

Microwave power level and exposure time alteration of compost tea efficacy, and growth of *Plectranthus amboinicus*

Abstract

The unique properties of selective heating at the molecular level, and the resultant enhancement effect of microwave in agri-food sciences have been amply demonstrated. This study examined variations in microwave irradiation power level (0, 100, 200, 300 and 400 W) and exposure times (5 and 10 min) effects on the potency of municipal solid waste (MSW) compost tea and *Plectranthus amboinicus* plant growth and nutrient composition. A linear regression equation showed slopes of 0.160°C/W for the 10 min exposure and 0.114°C/W for the 5 min exposure. The turbidity of the microwaved compost tea reduced as the microwave power level and exposure increased. Electric conductivity, total dissolved solids and salinity of the MSW compost tea increased by a factor of 0.08 at the 400 W power level. Plant sap °Brix, nitrate and calcium concentrations were increased by power levels of ≥ 300 W. Stem diameter was increased by an average factor of 0.08 for the 5 min and 10 min exposure times following application of the 300 W microwaved MSW compost tea. Chlorophyll content rose by a factor of 0.09 at 10 mins between the 200 W and the 300 W after which it remained unchanged. On the other hand, anthocyanin content was consistently higher in plants treated with the 5 mins microwaved MSW compost tea compared to the 10 mins treatment irrespective of the microwave power level. To understand the mechanism of action of microwaved vermicast, current study is focused on microbial communities in MSW compost tea.

Keywords: microwave irradiation, compost, organic amendment, *Plectranthus*, plant nutrition

Volume 3 Issue 4 - 2019

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Received: July 19, 2019 | **Published:** July 23, 2019

Introduction

Application of microwave technology in agriculture has gained considerable research attention due to its unique selective heating at the molecular level.^{1,2} The electromagnetic wave of microwave irradiation has frequency of approximately 2.45 GHz, which is higher than radio waves but lower than infrared waves.² The principle of operation of microwave technology is based on rapid movement of polar (water) molecules leading to collisions and friction that generate localized super heating.^{2,3} As such, the quantitative and qualitative effects of microwave irradiation are dependent on various factors such as power output level, exposure time, and the moisture content and heat capacity of the exposed material. These determine heat-load and extent of alteration in the properties of the exposed material. However, the effect of microwave irradiation on the efficacy of compost tea and plant growth performance is unknown.

The efficacy and importance of municipal solid waste compost are well documented, especially in improving soil structure, crop productivity and enhancing action transfer.⁴⁻⁶ Nevertheless, the major concern is the potential release of heavy metals and other solid contaminants from municipal solid waste compost into soils and environment. For that matter, source separation is used to minimize contaminants,⁷ while microwave technology was successfully used to extract heavy metals from sewage sludge.⁸ It is therefore worthwhile to investigate the use of microwave technology to enhance quality and efficacy of municipal solid waste compost tea while minimizing potential environmental hazards.

Plectranthus amboinicus, also known as Jamaican thyme, Mexican mint and others, is popularly used as ornamental, culinary and

medicinal plant in the tropics. It is valued for its bioactive compounds for the treatment of fever, skin diseases and control of diabetes mellitus.^{9,10} *Plectranthus amboinicus* is also used for flavoring beef, chicken, and goat meats to mask their strong smells.¹¹ Recent study indicated that vermicompost can enhance growth, antioxidants and anti-*Streptococcus* properties of *Plectranthus amboinicus*.¹² Water extracts and infusion of composts are becoming popular foliar spray or soil drench in the agricultural industry. For instance, diluted leachate of vermicompost was used to minimize leaf scorching and other physical damages, and to increase plant growth.¹³ Based on these previous studies, it was postulated that an increase in microwave irradiation power output level and time of exposure will enhance compost tea nutrient density to improve plant growth and nutrients uptake. Therefore, the objectives of this study were to determine variations in microwave power level and exposure time alteration of physical and chemical properties of municipal solid waste compost tea, and to assess its impact on *Plectranthus amboinicus* growth and nutrients uptake.

Materials and Methods

Location and materials

The experiment was performed in the Department of Plant, Food, and Environmental Sciences greenhouse from March to August 2017. Municipal solid waste compost was obtained from Fundy Compost Inc., Brookfield, NS, Canada. Soft-wood cuttings of *Plectranthus amboinicus* were obtained from a healthy mother plant in the department's greenhouse. Promix BX™ soilless potting mix medium (Premier Horticulture Inc., Quakertown, PA, USA) was purchased from a local retailer (Halifax Seeds Company, Debent, NS, Canada).

