MAGYAR AGRÁR- ÉS ÉLETTUDOMÁNYI EGYETEM

www.columella.hu

Columella
Journal of Agricultural and Environmental Sciences

Control of plant pathogen *Fusarium* spp. with compost, compost tea application – A review

Viktória OROSZ[1] – Attila TOMÓCSIK[2] – Ibolya DEMETER[1] – Tibor József ARANYOS[1] – Marianna MAKÁDI[1]

1: University of Debrecen, Institutes for Agricultural Research and Educational Farm, Research Institute of Nyíregyháza, 4400 Nyíregyháza, Westsik Vilmos u. 4-6., Hungary; e-mail: oroszviki1000@gmail.com

2: Agricultural Ltd. of Prügy 3925 Prügy, Petőfi út 11., Hungary

Abstract: Compost has been used in agriculture for a long time for nutrient supply. However, in recent decades the disease suppressive effects of the compost and its aqueous extracts are in the focus of the research. Several composts and their water extracts were investigated on different plant diseases especially on those caused by soil-borne pathogens all over the world. The mechanisms are not fully understood. Disease suppression by compost and compost extract is attributed to various mechanisms like the presence of antagonistic microbes and unidentified chemical factors, induction of systemic resistance in plants. Probably the components of the studied substances trigger chemical and biological factors in plants. *Fusarium* species cause wide spectrum of plant diseases, therefore studies of their control are the hot spots of the researches. The control of *Fusarium* spp. was investigated in the processed literature based on the possible mode of action of composts or compost extracts in various experimental conditions as *in vitro*, greenhouse, pot and field experiments. The results proved to be very promising so far. In this respect, compost and compost tea could be possible alternatives to the synthetic chemical pesticides in controlling plant pathogens in a more environmentally sound way.

Keywords: Agro-waste, soil-borne pathogen, plant disease suppression, fungi

Received 01 November 2020, Revised 01 December 2021, Accepted 01 December 2021

Introduction

Soil is inhabited by soil-borne pathogens, which could be a danger to crops. Therefore, broad spectrum of chemicals is widely used to control them for a long time now. These products are not specific, both pathogenic and non-pathogenic microbes are destroyed by their application. The most commonly used fumigants and other chemicals have proved to be harmful to people and the environment. It is therefore necessary to find alternative methods for controlling soil-borne diseases (Nicolopoulou-Stamati et al. 2016). According to the definition of International Biocontrol Manufacturers Association, the biocontrol agents or products have natural origin and limit the propagation of pests and pathogens. This is in accordance with the Directive 2009/128/EC of the European Parliament and of the Council which promotes the non-chemical disease control.

The agricultural use of composts is an excellent form of minimising waste production, reducing environmental pollution and recycling of organic materials (Diaz et al. 2007), and is in line with the principles of circular economy (Jones and Comfort 2017). During compost application soil is enriched with nutrients and organic matter and, its structure could be improved (Diaz et al. 2007).

In the late 1970s, it was stated that compost can suppress plant pathogens and reduce disease incidence, especially the soil borne plant diseases (Hoitink 1980). From the last decades the number of papers dealing with controlling effects of water extract from compost against foliar diseases were published (Yogev et al. 2010; Pane et al. 2012; Al-Mughrabi 2007).

Compost extracts were prepared by mixing compost and distilled water. Then the resulting slurry was incubated without agitation for a day (Koné et al. 2010; Bernal-Vicente et al. 2008). It can also be enriched with oxygen (Siddiqui et al. 2009). The slurry was filtered through cheesecloth, and the filtrate, termed an extract, was sprayed onto the aerial surfaces of plant or allocated into the soil (Kavroulakis et al. 2005; Bernal-Vicente et al. 2008). If the compost extract is effective in practice, it would be a potential alternative of fungicides and therefore, it could contribute to the sustainability of the agriculture (Yohalem et al. 1996).

In this review, the studies on composts and compost extracts against *Fusarium* spp. are in the focus. *Fusarium* species are imported pathogens in agriculture. They could cause significant damage during crop production. Different effective ways of compost, compost extract utilization for controlling plant diseases caused by *Fusarium* spp. were summarised and the future tasks of this scientific topic were revealed.

Effect of compost, compost tea application on plant pathogen *Fusarium* species

Compost and compost tea were found as an environmentally sound option for controlling plant diseases. The genus *Fusarium* contains a number of soil-borne plant pathogenic species (Crous et al. 2021). Many cultivated plants may be attacked by different *Fusarium* species, e.g. *Fusarium oxysporum* damages tomato (Dukare et al. 2011) and carnation plants (Postma et al. 2003); *Fusarium solani* f. sp. *pisi* weakens the pea populations (Lumsden et al. 1983); *Fusarium oxysporum* f. sp. *radicis-cucumerinum* infects cucumber cultures (Bradley and Punja 2010). *Fusarium* species produce many mycotoxins (e.g. fusaric acid, trichothecene, marticin) and cause common root rot, wilt diseases, stem rot and necrosis in worldwide in the course of crop production (Crous et al. 2021; Jakucs and Vajna 2003).

The disease suppressive effects of compost and compost extract are examined all over the world and the number of studied compost varieties is almost unlimited. In addition, to generic ingredients such as different animal manure, straw, plant residues, composts often contain local raw materials for example Chinese medicinal herbal residues (Zhou et al. 2016; Shen et al. 2013), shrimp power and seaweed (Dionne et al. 2012), citrus waste (Bernal-Vicente et al. 2008; Lopez-Mondejar et al. 2010), olive waste (Ntougias et al. 2008; Basallote-Ureba et al. 2016). Moreover, spent mushroom substrate (Meng et al. 2018; Borrero et al. 2009; Tiltson et al. 2002) and sewage sludge (Lumsden et al. 1983; Heck et al. 2019) were also used to make compost. The results are promising. In most cases, *Fusarium* infection has been controlled by tested compost or compost extracts both in *in vitro* and *in vivo* treatments. However, in some cases inconsistent results were found. An interesting result was reported by Mierzwa-Hersztek et al. (2018) where compost extracts strongly reduced fungal sporulation, greater extent than the growth of fungi hyphae. In contrast to these results citrus compost and their extracts reduced significantly the mycelial growth of *Fusarium oxysporum* f.sp. *melonis*, but did not reduce the spore germination in *in vitro* experiments (Bernal-Vicente et al., 2008). Compost extracts had *in vitro* inhibitory effects on the tested *Fusarium* while no *in vivo* inhibitory effects were found (Znaïdi et al. 2002). De Corato et al. (2016) and Bernal-Vicente et al. (2008) reported suppressive results both in *in vitro* and *in vivo* investigations.

Summary of works on the suppressing effects of composts and their extracts on

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

Fusarium species are presented in Table 1.

