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Effects of Compost and Vermicompost Teas as Organic Fertilizers

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ABSTRACT

Numerous studies have demonstrated that composted materials and their resulting teas can provide manifold benefits as organic fertilizers in sustainable agriculture. Indeed, compost teas have been shown to suppress a wide range of soil-borne diseases when used as foliar sprays and soil drenches, thereby ultimately affecting plant growth and yield. However, it is difficult to determine the exact suppression mechanisms involved, owing to the complex structure of compost microbial communities. General suppressive effects rather than specific ones are more common and, in addition the sterilisation of the teas has often resulted in a loss in disease suppressiveness. This suggests that biological mechanisms are predominantly involved in the suppression of soil-borne diseases by compost teas, although chemical and physical factors have also been implicated. The purpose of this chapter is therefore to give an overview of the effects of both compost and vermicompost teas on plant growth and soil fertility. Current knowledge on the impact of these products on disease suppressiveness is also addressed, together with the factors affecting theiry .

***Key words*:** Compost teas, Vermicompost teas, Soil borne plant-diseases, Soil ertility, Plant growth.

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INTRODUCTION

Overproduction of organic wastes can lead to the use of inappropriate disposal practices such as their indiscriminate and poorly-timed application of the material to agricultural soils. However, organic waste can be treated by oxygen-driven biological processes to produce good quality fertilisers, thus helping to protect the environment (Moral *et al.*, 2009; Domínguez *et al.*, 2010). Aerobic composting and vermicomposting are widely used during the recycling of a large variety of waste material (Domínguez *et al.*, 2010). Both of these processes transform the material into high quality amendments/fertilisers, which are rich in organic matter and nutrients (Insam and de Bertoldi, 2007; Lazcano and Domínguez, 2011). Unlike compost, vermicompost is produced at intermediate temperatures by the joint action of earthworms and micro-organisms (Domínguez, 2004).

The use of composts is beneficial to the soil in several ways, leading to increased amounts of soil organic matter, improvements in soil physical properties (higher porosity and aggregate stability and reduced bulk density) and modification of soil microbial communities (Knapp *et al.*, 2010; Lazcano *et al.*, 2012). There is substantial evidence that the use of composts enhances soil microbial biomass and activity (revised in Diacono and Montemurro, 2010). Accordingly, previous studies have demonstrated the potential of composted materials to stimulate plant growth either directly or indirectly through different chemical, physical and biological mechanisms, as reviewed by Lazcano and Domínguez (2011). On the one hand, they may directly affect the plant growth via the supply of nutrients; by altering water and air availability in the plant potting media and conditioning root growth; and/or through the promotion of plant growth regulating substances (PGRs; Fig. 1) or microorganisms (plant growth promoting microorganisms, PGPMs). And, on the other hand they may exert indirect effects on plant growth such as the mitigation or suppression of plant diseases (Fig. 1).

Spaccini *et al.* (2008) showed that aerated compost extracts contain most of the low-weight compounds associated with a compost matrix, most of which are of microbial origin and therefore potentially bioactive. The presence in vermicomposts of bioactive substances associated with the low molecular weight fraction of humic acids and which are capable of inducing changes in plant morphology and physiology has also been reported (Pant *et al.*, 2012). In fact, these authors found an improved shoot and root growth and mineral nutrient content of pak choi plants following the tea application. Additionally, there is considerable evidence that both compost and vermicompost teas can suppress a wide range of soil-borne diseases when used as foliar sprays and soil drenches (Marín *et al.*, 2013). All of the aforementioned indicates that they can be good candidates as organic fertilizers in sustainable agriculture. Indeed, there has been a considerable increase in research dedicated to the study of their effects on soil properties, as well as on plant growth and disease suppressiveness over the last few years.