The Promix BX™ was a general-purpose peat-based substrate composed of 75%-85% sphagnum peat moss; horticultural-grade perlite and vermiculite; dolomitic and calcitic limestone; a wetting agent, and mycorrhizal fungus (*Glomus intraradices*). A General Electric Microwave Oven (Model No. JES1295STC01, Mabe Canada Inc., Mississauga, ON, Canada) was used to irradiate the MSW compost tea.

Rooting of stem cuttings and planting

Approximately, 5-cm length soft-wood stem cuttings of the *Plectranthus amboinicus* each with three buds were planted in a 36 cell-tray filled with perlite alone in March 2017. Before planting, the stem-end of each cutting was dipped in STIM ROOT #1 (i.e. 0.1% indole-3-butryic acid) to promote rooting. The cuttings were placed in the nursery under mist irrigation system for two weeks to root. After rooting, plants were moved to the main growing area of the greenhouse to establish. The rooted cuttings were transplanted into 6-inch diameter plastic pots (i.e. one plant per pot) containing 500 g of Promix BX™ soilless mix alone. The plants were watered once every two or three days with distilled water. No additional nutrient supplement nor compost was added throughout the growing period. The mean temperature in the greenhouse was approximately 24°C during the day and 18°C at night, and a mean relative humidity of approximately 78%. Supplementary lighting was provided using a 600 J·s⁻¹ high-pressure sodium lamp to achieve a 12-hr light cycle when needed. Plants were harvested 16 weeks after transplanting.

Preparation and application of MSW compost tea

One-hundred (100) g of dry MSW compost at approximately 10% moisture content was placed in a conical flask and 2 l of distilled water and a magnetic stirrer were added. The mixture was stirred for 24 hr using Isotemp stirring plate (model LT1892X1, Thermo Fisher Scientific Inc., Markham, ON, Canada) to make a MSW compost extract referred to as MSW compost tea. The compost tea (200 l) was then microwaved at varying microwave power levels and exposure times in a microwavable pyrex glass bowl. The microwave power levels were 100, 200, 300 and 400 W at exposure times 5 and 10 mins. The control treatment was non-microwaved compost tea (0 W). The microwaved MSW compost teas were allowed to cool down before analysis and drenching of the respective growing media. Each potted-plant received 40 ml of the respective compost tea once every two weeks.

Experimental design and data collection

The 2-factor experiment consisted of six different levels of microwave power output levels and two different times of exposure to irradiation (see section 2.3 above). The treatments were arranged in a randomized complete block design with five replications. Time was the main plot and the microwave power level was the subplot. Each treatment combination or experimental unit consisted of five potted plants. The pots were rearranged weekly to offset any unpredictable occurrence due to variation in greenhouse environment that might influence the results.

MSW compost tea and growing medium analysis

The temperature of the microwaved MSW compost tea was recorded immediately after the microwave irradiation treatment. The turbidity of the microwaved MSW compost tea was recorded using a Turbidity meter (Oakton Instruments, IL, USA). Total dissolved solids

(TDS), electric conductivity (EC) and salinity of the microwaved MSW compost tea was recorded using Oakton PCTesterTM 35 multimeter (Oakton Instruments, IL, USA). Nitrate (NO³), potassium (K⁺), sodium (Na⁺) and calcium (Ca²⁺) ion concentrations were determined using LAQUA Twin ion meter (HORIBA. Minami-ku, Kyoto, Japan). At the end of the experiment, 10-g samples of the individual growing medium per treatment were liquefied in 40 ml distilled water, stirred for 5 mins and the EC, TDS, NO³, K⁺, Na⁺ and Ca²⁺ concentrations were determined as previously described. The same data as described above for the microwaved MSW compost teas were collected for the control treatment i.e. non-microwaved MSW compost tea.

Leaf tissue analysis

Leaves (50 g) of *Plectranthus amboinicus* were harvested from the third youngest leaf cluster for sap extraction using hydraulic plant sap press (Spectrum Technologies Inc, Aurora, Illinois, USA) and analyzed. °Brix was determined using a portable PAL-BX/RI ATAGO refractometer (ATAGO USA Inc., WA., USA). Also, the concentrations of NO³, Na⁺ and Ca²⁺ were determined as previously described.

