Effect of Compost Tea in Horticulture

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Abstract: Nowadays, modern agriculture looks for valid, sustainable, and green alternatives that are able to improve and maintain soil quality and fertility over time. Recycling organic waste as fertilizer is one of the strategies for sustainable production. Recently, the use of new products derived from compost, such as compost tea (CT), is increasing due to their positive effects on crops. This perspective wants to give an updated shot at the effect of compost tea in horticulture. In addition to the classification of compost tea, with a focus on production procedures and composition, the possible effects they have both on the control of phytopathogens in horticulture and the influence they can have on the content of bioactive molecules and nutrients were highlighted. It is interesting to note that compost teas can have an effect on the final content of micro and macronutrients, thus improving the nutritional qualities and also increasing the content of bioactive compounds that may play a role in maintaining and improving human health. The combined use of compost tea with other treatments is being explored as a promising and innovative direction.

Keywords: compost teas; horticulture; plant biostimulation; crop yield; phytopathogenic control; nutrients; bioactive compounds

1. Introduction

During the last decades, due to the constant growth of the world’s population, the production of food has increased steadily. For example, from the 60s to 2015, world grain production grew four times; this takes a small extension in the surface of land destined for these crops, while the use of agrochemicals increased nine times as much [1,2]. Intensive cropping systems are carried out using the constant use of synthetic chemicals; however, this leads to short and long-term effects harmful to both humans and the environment. This has prompted modern agriculture to look for valid, sustainable, and green alternatives that are able to improve and maintain soil quality and fertility over time. The amounts of bio-waste produced every year could be managed in an efficient and functional way. Recycling organic waste as fertilizer is one of the strategies for sustainable production [3–5]. The biomass waste composting process leads to a reduction in the residual biomass and, in addition, it guarantees the supply of humified soil organic matter, minerals, and beneficial microbial consortia associated with soil and plant, of which crops need to increase their nutrition state, vegetative vigor, health, and productivity [4]. Among the safe and innovative composting systems suitable for the production of quality compost, in addition to the industrial ones, there are those based on on-farm technologies [6]. Composting is a biological process where biodegradable organic compounds are transformed into compost. In recent years, in agriculture, the use of new products derived from compost, such as compost tea (CT), is increasing due to their positive effects on the crops [7–9]. Compost teas (CTs) are liquid organic formulations obtained using the aqueous extraction of composted materials for a defined
period of incubation with dechlorinated water under controlled conditions [10–12]. The compost teas contain a large number of plant macronutrients (such as nitrogen, phosphorus, and potassium in the ratios of 1.3-5-8), which contain phytohormones IAA, cytokinins, and salicylic acid and micronutrients (copper, zinc, iron, manganese); humic acids, heavy metals (lead, cadmium, chromium), with a ready effect as they are dissolved in aqueous solution and microorganisms, that can promote growth plant and help in the biocontrol of fungal pathogens and have positive effects on soil quality and plant health [13–15]. CTs typically have microbial consortia in suspension which includes protists, fungi, oomycetes, yeasts, actinomycetes and bacteria, which are useful to plants, due to their suppressive and/or growth-promoting properties [5]. The CT quality and efficacy are related to several factors, i.e., compost-to-water ratio, compost type, and aeration, which determine the development of specific groups of microorganisms [4,16,17]. In fact, the different microbial groups of compost tea have been attributed to useful activities that produce beneficial effects on plants, such as antagonistic and nutrient release. Bacterial strains isolated form CTs can be classified as PGPR (Plant growth–promoting rhizobacteria) [18]. These bacteria promote plant growth via different mechanisms that make plants more resistant to abiotic and biotic stresses [19]. Several studies have achieved satisfactory biostimulation results for different crops [20,21]. This perspective paper aims to illustrate the production methods of the various compost teas and their chemical-physical properties. Furthermore, it highlights the possible effects they have both on the control of phytopathogens in horticulture and the influence they can have on the content of bioactive molecules and nutrients.

