



# Reducing nitrogen loss and salinity during ‘struvite’ food waste composting by zeolite amendment



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## HIGHLIGHTS

- Zeolite addition at 10% conserved N and accelerated the food waste composting.
- A combination of zeolite and struvite composting helps reduce the compost salinity.
- 10% zeolite reduced the compost EC to 2.82 mS/cm during struvite composting.
- N loss was reduced to ~18% through zeolite–struvite composting process.

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## ABSTRACT

Struvite formation during composting through supplementation of Mg and P salts conserved nitrogen but in the same time increased the electrical conductivity (EC) of the compost limiting its application. Therefore the present study aimed at utilizing zeolite to control the EC under ‘struvite’ composting of food waste. Zeolite at 5% and 10% (dry weight basis) was supplemented to the composting mass receiving Mg and P salts and compared with treatment with Mg and P salts only and the control without any amendment. Addition of Mg and P salts effectively buffered the pH to ~8.0 but also increased the EC of the compost to 6.45 mS/cm. Co-amendment with 10% zeolite effectively reduced the EC down to 2.82 mS/cm and improved compost maturity. It also increased the adsorption of ammonium ions reducing ammonia loss to 18% resulting in higher total nitrogen content in the final compost.

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## 1. Introduction

Treatment of food wastes is becoming a stern issue worldwide due to their generation in significant quantities. During 2013, about 3648 tons of food wastes were landfilled every day, representing 38.2% of the municipal solid waste in Hong Kong (HKEPD, 2015). This not only creates a severe burden on the landfills but also create environmental problems like leachate and odour emission and greenhouse gas emission. Composting provides an effective alternative for food waste management by stabilizing organic matters in food waste and converting it to a soil conditioner or fertilizer. Food waste is a suitable substrate for composting because it is rich in organic matter with little concerns about heavy metals and pathogens. However, the specific characteristics of food wastes such as

high moisture (Shen et al., 2015; Zhou et al., 2014), acidity (Wang et al., 2013; Wong et al., 2009; Yu and Huang, 2009), high oil content (Meng et al., 2015) and high salinity (Wang et al., 2013; Yang et al., 2015) may retard the decomposition process. Of these problems, acidity and odour emission have received much attention (Sundberg et al., 2004; Wang et al., 2013; Wong et al., 2009). During food waste composting, the rapid degradation of high quantities of easily available organic matter intensively acidifies the composting mass, which eventually inhibits the microbes and the composting microbial process. Addition of alkaline materials such as lime can alleviate the low pH and help to achieve efficient organic degradation but in the same time causing the loss of N in the form of ammonia (Wong et al., 2009). In a composting process, loss of nitrogen as ammonia could account for up to 65% of the initial total N loss from the system reducing its competitiveness in the market. Therefore it is essential to control the acidity as well as the ammonia emission during food waste composting.

There have been attempts to encourage struvite formation to reduce ammonia loss by adding Mg and PO<sub>4</sub> salts during the composting process (Du et al., 2010; Fukumoto et al., 2011; Jeong and

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Hwang, 2005; Jeong and Kim, 2001; Lee et al., 2009; Ren et al., 2010; Wang et al., 2013). Wang et al. (2013) reported that addition of 1:2 M ratio of MgO and  $K_2HPO_4$  not just facilitated trapping ammonium through the formation of struvite but in the same time could alleviate low pH of food waste as well as reduce the N loss up to 57% when compared with food waste composting with 2.25% lime amendment. Lee et al. (2009) found that the rate of ammonia emission was inversely proportional to the amount of salts addition. Despite these advantages, most of the literature focused only on the influence of struvite salts on decomposition and nitrogen conservation without considering the resulting salinity following salts addition. Wang et al. (2013) observed that the EC of the struvite based food waste compost increased to >6 mS/cm which is higher than the limit ideal for the growth of non-saline tolerant crops (Richards, 1954). This may affect the general acceptability of using struvite formation as a means to conserve nitrogen during composting. Therefore, controlling the EC during struvite composting will facilitate the realization of the full benefits of the struvite composting.

Zeolite, as a natural mineral, has the ability to reduce the salinity, various gases emissions and heavy metals availability during composting. However, zeolite was not good enough to buffer against the low pH during composting as revealed by Singh et al. (2013). Therefore, the aim of the present study was to investigate whether supplementation of the zeolite with struvite salt together could enable synergistic achievement of both pH and EC buffering, and N conservation during food waste composting that has never been investigated before. The resulting composting product is expected to be useful in controlling nutrient release upon soil application.

