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Valorization of food waste and poultry manure through co-composting amending saw dust, biochar and mineral salts for value-added compost production

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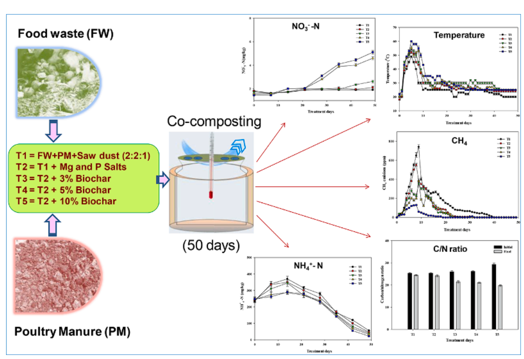
HIGHLIGHTS

- Food waste and poultry manure were co-composted with saw dust, biochar and salts.
- Biochar addition promotes and prolongs the thermophilic stage of composting.
- Final compost maturity was assessed by C/N ratio (19.75–24.45)
- CH_4 emission in biochar amended treatments was lesser.
- Combined effects of biochar and salts had more positive effects in inhibiting NH_4^+-N.

GRAPHICAL ABSTRACT



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ABSTRACT

The present study proposes a system for co-composting food waste and poultry manure amended with rice husk biochar at different doses (0, 3, 5, 10%, w/w), saw dust, and salts. The effect of rice husk biochar on the characteristics of final compost was evaluated through stabilization indices such as electrical conductivity, bulk density, total porosity, gaseous emissions and nitrogen conservation. Results indicated that when compared to

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Nitrogen conservation
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control, the biochar amendment extended the thermophilic stage of the composting, accelerated the biodegradation and mineralization of substrate mixture and helped in the maturation of the end product. Carbon dioxide, methane and ammonia emissions were reduced and the nitrogen conservation was achieved at a greater level in the 10% (w/w) biochar amended treatments. This study implies that the biochar and salts addition for co-composting food waste and poultry manure is beneficial to enhance the property of the compost.

1. Introduction

Global population is expected to increase to 9.6 billion by 2050 from 7.2 billion in 2011 (UN DESA, 2015). It is also estimated that urban population will rise from 52.1% in 2011 to about 67.2% in 2050 (United Nations, 2016). The growing urbanization influences the global socio-economic transformations, which affects the lifestyle, unemployment, resource utilization, water and sanitary issues and even the spread of diseases (Dowlath et al., 2021). Developed countries waste a large amount of food about 600 million tons annually, and wasting about 20% of the food supply (Jeon et al., 2020). Recent studies show that food waste (FW) of about 1.3 billion tonnes is generated world-wide annually and is expected to rise more in the next two decades (Petracchini et al., 2018). Ban to use food waste as animal feed, prohibition of land filling of FW, threats of greenhouse gases (GHG) emissions during incineration and increased administrative costs urges augmentation of newer strategies based on sustainable waste management instead of disposal strategies (Yeo et al., 2019). Composting of FW is also not very productive because of its low porosity, high bulk density, poor C:N ratio, easy acidification, among other factors (Awasthi et al., 2017; Voběrková et al., 2020), co-composting it with other organic wastes like manure, sludge, etc. are preferred. The concepts of co-composting help in reducing the time and labour and also benefit economically.

A recent report from National Bureau of Statistics of the People's Republic of China (2019) suggests about 4974 million chickens were produced in the year 2018. This also leads to the increased amounts of poultry manure (PM) released from poultry industries which can be an environmental threat if mishandled (Karuppannan et al., 2021). PM is an organic matter (OM) and a rich source of macro and micro nutrients required for plant growth. Anyhow, the raw poultry wastes has malodours and is ponderous, making it costly to transport and concomitant risks associated with it which may lead to severe ecological problems (Kolar Ladislav et al., 2011). Conventional composting has potential risks such as generation of hazardous gases, malodours causing environmental pollution. To mitigate the C and N losses as ammonia and carbon dioxide and to minimize the nutrient loss, addition of a stable and carbonaceous material like biochar is highly recommended. Biochar has extraordinary properties such as high porosity, high sorption capacity, potential bulking agent, improved aeration and can serve as a habitat for nitrifying bacteria that could breakdown organic matter with reduced emission of GHG and also improve the compost quality (Chen et al., 2017). Salts such as magnesium and phosphate can react with NH_4^+ from struvite. This struvite formation is suggested to be an efficient method for improving nitrogen conservation by reducing the acidification and ammonia emissions and to increase the phosphorous conservation (Li et al., 2011). As the nitrogen of ammonium can be conserved, emission of NH_3 can also be reduced. Many investigations have suggested the addition of alkaline materials that facilitate struvite formation can thus reduce nitrogen loss to a greater extent. Hence, it is worth to explore the effect of magnesium hydroxide and potassium hydrogen phosphate on gaseous emissions and nitrogen conservation during co-composting of PM and FW.

