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Synergistic Effect of Compost Tea, Micronutrients and Antioxidants on Downy Mildew Control of Sweet Basil under Greenhouse and Field Conditions

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ABSTRACT

This study investigated the synergistic effect of compost tea, micronutrients and antioxidants on downy mildew control of sweet basil in *in vivo* conditions. Compost tea was used as a soil additive, while other treatments were used as foliar sprays. The treatments were applied in the greenhouse three times, 15 days interval, at two rates as follows: compost tea (15 and 30 mL/pot), micronutrients (1 and 2 mg/L) and antioxidants (2 and 4 g/L). The treatments were used in the field three times, distributed over three cuts, at a rate of 1.5 L/plot of compost tea, 2 mg/L of micronutrients, and 4 g/L of antioxidants. The results showed that all treatments used in the greenhouse led to a significant decrease in sweet basil downy mildew (SBDM) compared to the control. Concentration B was more efficient in reducing disease than concentration A. The most effective treatments were copper hydroxide, compost tea/SA + Cu, compost tea/SA + Zn and compost tea/AsA + Cu. The corresponding reduction values were 79.4, 67.2, 55.8 and 48%, respectively, in disease incidence, and 85.1, 78.9, 74.5 and 71.1%, respectively, in disease severity. Similar results were obtained in the field during two successive seasons. Reduction in SBDM severity due to the synergistic effect of treatments through improvement of growth and yield features has been favorably expressed. Along with a significant increase in the content of the essential oil and its active components, the activities of defense-related enzymes (*i.e.* peroxidase and catalase), and photosynthetic pigments.

KEYWORDS: downy mildew; sweet basil; compost tea; micronutrients; antioxidants; growth and yield characteristics

1. INTRODUCTION

Sweet basil (*Ocimum basilicum* Linn.) is one of the aromatic plants of the Lamiaceae family. Its native to the tropical and sub-tropical areas of the world, then it widespread to the Mediterranean regions (Liber et al., 2011). The plant is mainly cultivated to obtain fresh or dry herb to extract essential oil, which is used in the manufacture of medicine, perfumes and foodstuffs (Purushothaman et al., 2018). Basil essential oil contains high levels of phenyl-propanoids (such as eugenol and methyleugenol) and terpenoids (such as linalool and 1,8-cineole), with antioxidant, antitumor, and antimicrobial properties (Tenore et al., 2016). In Egypt, the area planted with basil in 2021 reached 5,907 hectares, producing 335,708 tons of fresh herb (Abdelfattah et al., 2023). Downy mildew is one of the major foliar disease affecting sweet basil (Abdullah et al., 2022), which is caused by the obligate, biotrophic oomycete fungus *Peronospora belbahrii* Thines (Thines et al., 2009). This disease was first observed in Egypt during the 2013 season (Hilal and Ghebrial, 2014), and then spread rapidly through all basil growing areas, causing serious damages and losses to the crop (Ghebrial and Nada, 2017). Chemical fungicides have been used for many years to control plant diseases. However, the contamination of food sources with chemical residues has turned the attention of researchers to searching for viable, sustainable and safe alternatives to eliminate such diseases (Özkara et al., 2016). Recently, the demand for new products derived from composted materials, such as compost tea, as well as micronutrients and antioxidants has increased due to their positive impacts on crops (Giménez et al., 2020; Hansch and Mendel, 2009; Göre, 2009).

Compost tea is a liquid organic formulation extracted from compost after incubating it for a specific time using water free of chlorine or chemical additives under controlled conditions. This liquid has the ability to cause positive changes in the physical, chemical and biological properties of the soil (Bali et al., 2021). Compost tea contains a large number of macroelements (*i.e.* N, P, and K), plant hormones (*i.e.* cytokinin, IAA, and salicylic acid), microelements (*i.e.* Fe, Zn, Cu, and Mn), humic acids, and heavy metals (*i.e.* cadmium, lead, and chromium). These abiotic components have positive impacts on soil fertility and thus on plant health (Zaccardelli et al., 2018). Compost tea also contains a variety of beneficial microorganisms, including protozoa, fungi, bacteria, yeasts, oomycetes, and actinomycetes, due to their pathogen-inhibiting activity and/or plant growth-promoting properties (González-Hernández et al., 2021). Several reports have shown that compost tea-based applications can have protective effects against the occurrence of plant diseases. For example, Pane et al. (2007) found that treating vegetable crops with compost tea effectively suppressed powdery and downy mildews, gray mold and root rot. The same effects were also obtained against *Fusarium* sp., *Alternaria solani*, *Helminthosporium solani*, *Phytophthora infestans*, and *Rhizoctonia solani* in potato, and *F. oxysporum f. sp. lycopersici and R. solani* in tomato (Morales-Corts et al., 2018). Tegegn (2017) also reported that the use of compost tea significantly decreased the major diseases of faba bean caused by *Botrytis cinerea*, *A. alternate* and *Pyrenochaeta lycopersici*.

Micronutrients, *i.e.* copper, zinc and iron, play a vital role in plant nutrition. They are essential for photosynthesis, energy production, synthesis of primary and secondary metabolites, hormone absorption, gene expressions, signal transduction, and cell defense (Hansch and Mendel, 2009). They also activate metal-enzymes and produce phenols and lignin (Graham and Webb, 1991). Micronutrients influence the stability of cell membranes in vascular plants, protecting them from free radicals (Marschner, 1995). As mentioned by Hansch and Mendel (2009), micronutrients contribute to the induction of plant defense responses due to pathogen attacks by inducing acquired systemic resistance. Extensive reports have demonstrated the positive impacts of micronutrients on plant disease management. For example, Elad et al. (2021a) found that foliar sprays with zinc and manganese significantly reduced the severity of downy mildew in sweet basil by 46–71%. Similar results were also obtained when sweet basil plants were sprayed or irrigated with calcium, nitrogen, potassium, and magnesium (Elad et al., 2021b). In addition, foliar application of zinc significantly decreased the susceptibility of cabbage and turnip plants to powdery mildew (Tomlison and Webb, 1958) and wheat to take-all disease (Graham and Webb, 1991). Also, the application of zinc, manganese, and boron was effective against potato early blight, coffee rust, and wheat tan spot (Perez et al., 2020). In a similar vein, iron application significantly reduced the severity of wheat rust and banana anthracnose (Graham and Webb, 1991), and increased the resistance of cabbage and apple to *Olpidium brassicae* and *Sphaeropsis malorum*, respectively (Graham, 1983). In addition, low levels of copper increased the susceptibility of sunflower, barley and wheat to *A. helianthi*, *Claviceps purpurea* and *Septoria tritici*, respectively, while high levels reduced the susceptibility of peanut to *S. minor* (Hallock and Porter, 1981).

Antioxidants, *i.e.* salicylic acid (SA) and ascorbic acid (AsA) have achieved good results for induction of systemic resistance in plants against plant pathogens (Dutta, et al., 2016). This activity is due to its promotion of some morphological and physiological changes in defense-related compounds in the host (Göre, 2009). Salicylic acid is an important defensive endogenous plant hormone that mediates signal transduction pathways, which induce systemic acquired resistance (SAR) and local acquired resistance (LAR) (Durrant and Dong, 2004). SA application has been found to stimulate cell wall strengthening, ROS production, PR gene expression, and induction of proteins associated with pathogenesis and resistance to fungal, bacterial and viral diseases (Vallard and Goodman, 2004). In addition, foliar application of SA induced resistance in *Arabidopsis thaliana* against powdery and downy mildews (Genger et al., 2008), in tobacco against powdery mildew (Nakashita et al., 2002), in tomato against leaf blight (Spletzer and Enyedi, 1999), and in cherry fruits against fruit rot (Yao and Tian, 2005). On the other hand, the use of ascorbic acid has increased the resistance of a large number of plants against plant diseases, such as roselle against root rot and wilt (Ahmed et al., 2023), potato against early and late blights (Al-Gamal et al., 2007), and sunflower against powdery mildew (Yousef, 2021). As mentioned by Awadalla (2008), treating tomato with a mixture of SA and AsA increased resistance against early blight by stimulating tomatin (phytoalexin) production in leaves and stems, a compound toxic to pathogens. The purpose of this study is to investigate the synergistic effect of compost tea, micronutrients and antioxidants on downy mildew control of sweet basil under greenhouse and field conditions, as well as their effects on growth, yield and biochemical components of the plant.

2. MATERIALS AND METHODS

2.1. Plant and Soil Materials, Treatments and Experimental Site

The present study was conducted in the greenhouse and Experimental Farm of Fayoum Regional Res. Station, Fayoum Govern., Egypt during the 2021 and 2022 seasons, to study the synergistic effect of compost tea, micronutrients (*i.e.* Cu, Zn and Fe) and antioxidants (*i.e.* ascorbic acid and salicylic acid) compared with copper hydroxide fungicide (coprax 77% WP) in the control of SBDM. Sweet basil (Balady cv.) seeds were brought from the Horticultural Res. Inst, ARC, Egypt, and sown in the nursery on March 1st. Uniform seedlings, 45 days old and 20 cm height were transplanted into the greenhouse and field. The soil was analyzed according to the methods described by Özbek et al. (1995). The soil was classified as sandy loam (clay =14.3%, silt =19.2%, sand =66.5%, pH =7.4, EC =1.4 ds/m, and organic matter =1.03%. The N, P, and K values were 39.4, 7.3, and 154 mg/kg soil, respectively. Compost tea analysis was performed according to Olsen and Sommers (1982), as presented in Table 1.