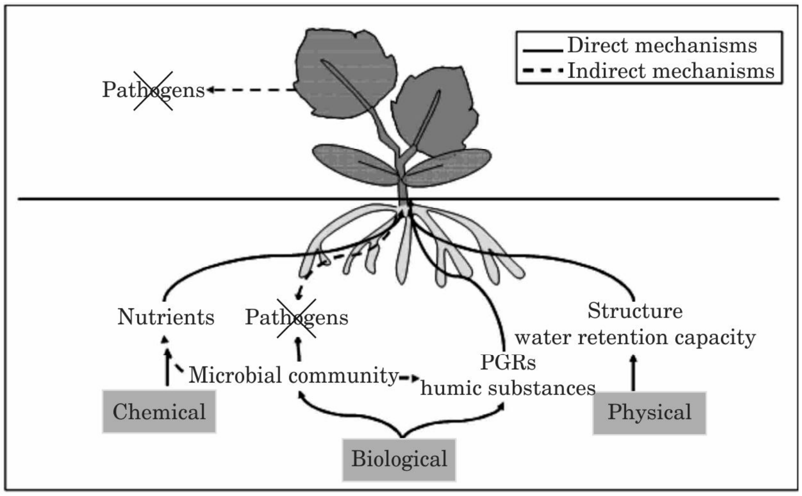

Fig. 1. Overview of the proposed chemical, biological and physical mechanisms by which composted materials may directly or indirectly influence plant growth and yield (from Lazcano and Domínguez, 2011).

The purpose of this chapter is to provide an overview of the effects of compost and vermicompost teas on plant growth and soil fertility. Current knowledge on the impact of these products on disease suppression is also addressed, together with the factors affecting the quality of the products. The mechanisms involved in the suppression of soil-borne diseases by compost teas are also discussed.

COMPOST TEAS: DEFINITION AND MAIN FACTORS AFFECTING THEIR QUALITY

Compost teas are simply defined as brewed, water extracts of composted materials (Ingham, 2000). However, they can be further categorised into aerated and non-aerated, depending on the method of production. Aerated compost teas (ACT) are produced by aerating the compost-water extracts during the fermentation (brewing) process; whereas non-aerated compost teas (NCT) are not aerated, or are only minimally aerated at the initial mixing stage of the fermentation process (Litterick *et al.*, 2004; Litterick and Wood, 2009). Both methods require a fermentation or brewing vessel, an inoculum (compost) and water, and they both involve incubation and filtration of the product prior to application (Scheuerell and Mahaffee, 2002; Litterick *et al.*, 2004). According to Weltzien (1991), NCT are generally produced by mixing one volume of compost with 4 to 10 volumes of water in an open container. The mixture is first stirred and then allowed to stand undisturbed, with no or minimal aeration, for at least three days at 15–20°C. Other authors have suggested stirring the NCT every two to three days during the fermentation process to facilitate the release of microorganisms from the compost particles (Brinton *et al.*, 1996).

Over the years there has been continuous debate about the benefits of aeration during the process of producing compost teas. Specifically, some advantages have been identified in relation to ACT processes, including shorter brewing times, greater microbial diversity, lower phytotoxicity and less potential for regrowth of human pathogens (Ingham and Alms, 2003). Arancon *et al.* (2007) observed a higher germination rate, height and leaf area of tomato and cucumber plants following the application of aerated vermicompost tea. However, these authors used an extraction period of only 2 days when preparing the compost teas, which may explain the lower effect of NCT on plant growth. Indeed, Welke (2004) reported that aeration of compost teas is not essential to enhance plant growth when a sufficiently long extraction period is used.

