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Addition of earthworm castings reduces gas emissions and improves compost quality in kitchen waste composting

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Abstract

In this study, we demonstrate that the addition of earthworm castings (EC) in kitchen waste composting reduces ammonia and greenhouse gas (GHG) emissions and improves compost maturity. Kitchen waste (KW) was mixed with sawdust at a ratio of 7:3 as the compost stock. Four treatments with different proportions of EC added (0%, 2.5%, 5.0%, and 7.5% on the basis of the initial kitchen waste mass) were designed and utilized in a composting process lasting 85 days. The results showed that the GHG and ammonia emissions were considerably reduced in the treatments with EC added. In addition, EC amendment prolonged the thermophilic stage and shortened the composting period. The addition of EC reduced ammonia, methane, and nitrous oxide emissions by 61%, 48%, and 94%, respectively, also indicating that nitrogen in the compost was conserved. Nitrogen and major nutrients were best preserved in the EC 7.5% treatment, which produced a compost product with a better nutrient profile. Furthermore, the total global warming potential of the KW composting process was reduced by 74% by using the mixture with EC. An effective reduction in GHG emissions was observed already with the addition of 2.5% EC, but a significant reduction in ammonia emissions was observed for the EC 7.5% treatment. Therefore, the results of this study suggest that EC is an effective additive in KW composting. More specifically, addition of EC at 7.5% of the initial KW mass was most recommendable for mitigating potential global warming effects and improving compost quality.

Keywords: Ammonia, Compost, Earthworm excrement, Global warming potential, Greenhouse gas

Introduction

More than 5.5 million tons of kitchen waste (KW) were generated in Korea in 2019 [1]. The quantity of KW generated in Korea has dramatically increased and is now recognized as a critical problem. Large amounts of KW cause environmental degradation via the widely used disposal methods such as landfilling and incineration, which pollute soil, water, and air [2]. These disposal methods are not appropriate for KW due to its high moisture content, and because of limited land space in general [3, 4].

By comparison, composting is a dynamic biological decomposition process wherein organic material is converted into a stabilized, humus-rich product, and nutrients are recycled [5, 6]. Composting is considered to be an effective, economical, and simple technology for disposing of organic waste. KW contains biodegradable organic compounds and is a valuable raw material for composting [7]. Nevertheless, substantial amounts of gases such as methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3) are emitted during the composting process. This is a major drawback as it not only reduces the amounts of reusable nutrients in the final product but also presents a contribution to global warming, which overall hinders the use of composting as a means of KW treatment [8]. Therefore, reducing gas emissions is necessary to make composting techniques more feasible.

A number of previous studies have investigated different additives such as coal ash [9], zeolite [10], and

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Ca-bentonite [2] for reducing gas emission in various setups of organic waste composting. Using earthworms to degrade organic matter, also known as vermicomposting, has also been studied. Earthworms accelerate the composting process by bioturbation, and produce a more nutritional end-product containing earthworm castings (EC). However, vermicomposting is not an accessible technique due to the earthworm breeding that occurs. The temperature of the compost feed should be kept below 35 ℃, which is not high enough for pathogen suppression, and typically a separation process is required. Instead of vermicomposting, EC alone could be used as an additive in organic waste composting. EC is a non-toxic material that has a low C/N ratio and high porosity, and it is already used on agricultural lands [11]. EC also has a complex structure and high cation exchange capacity due to its small particle size, which means it could also bind ammonium ions, thereby preventing nitrogen loss in KW composting [12,13]. Thus, it is expected that the gas emissions from composting with added EC will differ from that of vermicomposting or composting without additives. However, the effects of EC as an additive on NH_3 and greenhouse gas (GHG) emissions and compost quality in the KW composting process have not been adequately studied.

To identify a practical strategy for KW composting, it is necessary to conduct pilot tests to track the composting process and gas emissions when EC has been added to the compost. Therefore, in this study, we aimed to investigate changes in the chemical and nutrient characteristics of KW compost as well as NH_3 and GHG emissions when different quantities of EC were added to a KW composting process. The results of this research reveal an effective practice for alleviating gas emissions and enhancing the composting process for KW.

Methods

Composting materials and experimental design

KW, EC, and sawdust were the main raw materials used in this experiment. The KW was collected from a local municipal waste station, and contained typical food residues such as meat, fish, rice, vegetable, etc. The EC was obtained from a local market. Sawdust was mixed in as a bulk agent to adjust the moisture content to around 60% and the C/N ratio to around 26. The characteristics of the raw materials used for this experiment are described in Table 1. For the experiment, EC was mixed with KW at 0%, 2.5%, 5%, and 7.5% (relative to the mass of KW); these four treatments were labelled EC 0%, EC 2.5%, EC 5% and EC 7.5%, respectively.

Composting system and sampling

The experiment was conducted using 62-L plastic containers (length × width × height = 650 × 440 × 510 mm) covered with polystyrene. Air was pumped in from the bottom, and its flow rate was controlled at 0.1 m^3 m^{-3} min^{-1}. Temperature was monitored every 12 h using a data logger (EM50 Data logger, USA). The compost was thoroughly turned (manually) inside the containers prior to sampling on days 1, 8, 15, 22, 29, 36, 43, 57, 71, and 85 to avoid anaerobic conditions and to homogenize the compost pile. After mixing, compost samples were collected from a depth of 10 to 15 cm using a core. One portion was preserved at 4 °C and the other was dried, ground, and sieved with a 2 mm mesh.

