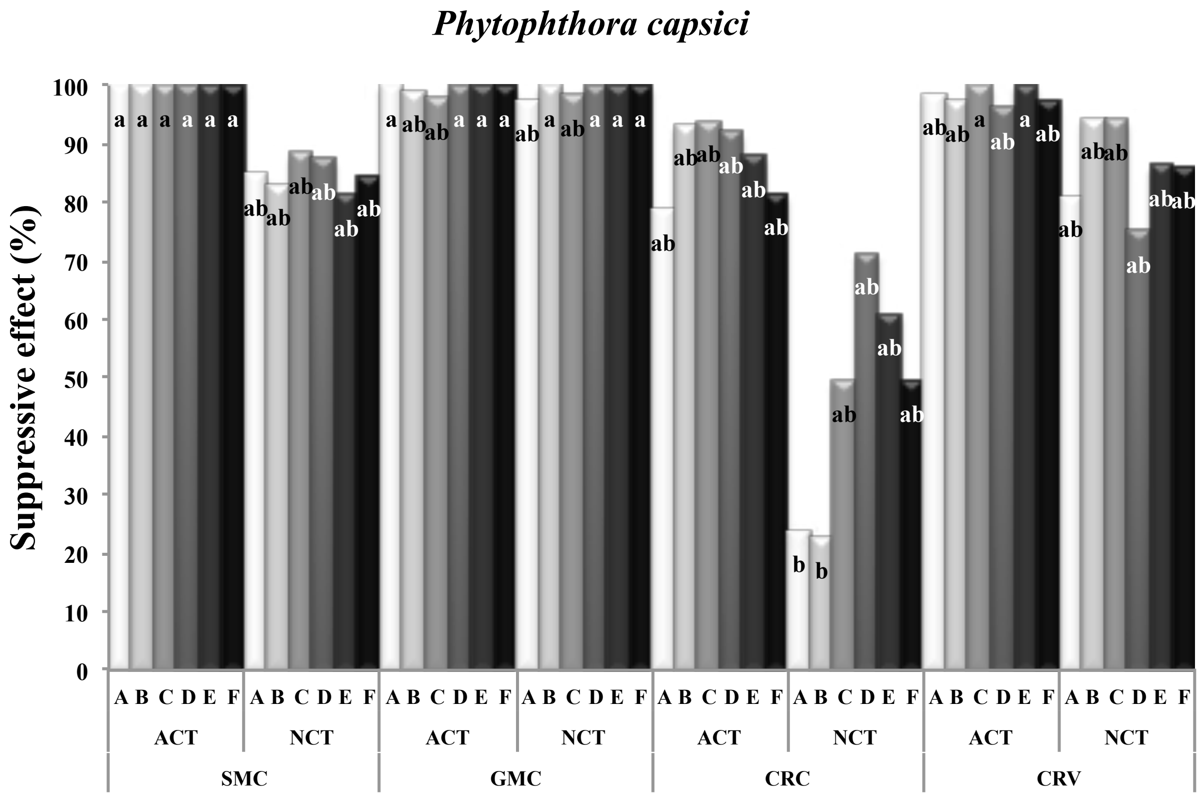

Figure 1. Inhibition percentages of *Phytophthora capsici* colonies in agar plates containing medium augmented with aerated compost tea (ACT) and non-aerated compost tea (NCT) from spent mushroom compost (SMC), grape marc compost (GMC), crop residues compost (CRC) and crop residues vermicompost (CRV). Compost teas were obtained in ratio 1:3 w:v and incorporated into PDA to concentrations of 5% (A), 10% (B) and 15% (C) v:v and ratio 1:4 w:v and incorporated into PDA to concentrations of 5% (D), 10% (E) and 15% (F) v:v. Different letters indicate significant differences according to One-Way ANOVA tests (*P*=0.05).

applications. Statistically significant differences between all compost tea treatments and the water experimental controls were observed (*P*=0.05). Results are shown in Figures 3 and 4. For *P. capsici* experiments, mean disease severity index ranged from 3.83 in water-control-T/R to 0 in ACT-R from CRC. For *P. parasitica* experiments, disease severity index ranged from 3.83 in the water-control-T to 0.4 in ACT-R from CRC and CVC. All applications were similarly effective, and no statistically significant differences were observed between teas from the different compost sources, nor between ACT and NCT. In addition, there was no statistically significant difference in most cases between compost tea-retreated plants (R) and non-retreated plants (T). For *P. capsici*, disease severity index varied from from 1.6 in NCT-T from SMC to 0 in ACT-R from CRC, whereas for *P. parasitica*, disease severity index ranged from 1.4 in ACT-R from GMC to 0.4 in ACT-R from CRC and CRV.

