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Use of additive and pretreatment to control odors in municipal kitchen waste during aerobic composting

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ABSTRACT

The effects of adding a bulking agent and chemically pretreating municipal kitchen waste before aerobic composting were studied using a laboratory-scale system. The system used 20-L reactors and each test lasted 28 days. The objective was to decrease NH_3 and H_2S emissions during composting. The bulking agent, dry cornstalks, was mixed with the kitchen waste to give a mixture containing 15% (wet weight) bulking agent. A combined treatment was also conducted, in which kitchen waste mixed with the bulking agent was pretreated with ferric chloride ($FeCl_3$). Less leachate was produced by the composted kitchen waste mixed with bulking agent than by the kitchen waste alone, when the materials had reached the required maturity. The presence of cornstalks also caused less H_2S to be emitted, but had little impact on the amount of NH_3 emitted. The $FeCl_3$ was found to act as an effective chemical flocculant, and its presence significantly decreased the amounts of NH_3 and H_2S emitted. Kitchen waste mixed with cornstalks and treated with $FeCl_3$ emitted 42% less NH_3 and 76% less H_2S during composting than did pure kitchen waste.

Introduction

Municipal solid waste (MSW) in many developing countries (*e.g.*, China) typically has a high water content (up to 75%) because it contains a relatively high proportion (>60%) of kitchen waste (He et al., 2005; Münnich et al., 2006; Norbu et al., 2005). Kitchen waste is organic waste that is produced in household and restaurant kitchens, and it can be separated from other types of MSW in the home or when the MSW is collected. Composting techniques are used with the aim of decreasing the volume and weight of kitchen waste, to produce a stable product that can be used for agriculture (Fialho et al., 2010). However, malodor problems can be caused by composting plants, and are particularly problematic in countries with high population densities (Domingo and Nadal, 2009; Pagans et al., 2006). Limits on NH_3 and H_2S concentrations in waste air emitted from plants that emit odorous gases have been set by the Chinese Ministry of Environmental Protection under standard GB 14554–1993 (Chinese Standard, 1993). This is because NH_3 and H_2S are responsible for malodor and health problems, and therefore decrease the environmental benefits of composting. Furthermore, their production decreases the amounts of reusable nutrients that are present in the compost that is produced (Caro and Gallego, 2009; Faloona, 2009).

In previous studies it has been found that 16%–74% of the initial total nitrogen (TN) content of the raw materials is lost during composting (Beck-Friis et al., 2001; Martins and Dewes, 1992; Raviv et al., 2002; Tiquia and Tam, 2000; Yang et al., 2013), and that 9.6%–46% of the initial TN is lost in NH_3 emissions (Fukumoto et al., 2003; Jiang et al., 2011; Luo et al., 2014; Morand et al., 2005). Volatile sulfur compounds (VSCs) have been found to be the predominant odorous chemicals in

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bioindustry emissions, and this is because they have very low odor thresholds and extremely negative hedonic values (Derikx et al., 1990; Komilis et al., 2004; Wu et al., 2010). H_2S is the most abundant of the VSCs produced during composting, making up 39.0%–43.0% of the total amounts of VSCs that are released, because of the partially anaerobic conditions that occur in piles of composting waste (Bogner et al., 2007; Higgins et al., 2006; Drennan and Distefano, 2010; Zhang et al., 2013). Both NH_3 and H_2S are major toxic odorous chemicals, so it is necessary to mitigate emissions of these gases during the composting process to increase the environmental benefits of composting waste.

It is always necessary to add a bulking agent to kitchen waste before composting, because kitchen waste has a high moisture content and low C/N ratio. The chosen bulking agent is added to give a mixture with a moisture content and C/N ratio suitable for composting. Cornstalks, as an economical bulking agent, are common waste materials in most areas of China, and adding them allows the composting process to be optimized. Cornstalks are rich in carbon and have a low density and low moisture content, making them suitable for use as a bulking agent for composting kitchen waste. Mixing cornstalks with raw kitchen waste can improve the sizes and numbers of inter-particle voids in a pile of composting waste, increasing air permeability in the pile. Because they add bulk to the waste, cornstalks can decrease the amount of leachate produced and improve the compost maturity (Yang et al., 2013). Cornstalks have been used as a composting bulking agent in many studies (Guo et al., 2012; Zhang et al., 2013).