Gas and compost analysis methods

The closed chamber method was used to determine methane (CH_4) and nitrous oxide (N_2O) emissions on days 1, 8, 15, 22, 29, 36, 43, 57, 71, and 85 during the composting period. The opaque chambers (diameter 24 cm) were fixed into the compost pile to a depth of 15 cm, only while sampling was taking place. Gas samples were

Table 1 Properties of materials used for this composting test

Parameter	Earthworm casting	Kitchen waste	Sawdust
pH	7.0 ± 0.1	4.9 ± 0.1	5.3 ± 0.1
EC (dS m^{-1})	2.2 ± 0.03	7.0 ± 0.1	0.25 ± 0.02
K (%)	1.17 ± 0.06	0.73 ± 0.09	0.01 ± 0.09
Ca (%)	5.02 ± 0.31	2.23 ± 0.30	0.18 ± 0.01
Mg (%)	1.08 ± 0.15	0.23 ± 0.02	0.02 ± 0.01
Na (%)	0.26 ± 0.05	2.04 ± 0.09	0.03 ± 0.01
Total Carbon (C, g kg^{-1})	81 ± 2.4	449 ± 13	487 ± 3.1
Total Nitrogen (N, g kg^{-1})	7.9 ± 0.7	51 ± 0.3	1.2 ± 0.0
Water extractable C (g kg^{-1})	1.2 ± 0.05	107 ± 13	5.6 ± 0.08
Water extractable N (g kg^{-1})	2.1 ± 0.08	16.4 ± 2.1	0.27 ± 0.004

collected at 0 and 30 min after the chamber was closed. The concentrations of CH_4 and N_2O were determined using a gas chromatograph (Shimadzu, GC-2010, Tokyo, Japan) equipped with a flame ionization detector (FID) with a methanizer and a ^{63}Ni electron capture detector (ECD), respectively. NH_3 concentration was measured as the aqueous concentration of ammonia in sulfuric acid, and analyzed by an AutoAnalyzer 3 (Bran Luebbe, Germany).

Gas emissions were calculated as gas concentrations per unit weight of compost over a specific time interval. Total fluxes of gases during the composting process were calculated on a mass basis (g kg^{-1}). Details related to the gas sampling and calculation of gas concentrations are explained in a previous study [14, 15].

The pH and electrical conductivity values were determined in a suspension of compost in distilled water (1:20, w/v). The extract was filtered through a 0.45 µm membrane filter to measure the dissolved organic carbon and nitrogen contents with a TOC-5050A analyzer (Shimadzu Corporation, Tokyo, Japan), and through a 5 µm filter paper to evaluate the germination index (GI). The GI was used to assess the phytotoxicity and maturity of the compost [16]. The GI was measured and calculated according to RDA, 2012 [17].

The carbon and nitrogen contents were analyzed with an elemental analyzer (CHNS-932 Analyzer, Leco). A segmented flow analyzer (Technicon Autoanalyzer II System, Germany) was used for quantifying NH_4^+-N and NO_3^--N in the composting materials, after extraction by mixing fresh samples with a 2 M KCl solution at a ratio of 1:10 (w/v).

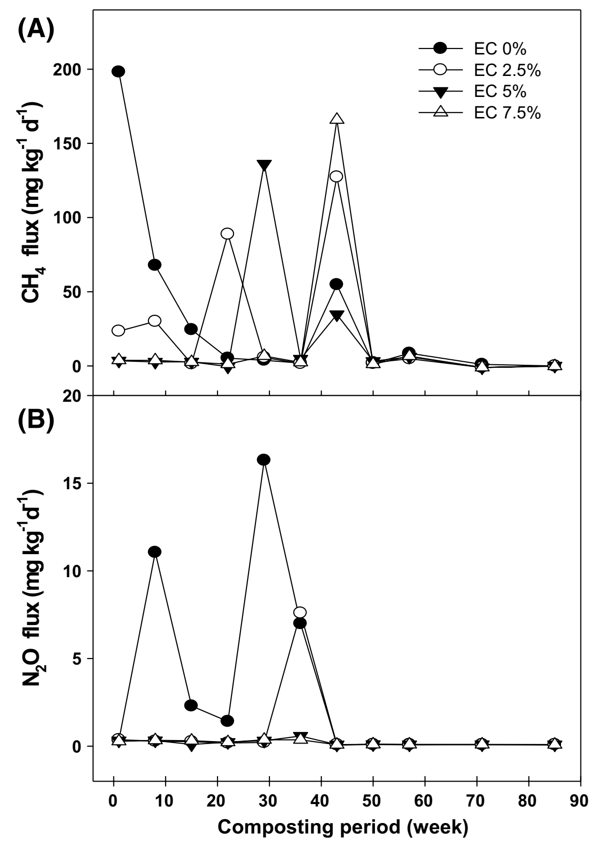

Fig. 1 Methane (**A**) and nitrous oxide (**B**) emissions during composting of different treatment mixtures. EC 0%: kitchen waste only; EC 2.5%: kitchen waste + earthworm castings 2.5%; EC 5.0%: kitchen waste + earthworm castings 5.0%; EC 7.5%: kitchen waste + earthworm castings 7.5%

Statistical analysis

For the statistical analysis, one-way ANOVA methods were employed using PSS 20.0 software. Pearson correlation analysis was performed to confirm the relationships between physiochemical properties and gas emissions using R software, with a statistical significance level of 0.05.

Results and discussion

Methane emissions

The CH_4 emissions from all 4 treatments are shown in Fig. 1A. The emission patterns were different among treatments. For the EC 0% treatment, CH_4 emissions dramatically increased and reached the highest peak among the treatments (198 mg kg^{-1} $days^{-1}$) within 10 days, and then sharply decreased to zero, while the EC 2.5%, EC 5.0%, and EC 7.5% treatments reached peaks on days 43 (127 mg kg^{-1} $days^{-1}$), 29 (136) and 43 (165), respectively, which was latter and lower than those of EC 0%. This may be due to the EC enhancing the air space and adjusting the moisture content, which could cause a reduction in the initial CH_4 emissions and provide a favorable environment for enhanced CH_4 oxidation by methanotrophs. With the progressive decomposition of the compost material, CH_4 emissions gradually declines in all treatments (Fig. 1A).

