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Enhancing Sustainability of Tomato, Pepper and Melon Nursery Production Systems by Using Compost Tea Spray Applications

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Abstract: Compost teas (CTs) are liquid organic formulates obtained by prolonged extraction, with or without aeration, of a quality compost into an aqueous medium. They can significantly improve plant growth and development likely through nutritive and/or biostimulant mechanisms. In nursery production chain of tomato, pepper and melon, the use of seven CTs was evaluated in order to substitute, totally or partially, chemical treatments with propamocarb-hydrochloride (47.3%) and fosetyl-Al (27.7%), a fungicide for the pathogenic oomycetes control. In general, CTs increased plant growth parameters, as suggested by measurements of root length (+9.1% and +8.1%, on average, on tomato and pepper, respectively), stem diameter (+12% on average, on tomato), number of leaves (+2.6% on average, on melon), and fresh biomass (+8.2% on average, on melon) in comparison with the chemical control. CT from artichoke and fennel composted residues have had the major impact on nursery performances of tomato, pepper and melon. After the first treatment of the polystyrene trays with the fungicide at sowing, our results indicated that CT may replace it in the following seedling production cycle, securing vegetative characteristics of nursery plants similar to the chemical control, that may incite fast starting of transplants in the field stage.

Keywords: biowaste recycling; disease control; humic acids; sustainable agriculture; plant-growth promotion

1. Introduction

Compost teas (CTs) are organic formulates obtained by the aqueous extraction of composted materials, for a defined period of incubation [1]. This process can take place with or without oxygen supply by aeration, obtaining aerated or non-aerated CT, respectively [2]. It is possible to utilize water, other extractants or their combinations, such as various wastewater from food industry (whey, marc, molasses, etc.) with the aim of conditioning the structure of the microbial population during the production phase [3]. Many extraction factors are able to affect the quality of the CT, including (i) the compost type, since compost with high microbial diversity has the potential to make a better CT; (ii) the compost-to-water ratio, that may currently vary between 1:40 (*w*/*w*) and 1:10 (*w*/*v*); (iii) aeration, since aerobic conditions contribute to develop beneficial microorganism populations [4,5]. Microbial community constituted mainly by Bacteria, Actinomycetes, Yeasts and Fungi, may confer to the recipient tea some beneficial properties for cultivated plants, such as biological control of diseases and biostimulation of the physiological status and productivity [6–8].

CTs can decrease plant disease severity when are used as foliar sprays or to drench the soil [3,9]. Various mechanisms are involved in controlling plant pathogens, however due to the presence of antagonistic microorganisms. Indeed, antagonist functions against plant pathogens could be attributed to microorganisms present in the tea through their ability to: exercise competition for space and nutrients [10]; directly kill pathogens by parasitism [11]; produce antimicrobial compounds and/or to induce systemic resistance in treated plants [12]. Moreover, the physicochemical properties of the CTs, especially nutrient and organic molecules contents (humic or phenolic compounds) may protect the plant against disease through direct toxicity toward the pathogen, inducing systemic resistance or improving the nutritional status [13]. Indeed, several previous studies indicated that cropping applications of compost and vermicompost teas may improve plant health, yields and their nutritional quality [9,14–22].

CTs may supply microbial biomass, fine particulate organic matter, organic acids, plant growth regulation-like substances and soluble mineral nutrients onto phylloplane (leaf surface) and into the soils [3,9,15]. Assessing relationships between biochemical properties of composts and their teas, would improve current understanding of the mechanisms for CT's effects on crop yield and nutritive quality [23]. CTs produced by plant-based organic matters are proposed as a sustainable alternative to agrochemicals for enhancing plant growth by improving the physico-chemical properties of the soil and their nutria-active effects, nutritive content and hormone-like compounds [24,25].

In this respect, CTs are viewed as potential alternatives to the use of synthetic chemical fungicides, as they provide a means of controlling plant pathogens that are considered safer for human health and the environment [26]. Their use may contribute to raise sustainability of nursery systems by replacing synthetic inputs. The increasing of legal limits related to the use of pesticides, fungicides and chemical compounds, has generated an interest towards the research of new bioactive compounds, to identify beneficial microorganisms and to understand how synergies provide stronger effects than any single substance or a microorganism that works alone.

An increasing number of studies reports CTs enhancing plant performances, emphasizing benefits from the use of CT as organic additive in plant cultivation and in the suppression of soil-borne diseases [1,22]. Application of fungicides contributes to high productivity through increased and stabilized yields. Between them, one of the most used is a fungicide that combines propamocarb (47.3%) with fosetyl-Al (27.7%) (Previcur Energy®), a synthetic chemical product recommended for the protection against *Pythium spp.* and stimulating seedlings tolerance to *Phytophthora spp.* as well as other biotic stresses. It can be applied, with preventive action, at any stage of development, before and after transplantation, with localized irrigation [27]. In addition to the direct fungicide action, Previcur Energy has also the ability to stimulate the self-defense systems in plants [28]. However, the reduction of chemical interventions, such as minimum use of pesticides, is a necessary practice to gain the goals of sustainability also in the vegetable nursery sector that are pursued in terms of reduction of cost of production, healthy of the operators and attention to the environment. In this view, organic matter-based natural products are considered a valid alternative to chemicals, for their bioefficacy, circular economy character and negligible impacts on water and wildlife [25].

The present study was carried out to evaluate the potential use of CTs within the nursery production chain, in order to enhance the sustainability of the vegetable plantlets production by substituting, even partially, some plant protection treatments. Seven on-farm produced CTs by aerated extraction of six composts (one biowaste compost and five different composted vegetables residues) and one made by solid residues of digestate (from anaerobic digestion) were assayed by spraying on tomato, pepper and melon seedlings during the whole nursery growing stage.

2. Materials and Methods

2.1. Preparation of CTs

CTs were produced "on farm" using a simple compost extractor in liquid phase with a forced air blowing system; the air was injected through a submersed branched tube connected to a compressor with an electronic timer [1] that activates an automatic ventilation (5 min every 3 h). The fermentation cycle was completed in seven days. Six different composts and one solid residue of anaerobic digestion were used to obtain CTs under dechlorinated tap water extraction. Each compost was placed in a plastic bag composed of a nylon with mesh of 3 mm of diameter and dipped in a 50-L polyethylene container, filled with dechlorinated tap water so to have 1:5 *v/v* ratio. At the end of the process, CTs were filtered (using nylon mesh of ø 2 mm) and stored at 4 °C until the use. In Table 1 are listed the produced CTs and the compost sources that were: C1—tomato (37%) and escarole residues (11%), woodchip (50%) and mature compost as starter (2%); C2—artichoke residues (78%), woodchip (20%) and mature compost as starter (2%); C3—artichoke (43.5%), fennel (23.5%) and escarole (11%) residues, woodchip (20%) and mature compost as starter (2%); C4—cauliflower residues (78%), woodchip (20%) and mature compost as starter (2%); C5—sweet corn (50%) and horticultural (48%) residues, and mature compost as starter (2%); C6—commercial biowaste compost (Gesenu, Perugia, Italy); D—solid digestate (100%) of manure and corn silage (Biogas Plan, Cicerale, Italy). The indicated percentages are in dry weight.