It is very expensive to use physical and chemical processes to remove odorous gases (Ahammad et al., 2008). Ferric chloride has been widely used to remove ammonia from wastewater because it is an effective flocculant and causes coagulation to occur (Aziz et al., 2010; Wilson et al., 2011). Adlan et al. (2011) reported that the concentration of nitrogen as ammonia in semi-aerobic landfill leachate could be decreased by 40% using a $FeCl_3$ coagulation process. Iron salts have also been used as pretreatments in anaerobic digestion processes, to control the production of VSCs (Dhar et al., 2011a; Ghyoot and Verstraete, 1997; Smith and Carliell-Marquet, 2008). H_2O_2 and iron salts can react with dissolved sulfide through a number of different pathways to form elemental sulfur and sulfates, and decreasing the dissolved sulfide concentration can decrease the potential for H_2S to be generated during the anaerobic digestion process (Walton et al., 2003). Dhar et al. (2011a) reported that using $FeCl_3$ as a chemical pretreatment for activated municipal waste sludge could decrease the H_2S concentration in the biogas produced by 20%–30%. $FeCl_3$ is considered to be a beneficial additive for mitigating odor production (Stephenson et al., 1994; Wilson et al., 2011). Park and Novak (2013) reported that adding 1.25% (wet weight) $FeCl_3$ to an anaerobic digester feedstock had a positive impact on the odor produced, with less H_2S being produced.

From an extensive literature search, it can be concluded that the majority of studies of bulking agents have been primarily focused on the stability and maturity of the compost, and most studies of iron salt pretreatments have been focused on odor emissions during anaerobic digestion processes. To the best of our knowledge, the effects of adding a bulking agent and using a $FeCl_3$ pretreatment on odor emissions during composting have not yet been systematically studied. Therefore, in the study described here, we aimed to comprehensively evaluate the impact of adding a bulking agent and using a $FeCl_3$ pretreatment on emissions of NH_3 and H_2S during the composting of kitchen waste.

1. Materials and methods

1.1. *Material and experimental setup*

Kitchen waste was collected from a sorting collection system at the Majialou MSW transfer station in Beijing, China. The kitchen waste consisted of, by wet weight, 53% uneaten vegetables, 27% fruit peel, 17% uneaten portions of meals, and 6% leaves. Cornstalks were obtained from a research station at the China Agricultural University. The cornstalks were passed through a cutting mill to produce pieces with sizes of 1–5 cm. The properties of the feedstocks are shown in Table 1.

The composting reactor was a custom-designed 20-L stainless steel cylinder measuring 25 cm long, 24 cm wide, and 42 cm high. Each vessel was insulated with two layers of stainless steel to minimize heat loss (Fig. 1). A stainless steel cap was fitted on the top of each reactor to facilitate its filling and emptying. There were two holes in the lid of each vessel to allow a temperature sensor to be inserted and to allow the gas within the vessel to be sampled. The temperature sensor was connected to a computer, which automatically recorded the temperature data. A 3-mm stainless steel grid was installed at the bottom of each reactor to support the composting bed and to ensure that the gases that were added were uniformly distributed. There were two holes in the bottom of each reactor to allow the reactor to be aerated (the aeration gas was added using a controllable aquarium pump) and to allow the leachate to drain away. Three sampling locations with plugs, each 5 cm in diameter, at different heights (0.1, 0.2 and 0.3 m from the bottom) were provided. The samples taken from different heights were mixed thoroughly.

Table 1 – Properties of the kitchen waste and cornstalks.

Materials	TOC (%) [a]	TKN (%) [a]	TS (%) [a]	C/N	NH_4^+-N (g/kg) [a]	NO_3^--N (g/kg) [a]	Moisture (%)	pH	Bulk density (kg/m^3)
Kitchen waste	35.6(0.54) [b]	1.76(0.02)	0.44(0.01)	20.22	2.39(0.02)	0.87(0.01)	74.4(0.44)	5.34(0.1)	656(5.8)
Cornstalk	43.5(0.72)	0.85(0.01)	0.25(0.01)	52.90	0.16(0.00)	0.62(0.04)	9.19(0.2)	7.44(0.2)	183(0.9)

TOC = total organic carbon; TKN = total Kjeldahl nitrogen; TS = total sulfur.
[a] On a dry-weight basis.
[b] Values in parentheses are standard deviations of mean values (n = 3).