Table 1. Chemical and microbiological analyzes of the compost tea used in the current study during the 2021 and 2022 seasons.

Chemical Analyses				
pH	**EC (dS/m)**	**Total N (%)**	**Total P (%)**	**Total K (%)**
7.5	2.15	0.41	0.12	0.37

Microbiological Examination		
Total Bacteria (cfu/mL)	**Total Fungi (cfu/mL)**	**Total Actinomycetes (cfu/mL)**
8.2×10^6	6.9×10^5	1.8×10^4

2.2. Pathogen, Sample Collection, Inoculum Preparation and Inoculation

Sweet basil samples naturally diseased with downy mildew were brought from different fields. To prepare the fungal inoculum, fresh sporangia developing on the upper surface of leaves were collected by washing these leaves in sterile distilled water mixed with Tween-20 (0.02%). The mixture was centrifuged for 5 min at 3000 rpm and then adjusted to 1 × 10^5 sporangia mL^{-1} using a hemocytometer (Ben-Naim et al., 2015). Healthy 45-day-old plants were inoculated by spraying them with the spore suspension and then left for 48 h at 20–23°C and 90% relative humidity to ensure infection (Garibaldi et al., 2007).

2.3. Preparation of Compost Tea

About 5 kg of mature plant compost was soaked in 50 liters of water (1:10 w/v) in special plastic units, then 100 mL of molasses was added to the mixture (Fayek et al., 2014). The mixture was left for 7-10 days at room temperature in these units, which were connected to a pump, to provide air during the fermentation process. When the color of the extract became light brown, the compost extract was filtered using layered muslin cloth. This was repeated several times until compost tea was obtained, and then used directly.

2.4. *In Vivo* Experimental Design

2.4.1. Greenhouse Experiments

During the 2021 season, greenhouse trials were designed to study the synergistic effect of compost tea, micronutrients and antioxidants on SBDM control using a randomized complete block design (RCBD), with 8 treatments, 3 replicates/treatment and 3 pots/replicate. Sweet basil seedlings, 45 days old and 20 cm high, were transplanted into pots (30 cm diam.), filled with sandy loam soil (1:3 w/w), with each pot containing 1-2 seedlings. Two weeks after transplanting, inoculation was performed with *P. belbahrii* suspension (1 × 10^5 sporangia mL^{-1}). Two days after inoculation, treatments were applied as follows: (T1): compost tea/AsA + Cu; (T2): compost tea/AsA + Zn; (T3): compost tea/AsA + Fe; (T4): compost tea/SA + Cu; (T5): compost tea/SA + Zn; (T6): compost tea/SA + Fe; (T7): copper hydroxide (2.5 mLL^{-1}); and (T8): control (untreated). Compost tea has been used as a soil additive, while other treatments have been used as foliar sprays. The treatments were applied three times with an interval of 15 days at two rates as follows: compost tea (15 and 30 mL/pot), micronutrients (1 and 2 mg/L) and antioxidants (2 and 4 g/L). The incidence and severity of SBDM were measured 7-10 days after application.

2.4.2. Field Experiments

Two successive trials were carried out in the field through the 2021 and 2022 seasons with an RCBD design and three replications. Each plot was 4 m long and 3.5 m wide (14 m^2), and consisted of 5 rows. Sweet basil seedlings, 45 days old and 20 cm high, were transplanted at a distance of 25 cm. The treatments were applied three times, distributed over three cuts, at a rate of 1.5 L/plot of compost tea, 2 mg/L of micronutrients, and 4 g/L of antioxidants. The severity of SBDM was calculated 7-10 days after application.

2.5. Measurements

2.5.1. Disease Assessment

The disease incidence (DI) of SBDM was estimated as follows:

$$\mathrm{DI}\ \% = (\mathrm{A}/\mathrm{B}) \times 100$$

Where A = no. of infected plants and B = total no. of plants.

Disease severity (DS) of SBDM was measured based on the scale given by Abdullah et al. (2022). This scale consists of 0-6 categories based on the area of leaves covered with mildew, as follows: 0 = no visible symptoms; 1 = 1–0%; 2 = 11–25%; 3 = 26–50%; and 4 = 51–75%; 5 = 76–95%; and 6 = 96–1000%. Disease severity was calculated as follows:

$$\mathrm{DS}\ \% = \sum (\mathrm{n} \times \mathrm{c})/(\mathrm{N} \times \mathrm{C}) \times 100$$

Where n = no. of infected leaves in each grade, v = numerical values of each category, N = total no. of examined leaves and C= the highest category in terms of no. of infections in the scale. Disease reduction (DR) was assessed as follows:

$$\mathrm{DR}\ \% = (\mathrm{C} - \mathrm{T}/\mathrm{C}) \times 100$$

Where C and T are the percentage of DI/DS in control and treatment, respectively.

2.5.2. Growth and Yield Characteristics

Sweet basil plants were harvested three times, by cutting them about 10 cm above the soil surface. The first cutting was made when flowering was complete and fruit set began, then the cutting was repeated every 45-55 days. During each cut, plant height (cm), no. of branches/plant, and weight of herb (fresh and dry) (kg/plot) were assessed.

2.6. Biochemical Analyses

2.6.1. Essential Oil (EO) Extraction

Sweet basil herb was collected from different treatments, dried and ground. About 200 g of the dried material was hydrodistilled in one liter of distilled water in a modified Clevenger-type apparatus for 2-3 hours. The resulting EO was passed over Na_2SO_4 to dry, and then stored in dark vials at 4 °C for further tests (Phu et al., 2019).

2.6.2. Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

GC/MS analysis of sweet basil EO was performed at the Regional Center for Nutrition and Feed, ARC, Egypt, using a gas chromatography mass spectrometry system (Agilent 7890A/5975C GCMS System) equipped with HP-5 column (30 m × 0.1 mm; 0.25 μm film thickness). The temperature was held at 60°C for 3 min, programmed at 20°C/min to 240°C and then held at this temperature for 8.5 min. Pure helium gas (99.995%) was used as the carrier gas at a flow rate of 1 ml/min. Mass spectra were taken at 70 eV., and the injector temperature was 280°C. Oil components were identified by comparing mass spectra and retention indices (RI) with those reported in the literature and those of the authentic samples (Adams, 2001). The comparative condensations of the separated compounds were evaluated on a percentage basis based on the chromatograms obtained from GC/FID/MS system.

2.6.3. Content of Photosynthetic Pigments

Chlorophyll a, chlorophyll b, and carotenoids were quantified according to the method of McLeroy-Etheridge and McManus (1999) using a spectrophotometer. Pigments were extracted from fresh leaves in aqueous acetone (85%: v/v). Absorbance was read at 452.5, 644 and 663 nm. The amount of pigments were estimated as follows:

Chl.-a (mg/mL) = $10.3 \times E663 - 0.918 \times E644$
Chl.-b (mg/mL) = $19.7 \times E644 - 3.87 \times E663$
Carotenoid (mg/mL) = $4.2 \times E452.5 - [(0.0264 \times \text{Chl.-a}) + (0.0426 \times \text{Chl.-b})]$
Pigment (mg/g FW) = $(C - V/1000 - W)$
Where E = absorbance, C = pigment conc., V = acetone vol. (mL) and W = sample weight (g)

2.6.4. Activity of Antioxidant Enzymes

Preparation of Enzyme Extract

Pre-weighed dry leaves were homogenized in 4 mL buffer (50 mmol L^{-1} Tris pH ¼ 8.5, 14.4 mmol L^{-1} 2-mercaptoethanol) and 1% insoluble polyvinyl polypyrrolidone. The extract was centrifuged (10,000 rpm) for 20 min at 4°C. The supernatant was used to estimate antioxidant enzyme activities (Cao et al., 2005). The total protein of enzyme extract was measured according to Bradford (1976).

Activity of Peroxidase (POX)

POX activity was measured using the method of Dazy et al. (2008). The photometric strength of the reaction was readied using the spectrophotometer at 470 nm in a 40 mmol L^{-1} hydrogen peroxide solution. Results were reported as POX mg $protein^{-1}$ min^{-1}.

Activity of Catalase (CAT)

CAT activity was assessed according to Sohrabi et al. (2012). Reaction was started through adding the protein extract. The reaction mixture involved 100 mmol L^{-1} phosphate buffer (pH 7), 0.1 mmol L^{-1} EDTA, 20 mmol L^{-1} H_2O_2 and 20 μL protein ex. 1 min after the start of the reaction, the spectrophotometer at 240 nm checked the reduction in H_2O_2 content, which was measured by the molar extinction coefficient (36 mol L^{-1} cm). Results were reported as CAT mg $protein^{-1}$ min^{-1}.