Table 1. Main physicochemical characteristics, pH, electric conductivity (EC), nitrogen content (N), and compost sources (C1-6, D) of the compost teas (CT1-7) used in this study. Different letters indicate significant differences among means according Tukey's HSD test at $p \leq 0.05$.

CT	pH	EC (mS cm^{-1})	N (%)	Compost Source	
CT1	7.37 ± 0.09 ef	4.31 ± 0.03 d	2.07 ± 0.19 ab	C1	[29]
CT2	8.95 ± 0.14 b	6.97 ± 0.10 a	1.75 ± 0.38 ab	C2	[29]
CT3	9.47 ± 0.06 a	6.62 ± 0.03 b	1.58 ± 0.19 abc	C3	[29]
CT4	7.55 ± 0.04 de	1.55 ± 0.03 g	1.55 ± 0.17 abc	C4	[6]
CT5	7.80 ± 0.16 d	3.90 ± 0.02 e	2.17 ± 0.17 a	C5	[6]
CT6	8.36 ± 0.04 c	5.04 ± 0.05 c	1.41 ± 0.28 bc	C6	[8]
CT7	7.07 ± 0.11 f	2.21 ± 0.02 c	1.05 ± 0.23 c	D	This work

2.2. Chemical Characterization of CTs

CTs was characterized for pH, electrical conductivity (EC) and total nitrogen (N) content. Electrical Conductivity (EC) and pH were directly measured in a subsample of the liquid teas as described by Pane et al. [1]. N content (%) was determined through Kjeldahl digestion and titration [29]. Total organic carbon (TOC) was determined with the potassium dichromate method as described in Pane et al. [8].

2.3. Microbiological Characteristics of CTs

Through serial ten-fold dilution (10^{-1}–10^{-7}) method, the abundance of fungi, yeasts, total bacteria, thermophilic bacteria (spore-forming bacteria) and pseudomonades populations in each CTs, was evaluated according methods previously described [29]. Fungi were counted on potato dextrose agar (Oxoid, Basingstoke, England) pH 6, added with 150 mg L^{-1} of nalidixic acid and 150 mg L^{-1} of streptomycin. Yeast were counted on rosebengal medium (Oxoid) 32 g L^{-1}, added with 0.1 g L^{-1} of chloramphenicol (Oxoid). Total bacteria were counted on selective medium (glucose 1 g L^{-1}, protease peptone 3 g L^{-1}, yeast extract 1 g L^{-1}, K_2PO_4 1 g L^{-1}, agar 15 g L^{-1}) added with actidione (cycloheximide) 100 mg L^{-1}. *Pseudomonads*-like bacteria were counted on selective agar medium without iron, added with actidione [30]. Finally, spore-forming bacteria were enumerated on Nutrient Agar [31] after heated at 90 °C for 10 min. Population densities are reported as log CFU mL^{-1} of CT.

2.4. Hygienic Quality of CTs

Escherichia coli and enterococci were enumerated in a sample of the CT [32]. The estimation of *E. coli* was performed using TBX medium (Oxoid). Plates were incubated at 44 °C for 24 h and blue colonies were counted as *E. coli*. Enterococci were enumerated on a Slanetz & Bartley medium (Oxoid). After plate incubation (37 °C for 48 h), red colonies were transferred on Bile Esculine Azide Agar (Merck, Darmstadt, Germany) and incubated at 44 °C for 2 h. When any blacking of the medium occurred, colonies were counted as Enterococci.

Sulphite-reducing *Clostridium* spores were determined according to APAT, IRSA-CNR [32] and APHA [33] methods. CTs samples were pre-treated at 80 °C for 10 min. Spores were enumerated using SPS agar (Merck). Plates were incubated at 37 °C for 24–48 h in an anaerobic jar, with the anaerobic atmosphere generating system Anaerogen (Oxoid). Black colonies surrounded by a black zone were considered as sulphite-reducing *Clostridium* spores.

2.5. Phytotoxicity of CTs

CTs at two different dilutions in water (1:2 and 1:10 ratio) were assessed for phytotoxicity on *Lepidium sativum* L. germination bioassay. Twenty seeds were placed in Petri dishes (diameter 90 mm) on sterile filter paper with 4 mL of the test solution [34]. For the control, the seeds were treated with sterile double-distilled water. At 72 h, the germination index percentage (GI %) was calculated as follows:

GI% = 100 × (G1/G2) × (R1/R2) [35], where G1 and G2 are germinated seeds in the sample and control and R1 and R2 are mean root lengths for the sample and for the control, respectively.

2.6. Experimental Set-Up and Design

The trials have been conducted at tray scale in a nursery farm located at Eboli (Lat. 40°33′ N, Long. 14°55′ E, Italy), with programmed temperature ranging from 19 to 25 °C (day/night), relative humidity ranging from 50 to 70%, and with a natural photoperiod and solar radiation. Three vegetable species, tomato (*Solanum lycopersicum* L.) cv. Augurio F1 (Clause), pepper (*Capsicum annuum* L.) cv. Friariello Napoletano PP00323 (Sativa) and melon (*Cucumis melo* L.) cv. 01ZS735 (ZETA seeds) were used in nursery experiments performed, on May 2012, in polystyrene trays at 170 compartments for tomato and pepper, and 60 for melon, filled with a specific peat-based horticultural medium (Klasmann-Deilmann GmbH, Geeste, Germany) with the following labeled characteristics: organic carbon 90.0% (*w*/dry weight) on 30% dry weight; density 140 kg m^{-3}, total pore space 85% (*v*/*v*), EC 0.35 dS m^{-1}, pH 6.0, water holding capacity 75% dry weight, N 170 mg L^{-1}, P_2O_5 120 mg L^{-1}, K_2O 220 mg L^{-1}, Mg 100 mg L^{-1}, S 130 mg L^{-1}. Seedling nutrition and pest managements were carried out according to the production rules of Campania Region, Italy. Polystyrene trays were mechanically irrigated every day up to the growing media water capacity. At the sowing time, an initial treatment with Previcur Energy (+P) and no treatment (−P) were split on each polystyrene tray (sub-plot factor), which thereby results separated into two halves (plots); then the study was arranged in a split-plot design with 85 (for tomato and pepper), and 30 (for melon) compartments (replicates) for each treatment. Then, CTs used at a dilution of 1:10 (*v*/*v*), were applied weekly at the rate of 0.5 L onto each tray (whole-plot factor) by spraying the aerial plant parts, using a back-pack sprayer for three weeks. During the spraying, plots were protected by a cardboard barrier to avoid drift effect. Summarizing, treatments consisted in: CTs without P at sowing (CT1–7), CTs with P at sowing (CT1–7 + P), which were compared to two controls, with no fungicide and no CT (NT) and fungicide without CT (P) accomplished on other trays. When the plants were ready for transplanting (four weeks after seeding for tomato and melon and six weeks for pepper), on a subsample of 20 plants per treatment, took from a central assay area designed excluding the four external rows in each experimental plot on the tray, to avoid the side effect, the following biometric parameters were recorded: plantlet height, root length, number of the leaves *per* plantlet (excluding the cotyledons), stem diameter, height at the first internode, length of the first true leaf, total fresh and dry matter per seedlings, the whole sanitary status of plants and, finally, SPAD units on the first completely developed leaves (Minolta SPAD Chlorophyll Meter).