Nitrous oxide emissions

According to previous studies, the production of N_2O occurs during an incomplete nitrification/denitrification process [18]. NH_3 emissions could be considered as an indirect source of N_2O. The EC 0% treatment mainly released N_2O until the mid-point of the composting process, but in the other treatments the N_2O levels remained near the baseline throughout the whole composting period (Fig. 1B). The considerable N_2O emissions released during the thermophilic phase could possibly be produced through NH_4^+ oxidization by methanotrophs, since temperatures of over 40 ℃ are a limiting factor for nitrifiers (Fig. 2D) [19, 20]. N_2O emission rates increased

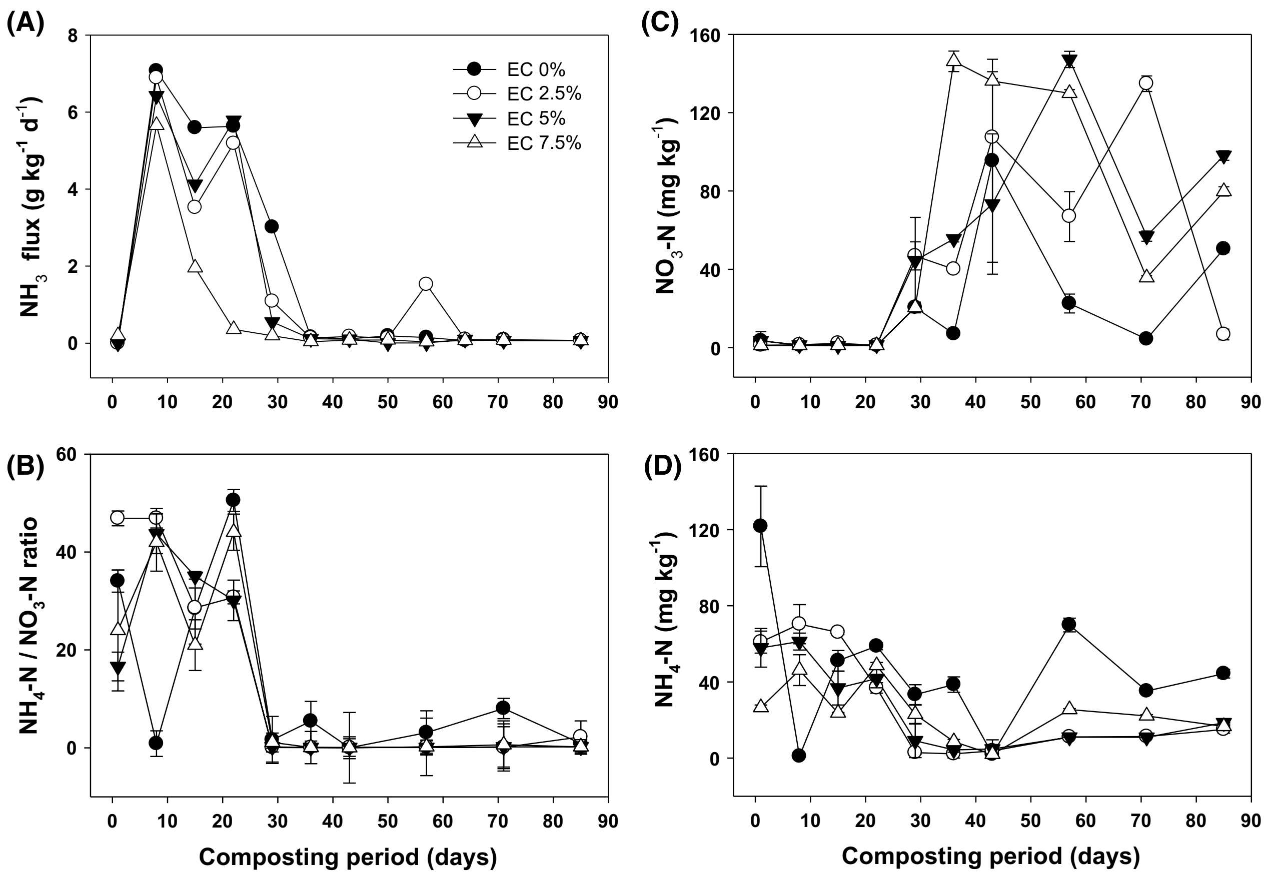

Fig. 2 Ammonia emission rate (**A**), ammonium-nitrogen (**B**), nitrate-nitrogen (**C**) and ammonium:nitrate ratio (**D**) for different treatments during composting. EC 0%: kitchen waste only; EC 2.5%: kitchen waste + earthworm castings 2.5%; EC 5.0%: kitchen waste + earthworm castings 5%; EC 7.5%: kitchen waste + earthworm castings 7.5%

when pH values were low, which agrees with the results reported by Chen et al. [21]. These results showed that relatively lower pH and temperatures of the compost pile were favorable for the production of N_2O during the thermophilic and mesophilic phases.