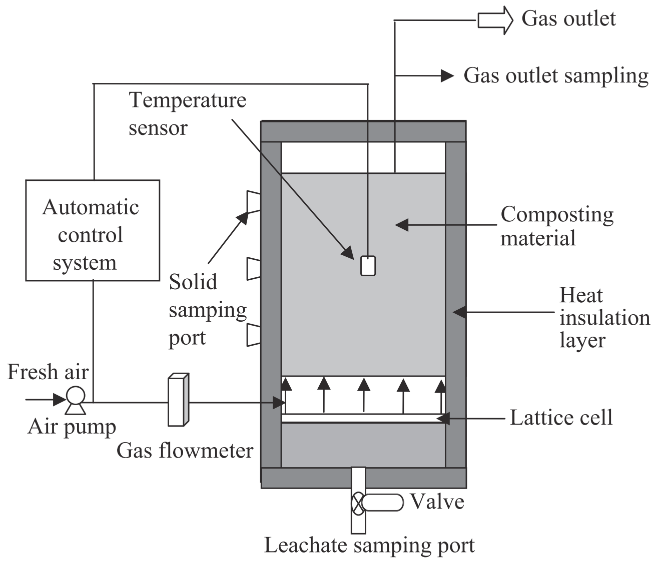

Fig. 1 – Diagram of composting vessel.

Four treatments, labeled as CK, FC, CS, and CS + FC, were carried out. The CK treatment was a control treatment, using only kitchen waste. In the FC treatment, $FeCl_3$ was added to the kitchen waste at the start of the composting process. In the CS treatment, the kitchen waste was mixed with cornstalks at the start of the composting process. In the CS + FC treatment, both cornstalks and $FeCl_3$ were added to the kitchen waste at the start of the composting process. In the treatments with cornstalks, the mixture used was 15% cornstalks by weight (the proportion of cornstalks was selected based on the results of an unpublished study conducted by our group). In the treatments using $FeCl_3$, the $FeCl_3$ was added directly to the feedstocks and mixed. On the basis of chemical reaction, a mole of Fe^{3+} could fix 3 moles of NH_4^+ by coagulation and a mole of S^{2-} required a mole of Fe^{3+} to produce FeS. The appropriate $FeCl_3$ dosage in the raw materials was calculated to be 10% (by molar mass) of the TN (by molar mass).

The trial lasted for 28 days, and a forced-draft aeration system was used. All of the treatments were continuously aerated at a rate of 0.2 L/(kg·min) (the mass of material being determined on a dry mass basis). The temperature in each vessel was recorded using the C-LGX program (Scan-2000x, Hongyuanpengao, China). Each composting pile was turned and mixed once each week.

1.2. Sample collection and analytical methods

A sample (200 g) of the solid material was taken from each vessel at the beginning and end of the composting process, and after each turning procedure had been performed. Each sample was divided into two parts. One part was stored at 4°C and the remainder was air-dried and ground to pass through a 1-mm sieve. The dried and ground samples were analyzed in triplicate for TN content, total organic carbon content, and total sulfur (TS) content. The analyses were performed using a Vario MACRO cube elemental analyzer (Elementar Analysensysteme, Hanau, Germany).

Gas samples were taken each day from the composting gas sampling port in each vessel. NH_3 was trapped in boric acid in a wash bottle and titrated against 0.1 mol/L H_2SO_4. The CO_2, O_2, and H_2S concentrations in the gas samples were measured using a portable biogas analyzer (Biogas-5000, Geotech, UK).