Leaf pigments and plant growth analyses

Chlorophyll content was estimated by SPAD value of leaf greenness from the 3rd and 4th youngest leaf per plant per treatment using SPAD 502 Chlorophyll meter (Spectrum Technologies Inc., Aurora, Illinois, USA). Anthocyanin content was also determined from the same tagged leaves using ACM-200 plus (Opti-Science Inc., Hudson, USA). Plant growth was estimated using stem diameter and total plant fresh weight at final harvest. The stem diameter was measured from the mid-section of the stem using a pair of Mastercraft calipers (Canadian Tire. Toronto, ON, Canada).

Data analysis

Data collected were subjected to a two-way analysis of variance (ANOVA) using Proc Mixed in SAS version 9.4 (SAS Institute Inc., Cary, NC). Fisher's least significant difference (LSD) test was used for mean comparison at an α -level of 5% when ANOVA showed significant difference at $P \leq 0.05$ between treatments. Microsoft Excel was used to plot graphs to show trends and cause and effect relationships.

Results and discussion

Heat-load as measured by temperature of the MSW compost tea rose linearly as the microwave power output level was increased from 0 to 400 W, irrespective of the time of exposure (Figure 1). The longer the exposure time, the higher the temperature of the MSW compost tea. It was found that the mean temperature of the MSW compost tea was 45°C at the 5 mins exposure and 58°C at the 10 mins exposure. Microwave energy output (E) is directly proportional to electromagnetic wave frequency (f) in the equation $E = f \times h$; where h is Plank constant.¹⁴ As such, an increase in power output level will increase the electromagnetic wave frequency and therefore, the heat-load of the exposed mass as observed in the present study. The linear regression equations in Fig. 1 showed highly significant ($P < 0.01$) coefficient of regression (R^2) values of approximately, 0.95. The slopes indicated rate of change in temperature per unit power level, which was higher in MSW compost tea at the 10 mins (0.160°C/W) of exposure compared to the 5 mins (0.114°C/W) of exposure.

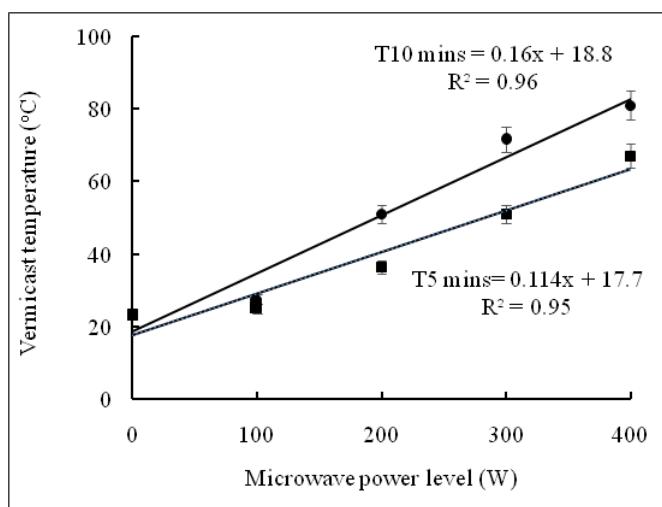


Figure 1 Compost tea temperature as affected by variations in microwave power output level and exposure time (■, 5 mins; ●, 10 mins).

Almost all of the quality parameters of the MSW compost tea were significantly ($P<0.001$) affected by the microwave power level, exposure time and their interaction (Table 1). Turbidity was used to assess the clarity of the compost tea. As the microwave power level increased from 100 to 400 W or the exposure time was increased from 5 mins to 10 mins, the turbidity of the compost tea significantly ($P<0.00$) reduced to clarity. The turbidity was not different between the 0 W (i.e. control, no microwave) and the 100 W or the 300 W and the 400 W treatments. It was previously suggested that carbonation or charring of organic matter occurs as microwave power level was

increased to ≥ 400 W at which the temperature of the material rose to 80°C .^{15,16} Therefore, the continuous reduction in turbidity as the power level was increased in the present study can be attributed to increased carbonation of the compost tea rose (Figure 1).