Ammonia emissions

Ammonia (NH_3) is a malodorous toxic gas, and CH_4 and N_2O are greenhouse gases that cause air pollution. NH_3 emissions mainly occurred within the first 30 days in all treatments (Fig. 2A), which accounted for 75–83% of total emissions. The emission patterns of NH_3 observed in this study were similar to those reported in previous studies on KW composting with additives [22]. The change in emissions was strongly correlated with the NH_4^+-N/NO_3^--N ratio, NO_3^--N, and DON (Fig. 5). This may be attributable to the conversion of NH_4^+ into NH_3, which is caused by the rapid degradation of organic N to inorganic N. Ammonium would subsequently volatilize under high-temperature and high-pH conditions. Peak emissions occurred on day 8 for all treatments: EC 0%, 7.07 g kg^{-1} $days^{-1}$; EC 2.5%, 6.89 g kg^{-1} $days^{-1}$; EC 5.0%, 6.42 g kg^{-1} $days^{-1}$; EC 7.5%, 5.66 g kg^{-1} $days^{-1}$. In the EC 7.5% treatment, NH_3 emissions started to decrease from day 15 and then reached a negligible level, while they dropped sharply to the lowest values by days 29 for EC 2.5% and EC 5.0% and 36 for EC 0%. The addition of EC was therefore effective in reducing NH_3 emissions during the initial stage of composting.

Changes in temperature, pH and degree of compost maturity

Temperature is considered to be an essential parameter in the composting process because it can reflect the organic matter degradation and microbial activity. Most other composting experiments have shown similar temperature change patterns [23]. The dynamic changes in temperature that occurred during the composting experiments are shown in Fig. 3A. The composting process is generally divided into thermophilic (> 50 ℃), mesophilic,

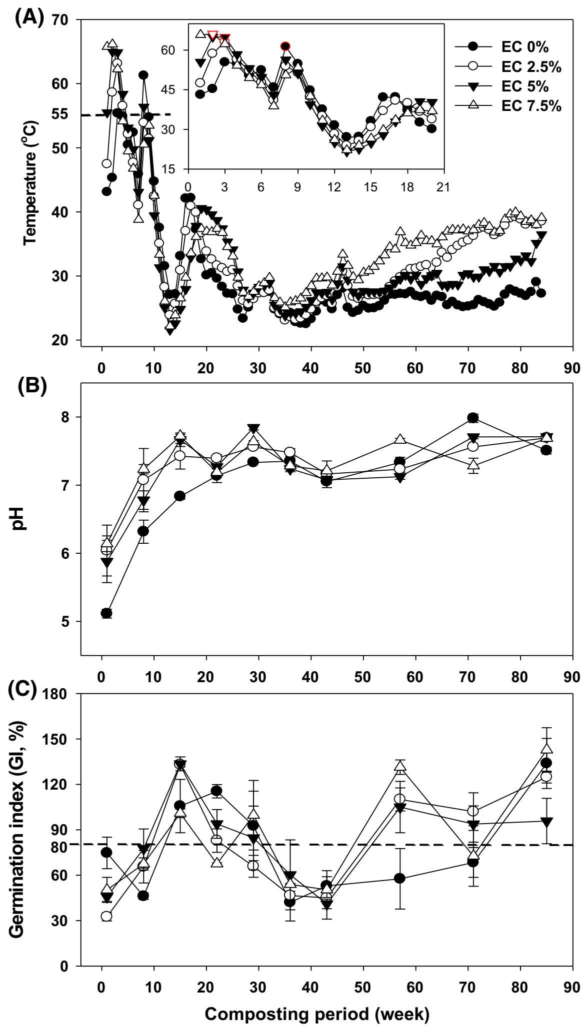

Fig. 3 Changes in temperature (**A**), pH (**B**), and germination index (GI) [indicating the degree of compost maturity] (**C**) during the composting process. EC 0%: kitchen waste only; EC 2.5%: kitchen waste + earthworm castings 2.5%; EC 5.0%: kitchen waste + earthworm castings 5%; EC 7.5%: kitchen waste + earthworm castings 7.5%

and maturation stages [24]. The EC-added treatments reached the thermophilic phase within 1–2 days, which lasted for 3–4 days at an average of 59.5–62.1 ℃. Meanwhile, EC 0% reached 55 °C on day 3 and its average temperature (55.13 ℃) was clearly lower than those of the EC treatments. Peak temperatures of 63.3, 65.0, and 66.1 ℃ were recorded on day 2 or 3 for the EC 2.5%, EC 5.0%, and EC 7.5% treatments, respectively, while the control reached a peak of 61.25 ℃ on day 8. After the peaks were reached, temperatures gradually declined for all treatments, remaining below 50 ℃ from day 10 onward. Temperatures slightly increased again between days 16 and 22, which marked the mesophilic stage. The temperatures of the EC treatments were higher than those of the EC 0% treatment in the maturation phase, due to the additive preventing heat loss. In general, the control treatment showed the lowest temperature amongst the treatments throughout the composting period, and the temperatures increased with increased EC addition. These results indicate that addition of EC promoted organic matter degradation and microbial activity.

All treatments showed similar trends in pH values (Fig. 3B); pH increased over the first 15 days before stabilizing between 7 and 8.5, which is normally considered as an optimal pH range for efficient composting [9]. The increasing pH in the thermophilic phase could be attributed to the increase in ammonia and degradation of acidic compounds (Fig. 2A). Until the mid-point of the composting process, the pH of the EC 0% control was slightly lower than those of the EC treatments. In the final stage, all treatments showed relatively stable pH values that were higher than the initial values. The pH of the EC 0% treatment increased from 5.11 to 7.51, that of EC 2.5% increased from 6.04 to 7.69; that of EC 5.0% increased from 5.88 to 8.34, and that of EC 7.5% increased from 6.14 to 7.69.

The phytotoxicity and degree of maturity of the compost were determined through the GI value. For all treatments, the GI gradually increased as the composting process progressed (Fig. 3C). The GI of the EC-added treatments reached values exceeding 80%, indicating maturity, by day 57, as compared to day 71 for the EC 0% treatment. These results suggest that co-composting of KW with EC could shorten the composting period, which would lead to reduced labor and operating costs for producing compost.