Mechanisms of action of composts and compost extracts

It is very difficult to separate the different mechanisms of action. Microbes in the compost effect in various ways against soil pathogens (antibiosis, parasitism, microbiostasis), but only some of the real possibilities could be in focus in individual experiments. Researchers suggested the most probable implementations based on their results. To approach a problem from several aspects could result in finding more opportunities for effective implementation. The different possible mechanisms are detailed in the following subchapters.

Microbe content of compost/compost tea

Biotic components of extracts play a significant role because some compost lost partially their suppressiveness after sterilization (Cotxarrera et al. 2002; EL-Masry et al. 2002). The sterilization by autoclaving or by microfiltration ceased inhibition effect of compost on the mycelial growth of the tested pathogens (Koné et al. 2010). During microfiltration not only microorganisms were filtered out, but also their by-products or metabolites (Siddiqui et al. 2009). EL-Masry et al. (2002) found that all autoclaved compost water extracts lost their antagonistic effects against the indicator fungi because autoclaving kills all sporulated and non-sporulated microorganisms. Xiong et al. (2017) pointed out a possible new role of some keystone species (e.g. *Trichoderma* and *Bacillus* spp.) of composts in modification of structure and function of indigenous microbial groups of soil.

Competition for resources

Microorganisms living in the same niche compete for nutrients and places. The most widely known form is siderophore production of *Pseudomonas* sp. which is effective against *F. oxysporum* f. sp. *dianthii* (Duijff et al. 1993). Larkin and Fravel (1998) also found the nutrient competition as the main effect against *Fusarium* infection on potato plants. Competition effect could be increased by the increasing number, richness and diversity of bacterial strains in soil after compost treatment (Fu et al. 2017).

Antagonism, antibiosis and parasitism

Antagonism means that one organism suppresses or interferes the normal growth and activity of another organism via different mechanism. Antibiosis is a process in which toxic metabolites can penetrate into the cell and inhibit its activity by chemical toxicity while in the course of parasitism the parasitic organism acquire some or all of their feed stuff requirements from other organisms. Fungal antagonists added to composts in different maturation ages could increase the disease suppressiveness against *Fusarium oxysporum* by the antagonist enrichment (Postma et al. 2003). However, in this case not only the original microbial community of the compost extract was used even so the experiment proved the effect of antagonism. The most probable antagonistic mechanism of these bacterial mixtures depends on the lysogenic activity of bacteria but it needs a direct contact between the bacteria and the phytopathogenic fungi (EL-Masry et al. 2002).

Mycoparasitism is a special type of parasitism when fungus attacks another fungus (e.g. *Trichoderma* sp. against *F. oxysporum*) (John et al. 2010). Other, widely used antagonistic microbes are within *Pseudomonas* (Wahyuni et al. 2010) and *Bacillus* (Dukare et al. 2011) genus.

Induced resistance in plants

Certain infection may activate induced resistance in plant. Two forms of induced resistance are known. Systemic acquired resistance (SAR) which are associated with a salicylic acid-dependent signalling pathway and the induction of pathogenesis-related (PR) proteins. In contrast, induced systemic resistance (ISR) are not salicylic acid dependent and it can be induced by defined bacterium taxa. Induced resistance in plants can be induced by soil or foliar application of compost tea in controlling foliar and soilborne pathogens (Zhang et al. 1998; Yogev et al. 2010; Kavroulakis et al. 2005). Therefore, the application of compost either soil amendment or foliar spray may be effective to improve the level of disease suppression in fields (Joshi et al. 2009). Molecular mechanism liable for compost-induced systemic acquired resistance is not fully understood so far but it can be concluded that compost-induced SAR differed from SAR induced by pathogens (Zhang et al. 1998).

However, microorganisms also play an important role for inducing resistance. Aimé et al. (2013) found that a non-pathogenic *F. oxysporum* F047 strain induces the systemic resistance of tomato plants against *F. oxysporum* f. sp. *lycopersici*.

Chemical factors

Compost extract contain biocontrol agents as well as unidentified chemical factors which play a role in different pathogenic fungal suppression (Cronin et al. 1996). High pH and high electrical conductivity (EC) of compost may affect the extent of the suppressive effect of the diseases (Lamprecht et al. 2017; Cotxarrera et al. 2002). Pathogens need different microelements for growth and sporulation. High pH and EC reduce these microelements availability hereby can decrease the virulence of plant pathogens (Cotxarrera et al. 2002; Amir and Riba 1990). Different nitrogen forms may be an influencing factor in the mechanism of action (Trillas-Gay et al. 1986; Tiltson et al. 2002). Calcium nitrate and ammonium sulphate content of compost significantly reduce the disease severity, on the other hand ammonium nitrate nitrogen had no effect of *Fusarium* wilt of radish (Trillas-Gay et al. 1986). Heck et al. (2019) studied the abiotic and biotic characteristics of compost-treated soil and concluded that the most consistent abiotic factors were EC pH, base saturation%, cation exchange capacity, P, K, Ca, Mg, Na, Zn, Mn and B.

Multiple effects

Combination of physico-chemical and biological characteristics of composts for suppressing plant diseases (Kavroulakis et al. 2005; Siddiqui et al. 2009; Zmora-Nahum et al. 2008) can be the real explanation for antifungal effect of compost/compost tea. Physico-chemical characteristics include physical and chemical aspects of compost that reduce disease severity by directly affecting the pathogen or host capacity for growth. Examples of these aspects include nutrient levels, organic matter, moisture, pH (Cronin et al 1996), and other factors (Cotxarrera et al. 2002). Kavroulakis et al. (2005) reported that the biological control of pathogens by compost depends on both biological and chemical factors. It is actually a complex and difficult process.

Effects of compost of different origins

Several studies investigated the effects of different composts. Disease suppression was significantly affected by storage method, composition of compost samples, as well as their interaction which indicate that the effect of the storage on disease suppression is compost-dependent (van Rijn et al. 2007; Saadi et al. 2010; Postma et al. 2003). Termorshuizen et al. (2006) did a large comparative assessment. The impacts of 18 different composts were examined on seven pathosystems among them *Fusarium oxysporum* f. sp. *lini*. None of the composts showed significant disease suppression against all

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

pathogens. The second highest disease suppression was found for *Fusarium oxysporum*. 14 composts of the examined 18 composts suppressed by more than 50% of the disease caused by the pathogen. At least one compost induced a disease suppression by more than 70% for each pathosystem. Similar results were published by Pane et al. (2011). They suggest that compost suppressiveness is often pathogen specific. Only one of the tested composts suppressed significantly all the studied pathogens. Probably there is no compost which could suppress all or many pathogens. However, if the suppressive properties of the compost are known, it can be applied in practice.

Ntougias et al. (2008) studied nine composts mixed with peat (after curing and following nine month storage) and assessed for their suppressive effects against two major soil-borne pathogens of tomato. The studied pathogens show great phylogenetic distance, had different life cycles and mode of action. Disease incidence in tomato by *Phytophtora nicotianae* was significantly reduced by all studied compost amendments. On the other hand, the effects of these compost applications for the protection from *Fusarium oxysporum* f.sp. *radicis-lycopersici* infection presented higher variability. Fresh composts usually caused significantly lower disease incidence values than prolonged stored composts.