2.7. Statistical Analyses

The collected data for the physical and chemical characteristics of the growing media and the biometrics parameters on plants (spatially independent measures) were analyzed by analysis of variance (ANOVA) using Statistica 10.0 software package; means were compared using Tukey's HSD test ($p \leq 0.05$). Principal Component Analysis (PCA), considering all parameters recorded, were performed to assess influence of Previcur Energy on CTs ability as an ecofriendly plant protection product. All the different results were Pearson's correlated and the coefficients were reported in a correlation matrix.

3. Results

3.1. CT Features

The different CTs showed variable levels of pH, electric conductibility (EC), total nitrogen (N), and total organic carbon (TOC) content (Table 1).

The highest pH and EC values were registered for CTs obtained from on farm composted artichoke and fennel residues and (CT3) artichoke residues (CT2), respectively; while the relatively high level of nitrogen was registered on CTs obtained from composts whose feedstock were sweet corn added with other horticultural residues (CT5) or tomato plus escarole residues (CT1). Instead, TOC varied in the range 0.44–1.30 g L^{-1} (data not shown).

Populations of culturable bacteria (total and thermophilic bacteria, *Pseudomonads*, fungi and yeasts) are showed in Table 2. Population levels detected in CTs for total bacteria and *Pseudomonads* resulted statistically comparable in all samples.

Table 2. Results of microbiological characterization of compost teas (CTs) used in this study. Data are expressed as log CFU mL^{-1}. Different letters indicate significant differences among means according Tukey's HSD test at $p \leq 0.05$.

CTs	Total Bacteria	Pseudomonads	Thermophilic Bacteria	Fungi	Bacteria:Fungi Ratio	Yeast
CT1	7.14 a	6.06 ab	5.56 a	1.96 c	3.64 b	3.81 ab
CT2	7.80 a	7.52 a	4.75 ab	2.25 c	3.46 b	2.60 bc
CT3	6.96 ab	6.46 ab	5.20 a	4.34 a	1.60 c	4.60 a
CT4	5.16 b	4.40 b	4.40 ab	2.60 bc	1.98 bc	1.47 c
CT5	6.30 ab	5.10 ab	5.00 a	2.10 c	3.00 bc	5.13 a
CT6	8.01 a	7.36 a	4.86 a	0.53 d	15.11 a	3.83 ab
CT7	6.79 ab	6.42 ab	3.75 b	3.06 b	2.21 bc	1.60 c

Similarly, thermophilic populations were low in CT7, while reached relatively high levels in all the others. Density of total fungi were largest in CT3 and lowest in CT6; while, yeasts were high in CT5 and 3, and low in CT4 and 7. In addition, *E. coli* and sulphite-reducing *Clostridium* spores were not found in CTs, whereas enterococci were detected only in CT2 (3.39 log CFU mL^{-1}) (data not shown).

CTs proved variable effects on the cress germination index percentage (GI%). GI% above the no phytotoxic threshold value of 80% were observed when CTs, sufficiently diluted in water (already at 1:10), were added on germinating *L. sativum* L. seeds for all the samples except for CT (Figure 1). Seedlings under treatment with CT1 showed relatively low level of GI%. However, root length of cress seedlings was relatively affected by CTs with a dose-dependent effect.

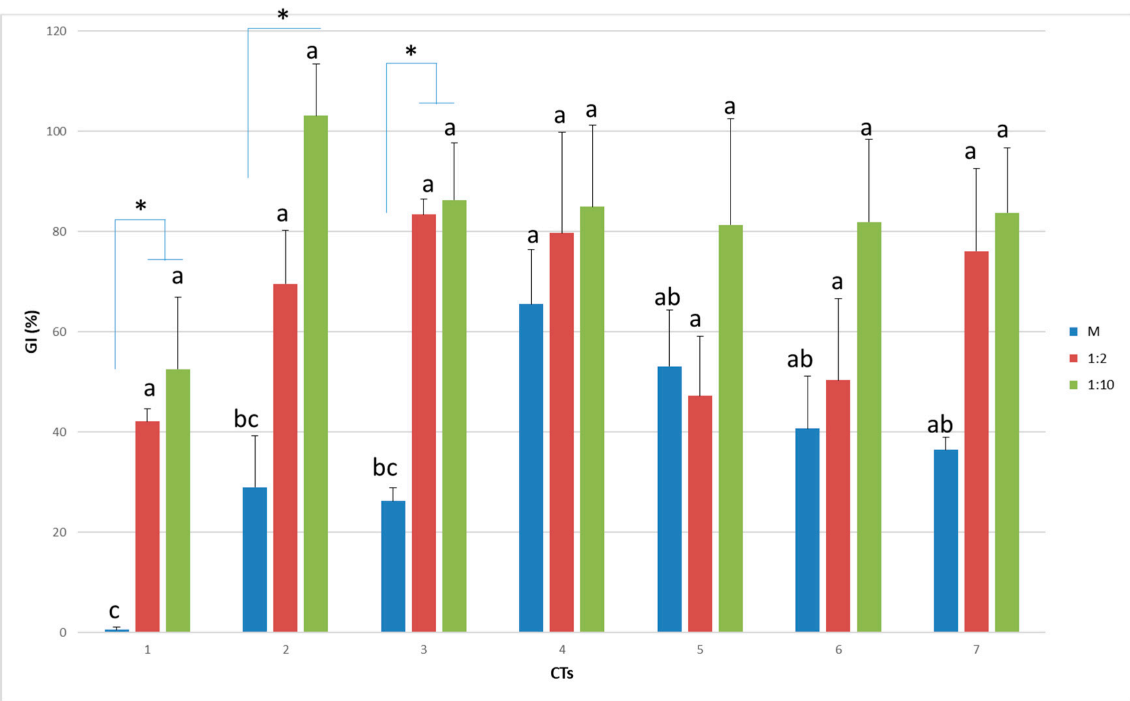

Figure 1. Germination index percentage (GI%) of *Lepidium sativum* L. seedlings treated with CTs (1–7) produced on-farm from composts listed in Table 1, not diluted (nd) and diluted (1:2 and 1:10). Bars indicate mean ± SE. Different letters on the bars indicate significant differences among CTs in the same dilution and asterisks indicate significant differences among dilutions in the same CT, according Tukey's HSD test at $p \leq 0.05$.