Nutrient contents

During composting, N is first transformed into NH_4^+-N, so changes therein can reflect N conversion [25, 26]. The decreasing trend in NH_4^+-N levels observed might be because of NH_3 volatilization and conversion to NO_3^--N (Fig. 2D). Conversely, NO_3^--N contents were low during the initial thermophilic phase and dramatically increased in the later stages (Fig. 3C). The activity of nitrifying bacteria can be promoted under temperatures of 40 ℃ and under aerobic condition [27, 28]. Therefore nitrification did not occur in our experiments, and this explains the low NO_3^--N concentrations measured during the thermophilic stage (Fig. 2C). NO_3^--N concentrations increased from day 29, when NH_3 emissions started to drop.

As shown in Fig. 4A, the total carbon (TC) contents in all the treatments slightly decreased and then increased within the first 36 days, and were constant by the end of the process. The decomposition and synthesis of organic

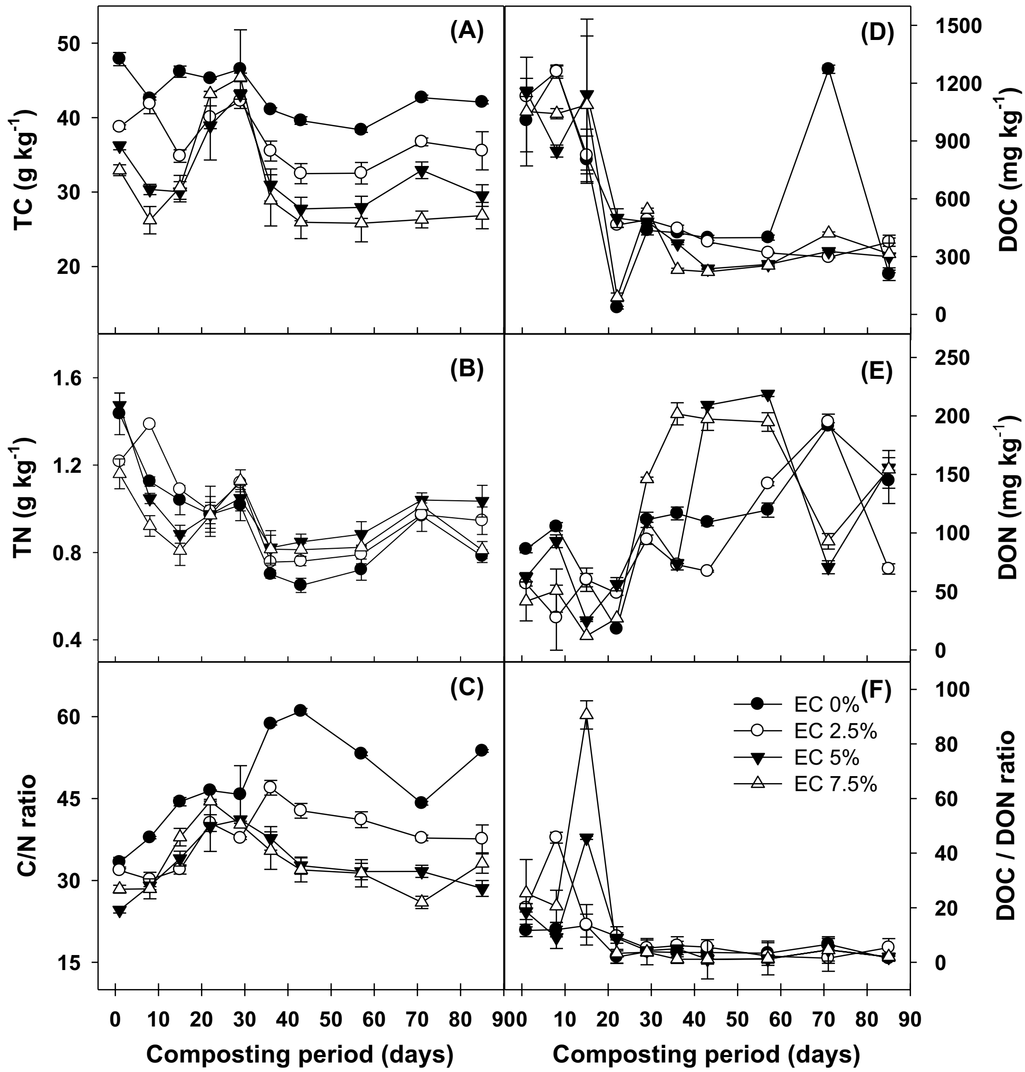

Fig. 4 Total carbon content (**A**), total nitrogen content (**B**), carbon:nitrogen ratio (**C**), dissolved organic carbon (**D**), dissolved organic nitrogen (**E**), dissolved carbon:nitrogen ratio (**F**) during composting. Error bars represent standard deviations of triplicate measurements. EC 0%: kitchen waste only; EC 2.5%: kitchen waste + earthworm castings 2.5%; EC 5.0%: kitchen waste + earthworm castings 5%; EC 7.5%: kitchen waste + earthworm castings 7.5%

substances occurs simultaneously during composting. This is the reason why the TC contents did not change significantly between the initial and final compost piles. Figure 4B shows the changes in total nitrogen (TN). A decrease was observed due to the loss of ammonia. Over the whole composting process, the change in the C/N ratio was highest for the EC 0% control (Fig. 4C), which is mostly due to N loss caused by NH_3 volatilization during the thermophilic stage. The dissolved organic carbon (DOC) concentration was higher during the initial phase, ranging from 1104 to 1154 mg kg^{-1}, and sharply decreased from day 22 to below 500 mg kg^{-1}. This pattern (Fig. 4D) agrees with the results presented by Zmora-Nahum et al. [29]. The changes are attributed to the available carbon being metabolized by microorganisms under thermophilic conditions. The DOC concentration showed a positive correlation with temperature and TN, but a negative correlation with NO_3-N ($p < 0.001$). Conversely, the increase in DON concentration occurred after the DOC had decreased (Fig. 4E), and was positively correlated with NO_3-N and negatively correlated with NH_4/NO_3 ($p < 0.001$) (Fig. 5).