In general, production of NCT is favoured over production of ACT because the method is simpler and requires less energy consumption, as specialized aeration equipment is not needed to produce the teas (St. Martin and Brathwaite, 2012). Moreover, several studies have shown that the methods used to produce NCT can be as effective as those used to produce ACT, in relation to suppression of phytopathogens and plant diseases (Cronin *et al.*, 1996; Welke, 2004; Scheuerell and Mahaffee, 2006; Koné *et al.*, 2010; St. Martin *et al.*, 2012; Marín *et al.*, 2013). For instance, St. Martin *et al.* (2012) observed that mycelial growth of *Pythium ultimum* was significantly inhibited in both aerated and non-aerated compost teas made from banana leaf and lawn-clipping composts. In fact, aeration of the compost teas during production did not consistently inhibit the mycelial growth in either type of compost, nor did increasing the brewing time beyond 18 h for ACT and 56 h for non-aerated compost tea. In another study, comparison of the efficacy of ACT and NCT has shown that aeration of the compost tea resulted in higher concentrations of human pathogens, such as *Escherichia coli* O157:H7, *Salmonella* and faecal coliforms, when nutrient supplements were added at the beginning of the brewing process (Ingram and Millner, 2007). This indicates that the addition of nutrients is another important factor in determining the quality of the teas. Besides the above-mentioned negative effect, the addition of nutrients may lead to an increase in overall microbial biomass and diversity (Naidu *et al.*, 2010, 2013; Fritz *et al.*, 2012) or to an increase in the specific group of microorganisms that are thought to have beneficial effects, thereby enhancing the disease suppression properties of the teas (Marín *et al.*, 2013). Sugar, grain, fish emulsion, kelp extract and humic acids (among others) have also been used as additives during production of aerated tea, to enhance the microbial activity of the finished product (Ingham, 2003). Pant *et al.* (2009) evaluated the effects of aerated vermicompost tea augmented with a microbial enhancer (ACTME) (*i.e.*, augmented with dry humic acid and kelp extract) on the growth, mineral nutrient content and antioxidant activity of pak choi (*Brassica rapa* cv Bonsai, Chinensis group) grown under organic (vermicompost) and synthetic (Osmocote) fertilization. Interestingly, the nutrient content was significantly higher in the ACTME than in ACT and NCT, whereas neither the microbial populations nor microbial activity differed in the different types of compost teas. Plant growth and total carotenoids were also not influenced by the type of production, particularly under organic fertilization.

Different factors such as dilution rate and application frequency have been reported to affect the quality of the teas and their efficacy in suppressing plant diseases (Arancon *et al.*, 2007; Litterick and Wood, 2009). Storage conditions have also been shown to affect tea properties. For example, Fritz *et al.* (2012) stored green leaf-based aerated vermicompost tea at three different temperatures (10, 22 and 36°C), for a period of 15 days, and observed an initial (after 24h) decrease in bacterial diversity (assessed by the Shannon-Weaver index), because fast growing bacteria suppressed other bacteria to an undetectable limit. This decrease was followed by an increase in diversity at all three temperatures; the increase was more pronounced at the highest temperature. Furthermore, the feedstock material used in both the composting and vermicomposting processes largely determines the physical, chemical and biological properties of the final products, and thus it is also expected to influence the tea quality (Weltzien, 1990; Scheuerell and Mahaffee, 2002; Siddiqui *et al.*, 2009; Pant *et al.*, 2012; St. Martin *et al.*, 2012). Pant *et al.* (2012) compared five different commercially produced composts and found significant differences in the total nutrient content, microbial activity and phytohormones in the resulting teas, which ultimately affected plant growth (pak choi). Specifically, higher levels of gibberellins (GA_4) and mineral N were detected in food waste vermicompost tea and aged chicken manure-based compost and vermicompost teas than in fresh chicken manure-based vermicompost tea and green waste compost tea. Accordingly, *in vitro* cultivation of pak choi with concentrations of GA_4 similar to those measured in the teas confirmed a direct positive effect of GA_4 on growth.. Pant *et al.* (2012) also reported that compost age may contribute to tea quality, as indicated by differences between fresh and aged chicken manure-based vermicompost teas. Mature composts are expected to release higher levels of soluble mineral nutrients and lower amount of phytotoxic organic acids and heavy metals than immature composts (Griffin and Hutchinson, 2007).