The trends in the EC, TDS and salinity of the MSW compost tea were similar (Table 1). Values of these three quality parameters increased slightly from the 0 to the 200 W treatment by a factor of 0.02 (Table 1). The EC, TDS and salinity then increased rapidly to their peak values by a factor of 0.08 at the 400 W power level. This pattern conformed to previous observation by Abbey et al.¹⁷ They found that TDS and EC values were increased to a peak when microwave power level was increased from 0 to 400 W at 5 mins exposure time. TDS and EC are associated with total mineral nutrients, which were found to be consistently higher in the MSW compost tea microwaved at 400 W for 10 min. The rapid collision and friction amongst polar molecules in addition to the increased temperature may have disrupted microbial cells and bio-labile compounds. These might have altered the chemistry of the MSW compost tea. As such, NO_3^- , K^+ , Na^+ and Ca^{2+} were increased at higher microwave power levels and extended time of exposure (Table 1). Ca^{2+} concentration was not affected by differences in exposure time. Hendricks and Pascoe¹⁸ demonstrated the use of microwave irradiation for increasing soil nutrients from dead microbial cells. They reported that microwaved soil generated more carbon dioxide-carbon, nitrogen, phosphorus and organic-carbon when 300 g of soil samples were heated at 700 W for 20 mins. Furthermore, Song et al.¹⁹ reported that varied exposure times to microwave irradiation increased density of predominant soluble solids. These may be the reason behind the trends in the EC, TDS, salinity and ionic concentrations of the MSW compost tea in the present study.

Table 1 Compost tea properties as affected by variations in microwave power level and exposure time

Treatments	Turbidity (NTU)	Electric conductivity ($\mu\text{S cm}^{-1}$)	Total dissolved solids (mg l ⁻¹)	Salinity (mg l ⁻¹)	K ⁺ (mg l ⁻¹)	NO ₃ ⁻ (mg l ⁻¹)	Na ⁺ (mg l ⁻¹)	Ca ²⁺ (mg l ⁻¹)
Microwave power output level (W)								
0	4.23a	426.00e	302.33e	174.33e	37.33c	103.00e	28.33d	15.00c
100	4.24a	428.67d	304.00d	175.17d	38.00c	206.67d	29.33c	14.67c
200	3.36b	434.00c	307.67c	177.67c	37.83c	221.67c	29.83c	16.33b
300	2.04c	446.83b	317.33b	183.17b	42.67b	266.67b	30.67b	17.50a
400	1.68c	468.67a	332.67a	192.00a	44.33a	360.00a	32.33a	17.17a
Time of exposure (mins)								
5	3.56a	432.93b	307.13b	177.27b	38.93b	205.93b	29.47b	16.20a
10	2.67b	448.73a	318.47a	183.67a	41.13a	257.27a	30.73a	16.07a
Power level	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Time	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ns
Interaction	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.005

NTU, nephelometric turbidity units; means followed by different letters within columns are significantly different at $P<0.05$ according to Fisher-protected least significant difference test at $\alpha = 0.05$.

400 W treated growing media compared to those of the 200 W and 300 W treatments. It appeared the less disturbance of organic matter and microbial population in the control (0 W) and the 100 W treatments may have increased rhizosphere activities such as the release of exudates from the microbes and roots. As the power level increased to 200 W and 300 W, the high temperatures of the MSW compost tea (Figure 1) probably destabilized the microorganisms and

the organic matter content. The high MSW compost tea temperature of 67°C for the 5 mins and 81°C for the 10 mins at microwave power level of 400 resulted in the highest TDS and EC. Two important effects of such high temperatures on microbial populations might be electrolyte leakage and thermal hydrolysis of bio-labile compounds, which might be the cause of the high TDS and EC in the MSW compost tea.

The initial properties of the MSW compost tea (Table 1) had an impact on the residual properties of the respective growing media that they were added to (Table 2). The trend in residual NO_3^- , Na^+ and Ca^{2+} concentrations were different compared to the TDS and the EC (Table 2). Overall, an increase in microwave power level increased residual mineral nutrient concentrations. Concentrations of NO_3^- , Na^+ and Ca^{2+} residues in the growing medium were highest in the 400 W treatments but were lowest in the 0 W and the 100 W treatments. Growing medium residual NO_3^- concentration was similar in the 200, 300 and the 400 W treatments while Ca^{2+} concentration was similar in

the 200 W and the 300 W treatments. Interaction between microwave power level and exposure time had effect on residual chemicals in the growing medium (Table 2). It is well known that EC was associated with soil salinity and soil health, which can usually be influenced by growing medium moisture content and organic materials.^{20,21} TDS is a measure of the aggregate of small organic and inorganic materials in the growing medium or MSW compost dissolved in water. In general, the high microwave power level significantly increased NO_3^- and Ca^{2+} concentrations of the growing medium and altered the growing medium chemical properties and plant growth performance.