The considerable NH_3-N loss in the EC 0% treatment resulted in this treatment having the lowest TN content in the final compost product (Fig. 4B). The addition of EC increased not only TN, but also levels of other nutrients

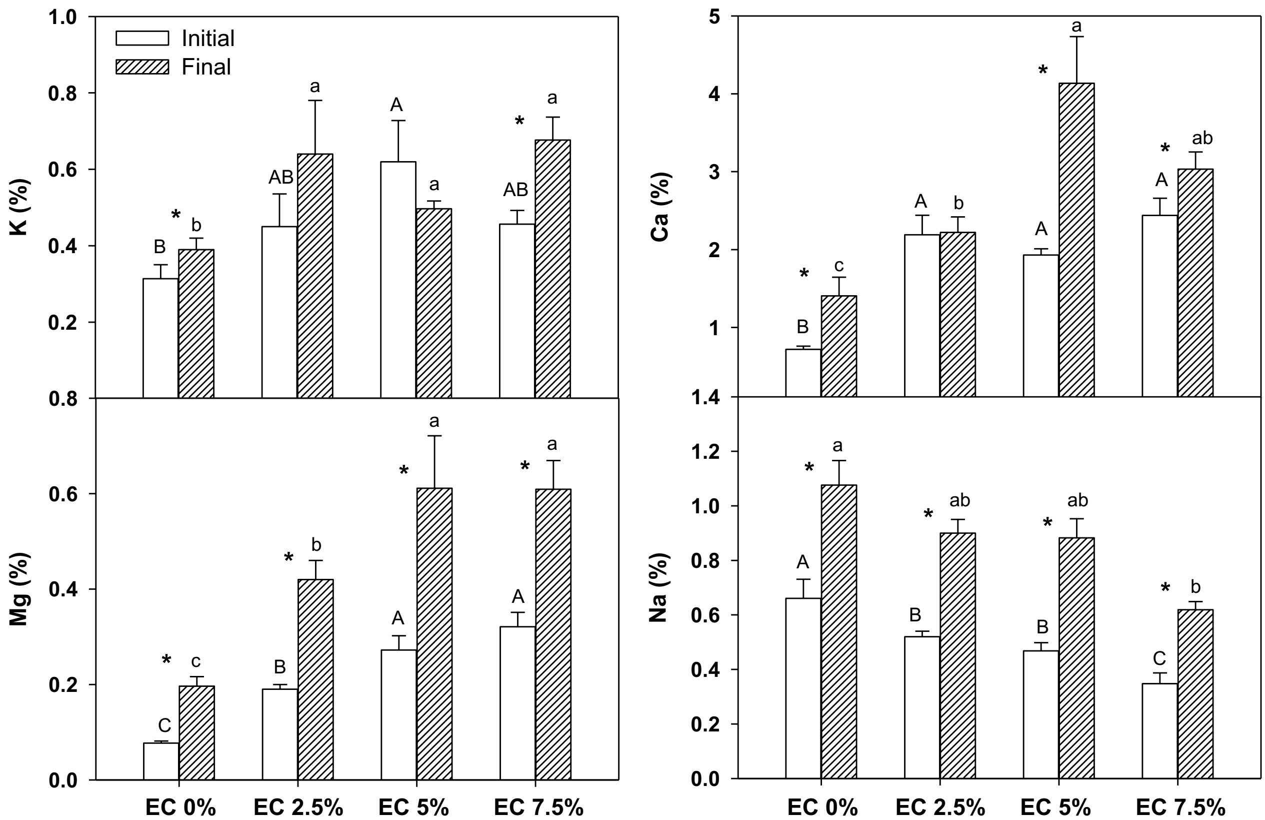

Fig. 5 Nutrient contents of the initial and final compost piles. * indicates a significant difference between initial and final compost pile within the same treatment. Different letters (capital letter: initial compost, small letter: final compost) indicate significant differences among treatments at $LSD_{0.05}$. EC 0%: kitchen waste only; EC 2.5%: kitchen waste + earthworm castings 2.5%; EC 5.0%: kitchen waste + earthworm castings 5%; EC 7.5%: kitchen waste + earthworm castings 7.5%

such as potassium (K), calcium (Ca), and magnesium (Mg) in the final compost product due to the high nutrient content of EC (Table 1). The K, Ca, and Mg concentrations of EC 7.5% were 1.74, 2.16, and 3.10 times higher than those of EC 0%, respectively, which indicates an overall improvement in compost quality (Fig. 5).