Various researches have recorded the biochar amended composting of PM and FW separately and to the existing knowledge, co-composting of PM and FW has not been addressed. Hence, the present study has been aimed to investigate the effect of biochar and salts augmentation in co-composting of FW and PM on the carbon and nitrogen conservation in the end product and to evaluate the quality of the final compost.

2. Materials and methods

2.1. Materials

All the raw materials used in study were collected locally in South Korea. Food waste was collected from restaurants and hotels. The solid waste, poultry manure was procured from a local poultry farm in Gangwon-do Province, Republic of Korea and stored at 4 ℃. The sawdust with a mesh size ranging between 2 and 5 mm was collected from a wood mill in Namwon. The rice husk biochar was purchased commercially from the vendor in Damyang. The biochar was prepared from rice husk through pyrolysis process at a temperature of 500–600 °C for 24 h with limited air access and passed via 2–5 mm sieve act as amendment with other materials. Standard protocols were followed to analyze the physical and chemical parameters of the raw materials (American Public Health Association, 2006) using analytical grade chemicals. Table 1 represents the physical and chemical parameters of all the raw substrates used for the present study. The pH of the FW was acidic (5.48), alkaline in biochar (8.7) while it ranged between 6.3 and 7.6 in sawdust and poultry manure. The C/N ratio of sawdust, PM, FW, and biochar was 42.1, 13.88, 14.6, and 78.8, respectively.

2.2. Feedstock preparation and experimental design

All the experiments were conducted in Kyonggi University, Suwon, Gyeonggi-do, Republic of Korea at a temperature of 20 ± 2 ℃. The experiment had 5 treatment groups labelled as T1 – T5. T1 contained a mixture of food waste, poultry manure and saw dust in a ratio of 2:2:1 with a total volume of 8 kg. Sawdust was added to maintain the C:N ratio which supports microbial activity. The T2 had all the mixtures as in T1 along with 0.5 M of 65.76 g magnesium hydroxide and 0.25 M of 104.4 g potassium hydrogen phosphate. The range of salt ratio was chosen from our preliminary studies and previous researcher's studies of Wang et al., (2013) and Cao et al, 2019). The treatments T3, T4 and T5 had the same composition as T2 added with 3, 5 and 10% rice husk biochar, respectively. The initial moisture content was adjusted to 65%. Each treatment was conducted in triplicate using a 30-L pilot-scale cylindrical composter (30 cm in inner diameter and 45 cm in depth). The feedstock mixtures were held over a 5-mm mesh grid plenum, and these were used for aeration (flow rate of 0.1 L/min/kg) by a peristaltic pump through the hole at the bottom of the compost reactor. The composting

Table 1
Physicochemical parameters of raw materials for composting.

Parameters	Sawdust	Poultry manure	Food waste	Biochar
Ph	6.31 ± 0.42	7.63 ± 0.47	5.48	8.7 ± 0.54
EC (mS/cm)	0.51 ± 0.01	8.34 ± 0.05	1.2	0.78 ± 0.02
Moisture content (%)	32.1 ± 1.86	79.1 ± 4.13	65	30.8 ± 1.78
C:N ratio	42.1 ± 2.67	13.88 ± 0.67	14.6	78.8 ± 3.20
Bulk density (g/cm^3)	0.100 ± 0.004	1.08 ± 0.05	1.00 ± 0.05	0.21 ± 0.01
Water holding capacity (g water/g dry sample)	2.89 ± 0.1	2.9 ± 0.1	4.31 ± 0.23	2.9 ± 0.11
Porosity (%)	88.63 ± 4.6	5.93 ± 0.5	5.8 ± 0.4	73.5 ± 4.9

experiment was carried out for 50 days and all the raw materials were mixed periodically thoroughly to attain even distribution. Operations such as analysis, mixing up of raw materials periodically, were similar to a previous study (Chung et al., 2021). The values presented are the average of individual experiments ± standard deviation.

2.3. Physicochemical and gaseous emission analysis

The parameters such as temperature, carbon dioxide (CO_2), ammonia (NH_3) and methane (CH_4) were measured on all the days of composting. Temperature was measured using a thermometer; NH_3 and CO_2 were analysed using detector tubes and portable biogas analyser (GA5000, Geotech, UK). The CH_4 was evaluated by gas chromatography. The pH, electrical conductivity (EC), ammoniacal nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) were evaluated on 0, 7, 14, 21, 28, 35, 42 and 49th day of composting. The pH and EC were measured in the 10 % (w/v) sample in water suspension using a portable multiparameter pH meter. For the estimation of NH_4^+-N and NO_3^--N, segmented flow analyser (Technicon Autoanalyzer II System, Germany) was used. The total porosity (TP), bulk density (BD), water holding capacity (WHC) and C:N ratio were analysed at 0 day and at 50th day of the composting. BD (g/cm^3), TP (%) and WHC (% of volume) were derived by the following calculations: BD = Dry weight/Volume; TP = (1-BD/Particle density) × 100; WHC = [(Wet weight-Dry weight)/Volume] × 100 (Inbar et al., 1993). C:N ratio was calculated from the estimated values of TC and TN with a CHNS elemental analyser (Vario Macro Cube).