The moisture content of each solid sample was determined in triplicate by drying 5 g of a fresh sample at 105°C until a constant weight was reached. Nitrogen as NH_4^+, NO_3^-, and NO_2^- were extracted from each solid sample using 2 mo/L KCl (using a fresh solid sample to KCl solution weight:volume ratio of 1:10) and analyzed using a segmented flow analyzer (Technicon Auto Analyzer 3, Seal, Germany). A water extract of each solid sample was prepared to allow the pH, electrical conductivity (EC), and the seed germination index (GI) to be determined. To produce a water extract, a fresh solid sample was mixed with deionized water at a 1:10 mass ratio and the mixture was shaken for 1 hr. The pH and EC were analyzed in accordance with the Chinese national standard method NY 525-2002. The GI was measured following the method described by Guo et al. (2012).

1.3. Statistical analysis

The mean value and standard deviation of three replicates of each treatment were reported. The data were analyzed using one-way analysis of variance. The least significant difference test was used to determine the significance of differences between mean values. SAS 8.2 for Windows software was used for all of the statistical analyses.

2. Results and discussion

2.1. Temperature and oxygen

The changes in the composting temperature are shown in Fig. 2. The composting materials went through the three

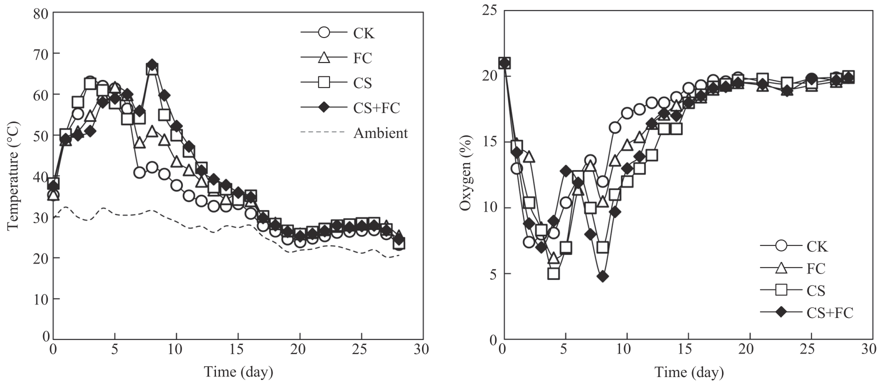

Fig. 2 – Temperature of the compost in the vessels and oxygen content in the outlet air during the composting processes. Standard deviations of mean values (n = 3) of temperature and oxygen content were in the range of 0.1–7.9°C and 0–4.1%, respectively. (CK = control; FC = $FeCl_3$ added; CS = cornstalks added; CS + FC = cornstalks and $FeCl_3$ added).

typical degradation phases (mesophilic, thermophilic, and curing phases). The compost temperature in each of the treatments reached the thermophilic phase temperature (>50°C) within the first 1–2 days of the composting process. The compost temperatures in the CS and CS + FC treatments (containing the bulking agent) remained above 50°C for longer than the compost temperatures in the other treatments. This was probably because the cornstalks decreased the moisture content of the kitchen waste, increasing the free air pore volume in the compost, which would have been conducive to the decomposition of the organic matter. The compost material in each treatment was turned and mixed regularly to homogenize and ventilate the compost. This caused the temperature in the treatments with cornstalks to slightly increase. The temperatures in the CK and FC treatments remained at the ambient temperature and did not rise when the compost was turned, because of the high moisture content and low porosity of the pure kitchen waste. Once the easily degradable material had been depleted, the composting process entered the curing phase and the temperature slowly approached the ambient temperature. The thermophilic phase (>50°C) lasted longer than 5–7 days in all of the treatments and met the sanitary requirements specified in the Chinese National Standard GB 7989-87. Statistical analysis showed that the cornstalks had a significant influence on the change in temperature that occurred (p = 0.000) but that the $FeCl_3$ pretreatment did not significantly affect the temperature (p = 0.799).

The oxygen content decreased rapidly during the first day of the composting process in all of the treatments, and slowly fluctuating, increasing trends were observed thereafter (Fig. 2). The temperature of the composting material increased because oxygen was consumed by aerobic microorganisms degrading the organic matter. The oxygen content returned to 21% as the composting temperature became close to the ambient temperature. The oxygen contents had reached ambient levels in all of the treatments after 15 days of composting. The oxygen content significantly negatively correlated with the temperature in all of the treatments (R = −0.721 to −0.805, p = 0.000). We concluded that more biological activity occurred and more oxygen was consumed in the CS and CS + FC treatments because the temperatures were higher in those treatments. This caused the oxygen contents to be lower in the CS and CS + FC treatments than in the CK and FC treatments.