2.7. Statistical Analyses

Data were statistically analyzed by ANOVA, using Web Agric. Stat Package software (WASP 2.0, Central Coast Agric. Res. Inst., Goa, India). Combined analysis of the two-season data, in addition to the Duncan range test, was used to compare significant differences between treatments tested at $P \geq 0.05$ (Gomez and Gomez, 1984).

3. RESULTS

3.1. Synergistic Effect of Compost Tea, Micronutrients and Antioxidants on SBDM Control in the Greenhouse

Data offered in Table 2 show that all treatments significantly reduced the incidence and severity of SBDM in the greenhouse. Concentration B was more effective than concentration A of all treatments. The most effective treatments were copper hydroxide, compost tea/SA + Cu, compost tea/SA + Zn and compost tea/AsA + Cu. The corresponding reduction values were 79.4, 67.2, 55.8 and 48%, respectively, in disease incidence, and 85.1, 78.9, 74.5 and 71.1%, respectively, in disease severity. While the least effective treatment was compost tea/AsA + Fe, which recorded a 16.9 and 25.2% reduction in disease incidence and severity, respectively.

Table 2. Synergistic effect of compost tea, micronutrients and antioxidants at two rates on the incidence and severity of SBDM in the greenhouse.

Treatment	Rate	Sweet Basil Downy Mildew (SBDM)			
		Disease Incidence %	* R %	Disease Severity %	* R %
T1	A	61.7 ± 2.4^{de}	20.4	34.1 ± 1.8^{de}	36.5
	B	40.3 ± 2.1^{h}	48.0	15.5 ± 1.3^{ij}	71.1
	Mean	51	34.2	24.8	53.8
T2	A	67.2 ± 2.8^{bc}	13.2	41 ± 2.1^{c}	23.6
	B	50.5 ± 2.5^{g}	34.8	28.3 ± 2.8^{f}	47.2
	Mean	58.8	24.0	34.6	35.4
T3	A	70.1 ± 3.0^{b}	9.5	44.3 ± 2.5^{b}	17.5
	B	58.6 ± 1.7^{ef}	24.3	36 ± 1.9^{d}	32.9
	Mean	64.3	16.9	40.1	25.2
T4	A	42.1 ± 2.1^{h}	45.6	20.5 ± 1.7^{h}	61.8
	B	25.4 ± 2.4^{j}	67.2	11.3 ± 1.1^{c}	78.9
	Mean	33.7	56.4	15.9	70.3
T5	A	56.3 ± 3.7^{f}	27.3	24.1 ± 2.3^{g}	55.1
	B	34.2 ± 2.9^{i}	55.8	13.7 ± 2.4^{jk}	74.5
	Mean	45.2	41.5	18.9	64.8
T6	A	63.5 ± 3.0^{cd}	18.0	31 ± 2.0^{ef}	42.3
	B	44.3 ± 2.1^{h}	42.8	17.2 ± 3.2^{i}	67.9
	Mean	53.9	30.4	24.1	55.1
T7	2.5 mLL^{-1}	15.9 ± 0.7^{k}	79.4	8 ± 0.6^{l}	85.1
T8	–	77.5 ± 1.9^{a}	–	53.7 ± 2.3^{a}	–

Data represent the mean of three replicates ± standard deviation (SD). Different letters indicate a significant difference between means (at $p \leq 0.05$) by Duncan's multiple range test. A, B = two rates of compost tea (15 and 30 mL/pot), micronutrients (1 and 2 mg/L) and antioxidants (2 and 4 g/L), respectively. * R = disease reduction values, which were calculated based on control.

3.2. Synergistic Effect of Compost Tea, Micronutrients and Antioxidants on SBDM Control in the Field

Data presented in Table 3 show that all treatments significantly reduced SBDM severity over three cuts for two seasons in the field. The most effective treatments were copper hydroxide, compost tea/SA + Cu, compost. tea/SA + Zn and compost tea/AsA + Cu. The corresponding disease reduction values were 83.6, 75.6, 72.9 and 68.7%, respectively in the first season, and 84.3, 77.8, 74.2 and 68.5%, respectively in the second season. While the lowest values were recorded by compost tea/AsA + Fe, reaching 27.4 and 29.5% in the first and second seasons, respectively.

3.3. Growth Characteristics

Data presented in Figure 1 show that all treatments significantly improved growth characteristics of sweet basil, including plant height and number of branches in both seasons. In this regard, plants treated with copper hydroxide, followed by those treated with compost tea/SA + Cu, compost tea/SA + Zn and

Table 3. Synergistic effect of compost tea, micronutrients and antioxidants on the severity of SBDM for three cuts during the 2021 and 2022 seasons in the field.

Treatment	SBDM Severity %				
	1st Season				
	1st Cut	2nd Cut	3rd Cut	Mean	* R
T1	11.4 ± 0.3^{e}	19.5 ± 0.8^{d}	20.7 ± 1.8^{e}	17.2	68.7
T2	27.1 ± 2.1^{c}	28.3 ± 1.7^{c}	39.1 ± 2.7^{c}	31.5	42.8
T3	33.5 ± 2.2^{b}	36.2 ± 1.7^{b}	50.3 ± 2.2^{b}	40.0	27.4
T4	9.5 ± 0.8 ^{e}	14.5 ± 0.6^{f}	16.2 ± 0.5^{f}	13.4	75.6
T5	11.3 ± 1.0^{e}	15.4 ± 0.6^{f}	18 ± 1.1 ^{f}	14.9	72.9
T6	16 ± 0.4 ^{d}	17 ± 0.5 ^{e}	27.3 ± 2.0^{d}	20.1	63.5
T7	5.1 ± 0.3 ^{f}	10.6 ± 0.7^{g}	11.3 ± 0.4^{g}	9.0	83.6
T8	41.7 ± 2.2^{a}	51 ± 1.9 ^{a}	72.6 ± 1.6^{a}	55.1	–
Treatment	2nd Season				
	1st Cut	2nd Cut	3rd Cut	Mean	* R
T1	9.1 ± 0.4 ^{ef}	18.4 ± 1.0^{d}	22 ± 1.9 ^{e}	16.5	68.5
T2	25.3 ± 1.8^{c}	23.9 ± 1.9^{c}	35.7 ± 1.6^{c}	28.3	46.0
T3	30.5 ± 1.5^{b}	35 ± 2.3 ^{b}	45.2 ± 1.9^{b}	36.9	29.5
T4	7.9 ± 0.4 ^{f}	11.8± 0.8^{fg}	15.1 ± 0.3^{g}	11.6	77.8
T5	10.5 ± 0.7^{e}	12.7 ± 0.4^{f}	17.3 ± 0.9^{f}	13.5	74.2
T6	13.4 ± 0.6^{d}	16.3 ± 1.1^{e}	25.2 ± 2.0^{d}	18.3	65.1
T7	4.8 ± 0.3 ^{g}	10.1 ± 0.4^{g}	9.7 ± 0.3 ^{h}	8.2	84.3
T8	39.5 ± 2.5^{a}	49.6 ± 2.4^{a}	68.1 ± 2.3^{a}	52.4	–

Data represent the mean of three replicates ± standard deviation (SD). Different letters indicate a significant difference between means (at $p \leq 0.05$) by Duncan's multiple range test. * R = disease reduction values, which were calculated based on control.

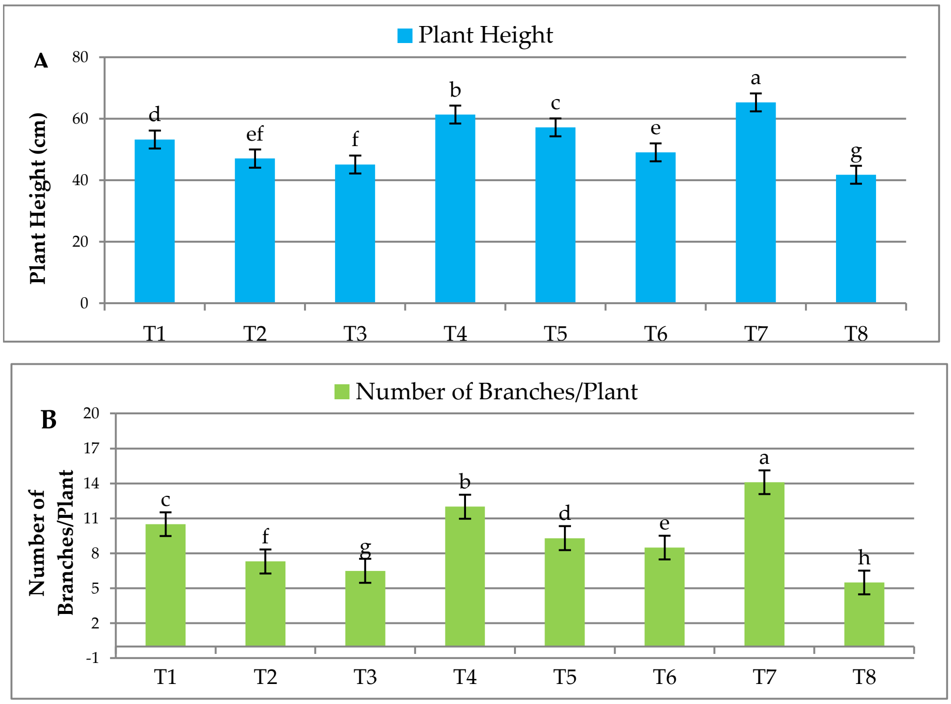

Figure 1. Effect of treatments on (A) plant height (cm) and (B) number of branches/plant of sweet basil. Data represent the mean of two experiments repeated over the 2021 and 2022 seasons. Vertical bars represent are the mean of three replicates ± standard deviation (SD). Different letters indicate a significant difference between means (at $p \leq 0.05$) by Duncan's multiple range test.

compost tea/AsA + Cu recorded the highest plant height values as follows: 65.3, 61.3, 57.2 and 53.2 cm, respectively. While plants treated with compost tea/AsA + Fe recorded the lowest value (45.1 cm) (Figure 1A). The best number of branches was recorded by copper hydroxide, followed by compost tea/SA + Cu, compost tea/AsA + Cu and compost tea/SA + Zn as follows: 14.1, 12.0, 10.5 and 9.3 branch/plant, respectively. While compost tea/AsA + Fe had the lowest value (6.5) (Figure 1B).