Based on these results we can conclude that each compost have to be tested for their effectiveness against different pathogens.

Conclusion and future possibilities

Agriculture has to satisfy the qualitative and the quantitative demands of the consumers. Compost and aqueous compost extracts still have some untapped potentials. They can be produced from waste materials in an inexpensive way. However, large amounts are spent on pesticides in agriculture. The question is how can decrease the quantity of pesticides by good quality composts and compost teas having proved effect against well-defined pathogens based on well-defined application technology. Application of composts and compost extracts improve soil quality by altering its physical, chemical and microbiological properties. They increase the organic matter content, water capacity, microbial species diversity and macro- and micro-nutrient supply of soils, which are fundamental for plant growth. In addition, application of composts as soil amendments and foliar sprays may be an effective way to improve the level of disease suppression in field situations. Many pathogenic fungi can induce disease in field plants, including members of the genus *Fusarium*. The main shortcoming of the field applications of compost extracts are the lack of standardization of preparation and application methods.

Only some recent investigations assessed the suppressiveness of many compost types on different pathogens. Results of the studies also suggest that compost suppressiveness is often pathogen specific. Generally, there was not compost which had significant disease suppression against all the examined *Fusarium* sp. and pathogens, in addition the pathogens were not affected similarly by all composts. Moreover, big differences in compost quality and their impact on plant health were observed. This may be due to the different microbial composition of the composts. Microbes have a major role in compost-mediated disease suppression and since composts from different organic sources vary notably in their microbial composition, these differences may result in variable disease suppression, as well.

One of the tasks is to find the best compost or compost extract for the selected *Fusarium* sp. or other pathosystem, thereby it contributes to reducing the risk of chemicals used in agriculture.

Another task is to find the true mode of action. It is quite difficult to separate the different mechanisms of actions. Studies usually focus only one action the researcher assumed. In fact, it is a very complex process therefore, more complex and even more studies of composts and aqueous compost extracts are needed.

The following tasks are the hot points of this research area: i) chemical examination of a wide range of the extracts, ii) detailed analysis of the microbial community of the extracts, iii) investigation of the effects of isolated microbes against *Fusarium* sp. and different plant pathogens both *in vitro* and in field experiments, iv) standardisation of composting process, compost tea producing process and the application method of the compost tea, v) storage of effective compost teas. After completing these tasks, not only the suppressiveness of composts and compost extracts could be used for the reduction of pesticides applied in agriculture but this method is also one of the most cost effective, environmentally sound alternative for organic waste recycling.

References

Aimé, S., Alabouvette, C., Steinberg, C., Olivain, C. (2013) The endophytic strain *Fusarium oxysporum* Fo47: a good candidate for priming the defense responses in tomato roots. Molecular Plant-Microbe Interactions. 26. 918-926. https://doi.org/10.1094/MPMI-12-12-0290-R

Al-Mughrabi, K.I. (2007) Suppression of *Phytophtora infestans* in potatoes by foliar application of food nutrients and compost tea. Australian Journal of Basic and Applied Sciences. 1(4). 785-792.

Amir, H., Riba, O. (1990) Influence de la salinité des sols de palmeraies sur les *Fusarium* I. Relation entre la densité des population des Fusarium et la conductivité des sols. Revue d'Ecologie et de Biologie du sol. 26. 147-158.

Bradley, G., Punja, Z.K. (2010) Composts containing fluorescent pseudomonads suppress fusarium root and stem rot development on greenhouse cucumber. Canadian Journal of Microbiology. 56. 896-905. https://doi.org/10.1139/W10-076

Bernal–Vicente, A., Ros, M., Tittarelli, F., Intrigliolo, F., Pascual, J.A. (2008) Citrus compost and its water extract for cultivation of melon plants in greenhouse nurseries. Evaluation of nutriactive and biocontrol effects. Bioresource Technology. 99. 8722-8728. http://doi.org/10.1016/j.biortech.2008.04.019

Blaya, J., López-Mondéjar, R., Lloret, E., Pascual, A., Ros, M. (2013) Change induced by *Trichoderma harzianum* in suppressive compost controlling *Fusarium* wilt. Pesticide Biochemistry and Physiology. 107. 112-119. https://doi.org/10.1016/j.pestbp.2013.06.001

Borrero, O., Trillas, I., Avilés, M. (2009) Carnation *Fusarium* wilt suppression in four composts. European Journal of Plant Pathology. 123. 425-433. https://doi.org/10.1007/s10658-008-9380-4

Cotxarrera, L., Trillas-Gay, M.-I., Steinberg, C., Alabouvette, C. (2002) Use of sewage sludge compost and *Trichoderma asperellum* isolates to suppress *Fusarium* wilt of tomato. Soil Biology & Biochemistry. 34. 467-476. https://doi.org/10.1016/S0038-0717(01)00205-X

Cronin, M.J., Yohalem, D.S., Harris, R.F., Andrews, J.H. (1996) Putative mechanism and dynamics of inhibition of the apple scab pathogen *Venturia inaequalis* by compost extracts. Soil Biology & Biochemistry. 28. 1241-1249. https://doi.org/10.1016/0038-0717(96)00131-9

Crous, P.W., Lombard, L., Sandoval-Denis, M., Seifert, K.A., Schroers, H.-J., Chaverri, P., Gené, J., Guarro, J., Hirooka, Y., Bensch, K., Kema, G.H.J., Lamprecht, S.C., Cai, L., Rossman, A.Y., Stadler, M., Summerbell, R.C., Taylor, J.W., Ploch, S., Visagie, C.M., Yilmaz, N., Frisvad, J.C., Abdel-Azeem, A.M., Abdollahzadeh, J., Abdolrasouli, A., Akulov, A., Alberts, J.F., Araújo, J.P.M.,

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

Table 1: Suppressing effects of compost and their extract on *Fusarium* species in different experimental conditions.