Evaluation of growth promotion effects of ACT and NCT on pepper seedlings

The effect of different treatments on morphological parameters and plant quality indices are shown in Table 1. Compost tea applications resulted in increases of most growth parameters assessed. Greater values for the parameters: number of leaves, roots, stems, and leaf dry weights, as well as total plant dry weights were recorded for plants treated with all

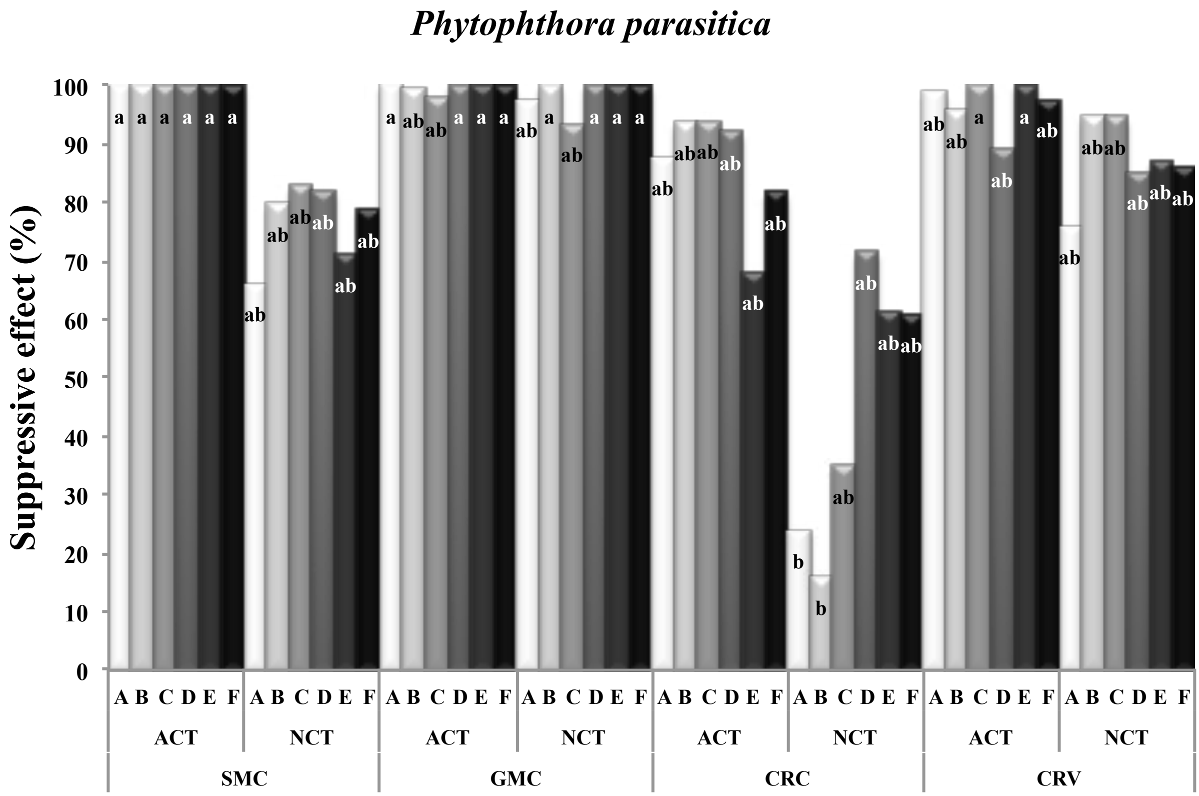

Figure 2. Inhibition percentages of *Phytophthora parasitica* colonies in agar plates containing medium augmented with aerated compost tea (ACT) and non-aerated compost tea (NCT) from spent mushroom compost (SMC), grape marc compost (GMC), crop residues compost (CRC) and crop residues vermicompost (CRV). Compost teas were obtained in ratio 1:3 w:v and incorporated into PDA to concentrations of 5% (A), 10% (B) and 15% (C) v:v and ratio 1:4 weight:volume and incorporated into PDA to concentrations of 5% (D), 10% (E) and 15% (F) v:v. Different letters indicate significant differences according to One-Way ANOVA tests (*P*=0.05).