2.2. Gaseous emissions

2.2.1. Ammonia emissions

The NH_3 emissions mainly occurred in the thermophilic phase in all of the treatments, because of the strong biodegradation of organic nitrogen to inorganic nitrogen (such as NH_4^+, which could evaporate as NH_3 at the relatively high temperatures that were reached). Relatively little NH_3 was emitted at the beginning of the composting period in each treatment, and the peak NH_3 emissions were reached between days four and eight, because the temperature and the amount of ammonia produced both increased in that period. High levels of NH_3 continued to be emitted for about two weeks after the peak, and then the amount of NH_3 emitted decreased because the easily degradable materials were exhausted and the degradation rate decreased. This NH_3 emission pattern has been reported in numerous studies (Morand et al., 2005; Szanto et al., 2007).

More than 80% of the NH_3 produced was emitted during the first 15 days in all of the treatments. Significantly less NH_3 was emitted from the FC and CS + FC treatments than from the CK and CS treatments, and the addition of $FeCl_3$ was found to have decreased the amount of NH_3 emitted by 38%. This could be attributed to NH_4^+ being fixed by being coagulated with $FeCl_3$. The amounts of nitrogen that had been fixed as NH_4^+ by day 28 were 3.86 g/kg (dry matter) in the CK treatment, 4.57 g/kg in the FC treatment, 2.35 g/kg in the CS treatment, and 3.21 g/kg in the CS + FC treatment. Statistical analysis showed that the $FeCl_3$ pretreatment had a significant influence on NH_3 emissions (p = 0.038). The CS treatment delayed the peak NH_3 emissions and decreased the amount of NH_3 emitted by 6.2% relative to the CK treatment. There were no statistically significant differences between the amounts of NH_3 emitted from the CK and CS treatments (p = 0.73), indicating that the addition of cornstalks had little impact on NH_3 emissions from composting kitchen waste. These results are similar to the results of tests performed by Yang et al. (2013). The CS + FC treatment decreased the amount of

NH_3 emitted by 42% relative to the CK treatment, and this was a greater decrease than what was found for the FC treatment (38%) and the CS treatment (6.2%). These results indicate that the $FeCl_3$ pretreatment was more effective than adding cornstalks in decreasing NH_3 emissions from composting kitchen waste.

2.2.2. Hydrogen sulfide

The H_2S emission rates and cumulative amounts of H_2S produced during composting in each treatment are presented in Fig. 3. The amounts of H_2S emitted increased gradually in all of the treatments and reached their peak values between day two and day four, then decreased sharply and leveled off after about 10 days. More than 80% of the H_2S produced was emitted during the first six days of composting in each treatment. The H_2S was primarily emitted during the early stages of the decomposition of the waste, as has been found in numerous previous studies (Dhar et al., 2011b; Schlegelmilch et al., 2005; Wu et al., 2010; Zhang et al., 2013). Less H_2S was emitted from the treatments with cornstalks and with $FeCl_3$ than from the CK treatment. The FC treatment decreased the amount of H_2S emitted by 33% relative to the CK treatment, possibly because FeS may have been produced during the composting process, decreasing the amount of dissolved sulfide (S^{2-}) present and decreasing the potential for H_2S to be generated. The impact of iron salts on the fates of odor precursors and VSCs has been reported previously (Dhar et al., 2011b; Komilis et al., 2004). Statistical analysis showed that there were significant differences between the amounts of H_2S produced in the CK and FC treatments ($p = 0.051$). The CS treatment decreased the amount of H_2S emitted by 62% relative to the CK treatment. This was probably because the cornstalks provided inter-particle voids or air spaces in the composting material and improved the water content regulation in the waste (Iqbal et al., 2010). This would have increased the porosity of the kitchen waste, leading to the improved distribution of O_2 within the waste and decreasing the occurrence of anaerobic sites within the compost pile. A low O_2 concentration in a compost pile is always considered to be the main cause of H_2S production during the composting of MSW (Higgins et al., 2006; Scaglia et al., 2011). Statistical analysis showed that there was a significant negative correlation between the oxygen content and production of H_2S in all of the treatments ($R = -0.621$ to -0.886, $p = 0.001$).