3.4. Yield Characteristics

Data in Table 4 show that all treatments significantly increased the fresh and dry weight of sweet basil herb during three cuts in both seasons. In the first season, plants treated with copper hydroxide, compost tea/SA + Cu, compost tea/SA + Zn and compost tea/AsA + Cu gave the highest values of fresh and dry weight of herb as follows: 25.5, 22.7, 20.8 and 19.3 kg/plot, respectively in fresh weight, and 5.5, 4.9, 4.5 and 4.2 kg/plot, respectively in dry weight. While plants treated with compost tea/AsA + Fe recorded the lowest values, 15.9 and 3.4 kg/plot in fresh and dry weight, respectively. In the second season, the best results for herb fresh weight (26.5, 24.1, 22.6 and 20.7 kg/plot) and dry weight (5.7, 5.2, 4.9 and 4.5 kg/plot) were obtained by treatment with copper hydroxide, compost tea/SA + Cu, compost tea/SA + Zn and compost tea/AsA + Cu, respectively. While treatment with compost tea/AsA + Fe recorded the lowest values of 16.7 and 3.6 kg/plot, in fresh and dry weight of herb, respectively.

Table 4. Synergistic effect of compost tea, micronutrients and antioxidants on fresh and dry weight of sweet basil herb for three cuts during the 2021 and 2022 seasons in the field.

Treatment	FW of Herb (kg/Plot)				DW of Herb (kg/Plot)			
	1st Cut	2nd Cut	3rd Cut	Mean	1st Cut	2nd Cut	3rd Cut	Mean
1st Season								
T1	17.4 ± 0.6 ^{c}	22.5 ± 1.7^{cd}	18 ± 1.1 ^{c}	19.3	3.8 ± 0.2 ^{c}	4.9 ± 0.3 ^{b}	3.9 ± 0.2 ^{cde}	4.2
T2	13 ± 0.6 ^{e}	20.1 ± 1.8^{de}	17.3 ± 2.1 ^{c}	16.8	3 ± 0.2 ^{de}	4.2 ± 0.3 ^{c}	3.6 ± 0.4 ^{de}	3.6
T3	12.7 ± 0.5 ^{e}	18.5 ± 0.8 ^{e}	16.5 ± 0.6 ^{c}	15.9	2.8 ± 0.2 ^{de}	3.9 ± 0.3 ^{c}	3.5 ± 0.4 ^{de}	3.4
T4	19.4 ± 0.9 ^{b}	27.2 ± 1.8^{ab}	21.5 ± 3.0^{ab}	22.7	4.2 ± 0.3 ^{b}	6 ± 0.3 ^{a}	4.5 ± 0.2 ^{bc}	4.9
T5	16.3 ± 0.3 ^{c}	24.5 ± 1.3^{bc}	21.6 ± 2.3^{ab}	20.8	3.6 ± 0.3 ^{c}	5.3 ± 0.3 ^{b}	4.6 ± 0.8 ^{b}	4.5
T6	15 ± 0.6 ^{d}	19.4 ± 1.0 ^{e}	19 ± 1.1 ^{bc}	17.9	3.2 ± 0.4 ^{d}	4.1 ± 0.3 ^{c}	4.1 ± 0.2 ^{bcd}	3.8
T7	23.5 ± 1.8 ^{a}	29.2 ± 2.4 ^{a}	23.8 ± 1.5 ^{a}	25.5	5.1 ± 0.2 ^{a}	6.2 ± 0.3 ^{a}	5.2 ± 0.3 ^{a}	5.5
T8	12.8 ± 0.6 ^{e}	17.5 ± 1.4 ^{e}	16.2 ± 0.7 ^{c}	15.5	2.7 ± 0.2 ^{e}	3.8 ± 0.3 ^{c}	3.4 ± 0.3 ^{e}	3.3
2nd Season								
T1	18 ± 0.9 ^{c}	23.7 ± 1.6^{cd}	20.4 ± 1.4 ^{b}	20.7	3.9 ± 0.3 ^{c}	5.1 ± 0.2 ^{d}	4.5 ± 0.2 ^{bc}	4.5
T2	14.7 ± 0.4 ^{d}	21.5 ± 1.8^{de}	16 ± 0.6 ^{d}	17.4	3.2 ± 0.3 ^{a}	4.5 ± 0.3 ^{e}	3.4 ± 0.3 ^{d}	3.7
T3	13.5 ± 0.4 ^{d}	19.6 ± 1.8 ^{e}	17 ± 0.4 ^{cd}	16.7	3 ± 0.3 ^{c}	4.3 ± 0.3 ^{ef}	3.5 ± 0.3 ^{d}	3.6
T4	20.3 ± 1.6 ^{b}	28.6 ± 1.9 ^{b}	23.4 ± 3.0 ^{a}	24.1	4.6 ± 0.5 ^{b}	6.1 ± 0.4 ^{b}	4.9 ± 0.2 ^{ab}	5.2
T5	17.5 ± 1.4 ^{c}	26 ± 2.0 ^{bc}	24.3 ± 1.1 ^{a}	22.6	3.8 ± 0.2 ^{a}	5.6 ± 0.2 ^{c}	5.3 ± 0.3 ^{a}	4.9
T6	17.2 ± 1.3 ^{c}	23.4 ± 1.8^{cd}	18.5 ± 0.9^{bc}	19.7	3.8 ± 0.3 ^{b}	4.9 ± 0.3 ^{d}	4.2 ± 0.3 ^{c}	4.3
T7	23.7 ± 1.4 ^{a}	31.5 ± 1.9 ^{a}	24.3 ± 1.1 ^{a}	26.5	5.1 ± 0.3 ^{b}	6.8 ± 0.3 ^{a}	5.2 ± 0.3 ^{a}	5.7
T8	13.2 ± 1.0 ^{d}	19.7 ± 1.2 ^{e}	15.1 ± 1.0 ^{d}	16.0	2.8 ± 0.3 ^{c}	4.1 ± 0.2 ^{f}	3.3 ± 0.3 ^{d}	3.4

Data represent the mean of three replicates ± standard deviation (SD). Different letters indicate a significant difference between means (at $p \leq 0.05$) by Duncan's multiple range test.

3.5. Essential Oil Content

Data in Figure 2 show that all treatments significantly increased essential oil of sweet basil in both seasons. The highest content was found in plants treated with copper hydroxide, compost tea/SA + Cu, compost tea/SA + Zn, and compost tea/AsA + Cu. The corresponding values of essential oil were 0.88, 0.83, 0.72 and 0.61 mL/300 g DW of herb, respectively. While the lowest content of 0.40 mL/300 g DW of herb was recorded by compost tea/AsA + Fe.

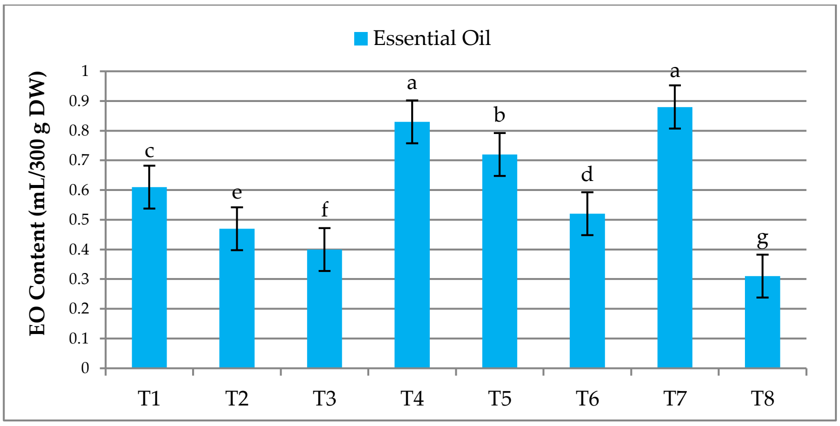

Figure 2. Effect of treatments on sweet basil EO content. Data represent the mean of two experiments repeated over the 2021 and 2022 seasons. Vertical bars represent are the mean of three replicates ± standard deviation (SD). Different letters indicate a significant difference between means (at $p \leq 0.05$) by Duncan's multiple range test.