2.4. Statistical analysis

All the experiments were done in triplicates and the data is presented as mean ± S.D. All the statistical analyses were carried out using Sigmaplot version 13.0.

3. Results and discussion

3.1. Influence of biochar amendment on temperature, pH and electrical conductivity

The temperature is considered as a crucial parameter in investing the progress and maturity of a composting process. The degradation of organic materials results in the generation of heat in the compost mass (Wang et al., 2016). The trend of temperature dynamics in all the treatments is depicted in the Fig .1a which was in a similar pattern with all the concrete stages (such as mesophilic, thermophilic, cooling and maturation) of a composting process. Except the T1, all other treatments (T2 – T5) achieved the thermophilic phase on the 4th day of initiation which was delayed by 1 day in the T1 treatment. On the 5th day, T1 reached its maximum temperature of 49 ± 0.98 ℃, whereas T2, T3, T4 and T5 reached their maximum temperature of 52 ± 1.56, 55 ± 2.75, 55 ± 2.75 and 60 ± 1.8 ℃. The thermophilic stage of the composting was not prolonged in the control (T1), whereas the prolonged thermophilic stage was evident in the treatments with the addition of salts alone and salts with different concentrations of biochar T5 > T4 > T3 > T2 > T1. The increase in the temperature of the treatments with salts alone and salts with biochar is because of the additional nutrients for biological activity. Some studies have reported that addition of salts will inhibit the microbial activity affecting the biodegradation process. Since the salts used in this study are at low concentrations, it did not affect the process. During the early phases of composting, the raise in temperature in biochar added compost setups can possibly related to the large surface area of the biochar, providing suitable conditions for the biodegradation of organic matters by the action of microbes (Awasthi et al., 2017).

These results indicate that the amendment biochar promotes and prolongs the thermophilic stage significantly, with 10% biochar being most effective. The prolonged thermophilic stages in the initial stages of composting help to eliminate the pathogenic microbes in the mixture (Zhang et al., 2021) and help in the maturity of the compost. After reaching the maximum temperature, the temperatures of all the treatments declined and reached the ambient levels ranging between 20 and 25 ℃. The turning of mixtures has been well reported to reallocate microbes and organic matter which facilitates the composting process. This turning up of mixtures has caused minor fluctuations in the temperature trends of all the treatments. The findings are in coherence with reports of Chung et al. (2021); Li et al. (2018) and Liu et al. (2020) in which effects of biochar amendment in chicken manure composting, the effect salt additives on swine manure composting, the influence of salt and biochar on swine manure composting were studied. The thermophilic stage of the composting lasted longer in the treatments added with biochar T5 > T4 > T3, which indicates the increase in temperature with the increase in the ratio of biochar.

The biodegradation of organic matter is very much affected by both the extreme pH levels. Particularly, nitrogen loss is very high due to ammonia volatilization the reduces the final compost quality (Chan et al., 2016). From the Fig. 1b, it is observed that the pH levels at the initial stage of composting was ranging between 5.65 and 6.03 and was in the increasing order with respect to addition of salts and biochar which is slightly acidic. During the thermophilic stage, the pH of the treatments showed increment for the first two weeks with increase in the biochar percentage and the maximum values were 9.05 ± 0.18 (T1), 9.10 ± 0.27 (T2), 9.20 ± 0.37 (T3), 9.23 ± 0.46 (T4), and 9.30 ± 0.19 (T5). The increase in pH is caused by the degradation of the organic matters, ammonization and the alkaline nature of biochar is known to be because of inorganic nutrients which further causes decrease in the conductivity of the manure (Chaher et al., 2020). Czekała et al. (2016) and Duan et al. (2019) had reported similarly in which the former performed co-composting of PM with wheat straw + biochar and the latter with just PM and biochar amendment. Awasthi et al. (2017) found out that increasing the dose of biochar influences the composting positively by providing suitable conditions for microbial enzyme activity.

Then the pH of composting substrates started to decline steadily which can be due to the ammonia volatilization and CO_2 emission. Zhang et al. (2016) recorded a decline in pH at late phases of composting is due to the nitrification by the bacteria. The pH values at finishing phase of composting for the treatments T1 – T5 were 8.01 ± 0.16, 8.30 ± 0.25, 8.29 ± 0.33, 8.47 ± 0.42, and 8.73 ± 0.17, respectively attaining a standard value. Although there was difference with respect to the dose of biochar, there was no significant difference with respect to addition of salts (T1 and T2), indicating that the salts augmentation had no effect on the pH of all the treatments.