compost teas in comparison to the experimental control, except for ACT from CRC. These increases were statistically significant in some cases. Thus, total plant dry weight was significantly greater for plants treated with NCT from SMC, GMC or CRV, and ACT from SMC, than for the control plants. The greatest increases were 18% for leaf dry weight (from NCT-CRV), 23% for stem dry weight (from NCT-GMC), 31% for root dry weight (from NCT-SMC) and 21% for plant dry weight (NCT-CRV), in comparison to the experimental control. NCT obtained from SMC gave the greatest increases in plant parameters, since this preparation increased all the parameters evaluated, and these increases were statistically significant in most cases.

The analysis of quality indices, calculated on the basis of the previous growth parameters, indicates that compost tea applications gave plants whose index values were positively altered compared with those obtained for control plants, for the four quality indices. Large values are desirable for DQI and SR indices, while small values are best for SLA and LAR indices. For LAR, all compost teas gave significantly improved values than the control. For SLA and DQI, six different compost teas gave significantly improved indices than the control, and for SR, three preparations significantly improved the values compared with the control results. The best treatments were the ACT and NCT from SMC and ACT from CRV, which provided significantly more favorable

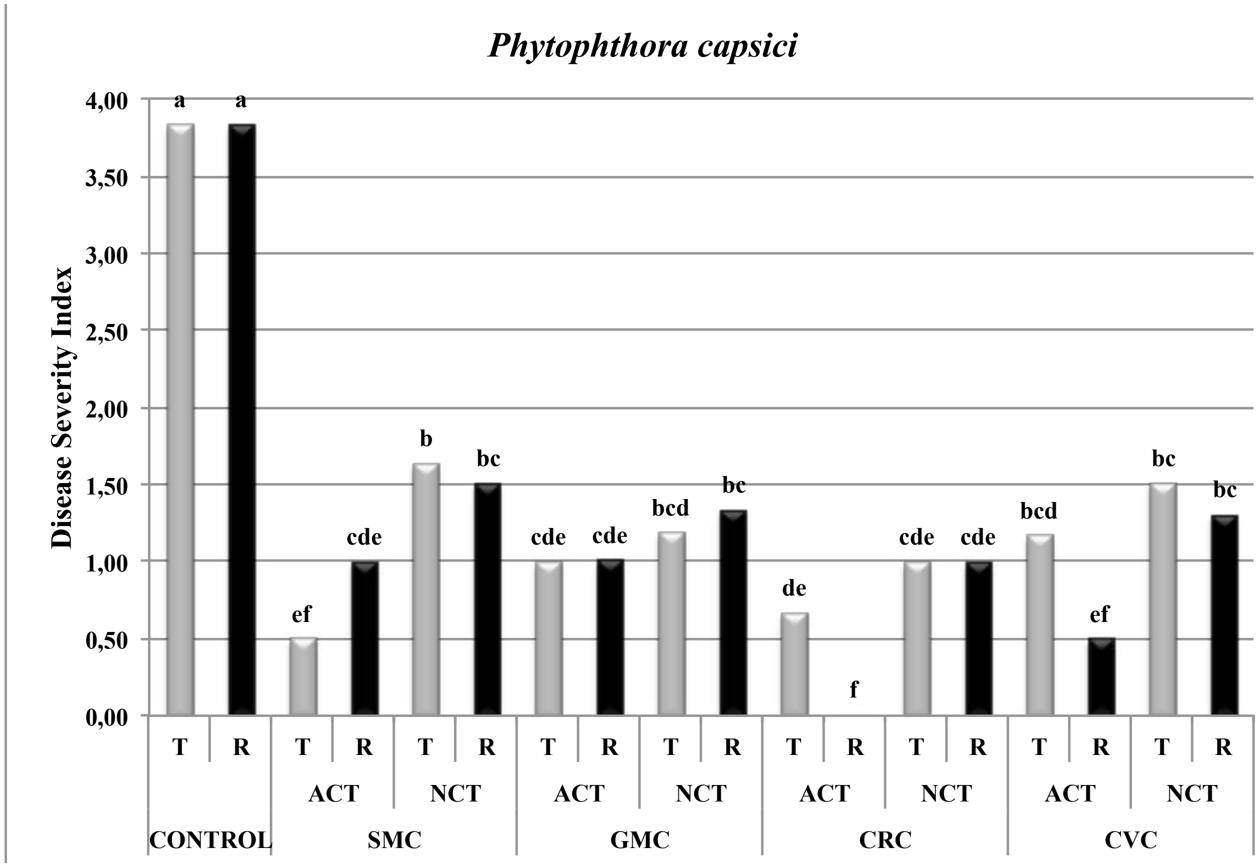