INFLUENCE OF COMPOST AND VERMICOMPOST TEAS ON PLANT GROWTH AND SOIL FERTILITY

In field studies, compost and vermicompost teas have been found to provide manifold benefits when used as total or partial substitutes for mineral fertilisers in peat-based artificial greenhouse potting media and as soil amendments, as shown by Arancon *et al.* (2007); Edwards *et al.* (2007); Sanwal *et al.* (2007); Al-

Mughrabi *et al.* (2008); Hargreaves et al (2009a,b); Pant *et al.* (2009, 2012); Lazcano *et al.* (2010); Naidu *et al.* (2010, 2013); Reeve *et al.* (2010); Siddiqui *et al.* (2011); Fritz *et al.* (2012); St. Martin *et al.* (2012). The advantages of compost teas as soil amendments include their capacity to maintain soil organic matter content and water holding capacity, enhance nutrient availability, suppress plant diseases and increase soil microbial diversity.

Table 1 provides an overview of several studies focused on the effects of compost and vermicompost teas on plant growth and soil fertility. For instance, Siddiqui *et al.* (2011) observed that the application of compost tea and inorganic fertiliser (NPK) at a rate of CT 50: NPK 50 significantly enhanced the vegetative growth, yield and antioxidant content of the medicinal herb *Centella asiatica* (L.) urban. Similarly, Reeve *et al.* (2010) reported a synergistic effect when using compost tea in combination with inorganic fertiliser, resulting in a higher shoot (22–61%) and root (40–66%) biomass of wheat seedlings relative to that observed when inorganic fertiliser was applied alone. Hargreaves *et al.* (2009a) found that NCTs made from municipal solid waste and ruminant composts provided equivalent levels of nutrients to strawberries as supplied by an inorganic fertilizer. However, the soil K content was lower after application of NCT, suggesting that the levels of this nutrient should be monitored when compost teas are the sole source of mineral nutrients. Sanwal *et al.* (2007) also demonstrated that the application of poultry manure and compost tea greatly increased the rhizome yield of ginger. In a recent study, Naidu *et al.* (2013) established that microbial-enriched compost tea, in combination with half strength fertigation nutrients, had a significantly greater effect on the growth and quality of muskmelons than full strength fertigation nutrients or untreated controls (water only). Indeed, these authors emphasized that the higher concentration of nutrients in the full strength fertigation treatment might have resulted in a mineral imbalance that hindered the generation of defence-related compounds, thereby leading to increased susceptibility to pathogen attack.

Furthermore, Arancon *et al.* (2007) and Edwards *et al.* (2007) demonstrated that the addition of vermicompost tea to the growing media of tomatoes and cucumbers enhanced the germination and growth of these plants. Likewise, Lazcano *et al.* (2010) observed that the incorporation in the growing media of vermicompost tea produced from rabbit manure increased the germination percentage of maritime pine seedlings. In fact, the N content of plants germinated after treatment with the tea was higher than in control plants (grown on perlite) and may have determined the faster maturation of the treated seedlings. Fritz *et al.* (2012) did not find any significant effects of tea application on crop yield (wheat and barley) in a field-scale experiment; however, there was an improvement in crop quality, as shown by sensory tests. In the same study, use of COMPOCHIP (*i.e.*, a microarray targeting pathogenic bacteria and bacteria typical of stabilized organic materials) revealed the presence of the saprophytic bacteria *Sphingobacterium* and *Actinomyces* and the

Table 1: Research studies focused on the effects of compost and vermicompost teas on plant growth and yield.

Compost type	***Crop***	***Remarks***	***Reference(s)***
Municipal solid waste (MSW) and ruminant composts	Strawberries (Fragaria x *ananassa, L.,* cv. Sable)	Similar amounts of most macro-and micronutrients were provided by CT treatments compared to both MSW and ruminant composts and inorganic fertiliser treatments	Hargreaves *et al.* (2009a)
MSW compost	Strawberries (Fragaria x *ananassa, L.,* cv. Sable)	Overall, CTs produced fruit of equal quality in terms of total antioxidant capacity and vitamin C than MSW compost; however, all treatments failed to provide sufficient N to strawberry plants and all fruit appeared to have leather rot; consequently, yield was decreased.	Hargreaves *et al.* (2009b)
Rabbit manure compost	Six different progenies of the maritime pine (*Pinus pinaster* Ait.)	The incorporation of vermicompost in the growing media of maritime pine increased germination by 16%, and particularly, addition of vermicompost water extract produced the best results. The different pine progenies responded differently to vermicompost application, suggesting that the genetic variability is an important factor to consider when vermicompost and other biologically active organic materials are used as potting amendments.	Lazcano *et al.* (2010)