2. Classification of Compost Tea: Focus on Production Procedures and Composition

Aerated compost teas (ACTs) are produced using continuous or discontinuous aeration of dechlorinated water for a period of time from 24 h to a week [10,22,23] to allow the proliferation of the microorganisms. Filtration is achieved via the use of a porous bag or screen. Practitioners often amend ACTs with nutrients or adjuvants during or after preparation [24]. Non-aerated compost teas (NCTs) involve no aeration of the maceration liquid, and incubation is performed for 7 to 14 days [22,25,26]. NCTs are associated with lower production costs and energy input and are more likely to be used in regions where there is no electricity or the cost of energy is prohibitive [27]. Therefore, ACTs contain microbial communities that are dominated by aerobic microorganisms, whereas NCTs are dominated by anaerobes. Although commonly implied, the association of ACTs with aerobic and NCTs with anaerobic environment or process has little scientific basis since there is no consensus on oxygen concentrations that define aerobic, micro-aerobic, and anaerobic CTs [28]. Moreover, it is still unclear whether a minimum oxygen level is needed for NCTs since they are produced without aeration. Several authors have evaluated the need for aeration during compost tea production [29–31]. Some authors, Davis et al. [32] and Ingham [31], indicate the standard that dissolving oxygen (DO) concentration should remain above 5.5 mg/L at room temperature and sea level during the production of ACTs. In most disease suppression studies, the DO levels of NCTs or ACTs are not measured or reported. Therefore, in the absence of standard DO concentrations that distinguish ACTs from NCTs and the close association of fermentation with the production of NCTs, the term brewing, used interchangeably with fermentation, seems more appropriate to describe the production process of both NCTs and ACTs [33]. The amount of compost used to make compost tea remains largely dependent on the size and type of the brewing vessel and equipment used [34]. The brewing vessel size used to produce compost tea varies from small (a few liters) to several hundred liters. It is important to limit the compaction of the compost, which can result in inadequate extraction of the nutrients and microorganisms, and to use clean equipment to prevent the formation of biofilms, which may negatively
affect compost tea quality. The best condition for producing good CTs are, as reported by Zaccardelli et al. [7], compost:water ratio 1:5; compost of good quality, especially if obtained from plant residues rich in aromatic molecules, such as artichoke, fennel, walnuts, aromatic plants, etc.; temperature of 28 °C during production process; oxygenation od 5 min every 3 h or 15 min every 6 h; extraction for 7 days [7] see Figure 1. Generally, it is possible to add different additives to compost tea, such as molasses, sugar, fish meals, whey, etc., but not always the addiction to these additives improve the quality and biological effects of the compost teas. To obtain a CT with higher quality, it is very important to use good-quality compost.

![Figure 1. Steps in compost tea production.](image)

### 3. Effect of Compost Tea on Growth and Field Parameters and Its Use in Control of Phytopathogenic Fungi and Bacteria in Horticulture

A broad literature concerning the studies about the effects of humic acids and different biostimulants on the growth, productivity, and protection of vegetable species is available. Instead, the literature concerning the study of the effects of CTs on vegetable crops is more limited. A study with compost tea was conducted on *Centella asiatica* L., where applications of CTs and NPK fertilizers at half doses increased vegetative growth and production [35]. Foliar applications of CTs have shown significant biostimulation effects on *Abelmoschus esculentus* plants with respect to morphological characteristics, i.e., height of the plants, root length, number of leaves, leaf area, and productivity, as well as physiological characteristics, such as chlorophyll content and photosynthetic rate [36]. On melons, applications to the roots of CT obtained from a compost of citrus fruit chain residues have increased total biomass related to the action of molecules with auxin- and cytokine-like activity [37]. Studies performed by Pane et al. [10] on canned tomatoes sprayed every 7 days, with CT obtained from compost of vegetable wastes, showed very high increases in fruit production without chemical control with fungicides, except for those used for controlling downy mildew. Still, on tomatoes, positive effects of CT treatments on shoot and root dry weight, chlorophyll content, and production were reported by Morales-Corts et al. [13] and on biostimulation and production by Durmus and Kızılkaya [38]. Treatments with aerated CTs increase by 24% and 32% production of lettuce and kohlrabi, respectively, cultivated under greenhouse [20]. Positive effects on the growth and production of pepper [5,14,39] and on potato [40–43] were registered in different experiments and locations. Villecco et al. [44] have registered positive effects on growth parameters and vegetative development on tomato, pepper, and melon plantlets cultivated in nurseries.

Positive effects on root-associated microorganisms for plant nutrition and nutrient uptake were registered by Jasson et al. [45], too.

Overall, these combined effects of compost tea on the morphological, physiological, and productive characteristics of the plants improve the agronomic performances of the crops [14].

Table 1 reports a number of examples of the stimulant activity of CTs on vegetable crops.
Table 1. Representative/main examples of the effect of compost teas on the growth and production of vegetable crops.