The soluble salt contents in the composting mixture are reflected on the electrical conductivity of the mixture. It can also be used to investigate the composts' phytotoxic nature (Bernal et al., 2009). In the present work, the alteration in the EC of all the treatments followed a comparable pattern of sudden increase at the initial stage due to degradation of organic matter which releases numerous ions and a slow decrease and saturation at the finishing phase of composting which is due to the precipitation of mineral salts. The control, without biochar and salts, reached its peak on the 21st day, whereas other treatments reached the peak within 14 days. The delayed peak in the T1 can be due to the slow degradation process. There were fluctuations recorded which is due to the mixing of composting mixtures. However, the EC values of the final compost were less in biochar amended treatments than those treatments without biochar. The initial EC recorded for the treatments T1-T6 were 2.98 ± 0.06, 2.80 ± 0.08, 2.75 ± 0.11, 2.68 ± 0.05, 2.45 ± 0.12 and finally saturated at the range of 2.87 ± 0.14 – 2.30 ± 0.05 (mS/cm), respectively (Fig. 1c). The EC values < 4.00 mS/cm are considered as safe for agricultural purposes (Jeong et al., 2017) and the present study results were within the allowed limits of EC.

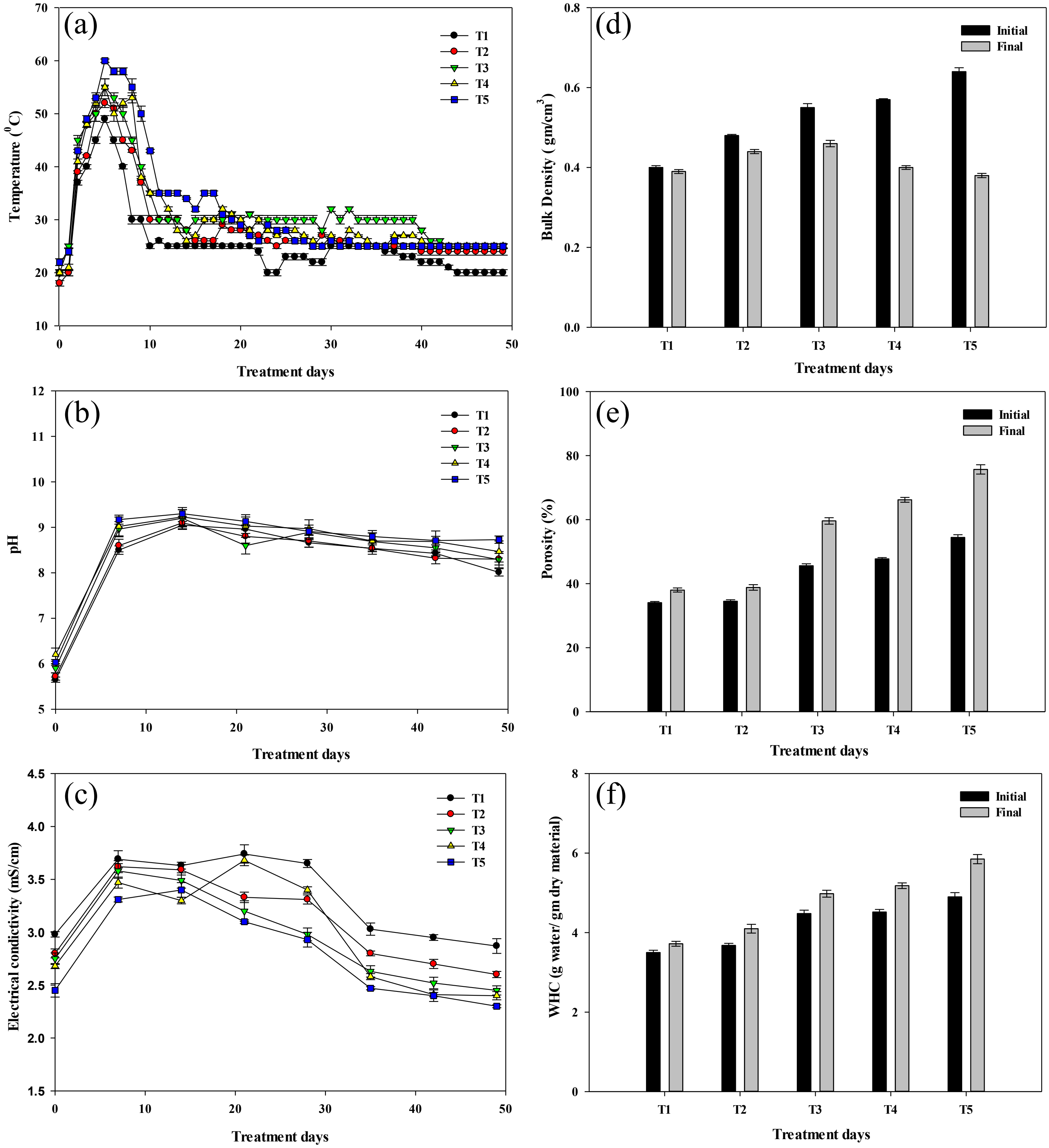

Fig. 1. Dynamics of (a) temperature, (b) pH, (c) electrical conductivity, (d) bulk density, (e) porosity, and (f) water holding capacity during co-composting of food waste and poultry manure amended with saw dust, biochar and salts.