3.2. CT Nursery Performances

Plants produced through the nursery trials did not show any phytopathological symptoms under natural conditions occurred in the farm where the experimentation took place. However, in a general view of the results, biometric features under CT treatments were better than the non-treated ones (Table 3). Precisely, CT alone did not affect growth performances as in the fungicide pre-treated cases.

Table 3. Significance probability levels, red colored if they are ≤0.05, resulting from Analyses of Variance for the selected morphological characteristics of tomato, pepper and melon seedlings as affected by compost tea (CT) and Previcur (P).

Treatment	Degree of Freedom	Plant Height	Root Length	Leaves	Height 1st Internode	Stem Diam.	Length 1st Leaf	Fresh Biomass	Dry Biomass	SPAD
Tomato										
CT	7	0.000	0.000	0.022	0.000	0.000	0.000	0.000	0.000	0.004
P	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CT × P	7	0.000	0.002	0.022	0.007	0.017	0.338	0.000	0.000	0.222
Pepper										
CT	7	0.000	0.085	0.012	0.000	0.000	0.000	0.000	0.888	0.024
P	1	0.000	0.291	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CT × P	7	0.000	0.053	0.001	0.000	0.002	0.030	0.000	0.981	0.015
Melon										
CT	7	0.002	0.498243	0.002	0.055	0.701	0.027	0.075	0.401	0.002
P	1	0.000	0.021978	0.016	0.006	0.000	0.000	0.000	0.000	0.000
CT × P	7	0.306	0.359540	0.004	0.769	0.380	0.111	0.621	0.824	0.012

SPAD = Soil Plant Analysis Development

The general plant development was promoted by the starting treatment with Previcur Energy: CTs proved to be effective in enhancing biometric parameters at comparable levels with plantlets produced under the methodologies traditionally adopted in the nursery farms. For example, root length increased, on average, +9.1% (varying between 10 and 21%) and +8.1% (varying between 0 and 16%) on tomato and pepper, respectively, stem diameter was +12% (varying between 0 and 24%) on tomato, the number of leaves +2.6% (varying between −3 and 15%) and fresh biomass +8.2% (varying between 0 and 20%) on melon, in comparison with the chemical control (P) (Tables 4–7).

On the other hand, without the starting treatment with Previcur Energy (NT control), CTs relatively increased, on average, the root length (+3.2% on average; varying between −9 and 18%) and the stem diameter (+50% on average; varying between 36 and 54%) on tomato (Table 4).

In the case of pepper, CTs increased the number of leaves (+5.1% on average; varying between 2 and 7%) and the height of the 1st internode (+15% on average; varying between 6 and 22%) (Table 5).

Table 4. Biometric assessments and SPAD values of tomato plants under CTs (CT1–7) produced on-farm from composts listed in Table 1, spray, with or without Previcur Energy application at sowing compared with the control Previcur Energy (P) alone and no treatment (NT). Different letters indicate significant differences among means according Tukey's HSD test at $p \leq 0.05$.

Treatment		Plant Height (mm)	Root Length (mm)	Leaves (n°)	Height 1st Internode (mm)	Stem Diam. (mm)	Length 1st Leaf (mm)	Fresh Biomass (g)	Dry Biomass (g)	SPAD (Unit)
Previcur Energy at Sowing	Spray									
+	CT1	67 ab	70 e	2.7 a	50 ab	2.3 ab	45 a–c	22.7 ab	2.47 ab	33.4 ab
+	CT2	70 ab	89 b–d	2.7 a	51 a	2.5 a	47 ab	21.9 ab	2.47 ab	32.2 ab
+	CT 3	52 cd	95 a–d	2.1 bc	42 b–d	2.0 b–d	40 cd	16.9 d	2.03 cd	33.3 ab
+	CT 4	67 ab	86 c–e	2.5 a–c	52 a	2.4 ab	48 a	19.8 b–d	2.16 bc	31.3 a–c
+	CT 5	69 ab	94 a–d	2.7 a	50 ab	2.5 a	43 a–c	20.4 bc	2.12 bc	33.7 ab
+	CT 6	59 bc	78 de	2.5 ab	45 a–c	2.3 ab	41 bc	18.0 cd	1.68 de	36.3 a
+	CT 7	72 a	84 c–e	2.7 a	50 ab	2.6 a	50 ab	24.3 a	2.16 bc	36.2 a
+	P	52 cd	78 de	2.7 a	38 cd	2.1 bc	44 a–c	22.3 ab	2.61 a	33.5 ab
−	CT 1	49 c–e	101 a–c	2.0 c	42 b–d	1.5 e	34 e	10.0 e	1.41 ef	25.8 c
−	CT 2	49 c–e	111 a	2.0 c	42 b–d	1.7 c–e	35 de	10.1 e	1.37 ef	28.6 bc
−	CT 3	43 de	110 a	2.0 c	38 cd	1.5 e	31 e	9.2 e	1.22 f	29.5 bc
−	CT 4	46 de	108 ab	2.0 c	39 cd	1.7 c–e	35 de	8.3 e	1.26 f	28.0 bc
−	CT 5	44 de	96 a–d	2.0 c	37 cd	1.6 de	32 e	8.7 e	1.18 f	31.2 ac
−	CT 6	38 e	85 c–e	2.0 c	34 d	1.7 de	32 e	8.3 e	1.25 f	29.5 bc
−	CT 7	43 de	95 a–d	2.0 c	37 cd	1.7 de	32 e	8.8 e	1.24 f	31.3 a–c
−	NT	43 de	94 a–d	2.0 c	37 cd	1.1 f	35 de	8.9 e	1.25 f	30.8 a–c

Table 5. Biometric assessments and SPAD values of pepper plants under CTs (CT1–7) produced on-farm from composts listed in Table 1, spray with or without Previcur Energy application at sowing compared with the control Previcur Energy (P) alone and no treatment (NT). Different letters indicate significant differences among means according Tukey's HSD test at $p \leq 0.05$.