Tested pathogen	Compost materials	Tested material	*in vitro*/plant	Effects	Supposed mechanism	References
Fusarium culmorum	Green waste, paper waste, sewage sludge, spent mushroom, horse manure, municipal solid waste.	Compost	Winter wheat	Two of eight tested composts were suppressive.	Pathogen specific; abiotic component.	Tilston et al. 2002
	Rape straw, wheat straw, chipped maize straw, fragmented waste material obtained during shelling of pea seeds, ground polymer materials, which were made of polyethylene and thermoplastic corn starch.	Compost extract	*in vitro*	Compost extracts strongly reduced fungal sporulation, greater extent than the growth of fungal hyphae.	Heavy metal.	Mierzwa-Hersztek et al. 2018
Fusarium foetens	Commercial compost.	Compost	Rooibos, oat, lupin	Both composts significantly suppressed damping-off caused by *Fusarium* spp.	Biological component; abiotic factors.	Lamprecht and Tewoldemedhin 2017
Fusarium graminearum	Cattle manure, sheep manure, chicken manure, horse manure, vegetable waste, ground straw.	Compost extract	*in vitro*	Inhibitory effect on the mycelial growth of fungus.	Role of microorganisms.	Kerkeni et al. 2007
	Rape straw, wheat straw, chipped maize straw, fragmented waste material obtained during shelling of pea seeds, ground polymer materials, which were made of polyethylene and thermoplastic corn starch.	Compost extract	*in vitro*	Compost extracts strongly reduced fungal sporulation, greater extent than the growth of fungal hyphae.	Heavy metal.	Mierzwa-Hersztek et al. 2018
Fusarium oxysporum	Horticultural waste, prune, cut grass, ditch plants, fruit, vegetable and garden waste with different maturation stages.	Compost	Carnation	Disease suppression.	Origin of compost; antagonism.	Postma et al. 2003
	Cattle manure, sheep manure, poultry manure, crushed wheat straw.	Compost extract	*in vitro* and potato	*In vitro*: all compost extracts had inhibitory effects. *In vivo*: no inhibitory effects.	Microorganism content of compost tea.	Znaïdi et al. 2002
	Paddy straw.	Composts and their extracts	Tomato	Severe reduction in pre- and post-emergence disease incidence.	Interactions among various modes of biocontrol by microorganisms.	Dukare et al. 2011
	Commercial compost.	Compost	Roiboos, oat, lupin	Both composts significantly suppressed damping-off caused by *Fusarium* spp.	Biological component; abiotic factors.	Lamprecht and Tewoldemedhin 2017

Table 1: (continued): Suppressing effects of compost and their extract on *Fusarium* species in different experimental conditions.

Tested pathogen	Compost materials	Tested material	*in vitro*/plant	Effects	Supposed mechanism	References
Fusarium oxysporum	Green waste	Compost extract	*in vitro*	The colony diameter of *F. oxysporum* was reduced to a small extent.	Microbial populations present in compost extract.	Milinković et al. 2019
	Chinese medicinal herbal residues, food waste (rice, bread, cabbage, boild pork), sawdust.	Compost extract	*in vitro*	Acetone extract of the compost showed the best performance against fungal growth. Antagonist properties of mature compost were stronger.	Antagonism; mycoparasitism.	Zhuo et al. 2016
Fusarium oxysporum f. sp. *basilici*	Cow manure, wheat straw, chicken manure.	Compost	Sweet basil	Significant reduce of disease severity.	Biotic factors.	Reuveni et al. 2002
	Agricultural and agro-industrial residues, plant green waste, municipal solid waste, cattle manure and other biowaste.	Compost	Basil	All green composts were capable of effectively suppressing the pathosystems under consideration.	Biological activity of composts' microbial community.	De Corato et al. 2019
Fusarium oxysporum f. sp. *conglutinans*	Canadium shangum peat, perlit	Compost	Radish	Unheated compost media significantly suppressed the population of the tested pathogen.	Biotic and abiotic factors.	Trillal-Gay et al. 1986
Fusarium oxysporum f. sp. *cubense*	Pig manure, cattle manure, Chinese medicine residue.	Compost	Banana	Cattle manure compost and Chinese medicine residue compost were the most effective.	Enzymatic and microbiological parameters; increased soil bacterial and actinomycetes populations.	Shen et al. 2013
	Sewage sludge.	Compost extract	Banana	The aqueous extracts of sewage sludge reduced fungal microconidial germination. Sewage sludge increased mycelial growth when compared with control.	Both biotic and abiotic characteristics.	Heck et al. 2019
Fusarium oxysporum f. sp. *cucumerinum*	*Caragana microphylla*-straw, chicken manure.	Compost	Cucumber	The number of *F. oxysporum* was significantly decreased by *C. microphylla*-straw compost application.	Microbial diversity.	Tian et al. 2016
Fusarium oxysporum f. sp. *dianthi*	Grape marc, cork, olive oil husk, cotton gin trash, rice husk, spent mushroom compost, peat, coir fibre, vermiculite.	Compost	Carnation	Grape marc compost was the most effective. Coir fibre, peat and vermiculite were conductive for this disease.	Microbiostasis.	Borrero et al. 2009
	Grape marc.	Compost	Tomato and carnation	Significant interaction was found.	Disease parameters affected by the water use of plants.	Sant et al. 2010

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

Table 1: (continued): Suppressing effects of compost and their extract on *Fusarium* species in different experimental conditions.

Tested pathogen	Compost materials	Tested material	*in vitro*/plant	Effects	Supposed mechanism	References
Fusarium oxysporum Schl f. sp. *lactucae*	Commercial compost.	Compost	Lettuce	Compost treatments were not suppressive in all the trials.	Microbial inhibitors.	De Corato et al. 2011
Fusarium oxysporum f. sp. *lini*	Horse manure, green waste, tree bark, slurries, urban biowastes, organic residues of wine grapes, woody wastes, poultry manure, woodcut, plants, spent mushroom, leonardite, urea, phosphate, catalyst, wood chips, municipal sewage sludge, yard waste, manure clay, plant residues - from four countries.	Compost	Flax	High disease suppression.	Pathogen specific effects but the mechanisms are not identified.	Termorshuizen et al. 2006
	Vegetable, fruit and garden waste, leaves and wood trimming, manure, clay.	Compost	Flax	75% of the assays resulted in significant disease suppression. Disease suppression was significantly affected by storage method.	Bacterial composition and microbial activity. Storage have a limited effect.	van Rijn et al. 2007
Fusarium oxysporum f. sp. *lycopersici*	Green waste.	Compost	Tomato	Significantly reduced *Fusarium* wilt symptoms.	Antagonism; competition for space and nutrients.	Cucu et al. 2020
	Agricultural and agro-industrial residues, plant green waste, municipal solid waste, cattle manure and other biowaste.	Compost	Tomato	All green composts were capable of effectively suppressing the pathosystems under consideration.	Biological activity of composts' microbial community.	De Corato et al. 2016
	Miscanthus, giant reed, wheat straw, agro-industrial co-products (coffee-ground, defatted olive marc, woodchip), plant-waste (artichoke, fennel, tomato).	Composts and their extracts	*in vitro* and tomato	Both *in vitro* an *in vivo* the suppression of the tested pathosystem was highly significant.	Pathogen-specific; compost microflora; antibiotic mechanisms.	De Corato et al. 2016
	Commercially avalable compost (vegetable and animal wastes, sewage sludge, yard waste)	Compost	Tomato	The compost effectively suppress *Fusarium* wilt.	Biotic and abiotic factors.	Cotxerrera et al. 2002

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

Table 1: (continued): Suppressing effects of compost and their extract on *Fusarium* species in different experimental conditions.