3.2. *Influence of biochar amendment on bulk density, porosity and water holding capacity*

Considering the importance of the BD, porosity and WHC in composting (Lee et al., 2017), in this study the initial and final values of these parameters were monitored and presented in the Fig. 1 (d, e, f). According to several studies, adding bulking agents like biochar helps maintain bulk density, which enables gaseous exchange and increases aeration, improving the composting process and retaining nutrients to improve product quality (Zainudin et al., 2020). The initial BD values of each treatment were found to be different and were higher with the increase in the dose of biochar mixed. But at the final stages of composting the BD of the biochar amended mixtures reduced greatly. The reduction in BD increased with the increase of biochar dose (Fig. 1d). The final BD of T1-T6 was 0.39, 0.44, 0.46, 0.40, 0.38 g/cm^3, respectively. The 10% biochar amended compost was within the acceptable limits of < 0.400 g/cm^3. When compared to the initial values of each treatment, the BD has reduced to about 2.5, 8.33, 16.36, 29.82 and 40.63%. Significant difference ($P < 0.05$) in BD reduction between the biochar amended and control groups was observed. The BD reduction is because of dehydration and is consistent with the temperature trends observed in this study. With a low BD, the final compost product has a high porosity. This is consistent with the total porosity findings in the current investigation, where the porosity (%) of all the treatments increased from 34.05 ± 1.02, 34.5 ± 1.73, 45.6 ± 1.82, 47.75 ± 1.43 and 54.45 ± 2.72% to 38.00 ± 1.14, 38.80 ± 1.94, 59.60 ± 2.38, 66.20 ± 1.99 and 75.7 ± 3.79% for T1, T2, T3, T4 and T5, respectively (Fig. 1e).

Porosity of the treatments with biochar (3, 5, and 10%) amendment increased (30.70, 38.63, and 39.02%, respectively) more when compared with the control (11.63%) and treatment with salts alone (12.46%). This increase in porosity is an indication of moisture content availability and prevention of loss caused by leaching thereby degrading the organic matter (Sánchez-García et al., 2015; Zhang and Sun, 2016). Similar to these results, WHC was also found to be increasing with the increase in the biochar dose amendment (Fig. 1f). WHC is an important property of the compost which will affect the soil to which it is applied. Application of compost with high WHC will increase the WHC of soil which will make the water available for the crops for prolonged days. Therefore, improvement in the yield can be achieved by conserving the water whenever available in the arid regions (Streubel et al., 2011). This indicates that the biochar amended compost mixtures has a prominent role in combating the issues related to water scarcity.

3.3. Variations in C:N ratio

Organic carbon and TN are the most important contents essential for microbial growth for the degradation of organic matters (Meng et al., 2018). The ratio of carbon to nitrogen is another vital factor which indicates the compost stability and maturity. A high C/N ratio causes nitrogen insufficiency and a low C/N ratio causes carbon insufficiency; both these conditions will inhibit the microbial growth affecting the composting operation. At the initial stage, C/N ratio can be at an optimum level (25:1 to 35:1), for obtaining a good compost as recommended by several researchers (Chung et al., 2021). According to this, the initial C/N ratio of all the treatments were in the optimum range 25.3 ± 0.76, 25.3 ± 1.01, 26 ± 1.30, 26.17 ± 0.79 and 29.26 ± 1.17 for T1 to T5, respectively (Fig. 2). The increased C/N ratio in biochar amended is due to the fact that biochar serves as an additional carbon source in the mixture of poultry manure and food waste (Zainudin et al., 2020). The C/N ratio declined significantly ($P < 0.05$), in all the treatments and the final values were 24.45 ± 0.73 (T1), 24.15 ± 0.97 (T2), 24.41 ± 1.07 (T3), 21.05 ± 0.63 (T4) and 19.75 ± 0.79 (T5). Specifically, the C/N ratio of T5 experienced a value below 20 which is considered as the maturity indicator. This could be because of the mineralization and biodegradation of organic matters present in the substrate mixtures through carbon deterioration and nitrogen increment (Kim et al., 2017). As discussed earlier, due to the negligible amount of salts added to reaction mixture, there was no significant effect on the C/N ratio of T2.