Treatment		Plant Height (mm)	Root Length (mm)	Leaves (n°)	Height 1st Internode (mm)	Stem Diameter (mm)	Length 1st Leaf (mm)	Fresh Biomass (g)	Dry Biomass (g)	SPAD (Unit)
Previcur Energy at Sowing	Spray									
+	CT1	88 b	65 a–d	4.9 b–f	64 c	1.9 c	33 a	20.4 ab	2.15 a	27.2 ab
+	CT2	105 a	66 a–d	5.1 a–d	70 a–c	2.2 bc	33 a	22.4 a	2.25 a	28.6 a
+	CT3	111 a	71 a	4.8 c–f	76 a	2.0 c	35 a	21.5 ab	2.18 a	28.7 a
+	CT4	105 a	69 ab	4.9 a–e	71 a–c	2.1 bc	34 a	20.3 ab	2.08 ab	27.5 ab
+	CT5	92 b	61 d	5.6 ab	63 cd	2.6 ab	34 a	17.1 b	1.95 ab	26.8 ab
+	CT6	102 a	64 a–d	5.4 a–c	73 ab	2.2 bc	34 a	17.1 b	1.84 a–c	27.8 a
+	CT7	87 b	66 a–d	4.6 d–g	65 bc	1.9 c	33 a	9.7 c	1.80 a–d	27.1 ab
+	P	105 a	61 d	5.6 a	66 bc	2.8 a	36 a	18.7 ab	2.04 ab	28.1 a
−	CT1	58 c	65 a–d	4.3 e–g	49 e	1.9 c	28 b	9.7 c	1.06 c–e	20.9 cd
−	CT2	63 c	66 a–d	4.0 g	54 e	2.1 bc	28 b	10.1 c	1.12 c–e	19.0 d
−	CT3	60 c	65 a–d	4.2 fg	52 e	1.9 c	27 b	10.2 c	1.06 c–e	18.8 d
−	CT4	64 c	64 b–d	4.0 g	55 de	2.0 c	27 b	9.5 c	1.01 de	22.8 b–d
−	CT5	57 c	63 cd	4.0 g	48 e	1.9 c	27 b	9.5 c	1.06 c–e	19.3 d
−	CT6	57 c	61 cd	4.1 g	50 e	1.8 c	26 b	8.7 c	0.99 e	19.1 d
−	CT7	58 c	64 b–d	4.0 g	51 e	1.9 c	27.8 b	8.6 c	0.99 e	19.5 d
−	NT	90 b	67 a–c	3.9 g	45 e	2.3 bc	32.5 a	11.9 c	1.30 b–e	24.3 a–c

Finally, melon benefit, on average, in term of increased number of leaves (+31%; varying between 5 and 47%), plant height (+10%; varying between 0 and 18%), root length (+4.1%; varying between 0 and 10%), fresh (+9.4%; varying between 2 and 21%) and dry biomass (+11%; varying between 0 and 20%) (Table 6).

Table 6. Biometric assessments and SPAD values of melon plants under CTs (CT1–7) spray produced on-farm from composts listed in Table 1, with or without Previcur Energy application at sowing compared with the control Previcur Energy (P) alone and no treatment (NT). Different letters indicate significant differences among means according Tukey's HSD test at $p \leq 0.05$.

Treatments		Plant Height (mm)	Root Length (mm)	Leaves (n°)	Height 1st Internode (mm)	Stem Diameter (mm)	Length 1st Leave (mm)	Fresh Biomass (g)	Dry Biomass (g)	SPAD (Unit)
Previcur Energy at Sowing	Spray									
+	CT1	37.7 a–e	115.3 a	2.63 a–c	24.9 ab	4.01 a–c	53.4 a–d	55.73 a–d	4.82 ab	33.27 a–e
+	CT2	38.9 a–e	107.2 a	2.93 a	23.1 ab	3.87 a–c	55.1 ab	70.98 a	6.00 a	35.53 a–c
+	CT3	44.4 a	114.3 a	2.77 ab	25.0 ab	4.11 a–c	58.1 a	68.95 a	6.01 a	34.70 a–d
+	CT4	40.4 a–c	110.3 a	2.60 a–c	22.7 ab	4.00 a–c	57.0 a	65.58 a	5.11 ab	36.80 ab
+	CT5	42.7 ab	112.0 a	2.67 a–c	22.4 ab	3.87 a–c	55.3 ab	61.65 ab	5.20 ab	31.63 a–f
+	CT6	44.8 a	115.4 a	3.10 a	25.4 a	3.89 a–c	58.7 a	65.97 a	5.50 ab	30.13 b–f
+	CT7	39.5 a–d	112.0 a	2.70 a–c	22.0 ab	4.33 a	57.2 a	58.90 a–c	5.19 ab	32.47 a–e
+	P	34.9 b–f	107.1 a	2.70 a–c	22.1 ab	4.21 ab	54.3 ac	59.07 a–c	5.37 ab	37.07 a
–	CT1	31.9 c–f	116.6 a	3.00 a	22.5 ab	3.50 a–c	46.1 e	40.37 cd	4.07 ab	27.50 ef
–	CT2	30.4 ef	120.8 a	2.13 bc	19.8 ab	3.53 a–c	46.7 de	41.00 cd	4.05 ab	28.80 c–f
–	CT3	33.0 c–f	120.1 a	2.90 a	22.8 ab	3.68 a–c	48.1 c–e	45.54 b–d	4.52 ab	25.57 f
–	CT4	31.9 c–f	123.7 a	2.60 a–c	21.8 ab	3.32 c	44.5 e	39.68 d	4.18 ab	27.30 e–f
–	CT5	33.6 c–f	118.7 a	2.57 a–c	23.2 ab	3.33 c	47.0 de	41.22 cd	4.15 ab	29.03 c–f
–	CT6	31.1 d–f	113.7 a	2.93 a	22.7 ab	3.53 a–c	50.1 b–e	42.32 cd	4.51 ab	28.20 d–f
–	CT7	28.0 f	108.1 a	2.50 a–c	18.1 b	3.28 c	44.7 e	38.38 d	3.74 b	32.13 a–f
–	NT	28.5 f	112.7 a	2.03 c	20.4 ab	3.42 bc	49.0 b–e	37.64 d	3.75 b	33.83 a–e

PCA analysis indicated that, in general, CT treatments used after the application of Previcur Energy, at sowing clearly separated in the score-plot ordination, from treatments with CTs alone, along the principal component that collected most of the variability.