Table 2 Growing medium chemical composition as affected by vermicast treated at varying microwave irradiation power level and exposure time

Treatments	Electric conductivity ($\mu\text{S cm}^{-1}$)	Total dissolved solids (mg l ⁻¹)	NO_3^- (mg l ⁻¹)	Na^+ (mg l ⁻¹)	Ca^{2+} (mg l ⁻¹)
Microwave power output level (W)					
0	1373.3a	920.0a	1213.3c	158.7b	77.3c
100	1354.0a	942.7a	3040.0b	160.7ab	75.3c
200	1157.3bc	836.7bc	7933.3a	154.7b	586.7b
300	1151.3c	803.3c	8000.0a	140.7c	600.0b
400	1274.0ab	910.0ab	8553.3a	167.3a	1113.3a
Time of exposure (mins)					
5 min	1276.0a	892.8a	5157.3b	156.0a	470.1a
10 min	1248.0a	872.3a	6338.7a	156.8a	510.9a
Power level	0.001	0.004	<0.001	<0.001	<0.001
Time	ns	ns	0.029	ns	ns
Interaction	ns	ns	ns	ns	ns

Means followed by different letters within columns are significantly different at $P<0.05$ according to Fisher-protected least significant difference test at $\alpha=0.05$

Plectranthus amboinicus leaf sap °Brix was highest in plants that received MSW compost tea microwaved at higher power levels of ≥ 300 W (Table 3) but was similarly reduced by the 0, 100 and 200 W treatments. Sap concentrations of NO_3^- and Ca^{2+} were high in the 200, 300 and 400 W treated plants compared to the 0 and 100 W treated plants. Leaf sap concentration of Na^+ was highest in plants

grown in the 400 W followed by the 100, 200 and 300 W, and the least was recorded by plants grown in the 0 W treatment. Overall, plants grown in the 0 W treatment had the least concentrations of all the mineral nutrients, while time of exposure of the MSW compost tea to microwave irradiation did not affect sap °Brix and concentrations of NO_3^- , Na^+ and Ca^{2+} .

Table 3 Leaf chemical status of *Plectranthus amboinicus* as affected by variations in microwave power level and exposure time

Treatments	°Brix	NO_3^- (mg l ⁻¹)	Na^+ (mg l ⁻¹)	Ca^{2+} (mg l ⁻¹)
Microwave power output level (W)				
0	0.70b	1500.00b	93.00c	110.00c
100	0.77b	1536.67b	109.83ab	120.00b
200	0.75b	2966.67a	108.33ab	140.00a
300	0.85a	3016.67a	99.33bc	136.67a
400	0.85a	3266.67a	111.50a	145.00a
Time of exposure (mins)				
5	0.80a	2473.33a	105.00a	131.33a
10	0.77a	2441.33aa	103.80a	129.33a
Power level	0.002	<0.001	0.011	<0.001
Time	ns	ns	ns	ns
Interaction	0.038	0.002	ns	ns

Means followed by different letters within columns are significantly different at $P<0.05$ according to Fisher-protected least significant difference test at $\alpha=0.05$

Pigmentation (i.e. chlorophyll and anthocyanin contents) was more responsive and varied at the 5 mins exposure time compared to the 10 mins exposure time across the different microwave power levels (Figure 2). At 100 W, the 5 min exposure remarkably reduced *Plectranthus amboinicus* leaf tissue chlorophyll content but rose to a peak value at 200 W before declining slightly at power levels ≥ 300 W (Figure 2, upper panel). On the other hand, chlorophyll content of the *Plectranthus amboinicus* was similar for treatments 0, 100 and 200 W at the 10 mins exposure time.