<table>
<thead>
<tr>
<th>Compost Tea (CT)</th>
<th>Crops</th>
<th>Effects on the Crops</th>
<th>Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT from a compost of mushroom</td>
<td>Star Flower African Ginger</td>
<td>Positive effect on root-associated microorganisms for plant nutrition and nutrient uptake</td>
<td>[45]</td>
</tr>
<tr>
<td>CT from a compost of 78.0% artichoke and 20% woodchips;</td>
<td>Lettuce and Kohlrabi</td>
<td>Biostimulation and increase in crop production</td>
<td>[20]</td>
</tr>
<tr>
<td>CT from a compost of 43.5% artichoke, 23.5% fennel, 11.0% escarole residues and 20% woodchips</td>
<td>Lettuce, Soybean, and Sweet Corn</td>
<td>Increase plant growth (shoot and root) and yield</td>
<td>[18]</td>
</tr>
<tr>
<td>CT from a compost of rice, straw, and Hinoki cypress bark; CT from a vermicompost</td>
<td>Onion</td>
<td>Improve yield and quality of rabi onion (N content, Total soluble solids (TSS) and pungency)</td>
<td>[46]</td>
</tr>
<tr>
<td>CT from a compost of horticultural crop residues, Poultry litter, and cow dung;</td>
<td>Onion</td>
<td>Increase plant height, number of leaves, and fresh and dry weights; increase chlorophyll content.</td>
<td>[47]</td>
</tr>
<tr>
<td>CT from a compost of chicken manure and green waste</td>
<td>Pak choi</td>
<td>Increase growth and mineral nutrient content</td>
<td>[48]</td>
</tr>
<tr>
<td>CT from a compost of mushroom, grape, and crop residues; CT from a vermicompost</td>
<td>Pepper</td>
<td>Increase plant growth</td>
<td>[39]</td>
</tr>
<tr>
<td>CT from a compost of vegetable wastes</td>
<td>Pepper</td>
<td>Biostimulation and increase in crop production and soil fertility</td>
<td>[14]</td>
</tr>
<tr>
<td>CT from a compost of green and pruning wastes</td>
<td>Pepper</td>
<td>Increase plant growth</td>
<td>[5]</td>
</tr>
<tr>
<td>CT from olive mill pomace, olive oil mill wastewater, and coffee grounds</td>
<td>Potato</td>
<td>Increase tuber yield</td>
<td>[40]</td>
</tr>
<tr>
<td>CT from compost of green and pruning residues</td>
<td>Potato</td>
<td>Increase growth and production characters (plant height, shoots high, yield, tuber size, and weight, number of tubers per plant, fried quality) and chlorophyll content (SPA units)</td>
<td>[41]</td>
</tr>
<tr>
<td>CT from a compost of olive oil mill wastewater, olive pomace, coffee grounds,</td>
<td>Potato</td>
<td>Increase plant growth</td>
<td>[42]</td>
</tr>
<tr>
<td>and phosphogypsum</td>
<td></td>
<td>Increase yield, shoot number, tuber weight, and tuber size</td>
<td>[43]</td>
</tr>
<tr>
<td>CT from the compost of grass cuttings and pruning debris, leaves and branches of</td>
<td>Potato</td>
<td>Increase plant development, yield, quality, phenolic content, antioxidant propriety, and flavonoid content</td>
<td>[8]</td>
</tr>
<tr>
<td>mainly Cypress, willow and poplar trees</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CT from the compost of onion waste and vineyard residue, implemented with</td>
<td>Spinach</td>
<td>Biostimulation and increased crop production</td>
<td>[49]</td>
</tr>
<tr>
<td>beneficial microorganisms</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CT from a compost of agricultural and municipal wastes</td>
<td>Tomato</td>
<td>Biostimulation and increased crop production</td>
<td>[49]</td>
</tr>
<tr>
<td>CT from a compost of leaves and stems of different Cupressaceae species and grass</td>
<td>Tomato</td>
<td>Increase shoot and root dry weight, stem diameter, chlorophyll content, and crop production</td>
<td>[13]</td>
</tr>
<tr>
<td>clippings; CT from a vermicompost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT from a compost of tomato wastes</td>
<td>Tomato</td>
<td>Biostimulation and increase in crop production</td>
<td>[38]</td>
</tr>
<tr>
<td>CT from a compost of horticultural residues, fennel wastes, and commercial biowaste</td>
<td>Tomato, Pepper, and Melon</td>
<td>Biostimulation and increased growth and vegetative development of the plantlets cultivated in nursery</td>
<td>[44]</td>
</tr>
</tbody>
</table>
Fungi diseases are an important limiting factor for the success of vegetable crops, both for quantitative and qualitative characteristics of the yields. Plant pathogens can cause serious production losses, but even very low levels of biotic defects in the final products can be poorly tolerated by the market, which reacts by imposing drastic price cuts or even rejecting the products.