The H_2S produced during the composting process may be absorbed by cornstalks because of the high adsorptive capacity of cornstalks. There was a significant difference between the amounts of H_2S produced in the CK and CS treatments ($p = 0.001$). The CS + FC treatment decreased the amount of H_2S emitted by 76% relative to the CK treatment, whereas the FC and CS treatments decreased the amount of H_2S produced by 33% and 61%, respectively. These findings

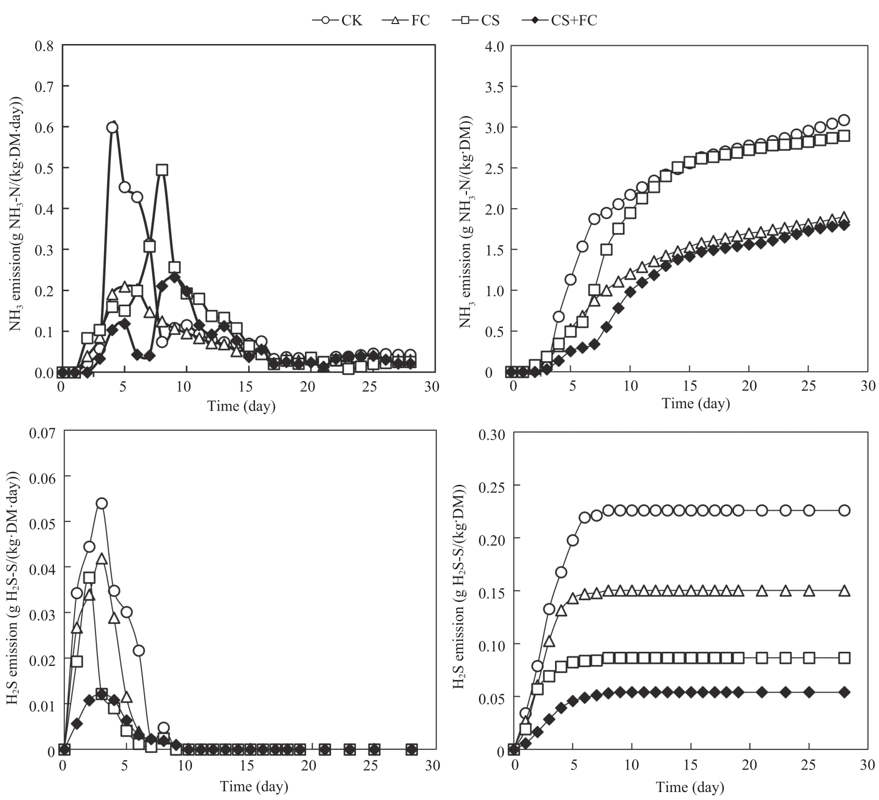

Fig. 3 – Emission rates and cumulative emissions of NH_3 and H_2S during the composting period. Standard deviations of mean values ($n = 3$) of emission and cumulative emission of NH_3 were in the range of 0.01–0.12 g NH_3-N/(kg/dry weight (DM)·day) and 0.02–0.32 g NH_3-N/kg DM. Standard deviations of mean values ($n = 3$) of emission and cumulative emission of H_2S were in the range of 0–0.02 g H_2S-S/(kg/(DM·day)) and 0.01–0.08 g H_2S-S/kg DM. (CK = control; FC = $FeCl_3$ added; CS = cornstalks added; CS + FC = cornstalks and $FeCl_3$ added).

indicate that adding cornstalks to kitchen waste is an effective method for controlling H_2S emissions, and that also using a $FeCl_3$ pretreatment decreases H_2S emissions further.