Principal component analysis of parameter measured on tomato revealed the highest levels of space-distribution of the CT samples (cases), according to the first two components that account for 80.24 and 10.33% of the variability, respectively (Figure 2A). CT treatments (CT 1, 2, 3 and 4) closely clustered together and resulted separate from the relative water control; whereas, the CT combined to Previcur Energy treatments are more scattered in the score-plot representations. For pepper, PCA indicate a distribution of the cases along the PC1 for 73.37% and PC2 for 16.70% of the assessed variability (Figure 2B). PCA on melon data shows a plot distribution of the treatments along the two components PC1 and PC2 accounting, respectively, the 64.22 and the 20.69% of the total variability (Figure 2C). Moreover, plane ordination showed two main distinctive clusters including CT-Previcur Energy and CT-alone treatments, well separated from the non-treated samples. On the other hand, the correlation matrix (Table 7) showed how different CT variables are interlinked with the nursery performances of tomato, pepper and melon seedlings.

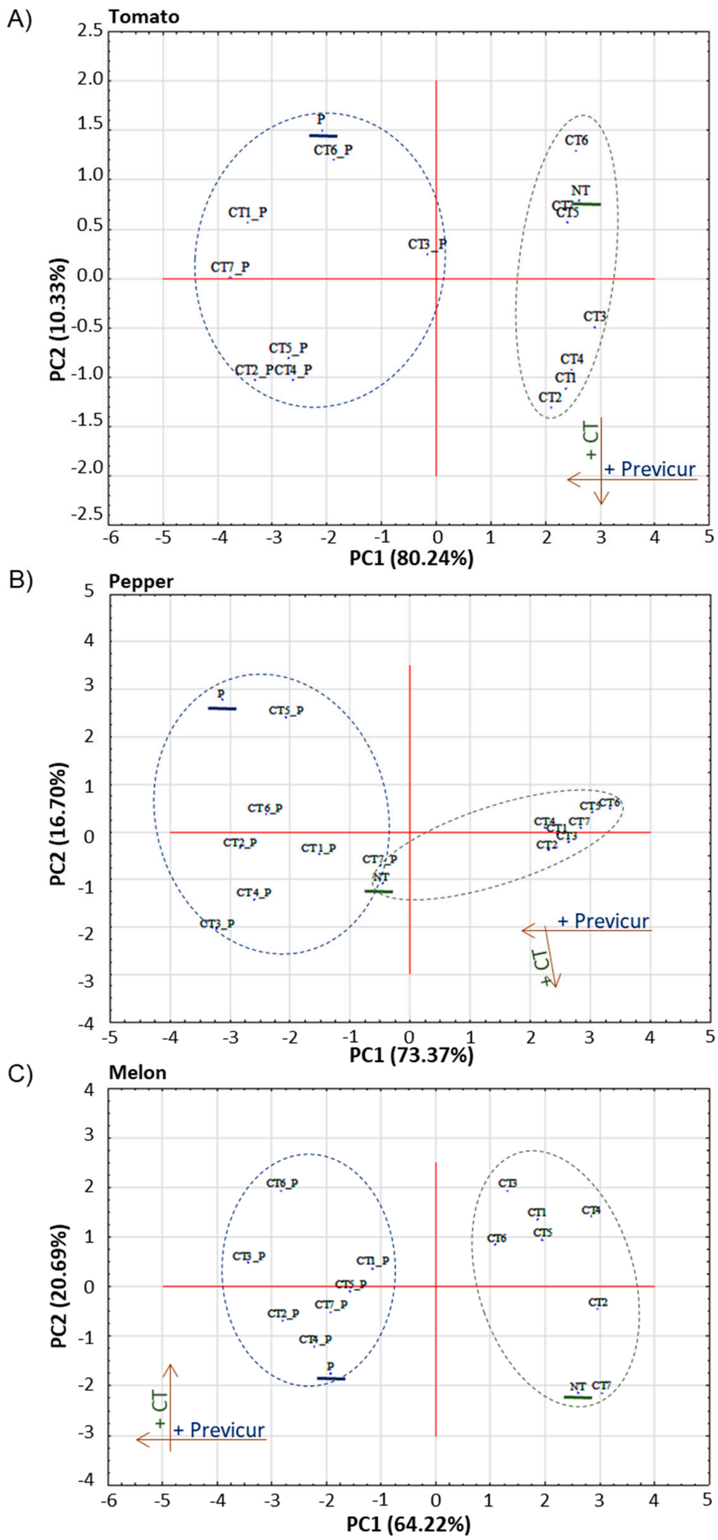

Figure 2. Principal component analysis score-plot distribution of nursery treatments on tomato (**A**), pepper (**B**), and melon (**C**) on the base of the assessed biometric plant traits, along the axes of principal component 1 (PC1) and 2 (PC2) describing percentages of the total data variability indicated in brackets. Cases are referred to CT treatments followed by Previcur Energy (CT1–7_P, grouped in blue circles), CT treatments alone (CT1–7, grouped in green circles), and the two controls Previcur Energy alone (P, underlined) and none-treatments (NT, underlined). Moreover, arrows show how the indicated Previcur Energy and CT treatments putatively affected the separation of the cases along the plot.

Table 7. Relationship between CT characteristics, including total bacteria (B), pseudomonads (Ps), thermophilic bacteria (Tb), fungi (F), bacteria: fungi ratio (B:F), yeast (Y), pH, electric conductivity (EC), total nitrogen (N), total organic carbon (TOC), germination index (GI) and assessments of plant height (Ph), root length (Rl), leaves number (Ln), height 1 st internode (Hi), stem diameter (Sd), length 1st leaf (Ll), fresh biomass (Fb), dry biomass (Db), and SPAD (S) on tomato, pepper and melon plants under CT + P and CT treatments showed by Pearson's coefficients as resulted from the regression analysis; |values| > 0.50 are showed in bold, colored in blue or red if they are positively or negatively correlated, respectively.