Therefore, the phytosanitary management of the crops represents a crucial element of the entire production process in intensive horticultural systems. In these contexts, disease control of plants is widely achieved via a large use of synthetic fungicides, but their use is in contrast with the growing demand for the reduction in chemical inputs in agriculture to ensure greater sustainability of production and human health.

Research of eco-compatible alternatives to chemical control has paved the way for the study of new natural formulations for controlling fungal plant pathogens. Among these, CTs are of great interest because they permit the replacement of partially or totally traditional fungicides to control many fungal and bacterial diseases of vegetable crops when CTs are used as foliar sprays or to drench the soil [24,26].

CTs have been studied in many horticultural systems, with very interesting results about their propriety to control plant diseases.

For some vegetable species, such as tomato, CTs seem to be able to control many phytopathogenic fungi, i.e., various powdery mildews (*Oidium neolycopersici*, *Leveillula taurica*, and *Erisiphe polygoni*), downy mildew (*Plutophthora infestans*), gray mold (*Botrytis cinerea*), alternariosis (*Alternaria* spp.), septoria (*Septoria lycopersici*), corky root (*Pyrenochaeta lycopersici*), and rhizottonosis (*Rhizoctonia solani*) [25,50–52].

Furthermore, again, on tomatoes, applications of CTs have also been reported for the suppression of some bacterial phytopathogens, such as *Pseudomonas syringae pv. tomato* ([51,53].

On potatoes, applications of CTs in open fields have controlled different pathogens of this crop, including *Helminthosporium solani*, *Alternaria solani*, *Fusarium* sp., *R. solani* [54], and *P. infestans* [55,56].

Several mechanisms have been proposed to explain the suppressiveness of CTs against plant disease pathogens [22,57]. Numerous studies agree on the fact that the main contribution to suppressiveness is due to biotic components of CTs, in particular microorganisms that are able as phytopathogen antagonists ([4] and references therein).

For this reason, CTs can be considered as a valid system for the biological control of crop diseases.

It’s reported that, following sterilization, CTs have a drastic reduction in their biocontrol efficacy [58]. Antagonistic propriety of the microorganisms contained in CT acts via the classic mechanisms of mycoparasitization, antibiosis [37], and competition for space, nutrients, and/or infection sites [52]. Moreover, nutrients of CTs may protect the plants via direct toxicity against the pathogens, inducing systemic resistance, or improving the nutritional status of the plants [25].

In fact, microbial community in CTs is not always essential for disease control. In a study conducted by Al-Dahamani et al. [53], it has been demonstrated that the suppressivity of a CT does not only depend on the presence of an antagonistic microflora but could also depend on the abiotic component of the CT.

Nutrients and organic molecules, such as humic and phenolic substances contained in CT, can, in fact, contribute significantly to the protection of the plant by exerting direct toxicity effects that inhibit and/or limit the pathogenic activity of the fungi. Moreover, the effects of these molecules can determine the improvement in the nutritional and physiological state of plants that exhibit less susceptibility to biotic stress.

In most cases, biotic and abiotic components have complementary and synergistic functions that reflect the suppressive properties of the CT.

For example, abiotic components play a fundamental role in their nutritional support, exerting selective pressure on the growth of the microorganisms contained in CTs influencing microbial structure and level of biodiversity.
Moreover, secondary metabolites produced by microorganisms during the fermentation of CTs can play a determinant role in the suppressiveness of a CT. Biotic and abiotic components of CTs can induce systemic resistance in plant hosts and reveal another mechanism of action already reported for this organic formulation.

By analyzing some enzymatic activities in plant tissue, such as polyphenoloxidase, peroxidase, and phenylalanine-ammonium-lyase, related to resistance induction, it was possible to detect this type of response to Choanephora cucurbitarum in Cucurbita cucurbitarum plants, treated with both CTs filter-sterilized or not [59].