## 2. Methods

### 2.1. Feedstock preparation

A synthetic food waste was prepared by mixing bread, boiled rice, cabbage and boiled pork in the ratio of 13:10:10:5 (dry weight basis), as described previously (Wong et al., 2009). The components of the food waste were cut into 1 cm<sup>3</sup> to obtain uniform particle size that enables good mixing in the bench-scale reactors. Then, the food waste was mixed with sawdust to adjust the C/N ratio to ~30 while the initial moisture content was adjusted to 55% through addition of deionized water. In addition, plastic spheres were added (500 g/7.5 kg wet composting mass) to adjust the bulk density to ~0.5 kg/L. Food waste composting mix was amended with Mg and  $PO_4$  salts in the form of magnesium oxide (MgO) and dipotassium hydrogen phosphate ( $K_2HPO_4$ ) on dry weight basis at 1:2 M ratio (Mg:P) (Wang et al., 2013) before the addition of 0%, 5% and 10% zeolite (w/w dry weight basis), and a control treatment without any amendment was also prepared for comparison purpose (Table 1). The zeolite used in the present study was a commercial zeolite, clinoptilolite, purchased from Zhejiang Shenshi Mining Industry Co., Ltd which has a diameter of 3.5–4.0 (Å) and cation exchange capacity of 120–160 meq/100 g. All treatments were performed in duplicates.

**Table 1**  
Dosage of different inorganic amendments in the four treatments.

Treatment	Zeolite (%)	MgO (M/kg)	$K_2HPO_4$ (M/kg)
Control (C)	0	0	0
0.05 M MgO and 0.1 M $K_2HPO_4$ (Mg:P)	0	0.05	0.10
Zeolite 5%, 0.05 M MgO and 0.1 M $K_2HPO_4$ (5% Z + Mg:P)	5	0.05	0.10
Zeolite 10%, 0.05 M MgO and 0.1 M $K_2HPO_4$ (10% Z + Mg:P)	10	0.05	0.10

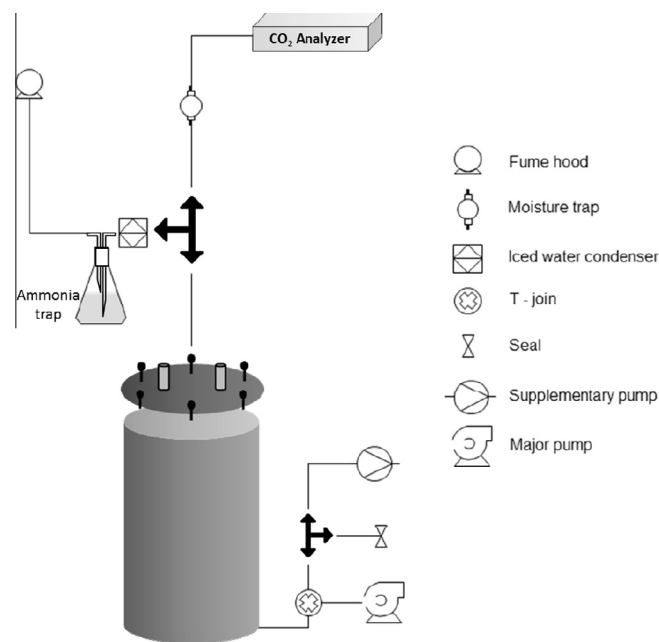
### 2.2. Composting setup and operation, and analyses

The substrates of each treatment were composted for 56 days in a 20-L bench-scale composter that was connected to a computer feed back controlled system (Fig. 1), which enables continuous logging of the temperature of the composting mass by a thermocouple, located at the center of the composting tank. At temperature higher than 65 °C, a feedback ventilation control was adopted to prevent overheating of the composting mass. Carbon dioxide emissions from the reactor outlet air were measured on-line using an infrared gas analyser (WMA-3, PP Systems, UK). Total ammonia loss from the composting reactor was estimated from the exhaust gas by absorbing ammonia onto boric acid for 1 h before titrated against hydrochloric acid (Meeker and Wagner, 1933). Moisture content of the composting mass was readjusted to 55% periodically on days 0, 3, 7, 10, 14, 21, 28, 35, 42, 49 and 56 before collecting 240 g sample for each treatments for physicochemical analyses.

Compost samples collected were oven-dried at 105 °C for 24 h to determine the moisture content while dried samples were ignited at 550 °C in a muffle furnace for 16 h to determine total organic matter (TOM) content. A 1:5 aqueous extract (w/v, dry basis) of the fresh composts with deionized water was used for the analysis pH, electrical conductivity (EC), extractable ammonium ( $NH_4^+$ -N) and seed germination index. The pH and EC were measured using an Orion 920 ISE pH meter and an Orion 160 conductivity meter, respectively. Total Kjeldahl nitrogen (TKN) and  $NH_4^+$ -N were analysed following the test methods for the examination of composting and compost (TMECC, 2002) while total organic carbon (TOC) was analysed following the Walkley–Black method (Nelson and Sommers, 1982). Cress seeds were used in the seed germination test to evaluate the compost maturity as per the HKORC (2005).

