Optimizing food waste composting process in fed-batch composter

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Optimizing Food Waste Composting Process in Fed-batch Composter

CHAN Man Ting

A thesis submitted in partial fulfillment of the requirements
for the degree of
Master of Philosophy

Principal Supervisor: Prof. Jonathan WONG Woon Chung
Hong Kong Baptist University
November 2014
DECLARATION

I hereby declare that this thesis represents my own work which has been done after registration for the degree of M Phil at Hong Kong Baptist University, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications.

Signature:

Date: November 2014
ABSTRACT

Composting is considered as an effective and sustainable food waste treatment technology from the perspectives of volume reduction, stabilization and releasing the pressure on landfills. Community composter is a decentralized composting facility in fed-batch operational mode which is usually being installed in the backyard of institutes, hospitals, housing estate etc. to handle the food wastes generated daily. Albeit numerous operational issues including high initial acidity and oil content, poor decomposition and odor generation are commonly encountered in these facilities, which make it difficult to be accepted by the public. Therefore, the aim of the present study is to develop a composting mix formulation that can provide a solution to all these issues in a fed-batch food waste composting process.

The first phase of this study aims at finding out an optimized formulation in a batch-scale food waste composting process through the use of alkaline amendments and microbial inoculum. For the first two experiments, artificial food wastes were prepared by mixing 1.3kg bread, 1kg boiled rice, 1kg cabbage, 0.5kg fully boiled pork and mixed with sawdust to obtain a C/N of 30 and adjusted moisture of the mixtures to 55%. The effect of different concentrations of zeolite compared to lime was studied in the first experiment. Zeolite was amended with food wastes and sawdust mixtures at 2% (ZI-2), 5% (ZI-5), 10% (ZI-10) to compare with lime in 2.25% (L-2.25) w/w (dry weight basis) and composted for 56 days. Results demonstrated that 10% of zeolite was optimal amendment rate compared to lower dosage of zeolite (2% & 5%) with stronger pH buffering capacity and greater decomposition efficiency. Addition of 2.25% of lime buffered the pH efficiently but increased the ammonia loss significantly which eventually reduced total nitrogen (TN) content of final product and posed odor emission problem. Amendment of 10% zeolite provided a higher adsorption affinity on ammonia resulting in 2.05% of TN value of final product which was higher than 1.72% of lime treatment. Furthermore, significantly higher seed germination 150% was achieved of ZI-10 compost compared to 135% of L-2.25 due to low ammonium content of product.

The first experiment showed that application of less than 10% zeolite was not sufficient to buffer the acidity; as a result, organic matter decomposition was inhibited. However, the cost and reduction in treatment percentage of food waste in 10% application rate of zeolite is an issue of concern. To tackle this dilemma, food waste was amended with struvite salts at 1:2 molar ratio of MgO and K₂HPO₄ (Mg:P) with or without zeolite amended at either 5% or 10% amendment (Mg:P, Z5 + Mg:P & Z10 + Mg:P) and a control treatment with food waste only was also included. Results showed that treatment of Z10 + Mg:P was synergistically achieved of pH and EC buffering, and N conservation but not for the case of 5% zeolite. Treatment of Z10 + Mg:P further reduced the N loss to 18% compared to 25% and 27% of Mg:P and Z5 + Mg:P respectively. However, there was insignificant difference in the final nitrogen content and decomposition rate among all treatments with struvite salts amendment. Comparing to the treatment of Z-10 of the first experiment to Z10 + Mg:P of the second experiment, Z-10 showed superior performance since better decomposition efficiency, shorter time to require to pass the GI (28 Days) and lower cost because of salts exclusion.

To develop a multipurpose formulation for the fed-batch operational food waste composter, high lipids problem in food waste cannot be neglected because it is a critical factor to hinder the decomposition efficiency. Inoculation of oil degradative microorganisms was reported as an effective approach to facilitate the lipids. Therefore, the third experiment was to investigate the overall composting performance supplemented with 10% zeolite and microbial consortium. 10% zeolite with bacterial consortium significantly reduced the lipid contents from 7% to 1%
compared to control treatments. Furthermore, treatments amended with 10% zeolite was proved to reduce ammonia emission and total volatile fatty acids level in the composting mass, therefore the total odor emission level can be reduced. Zeolite at 10% was found to be a suitable optimum additive for both synthetic and real-food wastes. Therefore, treatment of 10% zeolite with bacterial consortium is selected as an optimized formulation for further study of its application in a fed-batch composter.