3.6. Essential Oil Composition

Data presented in Table 5 and Figure 3 show qualitative and quantitative GC-MS analysis of sweet basil essential oil which identified the main components for all samples of the treatments studied. The results indicate that there are clear differences between the treatments in terms of the number and type of their compounds. The number of compounds identified ranged from 34 to 40 distributed among the different treatments. The known components of sweet basil essential oil are classified into three groups as follows: major components (more than 10%), minor components (less than 10% and more than 1%), and trace components (less than 1%). The results also show that T7 had the highest number of major components (4 components: linoleic acid ethyl ester, 2-propenoic acid, 3-phenyl-, methyl ester, sclareol, and linolenic acid, ethyl ester), followed by T1 (3 components: linoleic acid ethyl ester, linolenic acid, ethyl ester, and sclareol), and T4 (2 components: linolenic acid, ethyl ester and aurantio-obtusin). While T5 and T8 were in the lowest order (only one major component). In contrast, T3 does not contain any major components.

In general, it was found that the highest component in the essential oil of sweet basil in most treatments was "linolenic acid, ethyl ester", which ranged between 9.10 and 26.02% as follows: T4 (26.02%), T5 (24.53%), T1 (19.82). %). %), T2 (19.42%), T7 (10.08%), T6 (9.81%), T3 (9.10%), while this compound was not found in T8 (control). The next high component in the essential oil is "linoleic acid ethyl ester", which ranged between 5.74 and 22.46% as follows: T1 (22.46%), T7 (20.23%), T5 (7.93%), T4 (6.44%). and T6 (5.74%), while this compound was not found in T3 and T8. In addition, the "aurantio-obtusin" component ranged from 3.02 to 15.59% as follows: T4 (15.59%), T5 (7.09%), T2 (6.14%), T1 (5.43%), T3 (4.51%), T8 (3.61). %), T6 (3.29%), T7 (3.02%). Likewise, the component "2-propenoic acid, 3-phenyl-, methyl ester" ranged from 1.35 to 15.16% as follows: T6 (15.16%), T7 (13.97%), T5 (4.13%), T2 (2.91%), While this compound was not found in T1, T3 and T8.

Table 5. Chemical compounds identified in the essential oil of sweet basil (*Ocimum basilicum* L.) by GC-MS analysis of eight samples, representing treatments applied in the field.

No.	T1		T2		T3		T4	
	Compound	**%**	**Compound**	**%**	**Compound**	**%**	**Compound**	**%**
1	Hydrocinnamic acid	1.86	Hydrocinnamic acid	3.20	Furfural	0.11	Hydrocinnamic acid	2.45
2	Furfural	0.67	Furfural	0.92	p-Cymen-7-ol	0.12	Furfural	0.49
3	p-Cymen-7-ol	0.34	p-Cymen-7-ol	0.55	Eucalyptol	0.13	p-Cymen-7-ol	0.48
4	Eucalyptol	0.27	Eucalyptol	0.30	Linalool	1.30	Eucalyptol	0.28
5	Linalool	4.12	Linalool	3.95	Isoborneol	0.15	Linalool	1.64
6	Camphor	0.28	Camphor	0.24	8-Hydroxylinalool	0.18	8-Hydroxylinalool	0.28
7	Limonene-1,2-diol	0.49	Estragole	0.70	L-α-Terpineol	0.12	L-α-Terpineol	0.28
8	Estragole	0.50	Bornyl acetate	0.85	Estragole	0.29	Estragole	0.28
9	8-Hydroxylinalool	1.62	Cinnamaldehyde, (E)-	3.77	Citronellol	0.29	Bornyl acetate	0.38
10	Bornyl acetate	0.97	β-Elemen	0.81	Geraniol	0.29	Isocomene	0.35
11	Cinnamaldehyde, (E)-	1.98	β-Caryophyllen	0.37	Bornyl acetate	0.36	Eugenol	0.33
12	β-Elemen	0.73	α-Bergamotene	1.43	Safrole	0.48	Cinnamaldehyde, (E)-	2.98
13	β-Caryophyllen	0.42	γ-Selinene	0.35	Isosafrole	2.73	β-Elemen	0.57
14	α-Bergamotene	1.65	Humulene	0.73	Valencen	0.34	Caryophyllene	0.26
15	epi-γ-Eudesmol	0.28	β-Copaene	0.56	Caryophyllene	0.20	α-Bergamotene	0.69
16	Humulene	0.75	β-Cubebene	1.09	α-Bergamotene	0.44	β-Copaene	0.39
17	β-Copaene	0.65	8,14-Cedrane oxide	0.30	(+)-Aromadendrene	0.21	α-Ylangene	0.54
18	β-Cubebene	1.28	γ-Cadinene	1.46	Acorenone B	1.04	γ-Cadinene	1.13
19	(+)-Ledene	0.24	Spathulenol	0.70	Cubebol	0.29	γ-Selinene	0.27
20	8,14-Cedrane oxide	0.42	Cubebol	4.29	β-Copaene	0.65	Cubebol	0.80
21	γ-Cadinene	1.79	epi-Globulol	0.34	γ-Selinene	0.18	tau-Cadinol	4.72
22	trans-Calamenene	0.30	Phytol	1.25	Sclareol	0.21	epi-Globulol	0.34
23	Spathulenol	0.31	Citronellyl tiglate	0.69	γ-Cadinene	0.69	Isophytol	1.47
24	Caryophyllene oxide	0.28	Hexadecanal	1.37	Spathulenol	2.25	Phytol	1.27
25	Cubebol	1.12	Corymbolone	0.34	Cubebol	0.75	Sclareolide	2.02
26	tau-Cadinol	6.82	Geranyl isovalerate	0.77	γ-Eudesmol	8.55	Citronellyl tiglate	1.38
27	epi-Globulol	0.50	Aurantio-obtusin	6.14	tau.-Cadinol	4.97	2-Hexadecanol	1.53
28	Hexadecanoic acid, ethyl ester	2.06	Hexadecanoic acid, ethyl ester	2.41	epi-Globulol	1.12	Aurantio-obtusin	15.6

Table 5

29	Linolenic acid, ethyl ester	19.8	Linolenic acid, ethyl ester	19.4	Linolenic acid, ethyl ester	9.10	Linolenic acid, ethyl ester	26.0
30	Citronellyl tiglate	0.71	Linoleic acid ethyl ester	20.7	Geranyl tiglate	3.65	Linoleic acid ethyl ester	6.44
31	Kaempferol 3,7,4'-trimethyl ether	1.46	Kaempferol 3,7,4'-trimethyl ether	1.75	Farnesol	0.80	2-Propenoic acid, 3-phenyl-, methyl ester	1.35
32	Aurantio-obtusin	5.43	Isosafrole	4.29	Isocalamenediol	0.32	Casticin	6.18
33	Linoleic acid ethyl ester	22.4	2-Propenoic acid, 3-phenyl-, methyl ester	2.91	Hexa-hydro-farnesol	0.82	Isosafrole	1.36
34	Phytol	0.66	epi-Cubebol	0.52	Citronellyl tiglate	0.50	Lupeol	5.47
35	Isolongifolol	0.42	trans-Geranylgeraniol	7.05	Nerol acetate	0.59	Geranyl isovalerate	3.37
36	Corymbolone	0.42	Cedrol	0.98	Aurantio-obtusin	4.51	Cycloartanol	1.56
37	Sclareol	11.7	Batilol	2.04	β-Eudesmol	4.23	Batilol	3.65
38	Cedrol	1.05	epi-Globulol	0.34	Humulone	1.02	α-Amyrin	1.41
39	Batilol	3.16			Phytol	3.67		
40					Scoulerine	1.27		

Values represent the mean of three samples. T1: compost tea/AsA + Cu; T2: compost tea/AsA + Zn; T3: compost tea/AsA + Fe; and T4: compost tea/SA + Cu.

Table 5. Continue. Chemical compounds identified in the essential oil of sweet basil (*O. basilicum* L.) by GC-MS analysis of eight samples, representing treatments applied in the field.