### 2.3. Statistical analysis

All experiments were performed in duplicates and the results are presented as mean ± standard deviation. Data were analysed using one way analysis of variance (ANOVA) to test the significance at 5% level using IBM SPSS v.16 (IBM, 2013).



**Fig. 1.** Schematic diagram of the 20-L bench-scale food waste composter.

### 3. Results and discussions

#### 3.1. Changes of temperature and carbon dioxide evolution

A good thermophilic phase of at least 1 week is important for effective removal of pathogenic organisms to produce hygienic compost. Strauch and Ballarini (1994) reported that pathogens can be destroyed only when the temperature reach 55 °C or above. The temperature of all the treatments increased rapidly within two days indicating the rapid degradation of easily degradable organic matter that served as nutrient for the microbes and promoted their growth and activity (Wang et al., 2013). In the control, the temperature dropped drastically after three days (Fig. 2a) because it received no alkaline amendment to buffer against the organic acids produced during intensive degradation resulting in a decrease in pH making it unfavourable for microbial activity. For all other treatments with alkaline amendment, temperature reached over 55 °C within a day and maintained for a period of over 2 weeks before declining indicating that the alkaline amendment was effective in providing a good environment for microbial degradation.

Rate of CO<sub>2</sub> evolution directly reflects the microbial activity in the composting system. During the thermophilic phase, high

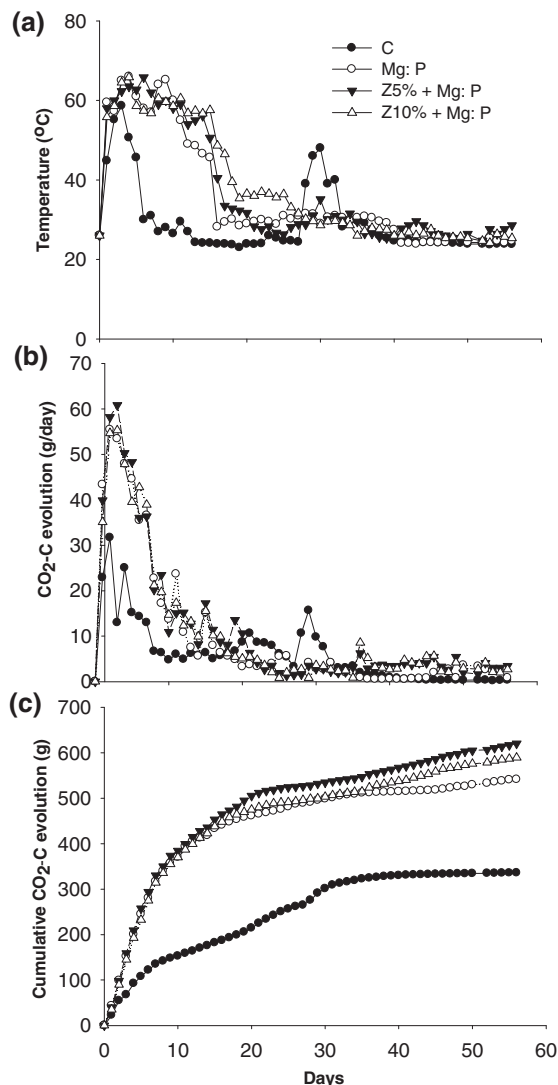
quantities of thermophilic bacteria are active resulting in high evolution of CO<sub>2</sub>. The CO<sub>2</sub> concentration in the exhaust gas reached the maximum level within 24 h which coincided with the rise in temperature and the beginning of thermophilic phase as reported previously (Wong and Fang, 2000). In correlation with a short thermophilic phase (Fig. 2a), the CO<sub>2</sub> emission was low and decreased drastically within 3 days (Fig. 2b) in the control. In all the struvite treatments, irrespective of the zeolite concentration, the CO<sub>2</sub> emission was almost similar for the first 40 days while after that the CO<sub>2</sub> emission from treatment with 5% zeolite was slightly higher than that with 10% addition. The profiles of CO<sub>2</sub> evolution are similar to that of temperature profiles (Fig. 2a) but the CO<sub>2</sub> evolutions decreased much faster than temperature due to the insulation of composters that effectively prevented the rapid heat loss from system as observed previously (Wang et al., 2013). There were no significant differences ( $P > 0.05$ ) in the cumulative CO<sub>2</sub> emission among the struvite treatments with different levels of zeolite amendment (Fig. 2c) indicating that their microbial activities and also the decomposition efficiency were almost similar. In contrast, cumulative CO<sub>2</sub> evolution observed in the control was significantly lower ( $P < 0.05$ ) than that of others because the acidic condition did not favor the microbial activities as evidenced from a short thermophilic phase. Similar results were reported previously (Wong et al., 2009; Wang et al., 2013).