Tested pathogen	Compost materials	Tested material	*in vitro*/plant	Effects	Supposed mechanism	References
Fusarium oxysporum f. sp. *melonis*	Citrus wastes, sludge obtained from citrus industry waste water treatment, green residues - in two proportions.	Composts and their extracts	*in vitro* and melon	Both citrus composts and their water extracts reduced significantly the mycelial growth, but did not reduce the spore germination in *in vitro* experiments. The *in vivo* assay confirmed the *in vitro* results.	Antagonistic microorganism; mycoparasitism (lytic enzyme).	Bernal-Vicente et al. 2008
	Commercial compost.	Compost	Melon	No suppressive effect.	-	De Corato et al. 2016
	Citrus wastes, sludge obtained from citrus industry waste water treatment, green residues.	Composts and their extracts	Melon	Pathogen incidence was significantly lower in than peat. In case of water extracts, one of them showed lower, other of them showed higher pathogen incidence than its solid matrix.	Biotic (antibiosis and mycoparasitism) and abiotic components; niche competition or plant acquired and/or induced resistance.	Lopez-Mondejar et al. 2010
	Sewage sludge.	Compost	Melon	Significant decrease in disease was observed.	Microorganisms of the compost.	Lumsden et al. 1983
	Cow manure, tomato plants.	Compost	Melon	All composts were highly suppressive and clearly effective compared to the peat in the course of period.	Microbial populations of compost; induced systemic resistance; storage had no negative effect.	Saadi et al. 2010
	Horticultural waste mixture, pepper plant waste, almond peel waste.	Compost	*in vitro*	1.4% of the selected microorganisms from different composts against *F. oxisporum* could inhibit the growth of the pathogen.	Compost maturity; antagonistic microorganisms.	Suárez-Estrella et al. 2007
	Ground tomato-plant residues mixed with separated cattle manure.	Compost	Melon	When both parts of the root system were grown in compost, disease severity was further reduced.	Induced resistance.	Yogev et al. 2010
	Vineyard pruning waste.	Compost	*in vitro* and muskmelon	In both cases compost showed higher biocontrol activity than peat against *Fusarium oxysporum*.	Biotic and abiotic characteristics of the compost.	Blaya et al. 2013

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

Table 1: (continued): Suppressing effects of compost and their extract on *Fusarium* species in different experimental conditions.

Tested pathogen	Compost materials	Tested material	*in vitro*/plant	Effects	Supposed mechanism	References
Fusarium oxysporum f. sp. *melonis*	Miscanthus, giant reed, wheat straw, agro-industrial co-products (coffee-ground, defatted olive marc, woodchip), plant-waste (artichoke, fennel, tomato).	Composts and their extracts	*in vitro* and melon	Both in vitro an in vivo the suppression of the tested pathosystem was highly significant.	Pathogen-specific; compost microflora; antibiotic mechanisms.	De Corato et al. 2016
	Steam-explosion liquid waste (giant reed, *Miscanthus sinenis*, Kenaf, wheat/barley straw), agro-industrial residues (defatted olive marc, coffee ground, wood chip, aspen chip, viticulture and vinery residue), plant green-waste (artichoke, fennel, tomato, escarole, potato, pepper), municipal solid waste, cow manure, household waste.	Composts and their extracts	*in vitro* and melon	Suppressive activity of composts and their extracts depending the feedstock origin both *in vitro* and *in vivo* assay.	Pathogen-specific; compost microbiota (depend on feedstock).	De Corato et al. 2018
	Agricultural and agro-industrial residues, plant green waste, municipal solid waste, cattle manure and other biowaste.	Compost	Melon	All green composts were capable of effectively suppressing the pathosystems under consideration.	Biological activity of composts microbiomes.	De Corato et al. 2019
Fusarium oxysporum f. sp. *radicis-cucumerinum*	Tomato, pepper plant waste, solid material separated from dairy farm liquid manure, pine bark.	Compost	Cucumber	Two composts significantly reduced the disease severity, while one compost had no effect.	Antibiotic production.	Bradley & Punja 2010
	Raw pruning residues, sewage sludge, sawdust, winery residues including grape stalks and grape pomace, tomato pulp with sawdust, organic fraction of municipal solid waste, olive mill extracted press cake, waste water, olive leaves.	Compost	Cucumber	Four of the examined six composts were significantly suppressed root and stem rot symptoms on cucumber.	Phenolic compounds.	Markakis et al. 2016
Fusarium oxysporum f. sp. *radicis-lycopersici*	Grape mark waste, extracted olive press cake, peat.	Compost extract	Tomato	Increased plant resistance on peat amended with compost.	Combination of physico-chemical and biological characteristics of compost; systemic resistance.	Kavroulakis et al. 2005
	Cattle manure, sheep manure, chicken manure, horse manure, vegetable waste, ground straw.	Compost extract	*in vitro*	Inhibitory effect on the mycelial growth of the tested fungi.	Microorganisms.	Kerkeni et al. 2007

Table 1: (continued): Suppressing effects of compost and their extract on *Fusarium* species in different experimental conditions.

Tested pathogen	Compost materials	Tested material	*in vitro*/plant	Effects	Supposed mechanism	References
Fusarium oxysporum f. sp. *radicis-lycopersici*	Grape mark waste, spent mushroom compost, olive tree leaves, olive wastewaters, olive press cake, extracted olive press cake.	Compost extract	Tomato	Most of compost amendments reduced the disease severity in varying degree. growth of the tested fungi.	Systemic resistance.	Ntougias et al. 2008
	Sphagnum peat moss with composted pulp and paper mill residues, peat.	Compost	Tomato	Markedly reduced symptom severity.	Induced resistance.	Pharand et al. 2002
	Bovine manure, chicken manure, sheep manure, shrimp powder, seaweed.	Compost extract	*in vitro*	Reduced mycelial growth.	Microbial communities; induction of plant defence reactions by microorganisms or by organic and inorganic compounds of the compost tea.	Dionne et al. 2012
Fusarium roseum var. graminearum	Cattle manure, sheep manure, poultry manure, crushed wheat straw.	Compost extract	*in vitro* and potato	*In vitro*: all compost teas had inhibitory effects. *In vivo*: no effects.	Microorganism content of compost tea.	Znaïdi et al. 2002
Fusarium roseum var. sambucinum	Cattle manure, sheep manure, poultry manure, crushed wheat straw.	Compost extract	*in vitro* and potato	*In vitro*: inhibitory effects. *In vivo*: no effects.	Microorganism content of compost tea.	Znaïdi et al. 2002
Fusarium solani	Cattle manure, sheep manure, chicken manure, horse manure, vegetable waste, ground straw.	Compost extract	*in vitro*	Inhibitory effect on the mycelial growth of fungus.	Role of microorganisms.	Kerkeni et al. 2007
Fusarium solani f. sp. *pisi*	Sewage sludge.	Compost	Pea	Disease was increased by compost.	Microorganisms of compost stimulated the soil microbial community.	Lumsden et al. 1983
Fusarium solani var. *cœruleum*	Cattle manure, sheep manure, poultry manure, crushed wheat straw.	Compost extract	*In vitro* and potato	*In vitro* and *in vivo*: inhibitory effects.	Microorganisms content of compost tea.	Znaïdi et al. 2002
Fusarium spp.	Spent mushroom substrate, pig manure, biogas residues.	Compost	Tomato and pepper	Compost application suppressed the pathogens between 20% and 90%.	Microbial population and activity.	Meng et al. 2018