	Ph	Rl	Ln	Hi	Sd	Ll	Fb	Db	S
Tomato CT + P									
B	−0.22	−0.28	0.05	−0.42	−0.14	−0.35	−0.02	−0.11	0.50
Ps	−0.22	−0.17	−0.03	−0.42	−0.11	−0.21	0.00	−0.10	0.46
Tb	−0.47	−0.18	−0.24	−0.35	**−0.63**	**−0.71**	−0.41	0.14	−0.28
F	−0.24	**0.57**	**−0.53**	−0.23	−0.33	0.08	−0.06	0.25	−0.31
B:F	−0.29	−0.43	0.01	−0.35	−0.10	−0.43	−0.35	**−0.68**	**0.57**
Y	−0.50	0.20	−0.28	**−0.56**	−0.50	**−0.87**	−0.50	−0.24	0.12
pH	**−0.68**	0.50	−0.64	**−0.65**	**−0.62**	**−0.64**	**−0.69**	−0.17	−0.23
EC	−0.49	0.22	−0.33	**−0.54**	−0.48	**−0.59**	−0.39	0.06	−0.07
N	0.04	−0.02	0.19	0.16	−0.16	−0.36	−0.09	0.42	−0.49
TOC	0.38	0.19	0.44	0.35	0.47	−0.05	0.03	−0.22	0.08
GI	−0.08	−0.46	0.10	−0.18	−0.27	−0.13	0.31	0.50	0.11
Tomato CT									
B	−0.19	−0.31	0.42	−0.05	−0.02	−0.21	0.44	0.36	−0.03
Ps	−0.19	−0.18	**0.52**	−0.04	0.12	−0.17	0.42	0.33	0.04
Tb	0.23	0.14	−0.03	0.31	**−0.77**	−0.03	0.45	0.34	**−0.56**
F	0.23	**0.68**	−0.06	0.25	−0.40	−0.24	0.18	−0.23	0.16
B:F	**−0.66**	**−0.74**	−0.09	**−0.59**	0.32	−0.19	−0.34	−0.03	0.02
Y	−0.22	−0.19	−0.21	−0.19	**−0.67**	**−0.56**	0.11	−0.24	0.09
pH	−0.10	0.40	0.45	0.03	−0.22	−0.19	0.26	−0.05	0.02
EC	0.06	0.27	**0.56**	0.21	−0.33	−0.15	**0.58**	0.26	−0.11
N	0.50	0.21	0.12	0.46	**−0.57**	0.23	0.44	0.29	−0.43
TOC	−0.20	−0.46	−0.29	−0.38	0.17	−0.11	−0.49	−0.50	0.42
GI	0.41	0.12	0.19	**0.53**	**−0.62**	−0.02	**0.84**	**0.68**	−0.48
Pepper CT + P									
B	0.03	−0.23	0.18	0.18	−0.09	−0.23	0.05	0.01	0.43
Ps	0.16	−0.04	0.00	0.32	−0.21	−0.23	0.01	0.03	**0.57**
Tb	0.15	−0.09	0.36	0.08	0.14	0.27	**0.70**	**0.55**	0.20
F	0.26	**0.70**	**−0.65**	0.22	−0.35	0.36	0.07	0.36	0.33
B:F	0.08	−0.37	**0.51**	0.27	0.16	0.05	−0.09	−0.45	0.04
Y	0.05	−0.35	0.60	0.00	0.48	0.49	0.28	0.10	0.03
pH	**0.82**	0.37	0.18	**0.74**	0.17	**0.55**	**0.64**	**0.54**	**0.89**
EC	0.49	0.09	0.22	0.44	0.11	0.20	**0.57**	**0.55**	**0.77**
N	−0.09	−0.39	**0.54**	−0.34	0.48	0.02	**0.61**	**0.52**	−0.13
TOC	−0.39	**−0.76**	**0.73**	**−0.55**	**0.82**	0.04	−0.28	−0.47	**−0.72**
GI	−0.29	−0.01	−0.28	−0.19	−0.48	−0.38	0.19	0.39	0.18
Pepper CT									
B	−0.37	−0.07	0.30	−0.27	−0.18	−0.01	−0.05	0.25	**−0.74**
Ps	−0.19	0.03	0.16	−0.03	−0.05	0.04	−0.04	0.22	**−0.73**
Tb	−0.20	0.12	**0.75**	−0.39	−0.16	−0.07	**0.59**	**0.51**	−0.11
F	0.32	**0.63**	0.08	0.33	0.27	0.36	0.48	0.20	−0.04
B:F	−0.42	**−0.77**	0.08	−0.28	**−0.55**	**−0.68**	**−0.52**	−0.39	−0.26
Y	**−0.57**	−0.21	0.45	**−0.69**	−0.46	−0.33	0.32	0.32	**−0.52**
pH	0.25	0.21	0.15	0.27	0.19	−0.24	**0.63**	**0.54**	**−0.55**
EC	0.01	0.29	0.33	−0.01	0.15	0.02	**0.59**	**0.69**	**−0.70**
N	−0.08	0.21	0.36	−0.39	0.14	0.15	**0.59**	**0.65**	0.06
TOC	−0.37	**−0.55**	−0.45	**−0.50**	−0.23	−0.33	−0.31	−0.16	0.08
GI	−0.29	0.48	**0.76**	−0.35	−0.05	**0.57**	0.32	0.45	−0.32

Table 7. *Cont.*

	Ph	Rl	Ln	Hi	Sd	Ll	Fb	Db	S
Melon CT + P									
B	0.12	0.20	**0.81**	**0.54**	−0.20	0.03	0.19	0.46	−0.48
Ps	0.10	0.04	**0.82**	0.44	−0.05	0.17	0.34	**0.60**	−0.32
Tb	0.14	0.44	0.04	**0.71**	**−0.55**	−0.41	−0.01	0.05	−0.07
F	−0.02	−0.14	−0.50	−0.21	**0.60**	0.11	0.16	0.32	**0.56**
B:F	0.48	0.42	**0.81**	**0.55**	−0.40	0.40	0.11	0.05	**−0.67**
Y	**0.54**	**0.51**	0.15	0.49	−0.43	−0.10	0.00	0.17	−0.47
pH	**0.51**	−0.10	**0.55**	0.48	−0.37	0.29	**0.84**	**0.92**	0.19
EC	0.26	−0.02	**0.59**	**0.55**	−0.40	−0.03	**0.58**	**0.79**	−0.02
N	−0.13	0.05	−0.24	0.19	**−0.67**	**−0.72**	−0.13	−0.17	0.03
TOC	0.20	−0.03	−0.20	−0.43	−0.40	−0.15	−0.29	−0.45	−0.43
GI	−0.40	0.32	0.03	0.48	0.13	**−0.53**	−0.32	0.02	−0.11
Melon CT									
B	−0.27	−0.40	0.05	−0.10	**0.60**	**0.68**	0.31	0.20	0.08
Ps	−0.43	−0.39	−0.10	−0.30	**0.58**	**0.57**	0.28	0.14	0.13
Tb	**0.75**	0.42	**0.53**	**0.79**	**0.66**	0.49	**0.60**	**0.56**	**−0.73**
F	0.06	0.19	−0.09	−0.20	0.16	−0.39	0.29	−0.09	−0.19
B:F	−0.08	−0.31	0.35	0.27	0.23	**0.76**	0.16	0.49	−0.01
Y	**0.74**	0.12	0.46	**0.76**	0.49	**0.67**	**0.69**	**0.57**	−0.44
pH	0.38	0.45	−0.05	0.30	**0.84**	**0.64**	**0.86**	**0.68**	**−0.60**
EC	0.25	0.22	−0.04	0.21	**0.87**	**0.66**	**0.73**	0.48	−0.43
N	**0.75**	**0.53**	0.13	**0.65**	0.20	0.13	0.21	0.18	−0.45
TOC	0.36	0.02	−0.09	0.33	**−0.62**	−0.01	−0.27	−0.09	0.28
GI	−0.09	−0.24	0.27	−0.04	**0.52**	0.12	0.16	−0.12	−0.10