#### 3.2. Changes in pH profile

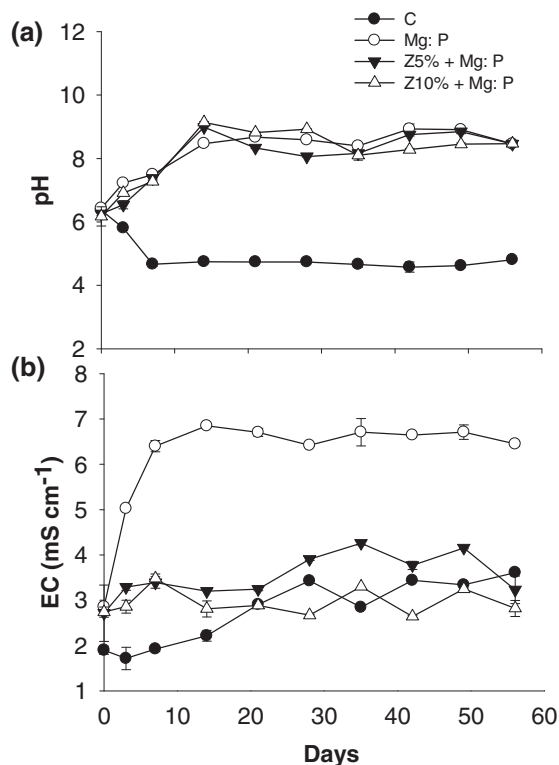
pH is a critical factor influencing the microbial activities and microbial community during composting. Under optimal conditions, pH, after an initial reduction, should increase from acidic to neutral range if the organic acids are decomposed successfully and a range of 7.0–8.0 is reported to be optimum for composting (Ivankin et al., 2014). As shown in Fig. 3a, the pH of the control decreased from 6.37 to 4.67 during the first week and then was stable around 4.5 until the end of the experiment which was likely due to the accumulation of organic acids. This would inhibit the microbial activities and prevent the degradation of the generated organic acids creating a circular effect (Wong et al., 2009; Wang et al., 2013). In contrast, addition of struvite salts increased the pH from around 6.0 to 8.5–9.0 during the first two weeks (Fig. 3a). Wang et al. (2013) reported that the addition of K<sub>2</sub>HPO<sub>4</sub> successfully buffered the pH by neutralizing the organic acids. Addition of 5% and 10% zeolite with struvite salts did not show any additional pH enhancement, indicating that the main pH buffering effect was due to struvite salts. After 8 weeks of composting the final pH values were ~8.4 in the struvite treatments while 4.81 in the control. Although, zeolite did not show a direct influence on pH, it can provide a good physical structure while the effects may not be instantaneous compared with Mg and P salts. Singh et al. (2013) observed that the zeolite amended treatments had slightly higher pH compared with the control treatment. Venglovsky et al. (2005) reported that the pH values of 1% and 2% zeolite amended treatments during the thermophilic stage of pig slurry composting were lower than that of the control, and this observation was linked to the adsorption of ammonium onto zeolite. Therefore, the pH buffering function of zeolite is still unclear and it depends on the availability of different soluble ions in the system while it may slightly reduce the ammonium-based buffering in the composting mass. Besides, the high dosage of zeolite could pose a dilution effect that would also affect the pH, and its adsorption property can be greatly varied under a changing pH condition.

#### 3.3. Changes in electrical conductivity (EC)

Compost with high EC releases excessive soluble salts and pose negative effect on plant growth and yield. During composting, it is unavoidable that the concentration of soluble salts is increased due



**Fig. 2.** Changes of temperature (a), CO<sub>2</sub> evolution (b), and cumulative CO<sub>2</sub> evolution (c) during food waste composting. C – Control, Mg:P – 1:2 Mg:PO<sub>4</sub>, 5% Z + Mg:P – 5% zeolite with 1:2 Mg:PO<sub>4</sub> and 10% Z + Mg:P – 10% zeolite with 1:2 Mg:PO<sub>4</sub>. Error bars represent the standard deviations.