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Compost type	***Crop***	***Remarks***	***Reference(s)***
Grape pomace and dairy manure composts	Wheat seedlings (*Triticum aestivum*)	Their findings support the use of compost extracts as fertiliser substitutes or supplements. They observed that a 1% compost extract alone was as effective as the highest fertiliser rate in terms of shoot height; such effects were dependent on the time period.	Reeve *et al*. (2010)
Empty fruit bunch and chicken manure	*Centella asiatica* (L.) urban	The integrated use of CT and inorganic fertiliser (NPK) at 50% increased the availability of nutrients and improved soil fertility.	Siddiqui *et al*. (2011)
Vermicompost composed mainly of green plant parts, cattle manure, and agricultural plant waste	Cereals (wheat and barley) and vegetables (*Raphanus sativus*, *Rucola selvatica*, and *Pisum sativum*)	No effects of tea application on plant yield; however, sensoric tests indicated an improvement in crop quality. Minor changes in the soil microbial community were found after tea application by foliar spray in both laboratory- and field-scale experiments.	Fritz *et al*. (2012)
Five compost types: chicken manure-based	Pak choi (*Brassica rapa* cv Bonsai, Chinensis group)	Applications of CT increased both growth and mineral nutrient content of pak choi	Pant *et al*. (2012)

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Compost type	***Crop***	***Remarks***	***Reference(s)***
thermophilic compost; green waste thermophilic compost; food waste vermicompost; chicken manure-based vermicompost (aged); and chicken manure-based vermicompost (fresh)		plants; such effects were dependent on the type of compost.	
Banana leaf (BLC) and lawn clipping (LCC) composts	Tomato cv. Calypso and sweet pepper cv. California Wonder seedlings	All CTs stimulated seed germination of tomato and root growth in sweet pepper. However, NCTs brewed for 56 h using LCC or BLC, and ACT produced from BLC brewed for 18 h, significantly reduced seed germination of sweet pepper.	St. Martin *et al.* (2012)
Empty fruit bunches and palm oil mil effluent composts	Muskmelon (*Cucumis melo* L.)	Increas.es in mean fruit fresh weight (kg), firmness (N) and mesocarp size (cm) of muskmelon fruits were recorded after the application of half strength fertigation nutrients in combination with the weekly foliar application of microbial-enriched CT.	Naidu *et al.* (2013)

ammonium-oxidising bacteria *Nitrosovibrio* and *Nitrosospira* in both vermicomposts and the resulting teas (Fritz *et al.,* 2012). *Nitrosovibrio* and *Nitrosospira* are responsible for ammonia oxidation, the first and rate-limiting step in the process of nitrification. As such, their presence in the samples indicates that these bacteria may play an important role in nitrogen cycling in the vermicompost tea environment. Nevertheless, most previous studies are often not comparable because of differences in experimental conditions, including the type and dose of application of compost tea, the duration of the experiment, the plant species to be grown, among others.