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

Ariyawansa, H.A., Bakhsi, M., Bendiksby, M., Ben Hadj Amor, A., Bezerra, J.D.P., Boekhout, T., Câmara, M.P.S., Carbia, M., Cardinali, G., Castañeda-Ruiz, R.F., Celis, A., Chaturvedi, V., Collemare, J., Croll, D., Damm, U., Decock, C.A., de Vries, R.P., Ezekiel, C.N., Fan, X.L., Fernández, N.B., Gaya, E., González, C.D., Gramaje, D., Groenewald, J.Z., Grube, M., Guevara-Suarez, M., Gupta, V.K., Guarnaccia, V., Haddaji, A., Hagen, F., Haelewaters, D., Hansen, K., Hashimoto, A., Hernández-Restrepo, M., Houbrakrn, J., Hubka, V., Hyde, K.D., Iturriaga, T., Jeewon, R., Johnston, P.R., Jurjević, Ž., Karalzi., İ., Korsten, L., Kuramae, E.E., Kušan, I., Labuda, R., Lawrence, D.P., Lee, H.B., Lechat, C., Li, H.Y., Litovka, Y.A., Maharachchikumbra, S.S.N., Marin-Felix, Y., Matio Kemkuignou, B., Matočec, N., McTaggart, A.R., Mlčoch, P., Mugnai, L., Nakashima, C., Nilsson, R.H., Noumeur, S.R., Pavlov, I.N., Peralta, M.P., Philips, A.J.L., Pitt, J.I., Polizzi, G., Quaedvileg, W., Rajeshkumar, K.C., Restrepo, S., Rhaiem, A., Robert, J., Robert, V., Rodrigues, A.M., Salgado-Salazar, C., Samson, R.A., Santos, A.C.S., Shivas, R.G., Souza-Motta, C.M., Sun, G.Y., Swart, W.J., Szoke, S., Tan, Y.P., Taylor, J.E., Taylor, P.W.J., Tiago, P.V., Váczy, K.Z., van de Wiele, N., van der Merwe, N.A., Verkly, G.J.M., Vieira, W.A.S., Vizzini, A., Weir, B.S., Wijayawardene, N.N., Xia, J.W., Yáñez-Morales, M.J., Yurkov, A., Zamora, J.C., Zare, R., Zhang, C.L. and Thines, M. (2021) *Fusarium*: more than a node or a foot-shaped basal cell. Studies in Mycology 98. 100116. https://doi.org/10.1016/j.simyco.2021.100116.

Cucu, M.A., Gilardi, G., Pugliese, M., Gullino, M.L., Garibaldi, A. (2020) An assessment of the modulation of the population dynamics of pathogenic *Fusarium oxysporum* f. sp. *lycopersici* in the tomato rhizosphere by means of the application of *Bacillus subtilis* QST 713, *Trichoderma* sp. TW2 and two compost. Biological Control. 142. 104158. https://doi.org/10.1016/j.biocontrol.2019.104158

De Corato, U., Patruno, L., Avella, N., Lacolla, G., Cucci, G. (2019) Composts from green sources show an increased suppressiveness to soilborne plant pathogenic fungi: Relationships between physicochemical properties, disease suppression, and the microbiome. Crop Protection 124. 104870 https://doi.org/10.1016/j.cropro.2019.104870

De Corato, U., Salimbeni, R., De Pretis, A., Patruno, L., Avella, N., Lacolla, G., Cucci, G. (2018) Microbiota from 'next-generation green compost' improves suppressiveness of composted Municipal-Solid-Waste to soil-borne plant pathogens. Biological Control 124. 1 -17. https://doi.org/10.1016/j.biocontrol.2018.05.020

De Corato, U., Sharma, N., Maccioni, O., Zimbardi, F. (2011) Supperessiveness of steam-exploded biomass of *Miscanthus sinensis* var. *giganteus* against soil-borne plant pathogens. Crop Protection 30. 246-252. https://doi.org/10.1016/j.cropro.2010.11.006

De Corato, U., Viola, E., Arcieri G., Valerio, V., Zimbardi, F. (2016) Use of composted agro-energy co-products and agricultural residues against soil-borne pathogens in horticultural soil-less systems. Scientia Horticulturae 210. 166-179. http://dx.doi.org/10.1016/j.scienta.2016.07.027

Diaz, L.F., de Bertoldi, M., Bidlingmaier, W., Stentiford, E. Ed. (2007) Compost science and technology. Waste management series 8. p. 364. ISBN-13: 9780080439600

Dionne A., Tweddell, R.J., Antoun, H., Avis, T.J. (2012) Effect of non-aerated compost teas on damping-off pathogens of tomato. Canadian Journal of Plant Pathology 34:1. 51-57. http://dx.doi.org/10.1080/07060661.2012.660195

Directive 2009/128EC (last access 26/07/2019) http://data.europa.eu/eli/dir/2009/128/2019-07-26

Duijff, B.J., Meijer, J.W., Bakker, P.A.H.M., Schippers, B. (1993) Siderophore-mediated competition for iron and induced resistance in the suppression of fusarium wilt of carnation by fluorescent *Pseudomonas* spp. Netherlands Journal of Plant Pathology 99. 277–289. https://doi.org/10.1007/BF01974309

Dukare, A.S., Prasanna, R., Dubey, S.C., Nain, L., Chaudhary, V. (2011) Evaluating novel microbe amended composts as biocontrol agents in tomato. Crop Protection 30. 436-442. https://doi.

org/10.1016/j.cropro.2010.12.017

EL-Masry, M.H., Khalil, A.I., Hassouna, M.S., Ibrahim, H.A.H. (2002) *In situ* and *in vitro* suppressive effect of agricultural composts and their water extracts on some phytopathogenic fungi. World Journal of. Microbiology. & Biotechnology. 18. 551-558.

Fu, L., Penton, C.R., Ruan, Y., Shen, Z., Xue, C., Li, R., Shen, Q. (2017) Inducing the rhizosphere microbiome by biofertilizer application to suppress banana *Fusarium* wilt disease. Soil Biology & Biochemistry 104. 39-48. https://doi.org/10.1016/j.soilbio.2016.10.008

Heck, D.W., Ghini, R., Bettiol, W. (2019) Deciphering the suppressiveness of banana *Fusarium* wilt with organic residues. Applied Soil Ecology 138. 46-60. https://doi.org/10.1016/j.apsoil.2019.02.021

Hoitink, H.A.J. (1980) Composted bark, a lightweight growth medium with fungicidal properties. Plant Disease 64(2). 142-147. DOI: 10.1094/PD-64-142.