Figure 3. Mean severity of *Phytophthora capsici* on retreated (R) and non-retreated (T) plants with aerated compost tea (ACT) and non-aerated compost tea (NCT) from spent mushroom compost (SMC), grape marc compost (GMC), crop residues compost (CRC) and crop residues vermicompost (CRV). Applied compost teas were obtained in ratio 1:4 w:v. Controls were retreated (R) or non-retreated (T) with tap water. Readings was performed 15 days after inoculating. Disease index values (Santos *et al.*, 2008) are 0, healthy plant; 1, symptoms beginning; 2, moderate symptoms; 3, severely affected plant; 4, dead plant. Different letters indicate significant differences according to One-Way ANOVA tests (P=0.05).

values than the control for all the indices calculated. Conversely, ACT from CRC and GMC gave the least improvements in the growth parameters, and the least improvements in the plant quality indices.

Discussion

The results from this study indicate that ACT and NCT from the four tested compost sources suppressed the *in vitro* and *in vivo* development of the two pepper pathogens *P. parasitica* and *P. capsici*. However, when ACT and NCT were sterilized by autoclaving or microfiltration they completely lost their *in vitro* inhibitory effects on mycelial growth of both pathogens. This suggests that biological components of the compost teas played decisive roles in pathogen inhibition. Several studies have reported that the ability of compost teas to inhibit phytopathogens depends on the microbiota they contain (Pane *et al*., 2012), and when these microbiota are eliminated by microfiltration or autoclaving, the suppressive properties are also eliminated (Weltzien, 1989). Pane *et al*. (2012) state that autoclaved and microfiltered teas did not inhibit *in vitro* growth of *Botrytis cinerea*, *Alternaria alternata* and *Pyrenochaeta lycopersici*. Siddiqui *et al*. (2009) found that heat and filter sterilized ACT prepared from agro-waste compost was not effective in suppressing wet rot of okra (caused by