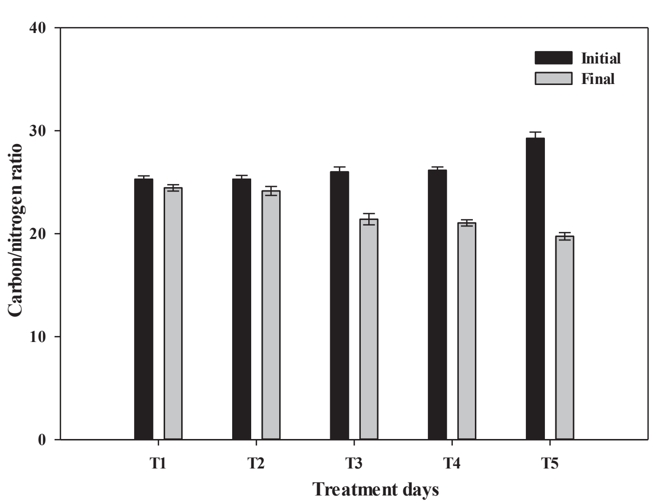

Fig. 2. Initial and final carbon to nitrogen (C:N) ratio of co-composting substrates (food waste and poultry manure) amended with saw dust, biochar and salts.

3.4. Changes in gaseous emission

In a composting process, the biodegradation of organic matters results in the emission of CO_2 and generation of CH_4 (Fillingham et al., 2017). The CO_2 emission trend of all the treatments were similar with increase in the emission at the initial stages reaching to the peaks followed by the decreased emission towards the final phase of composting. Similar to the reports of Chen et al. (2020), all the treatments attained their maximum emission on the 5th day of composting. The trends were corresponding to the temperature trends of this study and the emission rates decreased after the thermophilic stage which indicates the decrease in the microbial activity. From Fig. 3a, the maximum CO_2 emission was in T5 followed by T4, T3, T2 and T1. When compared to control T1 and the salts only added mixture T2 the CO_2 emission significantly increased in the biochar amended treatments (T5 > T4 > T3). This implies that the biochar incorporation to the FW and PM mixture enhanced the bacterial growth which enhanced the biodegradation of organic matter. This is in agreement with (He et al., 2018), where they suggested that the CO_2 emission rates are the reflection of microbial activity and mineralization of organic matters. This microbial activity and mineralization were supported by the addition of biochar. Biochar having large surface area with its porous nature enhanced the aeration to a larger extent and facilitated the oxygen supply inside the feed mixtures.

During composting, a molecule of carbon called CH_4, one of the important greenhouse gases, is released. CH_4 is an air pollutant and is produced due to the deoxidation during the anaerobic condition by methanogens (Awasthi et al., 2017; Chen et al., 2017). The anaerobic condition is the indication of shortage in oxygen supply inside the feed mixtures. Considering the report of IPCC: Climate Change 2014, that the global warming threat by CH_4 is 28 times more than CO_2, and the steps to reduce its emission becomes a priority. From Fig. 3b, the CH_4 emission in composting treatments was increasing and peaked at the earlier stages, especially during the thermophilic stages. This could be attributed to decomposition of large quantities of organic matter which uses up the oxygen in the compost creating an anaerobic condition which promotes the growth of methanogenic archaea. The CH_4 emission of treatments amended with biochar (T3, T4 and T5) is comparatively lesser than the treatments without biochar (T1 and T2). In all the treatments, CH_4 emission reduced by the end of the composting and in the treatments with biochar, the emission reduced earlier with increasing dose of biochar. Zero emission of CH_4 was observed on the 9th, 24th, 27th, 32nd and 40th day of composting for T6 to T1 treatments, respectively. Similar to many other parameters observed in this study, the incorporation of salts did not affect the reduction of CH_4 emission significantly. Again, this could be due to the very low amounts of salts added. These results consist with the results of (de la Rosa et al., 2014), where they suggested that the amendment of biochar reduces the methanogenic bacterial activity and increases the methane oxidizing bacterial activity. By reducing the methanogens activity CH_4 production is curbed by the biochar. The present study results also consistent with the results of Chen et al. (2020), where they used co-amendment of chicken manure with biochar and microbial consortium for composting chicken manure.

