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

Introduction
Application of microwave technology in agriculture has gained considerable research attention due to its unique selective heating at the molecular level. The electromagnetic wave of microwave irradiation has frequency of approximately 2.45 GHz, which is higher than radio waves but lower than infrared waves. 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. 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. 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, while microwave technology was successfully used to extract heavy metals from sewage sludge. 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. Plectranthus amboinicus is also used for flavoring beef, chicken, and goat meats to mask their strong smells. Recent study indicated that vermicompost can enhance growth, antioxidants and anti-Streptococcus properties of Plectranthus amboinicus. 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. 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, Debert, 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. JES129STC01, Mabe Canada Inc., Mississauga, ON, Canada) was used to irradiate the MSW compost tea.

### 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 x h; where h is Plank constant.15 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 (R²) 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.
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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<0.000) 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 Pascoe\(^{18}\) 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 (µS 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 | 322.67a | 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 | <0.001 | 0.003 |

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 α = 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 91°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.

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

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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\textsuperscript{3−}, Na\textsuperscript{+} and Ca\textsuperscript{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\textsuperscript{3−}, Na\textsuperscript{+} and Ca\textsuperscript{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\textsuperscript{3−} concentration was similar in the 200, 300 and the 400 W treatments while Ca\textsuperscript{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.\textsuperscript{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\textsuperscript{3−} and Ca\textsuperscript{2+} concentrations of the growing medium and altered the growing medium chemical properties and plant growth performance.

| Treatments | Electric conductivity (µS cm\textsuperscript{-1}) | Total dissolved solids (mg l\textsuperscript{-1}) | NO\textsuperscript{3−} (mg l\textsuperscript{-1}) | Na\textsuperscript{+} (mg l\textsuperscript{-1}) | Ca\textsuperscript{2+} (mg l\textsuperscript{-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 α=0.05

\textit{Plectranthus amboinicus} leaf sap oBrix 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\textsuperscript{3−} and Ca\textsuperscript{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\textsuperscript{+} 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 oBrix and concentrations of NO\textsuperscript{3−}, Na\textsuperscript{+} and Ca\textsuperscript{2+}.

| Treatments | oBrix | NO\textsuperscript{3−} (mg l\textsuperscript{-1}) | Na\textsuperscript{+} (mg l\textsuperscript{-1}) | Ca\textsuperscript{2+} (mg l\textsuperscript{-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 | 2441.33a | 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 α=0.05

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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.

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 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, 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).

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.
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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 that 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 sterileize 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.

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Conflicts of interest

The authors declare that there is no conflict of interest.

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