4. Discussion

CTs from on-farm agricultural composts may promote the sustainability of the vegetable transplant production under commercial conditions, by substituting some synthetic chemical inputs in the growing protocols [13]. Here, seven CTs prepared with different composts source from cropping residues and two outliers (biowaste compost and digestate) were assayed in the nursery seedling production. The general features of the organic liquid formulate were in a relatively short range of variation among samples. The absence of *Escherichia coli* and sulphite-reducing *Clostridium* spores in all CTs, indicated their very good microbiological quality. However, CT1–5 were able to supply the greater amount of N, while CT3 provided the highest quantity of microorganisms. CTs prepared from composted agricultural residues had suitable physicochemical and microbiological properties to be sprayed on the seedlings. Phytotoxicity assays performed on cress seedlings, suggest that water dilution of CTs is necessary before their application on plants, in order to avoid detrimental phytotoxic effects. Indeed, CT1, for example, that shoved an *in-vitro* reduced cress germination, increased nursery performances like the others when applied as spray on the canopy.

CTs are emerging organic tools to be applied for disease control and/or nutrient supply [9,35]. The accumulation of metabolites and antibiotics produced by beneficial microorganisms during the brewing of compost extracts, could also suppress plant pathogens and/or activate natural plant defense responses [12]. Living microorganisms present in CTs may also induce disease resistance as well as stimulate nutrient uptake and plant growth by producing hormone-like and/or volatile molecules with biostimulant effects, or increasing nutrient availability onto the phyllosphere [36].

In the current work, these bioactive products were applied to improve the quality of the transplants. Tomato, pepper and melon are vegetable crops diffused in several horticultural areas worldwide [37–39], so the demand for nursery seedlings is increasing due to the number of benefits that their use provide for the successive field or greenhouse productions [40]. Treatments with CT, as plant protection product, potentially concern innovative method that may be used to decrease crop dependence from synthetic chemical molecules.

Findings of this study indicate that CTs used as foliar spray, in combination with Previcur Energy, had a significant effect on growth and vegetative development of the young plants as noticed by the biometric measurements. In the absence of natural pathogenic attacks, it was not possible evaluate the biocontrol efficacy of CTs. However, the impact of treatments on plants showed, on the other hand, the contribution of CTs overall growing performances.

The effect of foliar applications of CTs on plant biomorphological traits, is strictly linked to the CT type that are used. In fact, CT2, produced by on-farm composted artichoke residues, and CT3, produced by on-farm composted artichoke and fennel residues incited the best agronomic performances on all three tested vegetable species. The better growth observed on the plants treated with CT from artichoke and fennel composted residues and from artichoke residues compost, could be explained by greater levels of mineral N present in these CTs. Their nutritive value may derive from the base composts. Actually, as resulted in a previous study [29], composts from artichoke agricultural residues were found richer in nitrates and potassium than those obtained with tomato waste. Here, Pearson's coefficients between the nursery data and the main CTs features showed a general positive correlation of EC measurements and some improved plant growth parameters, including number of leaves, stem diameter, leaf length and fresh biomass. As matter of the fact, nitrates as well as other macronutrients could have a significant role in CTs effectiveness.

CTs were able to increase some biometrical characteristics of the nursery plants, including root length, stem diameter, length of the 1st true leaf, height of the 1st internode, number of leaves, plant height, fresh and dry biomass. These parameters are used as quality indicators of the vegetable nursery production, since they influence stand establishment and early growth of vegetable transplants, including the tolerance to water stress [41–43]. The observations of this study about plant and root growth improvement occurring with CT application, are consistent with previous reports. Keeling et al. [44] showed that applying CT on oil seed rape plants at the initial stage of the growth, resulted in increasing both root development and plant growth. Siddiqui et al. [25] observed that CT enhanced plant growth and increased taproot length of okra. Increased root development with the application of CT, may have contributed to the better uptake of nutrients and increased size of leaves. This factor plays an important role in light interception, photosynthesis, water and nutrient use and dry matter production [45,46].

PCA analysis displayed both single and synergic effects of CT, when it was used alone or in succession to Previcur Energy. On the other hand, the correlation matrix highlighted a possible further role of the microbial population, in particular thermophilic bacteria, in supporting plant growth, suggesting that it would be greater when CTs were used alone. In agreement with these observations, previously [47] *Bacillus*-amended CTs have been reported to enhance tomato plantlets development in terms of total biomass and plant length. On the other hand, microbial-enriched CTs functioned as biofertilizer in foliar application on muskmelon with positive effects on fruit size and quality [48]. Microbial activity is also reported to have a role into the hypothetical biostimulation-related mechanisms of CT improving plant performances [23].

CTs represent an alternative or may potentially complement chemical fungicides in disease management and may improve fertilizers use efficiency by enhancing the plant physiological status by influencing both the primary and secondary plant metabolisms through nutriactive effects, hormone-like functions and microbial activity [25,26,49].

Among the essential components of CT, humic acids seems to play an important role in enhancing plant growth. It has been reported, indeed, that these complexes of molecules can increase biomass production by their direct action on the physiology and plant nutrition acting like phytormones, even when applied in purified form [50–57]. In our CTs interesting levels of organic C, possibly ascribable to the water dissolved compost humic fractions, were retrieved. The augmentative effect of humic compounds on biological membrane permeability, has repeatedly been claimed as responsible for better plant nutrition, through a major absorption of nutrients [58], mostly through a higher ion uptake in root tissues [59,60] and for stimulation of microbial growth and metabolism [61–63]. The positive influence of humic substances can be attributed to their direct involvement on cell respiration, photosynthesis, oxidative phosphorylation, protein polymerisation and other enzymatic reactions [64]. Moreover, other mechanisms may concern the release of N, P and other nutrients during their break-down.

5. Conclusions

Findings of this study clearly indicate that it is possible reduce the chemical impact of vegetable nursery production by introducing quality CTs, especially those obtained from green composts. The use of beneficial CTs can be a sustainable practice to replace the very impactful synthetic molecules, although largely used in the nursery farms. However, further experiments should be also conducted on other producing species to implement this method for the whole nursery chain and increase the potential diffusion and practical applications of the organic formulate. Upcoming perspectives of this study need to understand underlying mechanisms of CT action that are still largely unknown and may be focused on the evaluating field performances of the improved transplants. Future challenges for vegetable nurseries regard the implementation of sustainable crop managing means and the introduction of new technologies, such as digital and/or low energy consumption to increase productivity and economic returns [65].

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