No.	T5		T6		T7		T8	
	Compound	**%**	**Compound**	**%**	**Compound**	**%**	**Compound**	**%**
1	Hydrocinnamic acid	6.62	Hydrocinnamic acid	2.69	Hydrocinnamic acid	2.20	Hydrocinnamic acid	1.79
2	Furfural	2.11	Furfural	1.09	Furfural	0.52	Furfural	0.21
3	p-Cymen-7-ol	1.26	p-Cymen-7-ol	0.35	p-Cymen-7-ol	0.32	p-Cymen-7-ol	0.32
4	Eucalyptol	0.30	Eucalyptol	0.32	Eucalyptol	0.32	Eucalyptol	0.60
5	Linalool	6.22	Linalool	2.17	Linalool	3.45	3-Carene	0.14
6	Camphor	0.27	Estragole	0.70	Camphor	0.22	Linalool	3.70
7	Estragole	1.17	Isobornyl acetate	0.39	Estragole	0.46	Camphor	0.21
8	Bornyl acetate	1.16	Safrole	1.05	α-Longipinene	1.16	Isoborneol	0.29
9	Safrole	0.29	Eugenol	1.20	Bornyl acetate	0.54	8-Hydroxylinalool	0.20
10	2-Hexadecanol	0.29	Isosafrole	7.88	Cinnamaldehyde, (E)-	5.60	L-α-Terpineol	0.34
11	β-Elemen	0.70	α-Bergamotene	0.51	β-Elemene	0.64	Estragole	0.64
12	β-Caryophyllen	0.48	Humulene	0.85	α-Bergamotene	0.79	Geraniol	0.24
13	α-Bergamotene	1.50	α-Copaene	0.30	Humulene	0.41	Bornyl acetate	0.75
14	γ-Selinene	0.45	epi-Cubebol	0.33	β-Cubebene	0.60	Carvacrol	0.23
15	Humulene	0.89	γ-Cadinene	1.28	γ-Cadinene	1.07	Safrole	1.55
16	β-Copaene	0.51	Spathulenol	0.55	Cubebol	0.73	Acorenone B	0.20
17	β-Cubebene	1.05	Cubebol	1.18	tau-Cadinol	5.32	Eugenol	1.19
18	8,14-Cedrane oxide	0.54	epi-γ-Eudesmol	0.17	epi-Globulol	0.42	Isosafrole	7.56
19	γ-Cadinene	2.57	tau.-Cadinol	10.0	Phytol	1.18	Valencen	0.73
20	Spathulenol	0.31	epi-Globulol	1.00	Citronellyl tiglate	0.77	Caryophyllene	0.39
21	Corymbolone	0.98	Caryophyllene oxide	0.18	Corymbolone	0.30	α-Bergamotene	1.45
22	Apiol	2.92	Phytol	1.51	Ethyl pentadecanoate	1.35	β-Gurjunene	0.44
23	tau-Cadinol	8.34	Sclareolide	0.67	Aurantio-obtusin	3.02	Humulene	0.64
24	epi-Globulol	0.72	11-cis-Vaccenyl acetate	1.18	Sclareol	11.0	α-Copaene	0.45
25	Phytol	2.66	Geranyl isovalerate	1.09	Geranyl isovalerate	4.24	β-Cubebene	0.95
26	Citronellyl tiglate	1.44	Aurantio-obtusin	3.29	Cedrol	0.64	γ-Selinene	0.24
27	2-Propenoic acid, 3-phenyl-, methyl ester	4.13	Hexadecanoic acid, ethyl ester	1.19	Linolenic acid, ethyl ester	10.1	(+)-Ledene	0.30

Table 5

28	Hexadecanoic acid, ethyl ester	0.63	Quercetin-3,7,3',4'-tetramethyl ether	1.84	Hexadecanoic acid, ethyl ester	1.44	Hexadecanoic acid, ethyl ester	1.00
29	1,2-enzenedicarboxylic acid, butyl octyl ester	1.03	Linolenic acid, ethyl ester	9.81	2-Propenoic acid, 3-phenyl-, methyl ester	14.0	γ-Cadinene	2.08
30	Aurantio-obtusin	7.09	Linoleic acid ethyl ester	5.74	Linoleic acid ethyl ester	20.2	Cubebol	1.46
31	Linolenic acid, ethyl ester	24.5	2-Propenoic acid, 3-phenyl-, methyl ester	15.2	Kaempferol 3,7,4'-trimethyl ether	1.65	epi-γ-Eudesmol	0.86
32	Linoleic acid ethyl ester	7.93	Octadecanoic acid, ethyl ester	0.74	Betulin	0.71	Cedrelanol	10.7
33	Hexadecanal	1.74	Acorenone B	1.13	Isosafrole	1.30	epi-Globulol	1.57
34	Isobavachalcone	7.16	Xanthinin	0.66	Batilol	3.37	Caryophylene oxide	0.17
35			Isosafrole	1.00			Corymbolone	0.18
36			Lupeol	7.01			Phytol	1.29
37			Phytol	6.52			Spathulenol	0.93
38			β-Sitosterol	1.38			Aurantio-obtusin	3.61
39			γ-Sitosterol	2.53			Hexadecanal	3.24
40			Batilol	3.33			Phytol	4.25

Values represent the mean of three samples. T5: compost tea/SA + Zn; T6: compost tea/SA + Fe; T7: copper hydroxide; and T8: control.

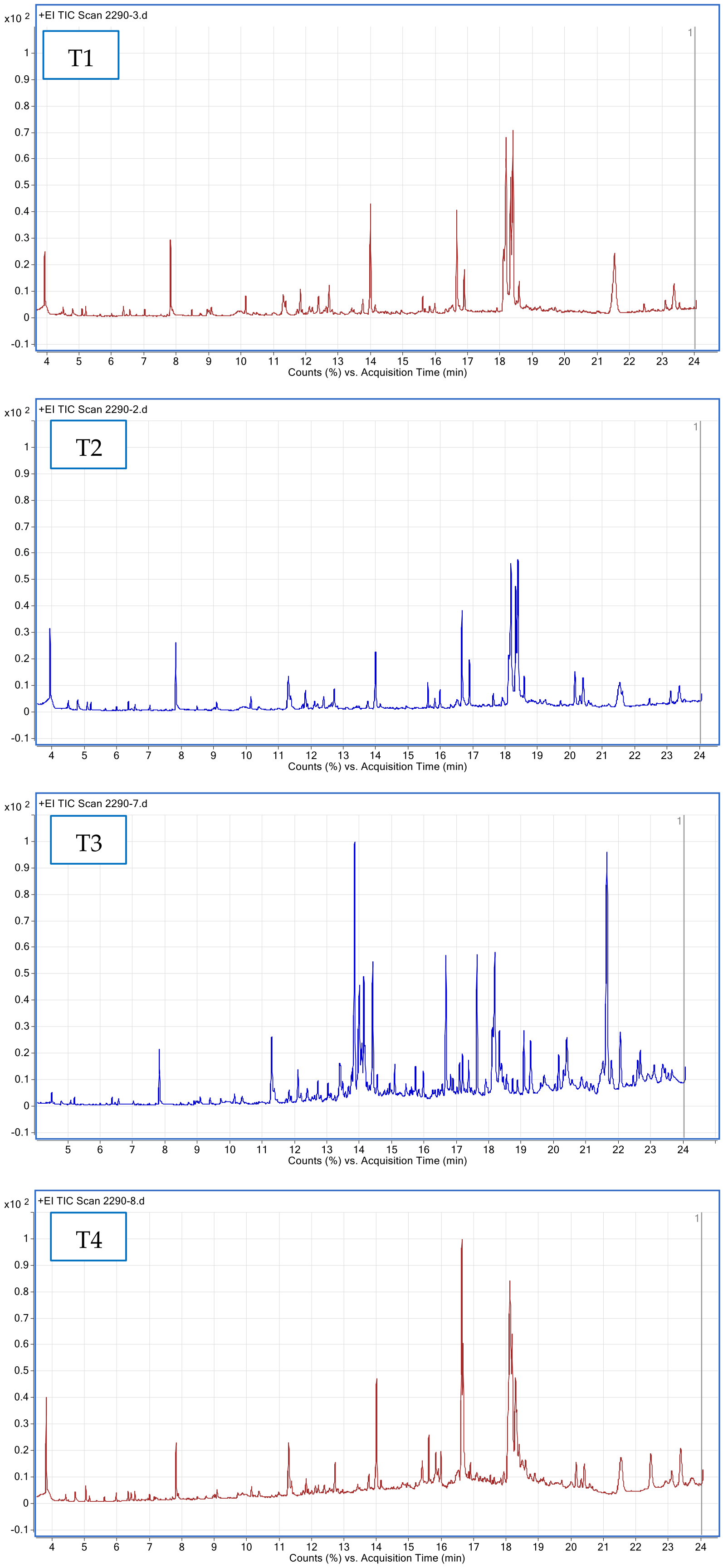

Figure 3. GC-MS analysis of four samples of sweet basil essential oil, representing the tested treatments (T1 to T4) applied in the field. T1: compost tea/AsA + Cu; T2: compost tea/AsA + Zn; T3: compost tea/AsA + Fe; and T4: compost tea/SA + Cu.

Figure 3. Continue. GC-MS analysis of four samples of sweet basil essential oil, representing the tested treatments (T5 to T8) applied in the field. T5: compost tea/SA + Zn; T6: compost tea/SA + Fe; T7: copper hydroxide; and T8: control.