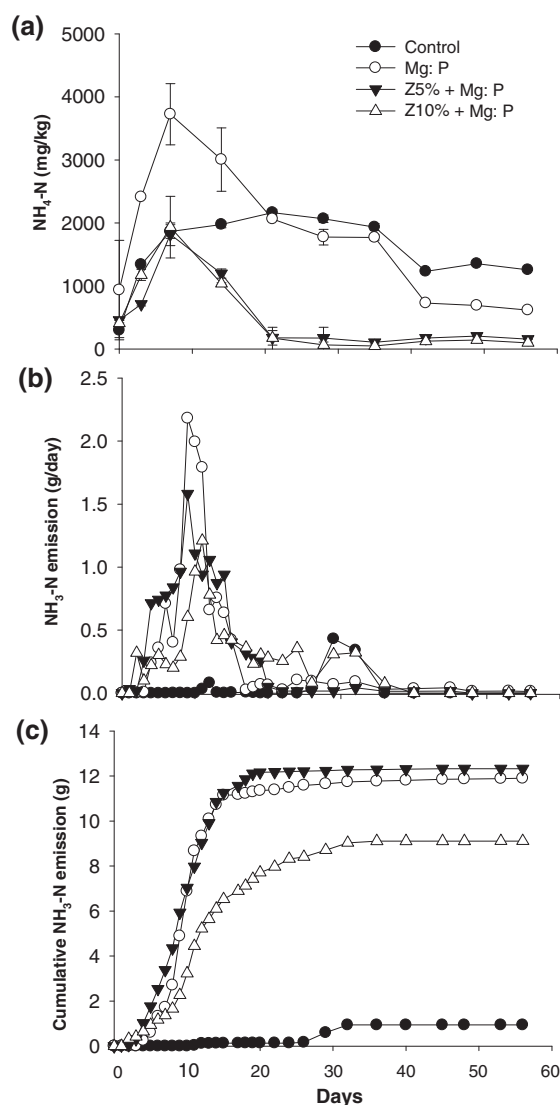
**Fig. 3.** Changes of pH (a) and EC (b) during food waste composting. C – Control, Mg: P – 1:2 Mg:PO<sub>4</sub>, 5% Z + Mg:P – 5% zeolite with 1:2 Mg:PO<sub>4</sub> and 10% Z + Mg:P – 10% zeolite with 1:2 Mg:PO<sub>4</sub>. Error bars represent the standard deviations.

to the degradation of complex organic matter. As shown in Fig. 3b, the initial EC of the treatments ranged between 1.9 and 2.6 mS/cm due to the differences in the composition of the different treatments (Fig. 3b). In the control, EC slowly increased to around 3.6 mS/cm after 8 weeks mainly due to the low degradation. In contrast, the EC of struvite treatment without zeolite (Mg:P) increased to a value of ~7 mS/cm after 2 weeks and the levels were more or less stable in this range until the end of the composting period resulting in a compost product with a final EC of 6.45 mS/cm. As hypothesized, the addition of zeolite significantly ( $P < 0.05$ ) reduced the EC of the composting mass and the decrease was directly related to an increase in zeolite amendment rate. The final EC of treatments receiving 5% and 10% zeolite amendment were 3.23 and 2.82 mS/cm, respectively. Thus these composts will not cause any phytotoxicity upon application (Richards, 1954). Due to molecular sieve structure and high cation exchange capacity (CEC) of ~120–160/100 g of zeolite, it can accommodate and allow the exchange of ions freely on its surface and adsorb the ions (Hedström, 2001), resulting in a decrease of the EC. During the struvite composting process, a wide variety of soluble ions, including Mg and PO<sub>4</sub> salts that were added to the system to trap the ammonium would contribute to the conductivity. Thus zeolite can be an indispensable tool for struvite composting.

#### 3.4. Changes in extractable ammonium nitrogen and ammonia emission

Concentrations of extractable ammonium nitrogen (NH<sub>4</sub><sup>+</sup>-N) in all the treatments increased during the first week and reached the peak values on day 7, except for the control. The release of NH<sub>4</sub><sup>+</sup>-N through ammonification coincided with the active degradation of organic matter during thermophilic phase (Fig. 4a). The peak concentration of NH<sub>4</sub><sup>+</sup>-N of struvite only treatment was 3725 mg/kg DW, which was significantly ( $P < 0.05$ ) higher than the 1818 and 1933 mg/kg DW of 5% and 10% zeolite treatments

on day 7; and then it decreased rapidly during subsequent period of composting. In the control, a peak concentration of ~1900 mg/kg was observed on day 7; and the concentrations fluctuated around this range until 35 days before decreased to around ~1300 mg/kg after 8 weeks. This observed trend in the control was mainly due to the lower decomposition and ammonification; and the low pH did not allow further transformation of inorganic nitrogen as nitrifiers might also be affected. A similar trend was also observed by Wang et al. (2013). Overall, treatments amended with zeolite had a lower concentration of NH<sub>4</sub><sup>+</sup>-N during the whole experimental period compared to struvite without zeolite amendment demonstrating a great affinity of zeolite for NH<sub>4</sub><sup>+</sup>-N; and the pH acts as a crucial factor affecting this affinity. In an acidic condition, NH<sub>4</sub><sup>+</sup>-N had to compete with H<sup>+</sup> for the adsorption sites; however, in an alkaline condition, the NH<sub>4</sub><sup>+</sup>-N would be transformed to NH<sub>3</sub>. Thus when the pH is neutral the ammonium adsorption onto zeolite will be higher as the optimum pH for adsorption is 6–7 (Kithome et al., 1998). Therefore, the conditions prevail during the first 2 weeks are crucial for exploiting the benefits of zeolite in composting systems. After the first week, the concentrations