2.3. Physical and chemical properties

Representative maturity indices for the composts in each of the treatments are shown in Table 2. Biodegradable components are decomposed by microorganisms during the composting process. However, organic nitrogen is mineralized at a lower rate than is organic carbon, causing the C/N ratio to decrease during the composting process. The C/N ratio is an important index for evaluating whether compost has been thoroughly stabilized. Adding cornstalks increased the carbon content and optimized the C/N ratio in the raw compost mixture. The C/N ratios were higher in the CS and CS + FC treatment raw materials than in the CK and FC treatment raw materials. A high C/N ratio is conducive to the degradation of organic matter. The C/N ratios decreased more (from 25 to 14) over time in the treatments with cornstalks than in the other treatments. The C/N ratios at the end of the composting process were in the range of 13–15 for all of the treatments.

The GI is an important indicator of compost maturity and phytotoxicity (Guo et al., 2012; Tiquia et al., 1996). The GIs increased as the toxic materials decomposed. Tiquia and Tam (2000) reported that a GI of more than 80% indicates that a compost is free of phytotoxic substances and is mature. Statistical analysis showed that adding cornstalks had a significant influence on the GI ($p = 0.002$). There were no significant differences between the GIs of the CK and FC treatments ($p = 0.095$). At the end of the composting process, the GI had increased by 34% and 23% in the CS and CS + FC treatments, respectively. This was probably because adding the cornstalks improved the ability of the microorganisms to decompose toxic substances. However, the GI was slightly lower for the compost from the CS + FC treatment than for the compost from the CS treatment. This could have been because adding $FeCl_3$ decreased the amount of NH_3 emitted, increasing the NH_4^+ content in the compost (the nitrogen as NH_4^+ contents were 2.35 g/kg in the CS compost and 3.21 g/kg in the CS + FC compost). Statistical analysis showed that there was a significant negative correlation between the nitrogen content as NH_4^+ and the GI ($R = -0.532$, $p = 0.021$).

The pH values in the mixtures in the four treatments ranged from 5.0 to 8.1 during the composting process. At the beginning of the experiment, the organic acids (such as acetic acid and butyric acid) that were produced by the microorganisms would have led to a decrease in pH (Eklind and Kirchmann, 2000). At the end of the composting process, the pH values in all of the treatments were satisfactory, at pH 7–8.5 (Masó and Blasi, 2008).

The EC can reflect the salinity of compost, and can be used to determine whether the salinity will have a negative impact on plant growth (Huang et al., 2004). By the end of the composting process, the ECs of the compost produced in all of the trials had decreased to <3.0 mS/cm, which is commonly regarded as the limit for safely growing plants (García et al., 1991). This can be attributed to the humification that occurred during the composting process, in which all kinds of small molecule organic acids and salts will have become fixed and large molecules will have been transformed into humus. Statistical analysis showed that there were significant differences between the ECs of the composts produced in the four treatments ($p = 0.008$).

The initial and final compositions and mass balances of the composts are shown in Table 3. Less dry matter was lost in the treatments with the cornstalks added than in the CK and FC treatments. The loss of total organic carbon followed a similar pattern to that for dry matter. Between 8% and 14% of the initial TN content had been lost in the form of NH_3 by the end of the composting process. After 28 days of composting, between 34% and 73% of the TN that had been lost was in the form of NH_3 emissions in all of the treatments. The total amount of NH_3 emitted reached 3.1, 1.9, 2.9, and 1.8 g/kg (in terms of dry matter) in the CK, FC, CS, and CS + FC treatments, respectively. Adding cornstalks and the $FeCl_3$ pretreatment decreased the loss of TN, and the decreases found were 10%, 37%, and 59% in the FC, CS, and CS + FC treatments, respectively. About 4.8% of the initial TN was fixed in the compost when the raw materials were treated with $FeCl_3$. Between 2% and 5.5% of the initial TS was lost as H_2S during the composting process. These results were similar to the results previously found by Zhang et al. (2013). Adding cornstalks decreased the loss of TS by 80% and decreased the amount of H_2S emitted by more than 60% relative to the CK treatment. It was evident that H_2S was the

Table 2 – Maturity indices of the composts produced.