Following the food waste zeolite composting formulation obtained in Phase I, the aim of Phase II was to develop an ideal composting mix formulation for on-site commercial composters. Although the results have been demonstrated 10% zeolite with bacterial consortium facilitated the composting efficiency in batch composter, those amendments may be over-estimated if applied in a fed batch composter by using real food wastes. With this constraint, the applicability of these additives in commercial fed-batch composter needs to be assessed using locally generated food wastes. Treatments included food waste and sawdust mixtures at 4:1 mixing ratio (wet weight basis) were mixed with 2.25% of lime (L2.25), 10% of zeolite (Z10) and 10% zeolite with bacterial inoculum (Z10+O) and a control of food waste with sawdust mixture only was also included. 35 kg compost mixture was fed into each composter respectively daily for a period of 42 days. Only Z10+O was the most suitable composting mix for fed-batch food waste composting process with continuous sustained high temperature (55-60°C), optimal moisture (55%-60%), alkaline pH and low EC during the experimental period. Bacterial inoculum significantly improved the lipids decomposition from 22.16% (C) to 3.10% (Z10+O) after the composting period. In contrast, lime and zeolite alone treatments could not maintain the optimal pH that led to reduce degradation and longer stabilization period. Only compost taken from Z10+O treatment could be classified as mature compost.

The aim of the third study phase was to examine an optimal application rate of food waste compost produced from decentralized food waste composter for plant. A plant growth experiment was conducted in this phase to evaluate the change in soil properties and plant growth of *Brassica chinensis* and *Lycopersicon esculentum*. The experiment was conducted in a loamy soil amended with 0%, 2.5%, 5% and 10% food waste compost amendment rate compared to the control soil with chemical fertilizer amendment only. Results indicated that 5% was the optimal application rate of food waste compost for both crops among all treatments which can be evidenced by the highest biomass production and nutrients value of the plant tissues. Plant available nutrients such as NH₄⁺, NO₃⁻, PO₄³⁻ were proportionally increased with increase in compost application rate. However, 2.5% of the food waste compost did not provide sufficient nutrients for plant growth and 10% showed negative effects due to increased salts content. Plants amended with chemical fertilizer had relatively low biomass production compared to compost amended treatments due to soil compaction and fast leaching of nutrients.

It can be concluded that application of 10% zeolite with microbial consortium is an ideal composting mix formulation for on-site commercial composters and 5% is an optimal application rate of food waste compost of *Brassica chinensis* and *Lycopersicon esculentum*. 
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Chapter 1 Aims and Objectives

1.1 Background

Solid waste management is a global stern issue. Nowadays, people consume resources extravagantly resulting in the generation of high quantities of unnecessary wastes. Hong Kong is one of the most populated cities to face with the solid waste problem. Every day, 13,458 tonnes of solid wastes (HKEPD, 2012) generated from the domestic, commercial and industrial sectors were ultimately disposed of at the three strategic landfills in Hong Kong. Food waste constitutes about 42% of the total municipal solid waste (MSW). Since there is no waste separation in place currently, disposal at the landfills is the primary method for food wastes. Food wastes disposed of at the landfills not only increase the burden of landfills but also pose environmental problems such as greenhouse gases emission, leaking of toxic leachate and odor emission if they are not properly managed (Kosseva and Webb, 2013). Based on the highly decomposable characteristic of food wastes, other alternative waste treatment technologies should be considered instead of landfilling in order to reduce the above mentioned environmental impacts.

Composting is considered as an eco-friendly organic waste treatment method in terms of volume reduction, stabilization, resource conservation and sustainability. Food wastes are suitable substrate for composting because they are high in organic matter, readily decomposable and concern of heavy metals and pathogens are very low. However, properties of food waste such as acidity (Cheung et al., 2010), loss of nutrients especially nitrogen (Li et al., 2013), emission of odor (Scaglia et al., 2011), high lipids content (Bekier et al., 2014) could pose challenges during composting. Over the last decade,
intensive studies have been conducted to tackle these problems.

Alkaline substances such as lime could neutralize the acidity and improve organic matter decomposition during food waste composting (Wong et al., 2009; Wang et al., 2013). Similarly, zeolite with specific morphological structure is a suitable candidate as an additive in composting to adsorb large quantity of different ions that can reduce salinity and enhance the nutrient values of final compost (Turan, 2008). Recently, addition of salts for struvite formation during composting was demonstrated to shows it capability to buffer the pH and conserve nitrogen by precipitation (Ren et al., 2010; Wang et al., 2013). Inoculation of thermo-tolerant lipolytic actinomycete during food waste composting effectively reduced crude fat and the maturation time compared to the control treatment (Ke et al., 2010).

However, most of these studies were conducted with batch scale composters. In contrast to the batch systems, fresh organic matter (feedstock) was added periodically and treated without discharging the by-products for a specific period of time in fed-batch system (Kwon and Lee, 2004). In such a situation, the efficiency of the alkaline substances and the struvite formation to positively influence the composting needs critical investigation. There is lack of such practical studies in a fed-batch commercial composter.