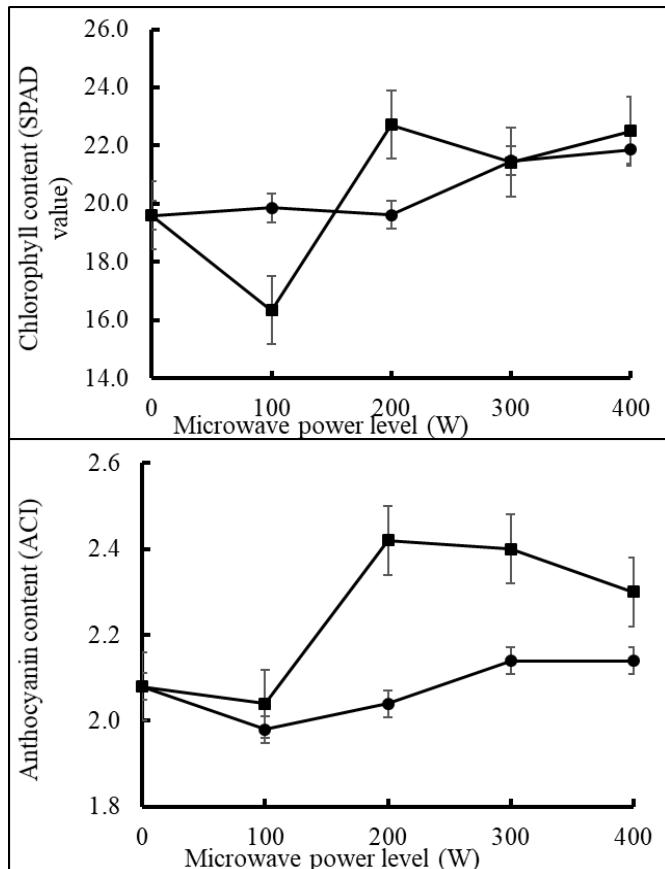


Figure 2 Chlorophyll (upper panel) and anthocyanin content (lower panel) of *Plectranthus amboinicus* as affected by variations in microwave power level and exposure time (■, 5 mins; ●, 10 mins).

Instead, chlorophyll content rose by a factor of 0.09 at 10 mins between the 200 W and the 300 W after which it remained unchanged. Anthocyanin content was consistently higher in plants treated with the 5 mins microwaved MSW compost tea compared to the 10 mins treatment (Figure 2, lower panel). There was a sharp (i.e. 18%) increase in anthocyanin content from the 100 W to the 200 W treatment exposed at 5 mins of microwave irradiation before it declined slightly when the power level was further increased to 400 W. For the 10 mins treatment, there was a slight reduction in anthocyanin content before it gently rose between the 100 W and the 300 W treatments. Thus, anthocyanin content of the *Plectranthus amboinicus* plants was significantly ($P<0.05$) increased when the MSW compost tea was microwaved at ≥ 200 W for 5 mins as compared to all the other treatment combinations. Perhaps, the 100 W treatment might have altered bioavailability of essential nutrients, which affected pigmentation. Hence, the overall similarity or slightly higher values of the chlorophyll and anthocyanin contents recorded in the control

non-microwaved MSW compost tea treated plants compared to that of the 100 W treatment. These two pigments are used as vital signs for plant health and tissue nutrient status. Chlorophyll is essential for photosynthesis and energy generation while anthocyanin affects plant eco-physiological strategies to resist environmental stress,²² which include edaphic stress.

Plant sap NO^{3-} or Ca^{2+} concentration was positively correlated with growing medium NO^{3-} and Ca^{2+} concentrations with an average r^2 value of 0.97 ($P<0.01$) or 0.94 ($P<0.01$). On the other hand, strong negative correlation existed between the growing medium EC and plant sap NO^{3-} ($r^2 = -0.81$, $P<0.05$) and Ca^{2+} ($r^2 = -0.76$, $P<0.05$) concentrations. Also, strong positive association between plant sap Ca^{2+} and NO^{3-} ($r^2=0.97$, $P<0.05$) or plant sap Ca^{2+} and °Brix ($r^2=0.75$, $P<0.05$) was found. These correlations suggested that alterations in MSW compost tea chemical composition influenced plant nutrient uptake. Response pattern of plant stem diameter to MSW compost tea microwaved at varied power levels were similar for the 5 mins and the 10 mins exposure times (Fig. 3, upper panel).