3.7. Photosynthetic Leaf Pigments

Data in (Figure 4A) show that all treatments significantly increased chlorophyll (a, b) and carotenoids in both seasons. The highest values of these pigments were found in plants treated with copper hydroxide, compost tea/SA + Cu, compost tea/SA + Zn and compost tea/AsA + Cu as follows: 6.56, 6.46, 5.67 and 5.05 mg/g leaf FW, respectively in chlorophyll a, 2.58, 2.52, 2.22 and 1.98 mg g^{-1} leaf FW, respectively in chlorophyll b, and 0.72, 0.67, 0.62 and 0.54 mg/g leaf FW, respectively in carotenoids. While compost tea/AsA + Fe recorded the lowest values of 3.37, 1.18 and 0.36 mg/g leaf FW for chlorophyll a, chlorophyll b, and carotenoids, respectively.

3.8. Antioxidant Enzymes Activity

As revealed in (Figure 4B), all treatments significantly improved the activity of peroxidase and catalase in both seasons. The highest activity was recorded by copper hydroxide, compost tea/SA + Cu, compost tea/SA + Zn and compost tea/AsA + Cu as follows: 0.57, 0.54, 0.50 and 0.47 unit/mg protein/min, respectively in peroxidase, and 6.86, 6.50, 6.18 and 5.14 unit/mg protein/min, respectively in catalase. While, the lowest activity was recorded by compost tea/AsA + Fe, reaching 0.35 and 4.50 unit/mg protein/min for peroxidase and catalase, respectively.

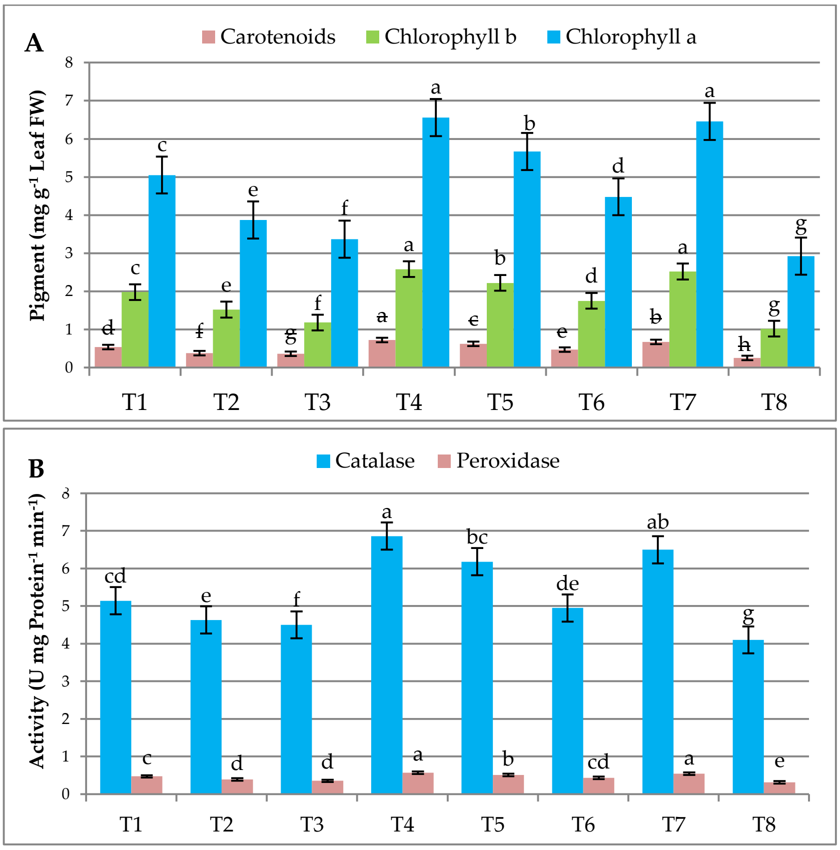

Figure 4. Effect of treatments on (A) photosynthetic leaf pigments and (B) antioxidant enzymes activity in sweet basil. Data represent the mean of two experiments repeated over the 2021 and 2022 seasons. Vertical bars represent are the mean of three replicates ± standard deviation (SD). Different letters indicate a significant difference between means (at $p \leq 0.05$) by Duncan's multiple range test.

4. DISCUSSION

Downy mildew is one of the major foliar disease affecting sweet basil (Abdullah et al., 2022), which is caused by the obligate, biotrophic oomycete fungus *Peronospora belbahrii* Thines (Thines et al., 2009). This disease was first observed in Egypt during the 2013 season (Hilal and Ghebrial, 2014). Under favorable conditions it has become a very destructive disease, causing serious damages and losses to the crop (Ghebrial and Nada, 2017). The major purpose of this investigation was to study the synergistic effect of compost tea, micronutrients and antioxidants on downy mildew control of sweet basil under *in vivo* conditions. Our results showed that all treatments used in the greenhouse led to a significant decrease in sweet basil downy mildew (SBDM) compared to the control. Concentration B was more efficient in reducing disease than concentration A. The most effective treatments were copper hydroxide, compost tea/SA + Cu, compost tea/SA + Zn and compost tea/AsA + Cu. While the least effective treatment was compost tea/AsA + Fe. Similar results were obtained in the field during the 2021 and 2022 seasons. This result is in agreement with that of Pane et al. (2007), who found that treating vegetable crops with compost tea effectively suppressed powdery and downy mildews, gray mold and root rot. The same effects were also obtained against potato diseases caused by *Fusarium* sp., *A. solani*, *H. solani*, *P. infestans*, and *R. solani*, and tomato diseases caused by *F. oxysporum* f. sp**.** *lycopersici* and *R. solani* (Morales-Corts et al., 2018). Tegegn (2017) also reported that the use of compost tea significantly decreased the major diseases of faba bean caused by *B. cinerea*, *A. alternate* and *P. lycopersici*. Moreover, Giménez et al. (2020) reported that the use of compost tea mitigated the damage caused by *Uncinula necator*, *Plasmopara vitícola*, *P. infestans*, *Sphaerotheca fuliginea*, *S. pannosa* var. *rosae,* and *Venturia inaequalis* in Arabidopsis, potato, cucumber, tomato, grapevine, rose, and apple. The positive impacts of compost tea in suppressing plant diseases can be attributed to it containing a variety of beneficial microorganisms, including protozoa, fungi, bacteria, yeasts, oomycetes, and actinomycetes, due to their pathogen-inhibiting activity and/or plant growth-promoting properties (González-Hernández et al., 2021). These microorganisms also have a synergistic effect in the biological control of different plant pathogens (Zaccardelli et al., 2018). The antagonistic ability of microorganisms in compost tea has been shown to operate through typical mechanisms of antagonism, mycoparasitization, and competition for space, nutrients, and/or sites of infection (Segarra et al., 2009). Also, soluble nutrients in compost tea can protect crops through direct toxicity to the pathogens, induce systemic plant resistance, or improve plant nutritional and physiological status (Koné et al., 2010). Additionally, the beneficial effects of compost tea on soil fertility have been shown to directly or indirectly affect the community of rhizosphere-associated microorganisms, thereby altering disease-causing conditions (Meshref et al., 2010).

Regarding the positive impacts of micronutrients on plant disease management, Elad et al. (2021a) found that foliar sprays with zinc and manganese significantly reduced the severity of downy mildew in sweet basil by 46–71%. Similar results were also obtained when sweet basil plants were sprayed or irrigated with calcium, nitrogen, potassium, and magnesium (Elad et al., 2021b). In addition, foliar application of zinc significantly decreased the susceptibility of cabbage and turnip plants to powdery mildew (Tomlison and Webb, 1958) and wheat to take-all disease (Graham and Webb, 1991). Also, the application of zinc, manganese, and boron was effective against potato early blight, coffee rust, and wheat tan spot (Perez et al., 2020). In a similar vein, iron application significantly reduced the severity of wheat rust and banana anthracnose (Graham and Webb, 1991), and increased the resistance of cabbage and apple to *O. brassicae* and *S. malorum*, respectively (Graham, 1983). In addition, low levels of copper increased the susceptibility of sunflower, barley and wheat to *A. helianthi*, *C. purpurea* and *S. tritici*, respectively, while high levels reduced the susceptibility of peanut to *S. minor* (Hallock and Porter, 1981). Concerning the effect of antioxidants on plant disease control, foliar application of SA induced resistance in *A. thaliana* against powdery and downy mildews (Genger et al., 2008), in tobacco against powdery mildew (Nakashita et al., 2002), in tomato against leaf blight (Spletzer and Enyedi, 1999), and in cherry fruits against fruit rot (Yao and Tian, 2005). On the other hand, the use of ascorbic acid has increased the resistance of a large number of plants against plant diseases, such as roselle against root rot and wilt (Ahmed et al., 2023), potato against early and late blights (Al-Gamal et al., 2007), and sunflower against powdery mildew (Yousef, 2021). As mentioned by Awadalla (2008), treating tomato with a mixture of SA and AsA increased resistance against early blight by stimulating tomatin (phytoalexin) production in leaves and stems, a compound toxic to pathogens. In general, antioxidants have achieved good results for induction of systemic resistance in plants against plant pathogens (Dutta, et al., 2016). This activity is due to its promotion of some morphological and physiological changes in defense-related compounds in the host (Göre, 2009). For example, SA application has been found to stimulate cell wall strengthening, ROS production, PR gene expression, and induction of proteins associated with pathogenesis and resistance to fungal, bacterial and viral diseases (Vallard and Goodman, 2004).