Decentralized food waste composter is an on-site small scale composting facility, usually designed for 1-300 kg/d (Sunberg and Jönsson, 2005) to treat food wastes on-site in order to save transportation cost. Since 2010, the Hong Kong government through the Environment and Conservation Fund has provided funding support through the Environment and Conservation Fund to encourage housing estates to set up their own
composters in order to instill the people to participate in food waste separation and recycling activities and also divert part of food wastes from landfills. However, many uncertainties do exist in operating principles of this kind of composters after reviewing the operation of some local commercial composters. The major concerns of these composting machines are the unclear formulation of composting mixture, odor, acidity and oil problems which will affect the composting process efficiency and product quality. Pathogens present in immature composts can pose health threat to compost users and plant growth (Selim et al., 2012). Besides, it would attract unwanted insects or rodents, causing hygiene problems at the facility and the community.

1.2 Research Objectives and Outlines of the Study

This M. Phil thesis is divided into three phases with the overall aim was to optimize the operation of the commercial composters to produce good quality compost that can be used as organic fertilizer. The experiments conducted in three phases are:

Phase I: Batch study of food waste composting using alkaline amendments and oil degradative inoculum
Aim: The aim of the project was to investigate the optimal food waste composting formulation in batch-scale composters.
Objective 1: To study the effect of different concentrations of zeolite on food waste composting.
Objective 2: To investigate the feasibility of co-composting of zeolite and struvite salts with food waste in order to synergistically achieve pH buffering, and reduction in electrical conductivity and nitrogen loss.
Objective 3: To study the efficiency of oil degradation by using specific bacterial inoculum on composting of food wastes from different sources such as Chinese and Western style food wastes.

Phase II: Optimization of Food Waste Composting for Fed-batch Commercial Composter

Aim: The aim of this phase was to focus on developing an ideal composting mix formulation for on-site commercial composters.

Objective: To study the practicability of applying the optimal formulation obtained from Phase I to fed-batch-scale composter.

Phase III: Land Application of Zeolite Amended Food Waste Compost

Aim: To study the effect of zeolite amended food waste composts produced from the commercial composters on soil properties and plant growth performance.

Objective: To determine the optimum application rate of zeolite amended food waste compost with soil and its effect on plant growth.
Phase 1
Batch Study
- Optimum zeolite application rate
- Effect of zeolite and struvite salts
- Effect of zeolite and oil degradative inoculum

Develop an ideal composting mix formulation of food waste composting process in batch composter

Study the applicability to apply the obtained formulate from batch composter to fed-batch composter

Phase 2
Fed Batch Study
- Develop an ideal composting mix formulation of food waste composting process in fed-batch composter

Optimize food waste compost application rate

Assess food waste compost on soil and plant growth

Compare food waste compost with chemical fertilizer

Phase 3
Compost Application
- Optimum application rate of food waste compost generated from fed-batch composter

Figure 1.1 Flow diagram to show the experimental approach of this study.
Chapter 2 - Literature Review: Optimizing Food Waste Composting Process in Fed Batch Composter

2.1 Introduction

In Hong Kong, 3,337 tonnes of food waste were being disposed of at landfills daily in 2014 (HKEPD, 2014). Proper treatment of this food waste can reduce the landfill space requirement as well as reduce the impact of organic waste degradation on the environment. To tackle this food waste disposal problem, apart from public education, an eco-friendly organic waste treatment is required to recycle this waste as resources. Composting is a robust biological process to recycle the organic wastes into stabilized, odorless, and nutrient-rich organic fertilizer, compost, which can fulfill the requirements of sustainability and environmental friendly.

Decentralized food waste composting is an on-site treatment technology that can be set up in small institutions, organizations and communities. These composters enable treatment at the site of production thus can efficiently save the cost and energy required for transportation. However, many uncertainties do exist in the operation of continuously fed community composters and the main issues are (1) onset of acidic conditions occur during the early phase of food waste composting that causes emission of acidic odor, inhibition of microorganisms and poor degradation of organic matter eventually lead to composting failure, (2) emission of ammonia when the pH of the composting mass is high (>9.0) causing odor emission and loss of nitrogen reducing the nutrient content of the compost product, and (3) the high oil content of the food wastes, especially the post-consumption food waste lead to the formation of lumps and prevent the active microbial degradation. Often the composts produced from this kind of decentralized
community composters show negative influence on plant growth due to poor stabilization. Therefore, a practical fed batch composting of food waste, generated locally, should be of prime importance to exploit the benefits of decentralized composting.