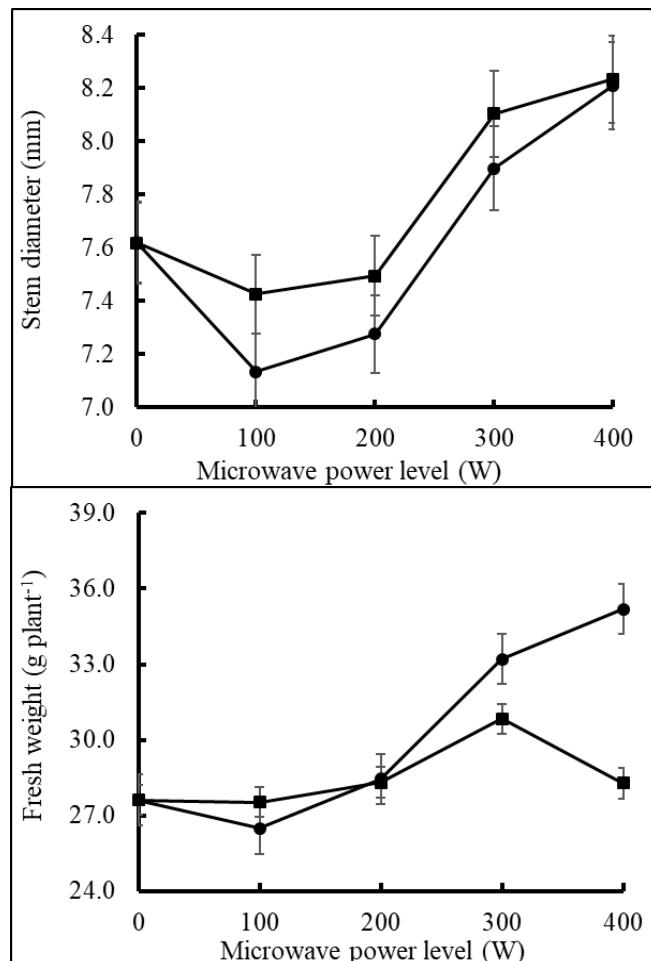


Figure 3 Stem diameter (upper panel) and plant fresh weight (lower panel) of Jamaican thyme (*Plectranthus amboinicus*) as affected by variations in microwave power level and exposure time (■, 5 mins; ●, 10 mins).

Stem diameter of Jamaican thyme plants were reduced following treatment with the 100 W microwaved MSW compost tea but increased slightly by the 200 W treatment. Stem diameter was increased by an average factor of 0.08 for the 5 mins and 10 mins exposure times following application of the 300 W microwaved MSW compost tea.

The difference in stem diameter between the 5 mins and the 10 mins exposure times was visually obvious but statistically minimal (Figure 3) (upper panel). Treatments 0, 100 and 200 W for both the 5 mins and the 10 mins exposure times gave similar harvested plant fresh weight (Figure 3) (lower panel). However, MSW compost tea treatments differences for plant fresh weight became apparent after the 200 W treatment (Figure 3) (upper panel). There was a steep increase in plant fresh weight from 200 W and 300 W, irrespective of exposure time. However, the slope was steeper for the 10 mins exposure time than that of the 5 mins exposure time.

Conclusion

Microwave technology can be safely used in the compost industry to enhance the physicochemical properties and efficacy of compost tea, as suggested by the present findings. The technology is currently widely used to sterilize growing media and food, and to extract active principles from agri-food products and byproducts. It was found that microwaved MSW compost tea showed higher potency than non-treated MSW compost tea. It was also found that time of exposure can influence the physical properties, chemical composition and efficacy of compost tea. There is the possibility of charring at higher microwave power levels and exposure time. For instance, charring at the harshest condition i.e. 400 W and 10 mins reduced turbidity or total particulate matter in the MSW compost tea but still increased total ionic concentration. As such, the critical microwave power level and exposure time will have to be determined for different processing volumes. In the present study, microwave irradiation treatment at power level 400 W and 10 min exposure time offered the highest nutrients concentrations and increased the overall health of *Plectranthus amboinicus* plants, growth and yield components. The results also indicated that the 200 W at 5 min exposure time improved leaf tissue chlorophyll and anthocyanin contents compared to all the other treatments. Microbiological community is a vital factor in organic amendments. Therefore, further studies should focus on the effects of microwave irradiation on microbial communities in MSW compost tea.

Funding

This research benefitted from funding provided by Compost Council of Canada.

Acknowledgment

The authors wish to thank Fundy Compost Inc., Brookfield, NS for providing the municipal solid waste compost for the study and Ms. Krista MacLeod for providing technical assistance for the greenhouse operation.

Conflicts of interest

The authors declare that there is no conflict of interest.

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