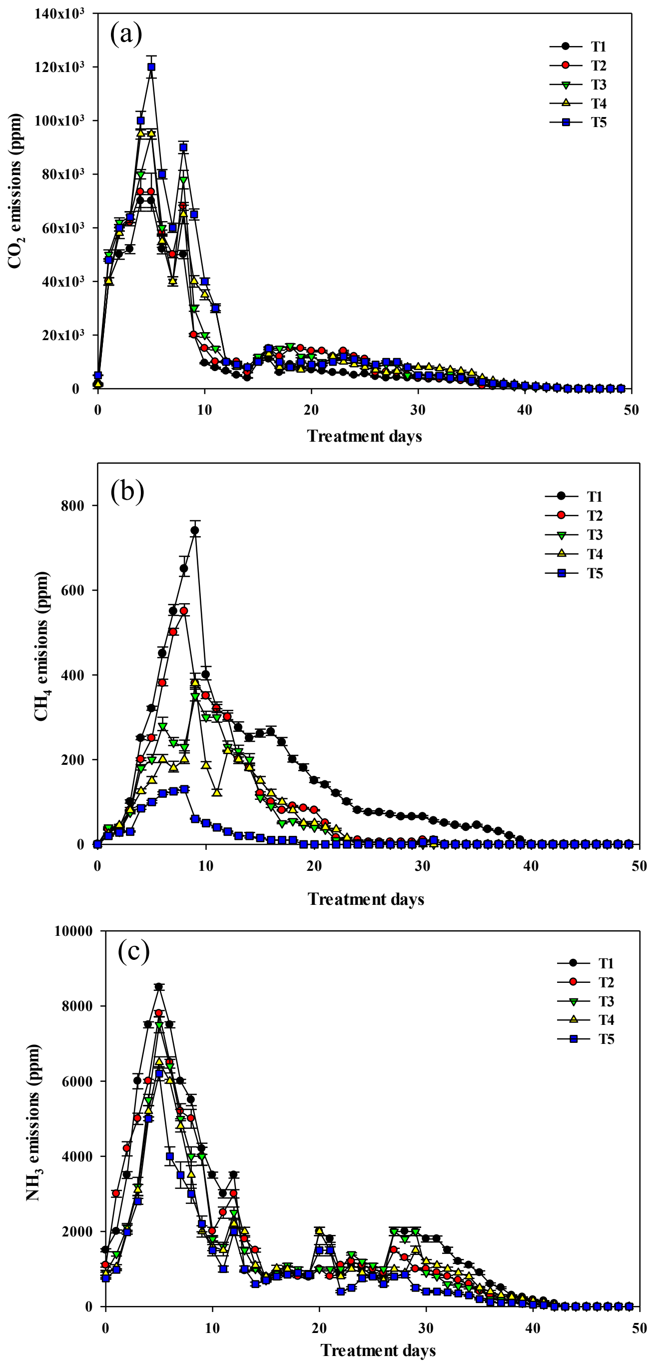

Fig. 3. (a) CO_2, (b) CH_4 and (c) NH_3 emissions during co-composting of food waste and poultry manure amended with saw dust, biochar and salts.

3.5. Nitrogen conservation

While composting livestock manure, apart from CO_2 emission, NH_3 emission is the important biochemical product and is the major form of nitrogen loss which impacts the compost quality (Kim et al., 2017)·NH_3 is also an indirect GHG that creates malodors leading to environmental pollution and thereby global warming. Awasthi et al. (2020) suggests that the carbonaceous materials like biochar can be added to the composting mixtures to mitigate global warming. In this study, NH_3 emission in the biochar amended treatment reduced significantly when compared to the treatments without biochar amendment. The NH_3 emission was observed in the following order T5 < T4 < T3 < T2 < T1 (Fig. 3c). All the treatments experienced a similar trend of increased emission in the earlier stages followed by reduction and saturation in the later stages of composting. Chen et al. (2017) and López-Cano et al. (2016) reported corresponding pattern in their researches with biochar amendment in sheep and layer manure composting, respectively. A maximum of 45% of nitrogen loss was prevented by biochar incorporation to the co-composting of PM and FW·NH_3 emission during the composting is unavoidable because of mineralization, the higher temperatures in the thermophilic stage and favorable pH altogether promoting ammonia volatilization (Yang et al., 2020). The reduction in NH_3 emission in biochar amended treatments is likely due to the exceptionally large surface area, adsorption ability that absorbs NH_3 gas. Simultaneously, porosity is also increased which reduces the anaerobic conditions thereby preventing nitrogen loss (Zhou et al., 2021). Additionally, conditions favorable for nitrifying bacteria also facilitate microbial metabolism in NH_3 emission reduction (Khan et al., 2014; López-Cano et al., 2016). Studies have reported that the addition of salts such as Mg and P results in struvite formation which reduces the loss of nitrogen in the composting process (Ren et al., 2010). Similarly, in the present study, a minimal reduction in nitrogen loss was witnessed in T2, while maximum reduction was seen in the salts and biochar mixed treatments.

The NH_4^+-N and NO_3^--N contents in the course of composting were also noted and presented in Fig. 4a. The NH_4^+-N concentration in most of the treatments elevated over the first two weeks of composting and peaked on the 14th day. When the thermophilic phase ended, the NH_4^+-N content increased between 7th and 14th day. However, the peaks of biochar amended treatments were low compared to the treatments without biochar. This could be due to the adsorption properties of the biochar, volatilization of NH_3 at high temperatures, rapid