Jakucs, E., Vajna, L (2003) Mycology. Agroinform Publishing and Printing Ltd. Budapest, p. 477. ISBN9635027761

Janvier, C., Villeneuve, F., Alabouvette, C., Edel-Hermann, V., Mateille, T., Steinberg, C. (2007) Soil health through soil disease suppression: Which strategy from descriptors to indicators? Soil Biology & Biochemistry 39. 1-23. https://doi.org/10.1016/j.soilbio.2006.07.001

John, R.P., Tyagi, R.D., Prévost, D., Brar, S.K., Pouleur, S., Surampalli, R.Y. (2010) Mycoparasitic *Trichoderma viride* as a biocontrol agent against *Fusarium oxysporum* f. sp. *adzuki* and *Pythium arrhenomanes* and as a growth promoter of soybean. Crop Protection 29. 1452–1459.https://doi.org/10.1016/j.cropro.2010.08.004

Jones, P., Comfort, D. (2017) Towards the circular economy: A commentary on corporate approaches and challenges. Journal of Public Affairs 17: e1680. https://doi.org/10.1002/pa.1680

Joshi, D., Hooda, K.S., Bhatt, J.C., Mina, B.L., Gupta, H.S. (2009) Suppressive effects of composts on soil-borne and foliar diseases of French bean in the field in the western Indian Himalayas. Crop Protection 28. 608-615. https://doi.org/10.1016/j.cropro.2009.03.009

Kavroulakis, N., Ehaliotis, C., Ntougias, S., Zervakis, G.I., Papadopoulou, K. (2005) Local and systematic resistance against fungal pathogens of tomato plants elicited by compost derived from agricultural residues. Physiological and Molecular. Plant Pathology 66. 163-174. https://doi.org/10.1016/j.pmpp.2005.06.003

Kerkeni, A., Daami-Remadi, M., Tarchoun, N., Khedher, M.B. (2007) In vitro assessment of the antifungal activity of several compost extracts obtained from composted animal manure mixtures. International Journal of Agricultural Research 2. 786-794.https://doi.org/10.3923/ijar.2007.786.794

Koné, S.B., Dionne, A.D., Tweddell, R.J., Antoun, H., Avis, T.J. (2010) Suppressive effect of non-aerated compost teas on foliar fungal pathogens of tomato. Biological Control 52. 167-173. https://doi.org/10.1016/j.biocontrol.2009.10.018

Lamprecht, S.C., Tewoldemedhin, Y.T. (2017) *Fusarium* species associated with damping-off of rooibos seedlings and the potential of compost as soil amendment for disease suppression. South African Journal of Botany 110. 110-117. http://dx.doi.org/10.1016/j.sajb.2016.07.009

Larkin, R.P., Fravel, D.R. (1998) Efficacy of various fungal and bacterial biocontrol organisms for control of *Fusarium* wilt of tomato. Plant Disease 82. 1022-1028.

Lopez-Mondejar, R., Bernal-Vicente, A., Ros, M., Tittarelli, F., Canali, S., Intrigiolo, F., Pascual, J.A. (2010) Utilization of citrus compost-based growing media amended with *Trichoderma harzianum* T-78 in *Cucumis melo* L. seedling production. Bioresource Technology 101. 3718-3723. https://doi.org/10.1016/j.biortech.2009.12.102

Lumsden, R.D., Lewis, J.A., Millner, P.D. (1983) Effect of composted sewage sludge on several soilborne pathogens and diseases. Phytopathology 73. 1543-1548. https://doi.org/10.1094/Phyto-73-1543.

Markakis, E.A., Fountoulakis, M.S., Daskalakis, G.Ch., Kokkinis, M., Ligoxigakis, E.K. (2016)

The suppressive effect of compost amendments on *Fusarium oxysporum* f.sp. *radicis-cucumerinum* in cucumber and *Verticillium dahliae* in eggplant. Crop Protection 79. 70-79. https://doi.org/10.1016/j.cropro.2015.10.015

Meng, X., Dai, J., Zhang, Y., Wang, X., Zhu, W., Yuan, X., Yuan, H., Cui, Z. (2018) Composted biogas residue and spent mushroom substrate as a growth medium for tomato and pepper seedlings. Journal of Environmental Management 216. 62-69. https://doi.org/10.1016/j.jenvman.2017.09.056

Mierzwa-Hersztek, M., Gleń-Karolcky, K., Gondek, K. (2018) Fungistatic activity of composts with the addition of polymers obtained from thermoplastic corn starch and polyethylene – An innovative cleaner production alternative. Science of the Total Environment 635. 1063-1075. https://doi.org/10.1016/j.scitotenv.2018.04.220

Milinković, M., Lalević, B., Jovičić-Petrović, J., Golubović-Ćurguz, V. (2019) Biopotential of compost and compost products derived from horticultural waste – Effect on plant growth and plant pathogens' suppression. Process Safety and Environmental Protection 121. 299-306. https://doi.org/10.1016/j.psep.2018.09.024

Nicolopoulou-Stamati, P., Maipas, S., Kotampasi, C., Stamatis, P., Hens, L. (2016) Chemical pesticides and human health: The urgent need for a new concept in agriculture. Frontier in Public Health 4. Article 148. https://doi.org/10.3389/fpubh.2016.00148

Ntougias, S., Papadopoulou, K.K., Zerkavis, G.I., Kavroulakis, N., Ehaliotis C. (2008) Suppression of soil-borne pathogen of tomato by composts derived from agro-industrial wastes abundant in Mediterranean regions. Biology and. Fertility of Soils 44. 1081-1090. https://doi.org/10.1007/s00374-008-0295-1

Oka, Y. (2010) Mechanisms of nematode suppression by organic soil amendments – A review. Applied Soil Ecology 44. 101-115. https://doi.org/10.1016/j.apsoil.2009.11.003

Pane, C., Celano, G., Villecco, D., Zaccardelli, M. (2012) Control of *Botrytis cinerea*, *Alternaria alternate* and *Pyrenochaeta lycopersici* on tomato with whey compost-tea applications. Crop Protection 38. 80-86 https://doi.org/10.1016/j.cropro.2012.03.012

Pane, C., Spaccini, R., Piccolo, A., Scala, F., Bonanomi, G. (2011) Compost amendments enhance peat suppressiveness to *Pythium ultimum*, *Rhizoctonia solani* and *Sclerotinia minor*. Biological Control 56. 115-124. https://doi.org/10.1016/j.biocontrol.2010.10.002

Pharand, B., Carisse, O., Benhamou, N. (2002) Cytological aspects of compost-mediated induced resistance against *Fusarium* crown and root rot in tomato. Phytopathology 92. 424-438. https://doi.org/10.1094/PHYTO.2002.92.4.424