**Fig. 4.** Changes in the concentrations of extractable ammonium (a), ammonia emission (b), and cumulative ammonia emission (c) during food waste composting. C – Control, Mg:P – 1:2 Mg:PO<sub>4</sub>, 5% Z + Mg:P – 5% zeolite with 1:2 Mg:PO<sub>4</sub> and 10% Z + Mg:P – 10% zeolite with 1:2 Mg:PO<sub>4</sub>. Error bars represent the standard deviations.



of  $\text{NH}_4^+\text{-N}$  decreased due to volatilization due to alkaline pH and possibly nitrification. Obviously, zeolite exhibited a great affinity to ammonium ions, as reported previously for soil and wastewater matrices (Kithome et al., 1999; Widiastuti et al., 2008).

Ammonia emission is inevitable during composting when the organic matter is mineralized, and the pH and temperature are high. Loss of  $\text{NH}_3$  from the composting mass poses serious odour problems and nitrogen loss from the composting mass results in low-nutrient product. Komilis and Ham (2006) reported that ~65% of initial nitrogen of food waste can be volatilized as  $\text{NH}_3$ . In this study, the nitrogen loss was reduced to 25.02% in struvite treatment and a similar value of 23.3% was reported previously during food waste struvite composting (Wang et al., 2013). Ammonia emission in the control treatment was the lowest mainly due to the acidic condition that prevented the volatilization of ammonium into  $\text{NH}_3$ , thus it cannot be considered as conservation. Whereas among the struvite treatments, 10% zeolite addition significantly reduced the  $\text{NH}_3$  emission ( $P < 0.001$ ) when compared with other struvite and control treatments. In contrast, 5% zeolite reduced the  $\text{NH}_3$  loss marginally when compared with Mg:P treatment, and the difference was not significant. 5% zeolite addition resulted in lower peak value than the struvite compost without zeolite addition, between days 11–14, (Fig. 4b) implying that the odour intensity can be reduced by zeolite. As presented in Fig. 4c, the cumulative  $\text{NH}_3$  loss of the 10% zeolite addition was 17.96%, which was significantly lower than the 5% zeolite addition (26.98%) and struvite compost without zeolite (25.02%) treatments. Results clearly indicate that the zeolite can be used to reduce the EC of the compost as well as achieve the benefits of the struvite-based nitrogen conservation. Thus an optimum zeolite concentration facilitate additional reduction of nitrogen loss.

Du et al. (2010) reported only 4% nitrogen loss during food waste composting when the composting mass was supplemented with  $\text{KH}_2\text{PO}_4 + \text{MgSO}_4$  at a molar ratio of 1:2:5 (Mg:P:N). Although the N loss was very low, the molar ratio adopted could not explain how almost all the nitrogen was trapped within the composting mass while no information on the EC was available. About 50% reduction in the nitrogen loss during struvite composting was reported by Fukumoto et al. (2011) and Wang et al. (2013) with struvite composting of swine manure and food waste, respectively. Considering the initial total nitrogen, the net nitrogen loss during food waste struvite composting represented about 21–23% (Wang et al., 2013), a value close to the level achieved in this experiment. In addition, Jeong and Hwang (2005) reported that the Mg and P salts in excess of 20% of the total nitrogen on molar basis might harm the composting process. Thus the rate of Mg and P addition used in this experiment and the reduction in nitrogen loss achieved are reasonable while zeolite could further help to reduce the conductivity of the compost produced. None of the previous struvite composting studies reported the level of conductivity in struvite composts, except the study of Wang et al. (2013), who reported the high EC as a negative impact of the struvite compost. This study demonstrated a potential approach to reduce the EC of struvite composting.

### 3.5. Changes in total organic carbon, total Kjeldahl nitrogen and C/N ratio

The total organic carbon (TOC) content during the composting process decreases since the microorganism would mineralize the organic carbon as their energy sources (Wong and Fang, 2000). As shown in (Fig. 5a), the organic carbon contents in all the treatments decreased along the composting process except control treatment since the acidified environment did not favor rapid microbial decomposition, while the 'struvite' treatments showed higher decomposition rate although there was no significant difference ( $P > 0.05$ ) among the three struvite treatments. Based on the