Treatment	Composting time	C/N ratio	Germination index (%)	pH	Electrical conductivity (mS/cm)
CK	Initial	20.22	21.37(1.07) [a]	5.34(0.20)	3.02(0.17)
	Final	13.58	69.49(3.56)	8.06(0.17)	2.37(0.21)
FC	Initial	21.53	13.66(0.98)	5.47(0.21)	3.45(0.06)
	Final	13.44	68.29(1.58)	8.05(0.03)	2.98(0.10)
CS	Initial	24.82	44.31(3.37)	5.22(0.08)	3.34(0.14)
	Final	14.90	104.37(5.82)	8.07(0.04)	2.98(0.08)
CS + FC	Initial	25.18	32.34(0.56)	5.14(0.02)	3.45(0.03)
	Final	14.36	93.12(4.61)	7.83(0.04)	2.78(0.02)

CK = control; FC = $FeCl_3$ added; CS = cornstalks added; CS + FC = cornstalks and $FeCl_3$ added.

[a] Values in parentheses are standard deviations of mean values ($n = 3$).

Table 3 – Mass, carbon, nitrogen, and sulfur balances in the composting treatments.

Treatment	Dry matter loss (%)	TOC loss (%)[a]	Nitrogen balance (%)[b]		Sulfur balance (%)[c]		Leachate (kg/kg)[d]
			NH_3-N	TN loss	H_2S-S	TS loss	
CK	35.73	51.2	13.5	27.3	5.2	13.0	0.21
FC	33.03	52.9	8.8	24.6	5.5	12.1	0.16
CS	29.11	48.2	12.7	17.2	2.3	2.6	0
CS + FC	28.23	49.3	7.9	11.2	1.9	2.4	0

[a,b,c]Percentages of the initial total organic carbon, total nitrogen, and total sulfur contents in the raw materials (on a dry weight basis).
[d]The amount of leachate produced is given relative to the fresh waste.
CK = control; FC = $FeCl_3$ added; CS = cornstalks added; CS + FC = cornstalks and $FeCl_3$ added.

main contributor to the total VSCs that were produced in all of the compost treatments. H_2S contributed about 40%, 45%, 88%, and 79% of the TS loss in the CK, FC, CS, and CS + FC treatments, respectively.

No leachate was produced in the CS and CS + FC treatments, whereas leachate was produced at a rate of 0.21 and 0.16 kg/kg in the CK and FC treatments, respectively. The moisture content of kitchen waste has been reported to force anaerobic decomposition conditions (by limiting free air space), which causes enhanced leaching during composting. Cornstalks, as a bulking agent, are composting amendments that are used to create inter-particle voids, providing air space in composting materials and regulating the water content of waste. As a result, adding cornstalks can decrease or even eliminate the production of leachate during the aerobic composting process.

The $FeCl_3$ pretreatment decreased NH_3 and H_2S emissions but had no effect on the generation of leachate. Some of the nitrogen and sulfur were lost in the leachates that were produced in the CK and FC treatments. Therefore, a combination of adding cornstalks and using $FeCl_3$ pretreatment is a viable management strategy for decreasing emissions of pollutants and improving the quality of the compost produced.

3. Conclusions

A combination of adding cornstalks and using a $FeCl_3$ pretreatment could effectively control odors produced during aerobic composting processes. Adding cornstalks eliminated the production of leachate during the composting process and improved the maturity of the final compost. Adding cornstalks also decreased the amount of H_2S produced by 61% and NH_3 emitted by 6.2% during the composting process compared to that released when only kitchen waste was composted, but the effect on NH_3 emissions was not significant. $FeCl_3$ was found to be an effective chemical flocculant that decreased the amounts of H_2S produced by 61% and NH_3 emitted by 38%. Using a $FeCl_3$ pretreatment was more effective than adding cornstalks in decreasing the amount of NH_3 emitted. Adding cornstalks was found to be an effective and simple method for controlling H_2S emissions. Kitchen waste mixed with cornstalks and treated with $FeCl_3$ emitted 42% less NH_3 and 76% less H_2S during composting than did pure kitchen waste. A combination of adding cornstalks and using a $FeCl_3$ pretreatment is a viable management strategy for achieving a mature compost and minimizing the amounts of odorous compounds that are produced when kitchen waste is composted.

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