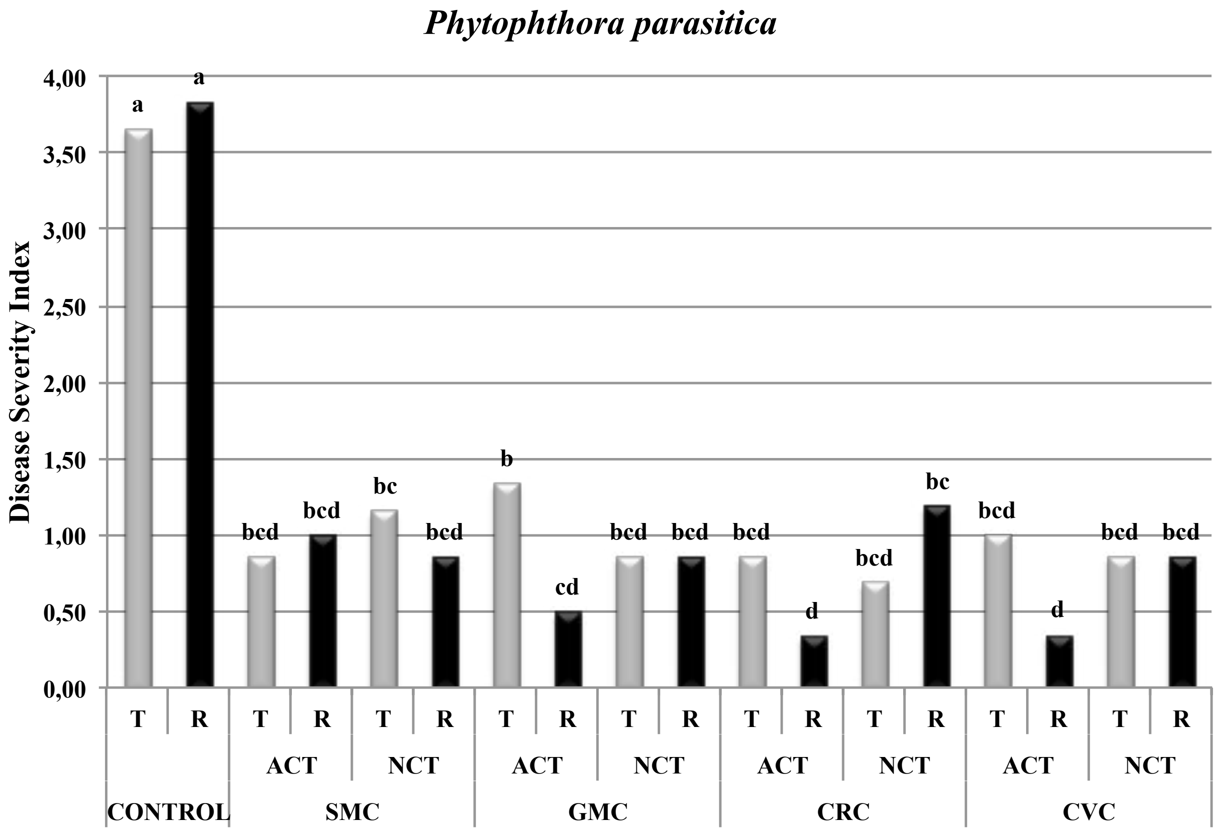

Figure 4. Mean severity of *Phytophthora parasitica* on retreated (R) and non-retreated (T) plants with aerated compost tea (ACT) and non-aerated compost tea (NCT) from spent mushroom compost (SMC), grape marc compost (GMC), crop residues compost (CRC) and crop residues vermicompost (CRV). Applied compost teas were obtained in ratio 1:4 w:v. Controls were retreated (R) or non-retreated (T) with tap water. Readings was performed 15 days after inoculating. Disease index values (Santos *et al*., 2008) are 0, healthy plant; 1, symptoms beginning; 2, moderate symptoms; 3, severely affected plant; 4, dead plant. Different letters indicate significant differences according to One-Way ANOVA tests (P=0.05).

Choanephora cucurbitarum), while the non-sterilized ACT was effective in preventing the disease. According to Koné *et al*. (2010), the presence of microbial antagonists in compost teas is necessary for direct inhibition of mycelial growth.

These antagonists could potentially use competition or parasitism to exert their direct effects on the pathogens, and may also produce antimicrobial compounds (antibiosis) when in direct confrontation with the pathogens. Some reports have shown that biosynthesis of toxic metabolites in bacteria and fungi could be enhanced or newly induced in the presence of competing microorganisms (Sonnenbichler *et al*., 1994; Martínez *et al*., 2006). In our study, antibiotic compounds released by compost tea microbiota during the compost tea incubation period must not have been great enough to provoke later inhibition, since sterilization of ACT or NCT (by autoclaving or microfiltration) had no effects on the micelial growth. Nevertheless, results from different studies confirm the presence of inhibitory effects in autoclaved (Elad and Shtienberg, 1994; Yohalem *et al*., 1994; Cronin *et al*., 1996) or microfiltered (Diánez *et al*., 2006) compost teas, probably due to specific microbial composition in those extracts and the interactions between them and respective pathogens.

Our results also showed that ACT from all sources generally gave rise to greater *in vitro* suppression than

Table 1. Morphological parameters and quality indices of pepper plants treated with aerated compost tea (ACT) and non-aerated compost tea (NCT) from spent mushroom compost (SMC), grape marc compost (GMC), crop residues compost (CRC) and crop residues vermicompost (CRV). Applied compost teas were obtained in ratio 1:4 w:v. Different letters indicate significant differences according to ONE-WAY-ANOVA test (P = 0.05). Bold values are significantly greater than the controls.