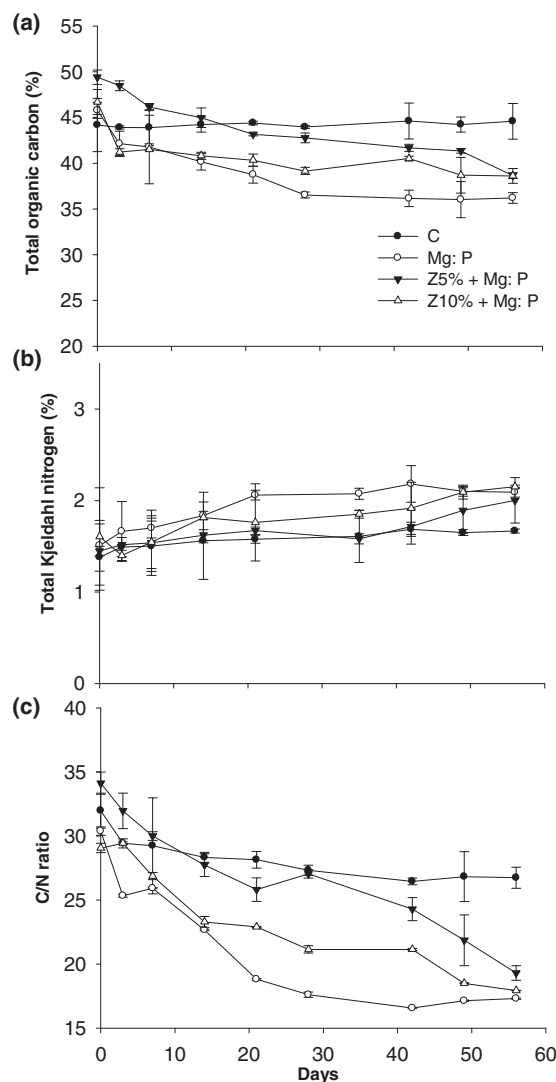


Fig. 5. Changes of total organic carbon (a), total Kjeldahl nitrogen (b), and C/N ratio (c) during food waste composting. C – Control, Mg:P – 1:2 Mg:PO<sub>4</sub>, 5% Z + Mg:P – 5% zeolite with 1:2 Mg:PO<sub>4</sub> and 10% Z + Mg:P – 10% zeolite with 1:2 Mg:PO<sub>4</sub>. Error bars represent the standard deviations.

changes in the TOC contents, the organic carbon degradation was calculated. A low organic degradation of 13.2% was observed in the control while 29.4–35.3% organic degradation was observed in struvite treatments. The level of degradation correlates well with the  $\text{CO}_2$  evolution (Fig. 2c).

During the initial stage of composting, due to the significant organic decomposition, the composting mass is reduced, but the nitrogen will not be consumed in the same rate as that of carbon. As a result, the total Kjeldahl nitrogen (TKN) increased mainly as a concentration effect, but the increase in the present experiment was not significant (Fig. 5b). Treatments amended with struvite salts are expected to enhance the nitrogen content in the final compost because of ammonium conservation through struvite formation. However, marked N conservation was noted only at 10% zeolite amendment rate indicating that it could facilitate the aerobic bacteria involved in nitrification resulting in N immobilization and conservation. However, further studies are required to comprehensively reveal this complex interaction.

In struvite composting treatments, the C/N ratio decreased gradually along the composting period. Among the struvite treatments, 0% and 10% zeolite behaved similarly while the 5% zeolite treatment behaved differently that could correlate well with the

**Table 2**

Selected physicochemical properties of compost product after 56 days of composting.

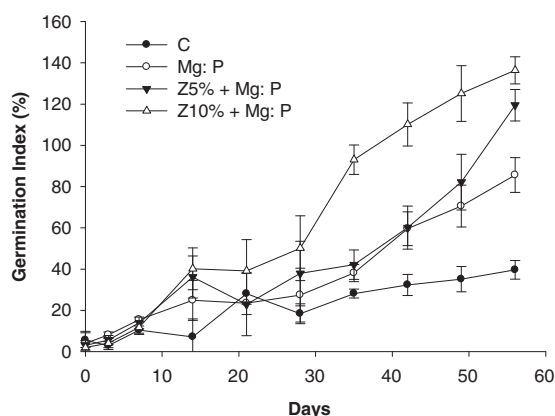
Parameters	Compost standards		Treatments			
	HKORC <sup>a</sup>	TMECC <sup>b</sup> /CCME <sup>c</sup>	C	Mg:P	5% Z + Mg:P	10% Z + Mg:P
Ammonium (mg/kg dw)	≤700	75–500	1257 ± 11a	615 ± 8b	156 ± 9c	97 ± 11d
pH	5.5–8.5	–	4.81 ± 0.04a	8.46 ± 0.07bcd	8.46 ± 0.07bcd	8.47 ± 0.06bcd
EC (mS/cm)	–	–	3.60 ± 0.01a	6.45 ± 0.05b	3.23 ± 0.30c	2.82 ± 0.18d
Organic matter (% dw)	≥20	≤40	97.3 ± 0.1a	93.5 ± 0.1b	86.4 ± 0.1c	79.7 ± 0.2d
Organic carbon (% dw)	–	–	44.6 ± 2.0a	36.2 ± 0.6b	38.7 ± 0.3 cd	38.6 ± 0.8 cd
Seed germination index (%)	≥80	80–90	39.7 ± 4.6a	85.6 ± 8.4b	119.5 ± 7.7c	136.4 ± 6.5d
C/N ratio	≤25	≤25	26.8 ± 0.82a	17.3 ± 0.05b	21.7 ± 0.58c	17.95 ± 0.2d
Total N (% dw)	–	–	1.69 ± 0.12a	2.09 ± 0.05b	2.00 ± 0.25c	2.15 ± 0.08d