A similar phenomenon had previously been highlighted in tomato and onion plants treated with no-aerated CT to control Alternaria solani and A. porri, respectively [60]. Transcriptomic studies performed on tomatoes at CREA of Pontecagnano (Italy) have shown that filter-sterilized CT is able to induce resistance in plants (not published data).

The variables of the production process profoundly influence the microbiological and molecular complexity of the CTs, on which the development of a suppressive action against plant pathogens largely depends. Among the parameters of the CT production process, the quality of the compost and the use of additives, both during the fermentation process or during the treatment of the plants, seem to be more able to influence the effectiveness of the compost tea with respect to other variables.

Composts with suppressive properties (e.g., poultry manure composted Urtica sp. and composted Lantana camara) are potentially able to generate high-quality compost teas that are particularly effective for biocontrol activities [61]. In addition to the intrinsic characteristics, the age of the compost can also influence the quality of the final product. Research has shown that aerated CTs, produced from immature composts tested on the broad bean/grey mold (Botrytis cinerea) system, were more suppressive than those deriving from more stable composts [23].

The addition of additives such as nutrients that promote microbial growth and/or substances with an antifungal action, such as humic acids [62] and/or antagonists for the production of fortified CTs [36], generally enhance suppressivity, increasing efficiency and broadening its spectrum of action. The addition of additives, even in small doses, can have macroscopic effects.

Whey, for example, added to a CT at the time of the treatment at a final concentration of just 1% resulted in a significant reduction in the symptoms of late blight (Phytophthora infestans) on potatoes [55]. Among the remaining production parameters, aeration does not appear to be excessively decisive for the efficiency of a CT. Direct comparisons of aerated and not-aerated CTs showed no significant differences for in vivo control of Pythium ultimum on cucumber [24] and on Xanthomonas vesicatoria on tomato [53].

In the case of the distribution of CTs, attention must be paid to the operating pressures, which must not exceed certain levels, in order to preserve the safety of the resident microflora. Compost teas can be applied by foliar spraying both in the preventive and curative effects such as suppressive effect, inhibition effect, and incrementation of the resistance against different pathogens.

The application of organic formulations for plant disease control is generally carried out in the same way as traditional fungicide, i.e., by wetting the leaves or the roots, facilitated using sprayers and/or mini-sprinklers.

A trial performed with various CTs has indicated that preventive applications of CT are more effective than curative ones as a consequence of the possibility of epiphytic development of tea microbes and the greater possibility of interaction of these microorganisms with the infectious propagules of the pathogens [25]. CTs are generally used diluted from 1:10 to 1:20. The doses of CT used, especially in open fields, depend on crop species to be protected. Generally, they vary from 50 to 140 L ha\(^{-1}\) in the case of Phytophthora infestans on potatoes and up to about 900 L ha\(^{-1}\) for the control of Septoria lycopersici on tomatoes [55].

Table 2 reports a number of examples of the biocontrol activity of CTs on vegetable crops.
Table 2. Representative/main examples of the effect of compost teas to control plant diseases.