Postma, J., Montanari, M., van den Boogert, P.H.J.F. (2003) Microbial enrichment to enhance the disease suppressive activity of compost. European Journal of Soil Biology 39. 157-163. https://doi.org/10.1016/S1164-5563(03)00031-1

Reuveni, R., Raviv, M., Krasnovsky, A., Freiman, L., Medina, S., Bar, A., Orion, D. (2002) Compost induces protection against *Fusarium oxysporum* in sweet basil. Crop Protection 21. 583-587. https://doi.org/10.1016/S0261-2194(01)00149-1

Roncero, M.I.G., Hera, C., Ruiz-Rubio, M., Maceira, F.I.G., Madrid, M.P., Caracuel, Z., Calero, F., Delgado-Jarana, J., Roldán-Rodriguez, R., Martínez-Rocha, A.L., Velasco, C., Roa, J., Martín-Urdiroz, M., Córdoba, D., Di Pietro, A. (2003) *Fusarium* as a model for studying virulence in soilborne plant pathogens. Physiological and Molecular Plant Pathology 62. 87-98. https://doi.org/10.1016/S0885-5765(03)00043-2

Saadi, I., Laor, Y., Medina, S., Krassnovsky, A., Raviv, M. (2010) Compost suppressiveness against *Fusarium oxysporum* was not reduced after one-year storage under various moisture and temperature conditions. Soil Biology & Biochemistry 42. 626-634. https://doi.org/10.1016/j.soilbio.2009.12.016

Sant, D., Casanova, E., Segarra, G., Avilés, M., Reis, M., Trillas, M.I. (2010) Effect of *Trichoderma asperellum* strain T34 on *Fusarium* wilt and water usage in carnation grown on compost-based growth medium. Biological Control 53. 291-296. https://doi.org/10.1016/j.biocontrol.2010.01.012

Shen, Z., Zhong, S., Wang, Y., Wang, B., Mei, X., Li, R., Ruan, Y., Shen, Q. (2013) Induced soil microbial suppression of banana fusarium wilt disease using compost and biofertilizers to improve yield and quality. European Journal of Soil Biology 57. 1-8. https://doi.org/10.1016/j.ejsobi.2013.03.006

Siddiqui, Y., Meon, S., Ismail, R., Rahmani, M. (2009) Bio-potential of compost tea from agro-waste to suppress *Choanephora cucurbitarum* L. the causal pathogen of wet rot of okra. Biological Control 49. 38-44. https://doi.org/10.1016/j.biocontrol.2008.11.008

Suárez-Estrella, F., Vargas-Garcia, C., López, M.J., Capel, C., Moreno, J. (2007) Antagonistic activity of bacteria and fungi from horticultural compost against *Fusarium oxysporum* f. sp. *melonis*. Crop Protection 26. 46-53. https://doi.org/10.1016/j.cropro.2006.04.003

Termorshuizen, A.J., van Rijn, E., van der Gaag, D.J., Alabouvette, C., Chen, Y., Lagerlöf, J., Malandrakis, A.A., Paplomatas, E.J., Rämert, B., Ryckeboer, J., Steinberg, C., Zmora-Nahum, S. (2006) Suppressiveness of 18 composts against 7 pathosystems: Variability in pathogen response. Soil Biology & Biochemistry 38. 2461-2477. https://doi.org/10.1016/j.soilbio.2006.03.002

Tian, Y., Wang, Q., Zhang, W., Gao, L. (2016) Reducing environmental risk of excessively fertilized soils and improving cucumber growth by *Caragana microphylla*-straw compost application in long-term continuous cropping systems. Science of the Total Environment 544. 251-261. http://dx.doi.org/10.1016/j.scitotenv.2015.11.091

Tilston, E.L., Pitt, D., Groenhof, A.C. (2002) Composted recycled organic matter suppresses soil-borne diseases of field crops. New Phytologist 154. 731-740. https://doi.org/10.1046/j.1469-8137.2002.00411.x

Trillas-Gay, M.I., Hoitink, H.A. J., Madden, L.V. (1986) Nature of suppression of *Fusarium* wilt of radish in a container medium amended with composted hardwood bark. Plant Disease 70 (11). 1023-1027. https://doi.org/10.1094/PD-70-1023

van Rijn, E., Termorshuizen, A.J., van Bruggen, A.H.C. (2007) Storage method affects disease suppression of flax wilt induced by composts. Soil Biology & Biochemistry 39. 2743-2749. https://doi.org/10.1016/j.soilbio.2007.05.019

Xiong, W. Guo, S., Jousset, A., Zhao, Q., Wu, H., Li, R., Kowalchuk, G.A., Shen, Q. (2017) Bio-fertilizer application induces soil suppressiveness against *Fusarium* wilt disease by reshaping the soil microbiome. Soil Biology & Biochemistry 114. 238-247. https://doi.org/10.1016/j.soilbio.2017.07.016

Yogev, A., Raviv, M., Hadar, Y., Cohen, R., Wolf, S., Gil, L., Katan, J. (2010) Induced resistance as a putative component of compost suppressiveness. Biological Control 54. 46-51. https://doi.org/10.1016/j.biocontrol.2010.03.004

Yohalem, D.S., Nordheim, E.V., Andrews, J.H. (1996) The effect of water extracts of spent mushroom compost on apple scab in the field. Phytopathology 86. 914-922. https://doi.org/10.1094/Phyto-86-914.

Wahyuni, W.S., Mudjiharjati, A., Sulistyaningsih, N. (2010) Compost extracts of vegetable waste as biopesticide to control cucumber mosaic virus. HAYATI Journal of Biosciences 17. 95-100. http://doi.org/10.4308/hjb.17.2.95

Zhang, W., Han, D.Y., Dick, W.A., Davis, K.R., Hoitink, H.A.J. (1998) Compost and compost water extract-induced systemic acquired resistance in cucumber and *Arabidopsis*. Phytopathology 88. 450-455. https://doi.org/10.1094/PHYTO.1998.88.5.450

Zhou, Y., Selvam, A., Wong, J.W.C. (2016) Effect of Chinese medicinal herbal residues on microbial community succession and anti-pathogenic properties during co-composting with food waste. Bioresource Technology 217. 190-199. http://dx.doi.org/10.1016/j.biortech.2016.03.080

Zmora-Nahum, S., Danon, M., Hadar, Y., Chen, Y. (2008) Chemical properties of compost extracts inhibitory to germination of *Sclerotium rolfsii*. Soil Biology & Biochemistry 40. 2523-2529.

DOI: 10.18380/SZIE.COLUM.2021.8.2.55

https://doi.org/10.1016/j.soilbio.2008.06.025

Znaïdi, I.A., Daami, M., Ben Khedher, M., Mahjoub, M. (2002) Study and assessment of compost of different organic mixtures and effects of organic compost tea on plant disease. Available from: http://orgprints.org/00003079