Compost	Treatment	Morphological parameter					
		Stem length (cm)	Stem base diameter (mm)	Leaf dry weight (g)	Stem dry weight (g)	Root dry weight (g)	Total dry weight (g)
SMC	ACT	13.89 cde	2.98ab	0.242 abc	0.1219 abc	0.116 abc	0.48 ab
	NCT	15.13 a	3.06 a	0.248 ab	0.1266 abc	0.130 a	0.50 a
GMC	ACT	15.07 ab	2.97 ab	0.228 cd	0.1141 bcd	0.106 bc	0.45 bc
	NCT	14.53 abc	2.83 c	0.222 cd	0.1303 a	0.122 ab	0.47 ab
CRC	ACT	14.36 abcd	2.87 bc	0.208 d	0.1053 d	0.103 c	0.42 c
	NCT	13.72 de	2.88 bc	0.219 cd	0.1131 cd	0.115 abc	0.45 bc
CRV	ACT	13.48 e	2.92 bc	0.224 bcd	0.1134 bcd	0.114 abc	0.45 bc
	NCT	14.27 bcde	2.95 ab	0.251 a	0.1284 ab	0.128 a	0.51 a
Control		14.85 ab	2.90 bc	0.213 d	0.1059 d	0.099 c	0.42 c

Compost	Treatment	Quality index[a]					
		No. of leaves	Leaf area (cm^2)	DQI	SR	SLA	LAR
SMC	ACT	10.00 abc	85.97 ab	0.085 ab	0.88 a	356.33 cde	181.46 cd
	NCT	10.47 ab	93.08 a	0.085 ab	0.87 ab	379.45 bc	187.96 bc
GMC	ACT	9.97 abc	88.08 a	0.072 cde	0.85 bcd	392.21 ab	197.24 b
	NCT	9.81 bc	76.47 c	0.077 bcd	0.84 cd	345.80 de	163.32 e
CRC	ACT	9.75 c	79.21 bc	0.068 de	0.84 cd	394.34 ab	192.77 bc
	NCT	9.94 abc	79.23 bc	0.078 abcd	0.85 abc	375.41 bcd	183.64 cd
CRV	ACT	9.94 abc	79.29 bc	0.081 abc	0.87 ab	356.88 cde	178.32 cd
	NCT	10.56 a	85.46 ab	0.088 a	0.86 abc	344.25 e	171.37 de
Control		9.72 c	87.37 ab	0.067 e	0.83 cd	414.56 a	212.99 a

[a] DQI: Dickson Quality Index; SR: Slenderness Index; SLA: Specific Leaf Area; LAR: Leaf Area Ratio Index

NCT, although both are considered effective. A similar effect was observed by Haggag and Saber (2007), who found that both ACT and NCT from either plant residues or chicken manure compost inhibited conidium germination of *Alternaria porri* (purple blight) and *A. solani* (early blight) in *in vitro* experiments. In contrast, Cronin *et al*, (1996) concluded that NCT from manure-based spent mushroom compost effectively inhibited the *in vitro* conidium germination of *Venturia inaequalis* (apple scab), whereas ACT had no effect. We consider that ACT and NCT effectiveness is dependent on their respective microbiotas, which depends in turn on the compost from which they are extracted. For this reason, each ACT or NCT has unique behaviour and must be individually tested for its interaction with a specific pathogen. The compost:water ratio and the concentrations of teas applied to the culture media had no clear effects on inhibition, which indicates that the organisms responsible for the suppression were at appropriate levels for pathogen suppression, even at the smallest ratio (1:4) and the lowest concentration (5%) tested here.

Our results from the Phytophthora blight *in vivo* assays showed positive effects of all treatments, with reductions in disease severity for both *P. capsici* and *P. parasitica*. No statistically significant differences were observed between most treatments, which emphasizes the effectiveness of all compost teas in controlling both diseases. These results are similar to previous *in vitro* results. According to the *in vitro* results, some compost teas, such as NCT from SMS [ratio 1:4 (v:v); 81–88% inhibition for *P. capsici* and 71–82% inhibition for *P. parasitica*] and CRC [ratio 1:4 (v:v); 50–71% inhibition for *P. capsici* and 61–72% inhibition for *P. parasitica*] were less effective in suppressing either *P. capsici* or *P. parasitica* than other treatments which gave 100% disease suppression. Nevertheless, *in vivo* results [ratio 1:4 (v:v)] showed these to be as effective as the remaining compost teas. This indicates that there is not always a perfect correlation between *in vitro* and *in vivo* results, since more factors are involved in *in vivo* assays (Cook and Baker, 1983).