<table>
<thead>
<tr>
<th>Compost Tea (CT)</th>
<th>Crops</th>
<th>Protection Effect</th>
<th>Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT from compost of grape and animal manure</td>
<td>Bean</td>
<td>Significant decrease in <em>R. solani</em> infection</td>
<td>[63]</td>
</tr>
<tr>
<td>CT from compost of cow and horse dung</td>
<td>Faba bean</td>
<td>Highly suppressivity against <em>Botrytis cinerea</em>, <em>Alternaria alternata</em>, and <em>Pyrenochaeta lycopersici</em></td>
<td>[64]</td>
</tr>
<tr>
<td>CT from compost of manure, onion, eggshells, and carrot waste; CT from compost of pine bark; CT from vermicompost</td>
<td>Ornamental plants (e.g., Campanula, Aphelandra, Gerbera, and others)</td>
<td>Suppressive effects on six pathogens: <em>Fusarium foetens</em>, <em>Rhizoctonia solani</em>, <em>Sclerotinia sclerotiorum</em>, <em>Pythophthora cryptogea</em>, <em>Pythium intermedium</em>, <em>P. ultimum.</em></td>
<td>[65]</td>
</tr>
<tr>
<td>CT from compost of mushroom, grape, and crop residues; CT from vermicompost</td>
<td>Pepper</td>
<td>Suppressive effect on <em>Phytophthora capsici</em> and <em>Phytophthora parasitica</em></td>
<td>[38]</td>
</tr>
<tr>
<td>CT from compost of green and pruning wastes</td>
<td>Pepper</td>
<td>Inhibition effect on <em>Rhizoctonia solani</em> and <em>Phytophthora capsici</em></td>
<td>[5]</td>
</tr>
<tr>
<td>CT from compost of olive oil mill wastewater, olive pomace, coffee grounds, and phosphogypsum</td>
<td>Potato</td>
<td>Inhibition effect and control of <em>Fusarium solani</em></td>
<td>[42]</td>
</tr>
<tr>
<td>CT from compost of agricultural waste compost; CT from vermicompost</td>
<td>Potato</td>
<td>Suppressive effect of potato bacterial wilt caused by <em>Ralstonia solanacearum</em></td>
<td>[17]</td>
</tr>
<tr>
<td>CT from compost of green and pruning residues</td>
<td>Potato</td>
<td>Suppressive effect on <em>Rhizoctonia solani</em></td>
<td>[41]</td>
</tr>
<tr>
<td>CT from compost of grass cuttings and pruning debris (leaves and branches of cypress, willow and poplar trees)</td>
<td>Potato</td>
<td>Higher resistance against <em>Rhizoctonia solani</em></td>
<td>[43]</td>
</tr>
<tr>
<td>CT from compost of onion and vineyard implemented with beneficial microorganisms</td>
<td>Spinach</td>
<td>Suppressive effects and protection of the plants against <em>R. solani</em></td>
<td>[8]</td>
</tr>
<tr>
<td>CT from compost of agricultural and municipal waste</td>
<td>Tomato</td>
<td>Positive impact on health and vegetative status of the plants</td>
<td>[49]</td>
</tr>
<tr>
<td>CT from a compost of leaves and stems of different <em>Cupressaceae</em> species and grass clippings; CT from a vermicompost</td>
<td>Tomato</td>
<td>Suppressive effect on <em>Rhizoctonia solani</em> and <em>Fusarium oxysporum f. sp. lycopersici</em></td>
<td>[13]</td>
</tr>
</tbody>
</table>

4. Influence of Compost Tea on Nutrients and Bioactive Components in Horticulture

The application of CTs on fruits and vegetables leads to biostimulating effects. These effects are represented by increases in production and, more generally, increases in plant biomass, but also by a physiological boost.

It is interesting to note that compost teas can have an effect on the final content of micro and macronutrients, thus improving the nutritional qualities and also increasing the content of bioactive compounds that may play a role in maintaining and improving human health.

In comparison with compost tea, the other types of compost, such as pumice, olive, and green waste, seem to have similar effects on micro and macro nutrients [66,67].

Jasson et al. [68] have evaluated different treatments of compost tea on antioxidant potential, phytochemicals, nutritional properties, and growth of wild ginger (*Siphonochilus aethiopicus*). The results of this study show that, even if measured growth parameters were not considerably improved, the administration of compost tea could maximize mineral accumulation, phytochemicals, and antioxidants in *S. aethiopicus* [68]. The concentration of polyphenols, which are plant precursors for antioxidant activity, was highest in rhizomes treated with undiluted compost tea, indicating compost tea’s influence on phytochemical
accumulation. Plant samples that were merely water-irrigated gathered the fewest minerals, whereas samples that were treated with 0.25 (vv) produced the highest levels of N, P, K, and Mn. This shows that *S. aethiopicus* only needs a small amount of compost tea to absorb vital minerals, including N, P, K, and Mn [68].

Compost tea and potassium humates were tested individually and in combination, applied once as water suspension at transplant, concomitant to the soil inoculation with the commercial microbial product *per* pot, and their effects on lettuce plants growth, minerals content, primary and secondary metabolite content, was assessed [69]. This research demonstrated that, compared to their individual applications, the interaction between various humic materials and commercial microbial consortia considerably improved the plants’ uptake of both macro- and micronutrients, leading to an increase in the production of lettuce biomass. Both the separate administration of the microbial inoculum and biostimulants, as well as their combination, influenced the mineral content of lettuce plants. The separate application of CT greatly increased the leaf concentration of P, K, Ca, and Mg in the absence of microbial inoculum, but the combination treatment significantly increased the concentration of N and S. Additionally, the MIX treatment in conjunction with the microbial inoculum, promoted the accumulation of important primary metabolites, primarily amino acids, and saccharides, in lettuce leaves. It also examined the modifications to the lettuce plants’ secondary polyphenolic metabolism and discovered that, in comparison to other treatments, the combination of potassium humic and compost tea materials greatly boosted the amount of powerful antioxidant chemicals found in the leaves. An optimally balanced molecular composition of bioactive molecules and protective hydrophobic domains, capable of modifying the humic molecular bioactivity, may be responsible for the stimulatory impact of the mixed humic extracts [69].