Data with the same letter among the treatments in a row for a parameter are not significantly different ( $P < 0.05$ ).<sup>a</sup> HKORC (2005): compost and soil conditioner quality standards for general agricultural use.<sup>b</sup> TMECC (2002): test methods for the examination of compost and composting.<sup>c</sup> CCME (2005): guidelines for grade A compost quality.

final TKN content of the compost material (Table 2). After 56 days of composting, the C/N ratios of the struvite treatments were <21.7 and meet the standard value of <25. In contrast, the C/N ratio of the control treatment was 26.8 and higher than the standard limit indicating the requirement for longer composting period.

### 3.6. Seed germination index

Seed germination index (SGI) is the most commonly used parameter to evaluate the phytotoxicity level of final compost and it directly examines the effect on the seed germination and seedling growth. A minimum value of 80% is considered to indicate the compost maturity at an extraction ratio of 1:5 (compost:water wet wt/v) (HKORC, 2005). Initially, the SGI were very low due to the active organic decomposition that generated high concentrations of  $\text{NH}_4^+\text{-N}$  and volatile fatty acids, which are toxic and inhibit the seed germination (Fig. 6). The SGI of the final compost products of the struvite treatments (with and without zeolite addition) were >80% and can be considered as mature while the addition of zeolite accelerated compost maturity. Due to the low organic degradation, high ammonium concentrations and possibly high organic acids, the compost from the control did not mature after 56 days and required longer time. For treatment with zeolite addition the shorter maturation time might be due to the establishment of a good physical structure, good buffering and adsorption of ammonium. Lin et al. (1998) reported that increasing the zeolite application rate in acidic soil could stabilize and reduce the amount of toxic substances, which were leached from the soil. Thus the zeolite provided a niche to adsorb the components that affect seed germination and accelerated compost maturity.



**Fig. 6.** Changes of seed germination index during food waste composting. C – Control, Mg:P – 1:2 Mg:PO<sub>4</sub>, 5% Z + Mg:P – 5% zeolite with 1:2 Mg:PO<sub>4</sub> and 10% Z + Mg:P – 10% zeolite with 1:2 Mg:PO<sub>4</sub>. Error bars represent the standard deviations.

Zeolite addition at 5% and 10% showed significantly ( $P < 0.05$ ) higher SGI than Mg:P after 8 weeks. It is interesting that despite the high EC, the struvite treatment without zeolite amendment also showed a GI of 85.6% but much lower than those with zeolite amendment indicating the inhibitory effects contributing from the Mg and P salts and also the ammonium ions. Wang et al. (2013) observed an inhibition on SGI due to the addition of struvite salts; thus systematic studies are required to assess the phytotoxicity of struvite composts before devising an application rate as well as to identify the exact species causing the increase in the EC. Except Wang et al. (2013), no other study reported the high EC of the struvite composts due to the addition of Mg and P salts, and the potential impact on their future application. Thus nitrogen conservation alone cannot be placed as a criterion to judge the struvite composts while their phytotoxicities must be investigated thoroughly. This study clearly indicated that zeolite offers a potential way to reduce the salinity of the struvite composts and in the same time improves nitrogen conservation.

## 4. Conclusions

Struvite formation through the addition of MgO and K<sub>2</sub>HPO<sub>4</sub> during food waste composting significantly conserved the  $\text{NH}_4^+\text{-N}$ , but increased the EC of final compost. However, supplementing 10% zeolite effectively reduced the EC to 2.82 mS/cm mainly through adsorption of ammonium/ammonia ions and possibly other cations. In addition, co-amendment of zeolite with Mg and P salts could further accelerate the maturity as evidenced through the high SGI and ~5 weeks was sufficient to achieve maturity against 7–8 weeks in other treatments. We recommend that 10% zeolite can be used to reduce the EC of struvite-based composting that also facilitates nitrogen conservation.

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