We consider that the first compost tea application at the time of seed germination allows compost tea microorganisms to establish on the young seedling roots and stem bases, especially in microbiologically non-diverse substrates. These microorganisms probably progressively develop as the seedlings grow, living on substances excreted by roots and substrate nutrients. At the time of pathogen inoculation a beneficial microbiological community has established on the plants, protecting them, and avoiding the pathogen action through different mechanisms, including competition for infection sites and nutrients (Al-Mughrabi *et al*., 2008), antibiosis (El-Masry *et al*., 2002) or induction of systemic resistance (Zhang *et al*., 1998; Siddiqui *et al*., 2009; Sang and Kim, 2011). Although plants treated with compost teas began to show disease symptoms, these did not progress, probably due to the explanation above. Additionally, no statistically significant differences were observed in most cases between plants receiving compost tea applications once at seed germination (non-retreated plants, T) and plants receiving another application just prior to pathogen inoculation (retreated plants, R). In general, beneficial microbiological communities from the first application seemed to be well established at pathogen inoculation, so that a new microbial supply did not appreciably affect disease control. The only exceptions were ACT from CRC and CVC in the *P. capsici* experiments and ACT from GMC in the *P. parasitica* experiments, where reduced disease severity indices in retreated plants (R) were observed in comparison to non-retreated plants (T). In these cases, better results were achieved by repeating the compost tea application just before pathogen inoculation, which indicates that an increase in the rhizosphere microbial populations can improve the pathogen control in some cases. Moreover, additional humic substances and antimicrobial compounds contained in compost teas applied just before pathogen inoculation could play a role in the observed effects.

Results from the evaluation of growth promotion demonstrated that different compost extracts had significant effects on pepper seedling growth. Thus, compost teas could be effective products at an extraction rate of 1:4 w:v and diluted to 15% in water in promoting dry weight quality indices of young pepper seedlings grown in commercial nurseries, despite being applied only once at sowing. On one hand, all the compost teas except ACT from CRC, improved leaf, stem and root dry weights, and consequently the total seedling dry weights in comparison to the experimental controls, although statistically significant increases were only observed in ACT and NCT from SMC and NCT from GMC treatments. Dry matter content influences plant resistance to stress caused by the transplanting and in subsequent field production (Masson *et al*., 1991). Consequently, the greater the dry matter content the more resistant plants are to transplanting stress, even at low temperatures (Tesi, 1987). According to Pimpini and Gianquinto (1991), production also increases on a logarithmic scale with the dry matter content of the aerial parts of plant to be transplanted. This suggests that the seedlings treated with ACT and NCT from SMC and ACT from CRV will have sufficient capacity to complete the transplant with good subsequent development. On the other hand, all compost teas significantly improved the SLA index values compared to the controls, except ACT from GMC and CRC whose index values did not differ from the controls, and all compost teas significantly improved the LAR index values. Both indices indicate the capacity of plants to resist the transplant. Thus, according to Masson *et al.* (1991), the tested compost teas are likely to make seedlings perform better after transplanting.

Controlled studies on the plant growth promotion effects of compost teas are rare. Most studies refer to regular compost tea applications throughout the growing season, whereas the present study has focused on a specific application at the sowing. The observed growth enhancement might be due to increasing biologically active compounds. The greater nutrient content and proportions of humic acids in compost teas could also have played indirect roles by improving substrate fertility, modifying substrate physical and chemical conditions, and directly by acting as powerful chelators and increasing nutrient availability to the plants (Pizzeghello *et al*., 2002; Ingham, 2003). Nevertheless, this effect has not been so decisive in our final results because compost teas were applied only at the time of sowing. The potential of compost teas for supplementing or replacing other fertilizers seems promising and warrants further testing both in greenhouse conditions and in open fields (Reeve *et al*., 2010). Many other studies have reported variable effects, but there is considerable evidence that compost extracts can improve plant production by decreasing disease incidence, improving plant nutrient status and generally promoting plant growth (Weltzien *et al*., 1990; Ingham, 2005; Arancon *et al*., 2007; Hargreaves *et al*., 2008;).

The results from the present study, strongly support the use of compost teas as an environmentally-friendly way to manage plant diseases and as plant growth promoters in crop production. Composting agro-waste residues and developing compost tea production can solve problems of handling and disposal, while providing useful alternatives to synthetic fungicides and fertilizers. These biological preparations probably suppress plant disease and promote plant growth. Nevertheless, further research is required to complete our knowledge about the use of compost teas in horticulture.

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