The agricultural industry, in general, is responsible for the production of large volumes of residual by-products. The majority of the total biomass generated consists of these wastes, which have been burned to produce steam, utilized as fertilizer, planted on the ground, or buried. There is a need for alternative uses of these residues due to the high expense of these technologies and the risks they pose to the quality of the water, soil, and air. So, it is clear that innovative approaches to using agro-residues are required for the management of agricultural waste to be sustainable. Composting seems to be a lucrative area in agriculture biotechnology where agro-waste management is aimed at minimizing waste output, reducing environmental contamination, and boosting substrate recycling capacity [59]. The influence of compost tea from Oyster Mushroom Waste on the growth and the flavonoid content in the black rice was evaluated by Khoerunnisa et al. [71]; the results displayed an increase in both the growing rate and flavonoid content depending on the treatments administered to the plants, in particular it was showed that the administration of compost tea of 45% lead to best rice growth, while the concentration of 35% lead to a best flavonoids content [71]. An example of the combined use of compost tea with other treatments is given by Lu et al. [72], who investigated how hydroponically grown plants respond to UV light exposure and compost tea treatment. Garnet Giant mustard greens were grown both indoors and outdoors, with or without UV light blocking and with or without the addition of compost tea. In greenhouses, outside plants produced more dry mass than inside plants did. Supplementing with compost tea increased nitrogen and mineral accumulations in the absence of UV protection. The mustard greens’ antioxidant capacities increased with increased UV exposure, while being supplemented with compost
tea decreased their antioxidant capacities. Treatment with compost tea enhanced good bacteria and lowered pathogenic fungi [72]. The impact of organic fertilizer solutions on the productivity, quality, and antioxidant capacity of hydroponically grown cucumber (*Cucumis sativus* L.) fruits produced in a greenhouse has been studied by Santiago-López et al. [73]. Fruit with the highest antioxidant capacity were those treated with compost tea; they had a 42.0% greater antioxidant capacity than fruits grown with inorganic fertilizer [73]. A significant increase in the concentration of N, P, K, and chlorophyll was also observed by Mostafa et al. [74] in vine leaves treated with CTs of different origins, distributed alone or combined, with or without citric acid. The same authors have found an increase in production and the improvement in some characteristics linked to total sugars and anthocyanins in the skin of the berry.

Hargreaves et al. [75] compared, on blueberry, the effect of soil applications of different types of compost and foliar applications of the relative CTs. The different treatments determined similar production levels, the total antioxidant capacity of the fruits, and vitamin C content, while the concentration of K in leaves and fruits was lower in the treatment with CTs.

Baldotto et al. [76] reported a positive response of pineapple seedlings (cv Vitória) propagated in vitro when subjected to epigeal treatments with humic acids isolated from vermicompost. The application of the treatments leads to an increase in vegetative growth (sprouts and roots) and the content of mineral elements (N, P, K, Ca, Mg). Table 3 reports a number of examples of the biostimulating effects of CTs on crops.