Table 2 Ammonia emission and global warming potential (GWP) values during composting

Treatment	EC 0%	EC 2.5%	EC 5%	EC 7.5%
NH_3 (g kg^{-1} C.W)	153.8	133.5	121.4	60.3
GWP-CH_4 (gCO_2 eq. kg^{-1} C.W)	63.9	49.4	33.3	33.4
GWP-N_2O (gCO_2 eq. kg^{-1} C.W)	84.02	19.95	4.75	4.73
Total GWP (gCO_2 eq. kg^{-1} C.W)	147.9	69.35	38.05	38.13

Global warming potential (GWP)

The addition of EC was effective in reducing gas emissions over the KW composting period. Table 2 shows the total fluxes of NH_3, CH_4, and N_2O during the composting process. Total GHG emissions were expressed as CO_2-C equivalents using the global warming potential (GWP) coefficients of 1 for CO_2, 25 for CH_4, and 298 for N_2O [30]. The total GWP values of the EC 0%, EC 2.5%, EC 5.0%, and EC 7.5% treatments were 147.9, 69.35, 38.05, and 38.13 g CO_2 eq. kg^{-1}, respectively. The EC-added treatments showed 76–94% lower N_2O emissions relative to that of EC 0% due to the restricted denitrification related to the improved air permeability of the composting piles (Fig. 2B). The addition of EC also decreased CH_4 production by 23–48%. Overall, EC addition resulted in a 53–74% reduction in the GWP. A mixing rate of only 2.5% EC was already effective in decreasing potential global warming impacts, but 5.0% and 7.5% EC mixing rates increased this reduction to 74%. The addition of EC was also effective in reducing NH_3 emissions. When 2.5% and 5.0% EC was incorporated into the composting pile, NH_3 production was reduced by 13% and 21%, respectively, relative to the EC 0% control treatment. NH_3 emissions were even more significantly reduced (by 61%) in the EC 7.5%

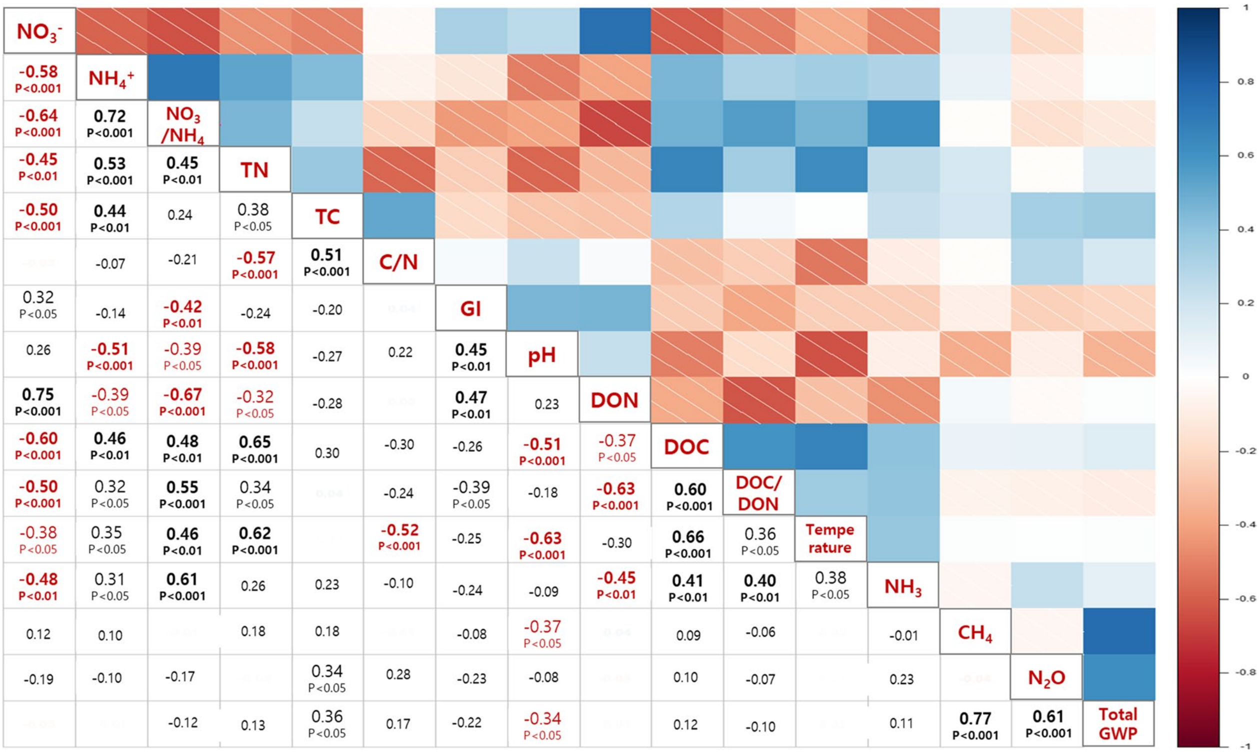

Fig. 6 Correlation analysis based on heat map of physiochemical properties and gas emissions of compost piles. P values of 0.05, 0.01, and 0.001 denote significance at the 5, 1, and 0.1% levels, respectively. EC 0%: kitchen waste only; EC 2.5%: kitchen waste + earthworm castings 2.5%; EC 5.0%: kitchen waste + earthworm castings 5%; EC 7.5%: kitchen waste + earthworm castings 7.5%

treatment, which can be explained by the high cation exchange capacity of EC (Table 2, Fig. 6).

The addition of EC in KW composting could mitigate total GHG emissions and improve compost quality. Although the results presented in this study provide a solid basis for the management of kitchen and organic wastes in general, pilot tests are still needed to evaluate the commercial feasibility.

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Authors' contributions
NHA and SML reviewed the results from the study and supervised the whole project. HYH designed and conducted the field research. HYH and CRL analyzed and wrote the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets supporting the conclusions of this study are including within this manuscript.

Declarations

Competing interests
The authors declare that they have no competing interests.