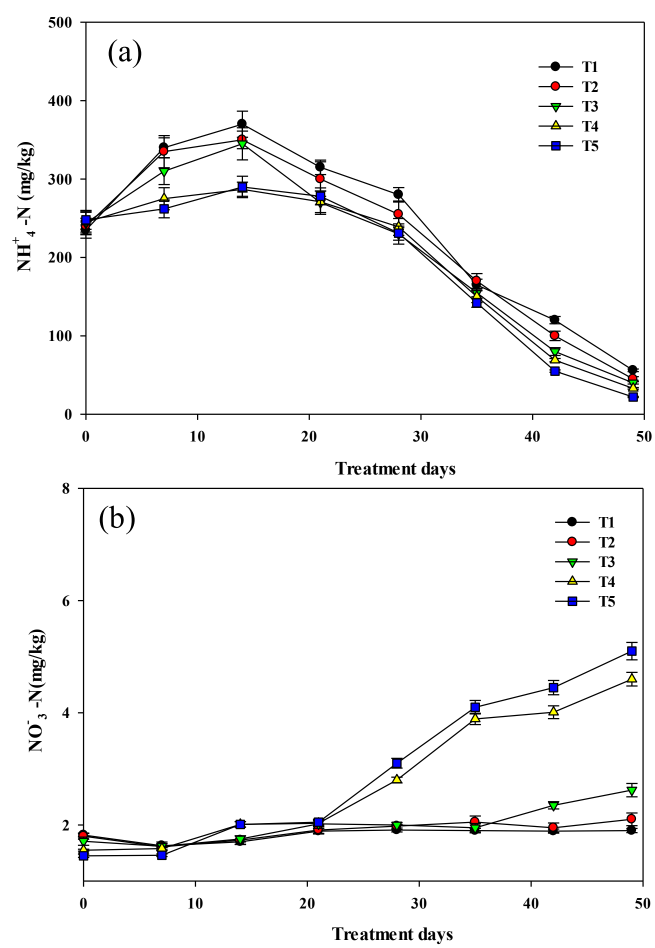

Fig. 4. (a) NH_4^+-N and (b) NO_3^--N changes during co-composting of food waste and poultry manure amended with saw dust, biochar and salts.

mineralization and the promotion of nitrobacteria (Khan et al., 2014). The reduction NH_4^+-N contents from 235, 240, 244, 245 and 248 to 56, 45, 40, 33 and 22 ppm for T1 to T5 respectively, is an indication of the affinity of biochar resulting in the decrease of ammonia which agrees with the NH_3 emission trend (Fig. 3c). Ammonification, nitrification and denitrification are the major reactions occurring during nitrogen conversion in a composting process. Researchers suggest that the salts incorporation results in struvite formation which reduces the NH_4^+-N content. Jeong and Kim (2001) reported that the addition of Mg and P salts did not impact on the mineralization. Similarly, it was reflected in this study by reduced emission of NH_4^+-N compared to control. However, the combined effects of both biochar and salts had more positive effects in inhibiting the NH_4^+-N concentration. The changes in the NO_3^--N content of all the treatments are given in Fig. 4b. At the initial stages, the NO_3^--N concentration was found to decline which is due to the nitrification. After the 7th day, NO_3^--N concentration started to increase as a result of thermophilic stage completion facilitating the growth and activity of nitrifying bacteria. The increase in NO_3^--N concentration was enhanced with the higher concentration of biochar. At the maturation stage, the NO_3^--N in control (T1) was ~62% lower than the treatment with biochar (%).

This clearly demonstrates that the co-amendment of salts and biochar results in reduced NH_4^+-N content and the least cumulative emission of NH_3, as a consequence of combined effects of both salts and biochar. Salts facilitated the struvite crystals formation which is considered to be the efficient nitrogen conservation method; salts, when mixed with composting material stores the NH_4^+-N as struvite crystals. The rice husk biochar adsorbs the nitrogen compounds, thereby reducing its mineralization. Due to the aforesaid properties of rice husk biochar along with its ion exchange sites adsorbs the nitrogen compounds, thereby reducing its mineralization. This is also considered as an indirect mechanism that leads to the reduction in NH_3 emissions.

4. Conclusions

In this study, a feasible method for co-composting food waste and poultry manure has been revealed. It is evident that the co-amendment of biochar and salts could act synergistically on the co-composting process. Biochar amendment at the maximum dose along with salts effectively degraded the feed mixtures, reduced the emission of gases and helped in preserving the nitrogen content thereby improving the nutrient content of the final compost. Thus, the biochar-salt co-amendment could help in co-composting the food waste and poultry manure as well as to enhance the soil attributes to which the compost is added.

CRediT authorship contribution statement

Balasubramani Ravindran: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Project administration, Supervision, Resources, Funding acquisition. **Natchimuthu Karmegam:** Methodology, Software, Validation, Data curation, Writing – review & editing. **Mukesh Kumar Awasthi:** Methodology, Software, Validation, Data curation, Writing – review & editing. **Soon Woong Chang:** Methodology, Software, Validation, Data curation, Writing – review & editing. **P.K. Selvi:** Methodology, Software, Validation, Data curation, Writing – review & editing. **Ramalingam Balachandar:** Methodology, Software, Validation, Data curation, Writing – review & editing. **Sasikala Chinnappan:** Writing – review & editing. **Nur Izyan Wan Azelee:** Writing – review & editing. **Ganesh Munusamy-Ramanujam:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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