INFLUENCE OF COMPOST AND VERMICOMPOST TEAS ON SOIL-BORNE PLANT DISEASES

An overview of several studies dealing with the efficacy of compost and vermicompost teas (aerated and non-aerated) in minimising a range of fungal diseases when used as foliar sprays or soil drenches is given in Table 2. Specifically, Dionné *et al.* (2012) found that application of NCTs prepared from five different types of compost reduced the mycelial growth of several pathogenic fungi including *Pythium ultimum*, *Rhizoctonia solani*, *Fusarium oxysporum* f. sp. *radicis-lycopersici* and *Verticillium dahliae in vitro*. Sterilization of the NCT caused complete or partial loss of the inhibition of mycelial growth of these pathogens. This confirms that the microbial content constitutes a crucial factor in the efficacy of the teas for disease suppression, as reported by El-Masry *et al.* (2002); Al-Mughrabi *et al.* (2008), Naidu *et al.* (2010) and Xu *et al.* (2012), among others. Nevertheless, Hardy and Sivasithamparam (1991) found that sterile extracts of composted eucalyptus-bark and pine-bark container media had a stimulatory effect on the formation of sporangia of *Phytophthora* spp., whereas non-sterile extracts inhibited sporangial formation and even induced lysis. Elad and Shtienberg (1994) observed that in most cases pasteurisation of compost extracts did not nullify *Botrytis cinerea* disease reduction. These findings suggest that compost extracts may also exert an abiotic effect on disease control. Zmora-Nahum *et al.* (2008) established that chemical and biological mechanisms in compost may operate in tandem. These authors found that basic pH and high effective NH_3 concentration in the compost have a direct effect on the viability of sclerotia. Germination of sclerotia was completely inhibited in sterile extracts of non-cured compost extracts at concentrations above a threshold level of 0.5 mM NH_3. Interestingly, loss of suppression was recorded when extracts of cured compost were used. Changes in the effective NH_3 concentration of the compost, as well as a decrease in pH during curing could at least partly explain such findings.

Recent studies have also demonstrated the presence in diverse types of vermicomposts of various bacteria that are useful for different biotechnological purposes (Yasir *et al.*, 2009; Gopalakrishnan *et al.*, 2011; Fernández-Gómez *et al.*, 2012). In these studies, *Streptomyces* were detected (using COMPOCHIP)

Table 2: Research studies focused on the use of compost and vermicompost teas to suppress soil-borne diseases.

Phytopathogen	***Crop***	***Compost type***	***Brewing method/ duration***	***Brewing additives***	***Reference(s)***
Pythium debaryanum, *Fusarium oxysporum f.sp. lycopersici*, *Sclerotium bataticola*	*In vitro*	Leafy fruit, garden and crops-based composts	Compost extract	None	El- Masry *et al.* (2002)
Erysiphe pisi and *E. cichoracearum*	Pea seeds	Not specified	Vermicompost extract	None	Singh *et al.* (2003)
Pythium ultimum	Cucumber plants	Yard trimmings, mixed vegetation (vermicompost), vegetative and animal manure-based composts	ACT: 36 h NCT: 7–9 d	Kelp and humic acid extract	Scheuerell and Mahaffee (2004)
Rhizoctonia solani, *Fusarium oxysporum* f. sp. *radicis-lycopersici*, *F. oxysporum* f. sp. *lycopersici race 0*, *F. oxysporum* f. sp. *lycopersici race 1*, *F. oxysporum* f. sp. *radicis-cucumerinum*, *Verticillium dahliae*, *Pythium aphanidermatum*, *Phytophthora parasítica*, *Verticillium fungicola*	*In vitro*	Grape marc	ACT: 24 h	None	Diánez *et al.* (2006)

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Phytopathogen	***Crop***	***Compost type***	***Brewing method/ duration***	***Brewing additives***	***Reference(s)***
Phytophthora infestans	Potato	Combination of thermal compost, static wood chips compost and vermicastings	ACT: 24 h	A wide range of additives were tested: kelp, humates, rock dusts, grain/alfalfa meals, soluble plant sugar sources, and liquefied fish	Al-Mughrabi (2007)
Choanephora cucurbitarum	Okra plants	Rice straw and empty fruit bunch of oil palm compost	Compost extract	*Trichoderma*-enriched	Siddiqui *et al.* (2008)
Sclerotium rolfsii	*In vitro*	Municipal sewage sludge and yard waste composts	Compost extract	None	Zmora-Nahum *et al.* (2008)
Pythium aphanidermatum	*In vitro* *In vivo*: Tomato seedlings	Solid olive mill wastes, *Posidonia oceanica* and chicken manure-based composts	NCT: 6 d	None	Jenana *et al.* (2009)
Erysiphe polygoni	Tomato plants	Market, urban and garden wastes compost	ACT: 7 d	None	Segarra *et al.* (2009)
Choanephora cucurbitarum	*In vitro* *In vivo*: Okra plants	Rice straw and empty fruit bunch of oil palm compost	ACT: Not specified	None	Siddiqui *et al.* (2009)