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References
1. Korea Ministry of Environment (2019) Study on Preparation of Enhancement of Domestic Management System of the Waste in International Trade; Final Report, KME Report; Korea. Ministry of Environment: Seoul, Korea
2. Wang Q, Li R, Cai H, Awasthi MK, Zhang Z, Wang JJ, Ali A, Amanullah M (2016) Improving pig manure composting efficiency employing Ca-bentonite. Ecol Eng 87:157–161
3. Saer A, Lansing S, Davitt NH, Graves RE (2013) Life cycle assessment of a food waste composting system: Environmental impact hotspots. J Clean Prod 52:234–244
4. Cheng H, Li YM, Li L, Chen R, Li YY (2020) Long-term operation performance and fouling behavior of a high-solid anaerobic membrane bioreactor in treating food waste. Chem Eng J 394:9
5. Zhang H, Li G, Gu J, Wang G, Li Y, Zhang D (2016) Influence of aeration on volatile sulfur compounds(VSCs) and NH3 emissions during aerobic composting of kitchen waste. Waste Manag 58:369–375
6. Li Y, Luo W, Li G, Wang K, Gong X (2018) Performance of phosphogypsum and calcium magnesium phosphate fertilizer for nitrogen conservation in pig manure composting. Bioresour Technol 250:53–59

7. Song ZW, Sheng T, Deng WJ, Wang J (2019) Investigation of rice straw and kitchen waste degradation through vermicomposting. J Environ Manage 243:269–272
8. Onwosi CO, Igbokwe VC, Odimba JN, Eke IE, Nwankwoala MO, Iroh IN, Ezeogu LI (2017) Composting technology inwaste stabilization: on the methods, challenges and future prospects. J Environ Manag 190:140–157
9. Wong JWC, Fung SO, Selvam A (2009) Coal fly ash and lime addition enhances the rate and efficiency of decomposition of food waste during composting. Bioresour Technol 100:3324–3331
10. Villasenor J, Rodriguez L, Fernandez FJ (2011) Composting domestic sewage sludge with natural zeolites in a rotary drum reactor. Bioresour Technol 102:1447–1454
11. Lim SL, Wu TY, Lim PN, Shak KPY (2015) The use of vermicompost in organic farming: overview, effects on soil and economics. J Sci Food Agric 95:1143–1156
12. Edwards CA, Arancon NQ, Sherman R (2010) Vermiculture Technology: Earthworms, Organic Wastes, and Environmental Management. CRC Press LLC, Boca Raton, USA
13. Lim SL, Lee LH, Wu TY (2016) Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: recent overview, greenhouse gases emissions and economic analysis. J Clean Prod 111:262–278
14. Han Z, Sun D, Wang H, Li R, Bao Z, Qi F (2018) Effects of ambient temperature and aeration frequency on emissions of ammonia and greenhouse gases from a sewage sludge aerobic composting plant. Bioresour Technol 270:457–466
15. Hwang HY, Kim SH, Kim MS, Park SJ, Lee CH (2020) Co-composting of chicken manure with organic wastes: Characterization of gases emissions and compost quality. Appl Biol Chem 63:1–10
16. Yang F, Li G, Shi H, Wang Y (2015) Effects of phosphogypsum and superphosphate on compost maturity and gaseous emissions during kitchen waste composting. Waste Manag 36:70–76
17. RDA (Rural development administration, Korea) (2012) Quality control and utilization of livestock manure. National institute of agricultural sciences, Jeon Ju. (11–1390802–000592–01)
18. Yang F, Li Y, Han YH, Qian W, Li G, Luo W (2019) Performance of mature ompost to control gaseous emissions in kitchen waste composting. Sci total Environ 657:262–269
19. Kits KD, Campbell DJ, Rosana AR, Stein LY (2015) Diverse electron sources support denitrification under hypoxia in the obligate methanotroph Methylomicrobium album strain BG8. Front Microbiol 6:1072
20. Jiang T, Ma X, Tang Q, Li G, Schuchardt F (2016) Combined use of nitrification inhibitor and struvite crystallization to reduce the NH_3 and N_2O emissions during composting. Bioresour Technol 217:210–218
21. Chen M, Huang Y, Liu H, Xie S, Abbas F (2019) Impact of different nitrogen source on the compost quality andgreenhouse gas emissions during composting of garden waste. Process Saf Environ Prot 124:326–335
22. He Z, Lin H, Hao J, Kong X, Tian K, Bei Z, Tian X (2018) Impact of vermiculite on ammonia emissions and organic matter decomposition of food waste during composting. Bioresour Technol 263:548–554
23. Mehta CM, Palni U, Franke-Whittle IH, Sharma AK (2014) Compost: its role, mechanism and impact on reducing soil-borne plant diseases. Waste Manag 34:607–622
24. Chang R, Li Y, Li J, Chen Q, Zhao H, Qi Z (2019) Influences of the Thermophilic Period on Biodegradation and Nitrogen Loss in Stimulated Vegetable Waste Composting. Glob Ecol Conserv 18:e00623
25. Guo R, Li G, Jiang T, Schuchardt F, Chen T, Zhao Y, Shen Y (2012) Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost. Bioresour Technol 112:171–178
26. Wang Q, Awasthi MK, Zhao J, Ren X, Li R, Wang Z, Wang M, Zhang Z (2017) Improvement of pig manure compost lignocellulose degradation, organic matter humification and compost quality with medical stone. Bioresour Technol 243:771–777
27. Zhang L, Sun X (2014) Changes in physical, chemical, and microbiological properties during the two-stage co-composting of green waste with spent mushroom compost and biochar. Biores Technol 171:274–284
28. Caceres R, Malinska K, Marfaa O (2018) Nitrification within composting: A review. Waste Manage 72:119–137
29. Zmora-Nahum S, Markovitch O, Tarchitzky J, Chen Y (2005) Dissolved organic carbon as a parameter of compost maturity. Soil Biol Biochem 37:2109–2116
30. Intergovernmental Panel on Climate Change (IPCC) (2007) Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. Climat Change 366:104

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