**Table 3. Representative/main examples of biostimulating effects of compost tea.**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Crops</th>
<th>Biostimulating Effect</th>
<th>Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost tea</td>
<td>Wild ginger</td>
<td>Maximize accumulation of minerals, phytochemicals, and antioxidant</td>
<td>[68]</td>
</tr>
<tr>
<td>Compost tea and potassium humates</td>
<td>Lettuce</td>
<td>Increased concentration of minerals, primarily amino acids, saccharides, and antioxidants</td>
<td>[69]</td>
</tr>
<tr>
<td>Compost tea and humic acids</td>
<td>Faba bean</td>
<td>Increased nutritional content, total sugars, and crude protein</td>
<td>[70]</td>
</tr>
<tr>
<td>Compost tea from Oyster Mushroom Waste</td>
<td>Black Rice</td>
<td>Increased growth rate and flavonoid content</td>
<td>[71]</td>
</tr>
<tr>
<td>Compost tea and UV exposure</td>
<td>Garnet Giant Mustard</td>
<td>Increased nitrogen and mineral accumulation</td>
<td>[72]</td>
</tr>
<tr>
<td>Compost and vermicompost tea</td>
<td>Cucumber (<em>Cucumis Sativus</em> L.)</td>
<td>Increased antioxidant capacity</td>
<td>[73]</td>
</tr>
<tr>
<td>Compost tea</td>
<td>Grape</td>
<td>Increased N, P, K, and chlorophyll content in petioles, higher production, and total sugar and anthocyanin content in grape skins</td>
<td>[74]</td>
</tr>
<tr>
<td>Compost tea</td>
<td>Blueberry</td>
<td>Increased K concentration in leaves and fruit, increased Na content of leaves</td>
<td>[75]</td>
</tr>
<tr>
<td>Humic acids isolated from vermicompost</td>
<td>Ananas</td>
<td>Improved growth, increased nutrient content (N, P, K, Ca, Mg)</td>
<td>[76]</td>
</tr>
</tbody>
</table>

**5. Conclusions and Further Remarks**

Despite the increasing amount of studies and experiments conducted on compost tea and on their beneficial effects on plant growth, plant health, increasing soil fertility via increased microbial diversity, and compost tea as plant disease suppressant agents, the overall challenge remains the improvement in results in commercial crop production systems. CTs represent new tools for low-impact vegetable production with benefits for human health and environmental safety [57]. Compost tea contains the best alternative source of liquid organic nutrients for horticultural and agricultural use. Compost tea production involves two primary methods: Aerated Compost Teas (ACTs) and Non-Aerated Compost Teas (NCTs). ACTs are produced using aerating dechlorinated water for 24 h to a
week, encouraging microorganism growth. Filtration employs porous bags or screens, and practitioners often enhance ACTs with nutrients [10,22–24]. Conversely, NCTs lack aeration and are incubated for 7 to 14 days, offering cost-efficient alternatives, especially in regions with energy limitations [22,25–27]. Several mechanisms have been hypothesized for the altered effects associated with compost tea use, including increased nutrient availability and uptake, especially when applied as a foliar treatment [77]. Other mechanisms include increases in soil organic matter and nutrient turnover via microbial activity [77]. An added benefit comes from the suppression of plant pathogens, which offers the best opportunity for maximum growth. CTs hold promise for disease control. They have been effective against various pathogens such as powdery mildews, downy mildew, gray mold, and more, particularly in tomatoes and potatoes [25,50–52,54–56]. The biocontrol efficacy of CTs largely depends on both biotic and abiotic components. Microorganisms play a role via mechanisms like mycoparasitization and antibiosis, while abiotic components like nutrients and organic molecules contribute to direct toxicity and systemic resistance [25,37,52]. The production process variables influence CT effectiveness. Compost quality, additives, and compost age impact the final product’s suppressive action. Additives such as humic acids and antagonists enhance suppressivity and broaden its spectrum of action [23,36]. Aeration does not significantly influence CT efficiency, and CTs are applied similarly to traditional fungicides using foliar spraying [24,53]. Preventive CT applications tend to be more effective due to microbial interactions with pathogens [25]. As an amendment, its versatility even enhances its source material [12]. The application of CT on fruits and vegetables leads to biostimulant effects [78]. Increases in production and, more generally, increases in plant biomass, as well as a physiological drive, are indicative of these impacts [7]. It is interesting to learn that compost teas can influence the final content of micro and macronutrients, thereby increasing nutritional characteristics and also increasing the content of bioactive substances, which can help maintain and improve human health [68,71]. Compost tea has shown the potential to be an ideal beneficial product in any crop system. In conclusion, compost tea is a valid alternative to chemical fertilizers. The increasing use of CT could improve the productivity and quality of the horticultural supply chain, reduce the amount of agricultural waste, mineral fertilizers, plant fungicides, and soil fumigation, and improve the integration of the results into commercial agricultural production systems. Furthermore, on-farm composting satisfies the needs of the bioeconomy because it enhances agricultural waste or biomass unsuitable for energy production, solving the problem of agricultural waste disposal [57]. Composting appears to be a profitable field of agricultural biotechnology where efforts are made to manage agricultural waste to reduce waste generation, clean up the environment, and increase the recycling capacity of the substrate. Furthermore, the production of CT is a biological and sustainable process that can also be reproduced on farms.

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