Table 2: (*Contd...*)

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Phytopathogen	***Crop***	***Compost type***	***Brewing method/ duration***	***Brewing additives***	***Reference(s)***
Fusarium moniliforme	*In vitro*	Paper sludge and dairy sludge vermicompost	Vermicompost extract	None	Yasir *et al.* (2009)
[1]*Alternaria solani*, *Botrytis cinerea*, and *Phytophthora infestans* [2]*Oidium neolycopersici* and *Botrytis cinerea*	[1]*In vitro* [2]*In vivo*: Tomato plants	Five compost types: chicken manure, sheep manure (four sources; SM1-SM4), bovine manure, shrimp powder, and seaweed	NCT: 14 d	None	Koné *et al.* (2010)
Phytophthora capsici	Pepper plants	47 compost samples from six commercial compost facilities	Compost extract: 30 min	None	Sang *et al.* (2010)
Fusarium oxysporum f.sp. *lycopersici* (Fol), *Pythium ultimum*, *Phytophthora infestans*, *Sclerotina sclerotiorum, Verticillium dahlia*	*In vitro* *In vivo*: Tomato plants	Olive mill wastes	Compost extract	None	Alfano *et al.* (2011)
Pythium ultimum, *Rhizoctonia solani*, *Fusarium oxysporum* f. sp. *radicis-lycopersici* and *Verticillium dahliae*	*In vitro* *In vivo*: Tomato	Five compost types: seaweed, shrimp powder, and chicken, bovine and sheep manure	NCT	None	Dionné *et al.* (2012)
Pythium ultimum	Tomato and sweet pepper	Banana leaf and lawn clipping composts	ACT: 18, 27 and 36 h NCT: 56, 112 and 168 h	None	St. Martin *et al.* (2012)

Table 2: (*Contd...*)

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Phytopathogen	***Crop***	***Compost type***	***Brewing method/ duration***	***Brewing additives***	***Reference(s)***
Fusarium oxysporum f.sp. *niveum*, *Fusarium oxysporum* f.sp. *cucumerinum*, *Fusarium oxysporum* f.sp. cubense, *Fusarium oxysporum* f.sp. *melonis* and *Rhizoctonia solania* AG4	Lettuce and cress seeds	Pig manure and rice straw compost	ACT: 36 h NCT: 7-9 d	None	Xu *et al*. (2012)
[1]*Sclerotinia sclerotio- rum*, *Didymella bryoniae*, *Phytium aphanidermatum*, *Phytophthora parasitica*, *Botrytis cinerea*, *V. dahliae*, and *Lecanicillium fungicola* [2]*Didymella bryoniae*, *Podosphaera fusca*	[1]*In vitro* [2]*In vivo*: Melon plants	Four compost types: spent mushroom substrate compost, grape marc compost, and crop residues compost and vermicompost	ACT: 14 d NCT: 14 d	None	Marín *et al*. (2013)
Golovinomyces cichoracearum DC	Muskmelon F-1 variety 'Emerald Jewel'	Empty fruit bunches and palm oil mil effluent	ACT: 3 d	Yeast extract and humic acid	Naidu *et al*. (2013)

in different vermicomposts, irrespective of the parent material used for the process. Accordingly, Yasir *et al.* (2009) detected 22 strains, most of them identified as *Streptomyces* spp., with strong antifungal activity against several plant pathogenic fungi in a vermicompost made from dairy sludge and paper sludge. Similarly, Gopalakrishnan *et al.* (2011) reported the antifungal activity of four species of this genus (*Streptomyces tsusimaensis*, *Streptomyces caviscabies*, *Streptomyces setonii*, and *Streptomyces africanus*) against *Fusarium oxysporum* f. sp. *ciceri* in a vermicompost made from plant debris. In a recent study, Fritz *et al.* (2012) observed that the species composition of vermicompost samples was similar to that in the respective teas, thus indicating that the microbial content of the vermicompost strongly affected the microbial content of the tea. Together, these findings indicate the potential usefulness of vermicomposts and the resulting teas in the biocontrol of soil-borne plant diseases caused by pathogenic fungi.