In this study, the reduction of SBDM severity due to the synergistic effect of the treatments was expressed positively through the improvement of growth and yield features of sweet basil. These results are in agreement with those of Siddiqui et al. (2008), who found that foliar application of compost tea significantly stimulated growth characteristics of *Abelmoschus esculentus*, including plant height, root length, and number and area of leaves. In addition, Abdel-Haleem et al. (2022) reported that soil supplementation with a mixture of compost tea, vermicompost, and compost significantly increased the growth, yield, and quality of onion crop. Moreover, Mohamed et al. (2021) found that foliar application of compost tea mixed with seaweed extract significantly increased the weight, length and diameter of sweet pepper fruits. The positive effects of compost tea in improving crop growth and productivity can be due to it containing a variety of macroelements, plant hormones, microelements, humic acids, and heavy metals. These abiotic components aid in nutrient uptake, soil fertility, stimulate rhizosphere-associated microorganisms, and enhance the physiological and nutritional status of the plant (Jasson et al., 2017). Moreover, compost tea contains diverse groups of beneficial microorganisms or their metabolic compounds, which act as plant growth stimulant and/or improve the chemical, physical, and biological properties of soil (Zaccardelli et al., 2018). In a similar vein, micronutrients play a vital role in plant nutrition, thus improving growth and resulting yield. For example, copper is important for photosynthesis, mitochondrial respiration, carbon and nitrogen metabolism, protection of cells from oxidative stress, and cell wall synthesis. It is also essential for enzymes involved in lignin synthesis, such as polyphenol oxidase and phenolase (Bussler, 1981), and acts as a cofactor for ethylene receptors (Rodríguez et al., 1999). In addition, zinc contributes to protein synthesis, transcription factor function, energy production, and the structure and integrity of cell membranes. As reported by Kramer and Clemens (2005) about 1,200 proteins have been discovered that contain, bind, or transport zinc. Iron is essential for photosynthesis, nitrogen uptake, mitochondrial respiration, synthesis of jasmonic acid and gibberellin hormones, scavenging of ROS and resistance to different pathogens (Hansch and Mendel, 2009). As for the effect of antioxidants on improving growth and yield characteristics, El-Hady et al. (2021) found that treating tomato with a mixture of salicylic acid and propolis gave good results for plant length and height and the number of branches, leaves, and fruits. Also, Yousef (2021) reported that the mixture of salicylic acid and *T. harzianum* was effective in increasing the fresh and dry weight of sunflower. Likewise, Ahmed et al. (2023) found that a mixture of salicylic acid, ascorbic acid, and potassium silicate significantly improved the growth and yield parameters of roselle. In general, SA application has been found to regulate many biological and physiological functions, such as transpiration, cell membrane permeability, ion uptake, photosynthesis, stomatal conductance, transportation, and growth development (Ibrahim et al., 2019). Application of SA has been found to increase crop productivity by reducing various stresses (Khan et al., 2015), altering hormonal status (Shakirova et al., 2003), or enhancing osmoregulation and activities of antioxidant-enzymes (Faried et al., 2017). On the other hand, the use of ascorbic acid is associated with some physiological functions, including photosynthesis, cell division and expansion, and flower development (El-Sayed et al., 2014). It is also involved in metabolic activities, cell signaling, and regulation of some physiological roles that help the plant withstand various stresses (Desoky et al., 2020).

Our results revealed that all treatments significantly increased chlorophyll (a, b) and carotenoids. These results are in agreement with those of Morales-Corts et al. (2018) and Abdel-Haleem et al. (2022), who found that treating onion and tomato with compost tea resulted in a significant increase in chlorophyll content. Also, El-Hady et al. (2021) reported that treating tomato with a mixture of salicylic acid and propolis significantly improved chlorophyll (a, b) and carotenoids. In the current study, all treatments resulted in an increase in peroxidase and catalase activities. This finding is consistent with that of Siddiqui et al. (2008), who found that treating okra with compost tea increased the activities of peroxidase, phenylalanine-ammonium-lyase, and polyphenol oxidase. Likewise, Ahmed et al. (2023) reported that treatment of roselle with a mixture of ascorbic acid, salicylic acid, and potassium silicate significantly increased the activity of polyphenol oxidase, peroxidase, and phenylalanine ammonia-lyase. In addition, Yousef (2021) reported that the highest activity of peroxidase, polyphenol oxidase, and catalase in sunflower was induced after treating with salicylic acid. Similarly, El-Hady et al. (2021) found that treatment of tomato with a mixture of salicylic acid and propolis showed the highest activity of superoxide dismutase, peroxidase, and catalase enzymes. In general, antioxidant enzymes play a vital role in plant tolerance to stress caused by bacterial fungal, and viral invasions (Ahmed et al., 2021; Ahmed et al., 2023). Peroxidase is essential for the synthesis of antimicrobial compounds, *i.e.* lignin and phenols (Nikraftar et al., 2013). These compounds provide resistance to physical, chemical, and biological attacks on crops (Pandey et al., 2017). Peroxidase is also related to some physiological properties, including IAA oxidation, phenol oxidation, polysaccharide cross-linking, cell elongation, oxidation of cinnamyl hydroxyl alcohols to free radical intermediates and wound healing (Vidhyasekaran, 1997). Catalase is a heme-containing homotetrameric enzyme that catalyzes the hydrolysis of harmful H_2O_2 into H_2O and O_2 and is abundantly localized in peroxisomes also found in the cytosol, mitochondria and chloroplasts (Mullen et al., 1999). It also contributes to the development of plant growth and plant resistance to pathogen attacks (Yang and Poovaiah, 2002).

5. CONCLUSION

Downy mildew is one of the major foliar diseases affecting sweet basil in its growing areas in Egypt, causing severe losses in the herb and consequently the resulting essential oil. Here, we tested the synergistic effect of compost tea, micronutrients and antioxidants on SBDM control under *in vivo* conditions. All applied treatments significantly reduced SBDM severity compared to control plants. The most effective treatments were copper hydroxide, compost tea/SA + Cu, compost tea/SA + Zn and compost tea/AsA + Cu, while the least effective treatment was compost tea/AsA + Fe. Reduction in SBDM severity due to the synergistic effect of treatments through improvement of growth and yield features has been favorably expressed. Along with a significant increase in the content of the essential oil and its active components, the activities of defense-related enzymes, and photosynthetic pigments.

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الملخص العربي

التأثير التآزري لشاي الكمبوست والمغذيات الصغرى ومضادات الاكسدة على مقاومة البياض الزغبي في الريحان الحلو تحت ظروف الصوبة والحقل

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[٣]المعمل المركزي للمناخ الزراعي – مركز البحوث الزراعية
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أجريت هذه الدراسة للتحقيق في التأثير التآزري لشاي الكمبوست والمغذيات الصغرى ومضادات الاكسدة في مقاومة البياض الزغبي في الريحان الحلو تحت ظروف الصوبة والحقل. تم اضافة شاي الكمبوست للتربة في حين استخدمت بقية المعاملات الاخرى كرش ورقي. طبقت المعاملات في الصوبة ثلاثة مرات بفاصل ١٥ يوم وذلك بمعدلين على النحو التالي: شاي الكمبوست (١٥ و٣٠ مل/اصيص)، المغذيات الصغرى (١ و٢ ملجم/لتر)، مضادات الاكسدة (٢ و٤ جم/لتر). طبقت المعاملات في الحقل ثلاثة مرات موزعة على ثلاثة حشات، وذلك بمعدل ١,٥ لتر/مكرر من شاي الكمبوست، ٢ ملجم/لتر من المغذيات الصغرى، و٤ جم/لتر من مضادات الاكسدة. اظهرت النتائج ان كل المعاملات المطبقة في الصوبة ادت الى خفض معنوي في المرض مقارنة بالنباتات الغير معاملة. حيث كان التركيز ب اكثر فعالية في خفض المرض من التركيز أ. وكانت المعاملات الاكثر فعالية هي هيدروكسيد النحاس، شاي الكمبوست/حامض سالسيليك + النحاس، شاي الكمبوست/حامض سالسيليك + الزنك، شاي الكمبوست/حامض الاسكوربيك + النحاس. وكانت القيم المقابلة للخفض في نسبة المرض هي ٧٩,٤، ٦٧,٢، ٥٥,٨، و٤٨%، على الترتيب، والقيم المقابلة للخفض في شدة المرض هي ٨٥,١، ٧٨,٩، ٧٤,٥، و٧١,١%، على الترتيب. وقد تم الحصول على نتائج مماثلة في الحقل خلال موسمين متتاليين. وقد انعكس الانخفاض في شدة المرض ايجابياً على تحسن ملحوظ في صفات النمو والمحصول، الى جانب حدوث زيادة معنوية في محتوى الزيت العطري ومكوناته الفعالة، وانشطة الانزيمات المتعلقة بالدفاع (مثل البيروكسيديز والكتاليز)، وصبغات التمثيل الضوئي.