It is often difficult to determine the exact suppression mechanisms, especially in composts and vermicomposts, owing to the complex structure of the microbial community (Boulter *et al.*, 2002; Lazcano and Domínguez, 2011). Indeed, general rather than specific disease suppression effects are more common following the addition of compost and vermicompost teas, as a broad range of organisms may act as biocontrol agents (Hoitink *et al.*, 1997; Arancon *et al.*, 2007; Lazcano and Domínguez, 2011; St. Martin and Brathwaite, 2012). The microorganisms present in the tea may act as pathogen antagonists by competing for space and nutrients, and/or by the production of antimicrobial compounds (antibiosis), as well as of lytic and other extracellular enzymes (Diánez *et al.*, 2006, 2007; Koné *et al.*, 2010; Alfano *et al.*, 2011; St. Martin and Brathwaite, 2012). Diánez *et al.* (2006) reported that inhibition of the growth of nine pathogenic fungi, including *Rhizoctonia solani* and *Pythium aphanidermatum*, was due to the siderophores excreted by the microorganisms present in grape marc compost tea. The presence of microbial groups that actively grow on substrates containing chitin and cellulose, the two major constituents of phytopathogenic fungi and oomycete cell walls, may play an important role in disease suppression mechanisms based on pathogen cell-wall hydrolysis (mycoparasitism, hyperparasitism) (Kavroulakis *et al.*, 2010). Disease suppression may also be accompanied by an increase in the production of defence substances (*i.e.*, phenolic compounds) by the plant following the application of compost and vermicompost teas (Singh *et al.*, 2003; Siddiqui *et al.*, 2009). This mechanism, which is known as induction of systemic resistance (ISR), involves expression of pathogenesis-related (PR) genes, production of defence-related enzymes such as -1,3-glucanase, chitinase, and peroxidase and the accumulation of phytoalexin (Sang *et al.*, 2010; Sang and Kim, 2011). Sang *et al.* (2010) found that the use of compost water extracts suppressed infection of leaves by *Phytophthora capsici via* ISR, specifically by enhancing the expression of PR genes and the chemical and structural defences of pepper plants, including H_2O_2 generation in the leaves and lignin accumulation in the stems. These authors also observed that compost extracts were effective in suppressing other fungal pathogens (*Colletotrichum coccodes* in pepper leaves and *C. orbiculare* in cucumber leaves) *via* ISR, whereas they did not observe inhibition of other bacterial pathogens, such as *Xanthomonas campestris* pv. *vesicatoria* in pepper leaves and *Pseudomonas syringae* pv. *lachrymans* in cucumber leaves. Overall, the efficacy of compost teas in disease control depends on the target pathosystem (pathogen and host plant), the methods of producing the teas and the method of application, as well as on compost feedstock and the degree of maturity (St. Martin and Brathwaite, 2012).

CONCLUSIONS AND PERSPECTIVES

Despite the increasing amount of information regarding the impact of compost teas on plant growth and disease suppressiveness, there are still some crucial issues to be addressed. For instance, it would be relevant to delve deeper into whether compost tea preparations can be made reproducible and if there exists a general recommendation for the process. Moreover, it is important to determine on the one hand the best way in which to store the tea, whether at ambient temperature, at 4°C or frozen; and on the other hand, how to get a more concentrated product, *i.e.*, by applying high pressure. Further studies aimed at evaluating the use of compost tea in combination with other organic fertilisers in sustainable agriculture are also needed. Along these lines, microbiological profiles could be investigated so as to check if they can be used as potential indicators of disease suppressiveness.

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