2.2 Definition of Composting

Composting is a biological decomposition process to break down and stabilize organic compounds mediated by the microorganisms such as bacteria, fungi and actinomycetes. Heat, gases, vapor, water and humus are produced during decomposition of organic matter. The final mature compost should be stable and free of pathogen and can be used as soil amendment in gardening or agriculture (Haug, 1993).

2.3 Composting Process

Composting mainly consists of four different phases and each phase is mediated by specific microorganisms under different temperatures. The microbes degrade the organic matter and produce by-products during each phase, which can be utilized by the microbes in next phase as their energy resources (Gray et al., 1971).

Phase 1: Incubation or mesophilic phase

This phase is an incubation or mesophilic phase at the beginning of the composting and last for 2-3 days during which mesophilic microbes start to degrade the readily available organic matter. The heat generated during this organic degradation increase the temperature of the composting mass.

Phase 2: Thermophilic phase

As the temperature gradually increases above 40°C, the population of mesophilic microbes is decreased and thermophilic microorganisms increase to dominate under this
high temperature. The temperature can reach 60-70 °C depending on the insulation of the composting system. Such high temperature is able to accelerate decomposition of complex organic compounds such as fats, proteins, cellulose and hemicelluloses. This period is regarded as disinfection period since most of the pathogens are destroyed effectively during this period. However, continuous heating up of the composting material to >65 °C can even kill the thermophilic microbes and suppress the decomposition process; thus regular turning and sufficient aeration are required to prevent the overheating of the mass and also fulfill high oxygen demand of microorganisms. This phase can last for a few weeks depending on the substrate property.

**Phase 3: Cooling phase**

When the organic substrates are nearly run out and not able to sustain the intensive microbial activities, the temperature drops and the population of thermophilic bacteria is gradually decreased. When the temperature drops below 45°C, mesophilic bacteria will reinvade the composting mass and this phase usually last for 3 – 4 days.

**Phase 4: Maturation phase**

The temperature will continue to drop until reaching the ambient levels in this phase. Composting mass after the cooling phase cannot directly be applied on land because it may contain toxic metabolites and need some time to stabilize. Actinomycetes, protozoa and fungi are the dominant microbes in this phase, which further stabilize the compost and give the fresh earthy smell of the final product. Figure 2.1 shows the temperature and pH change along the composting process in a typical composting process (Gray et al., 1971).
2.4 Food Waste Composting

Food wastes contain a high amount of organic matter that can be naturally decomposed by microorganisms. Due to the rapidly decomposable nature, food wastes may generate environmental concerns such as emission of odor (Scaglia et al., 2011) and propagation of bacteria or pathogens (Hamer, 2003). Traditionally, landfilling and incineration were the major treatment methods of food wastes but there are many constraints of these two methods (Cangialosi et al., 2008). A lot of land resources are required if all the organic wastes are disposed in the landfills that also causes greenhouse gases emission, production of leachate and odor. Besides, restored landfills can be only used for restricted purposes like recreation.

Incineration is an effective method to drastically reduce the volume of solid wastes and simultaneously generate electricity while combustion. However, air contaminants can be generated during combustion which pose a significant health effect to human or vegetation (Meneses et al., 2004). Food wastes contain high moisture with low heating
value which needs more energy input to ignite and combust (Chang et al., 2007). In contrast, composting is an ideal method to handle the organic waste towards the benefits of volume reduction, sanitation and recycling. Moreover, there is less concern of heavy metals and pathogens of the food waste compost compared to other substrates. Food wastes of Hong Kong are predicted to contain high moisture, fat and oil content due to traditional Chinese cooking habits which can retard the microbial decomposition efficiency during composting. The common challenges of food waste composting are described below.

2.4.1 Acidity

In a composting process, a pH range of 6.5 – 7.5 can enhance the microbial activity and decomposition efficiency (Kopčić et al., 2014). Below this optimal range, microbial activity can be inhibited and composting period will be longer. Composting is easy to suffer from acidity problem because large amount of organic acids are produced when rapid decomposition of readily available organic matter occurs at the early stage (Cheung et al., 2010). In a successful composting process, most of the organic acids can be used up by microorganisms as their substrates. However, not all the composting processes enable to decompose the organic acids in a short period. The time require to completely decompose organic acids depends on the total amount of organic acids which can be varied with different kind of substrates.

Using food waste as the main substrate of composting can generate high amount of organic acids compared to other organic materials because it has highly decomposable organic matter and the pH of the substrate itself is low. The acidity causes odor emission, retardation of decomposition and prolonging the composting period. Sundberg et al.
(2013) reported that high quantities of odor producing bacteria (lactobacteria and clostridia) were found in a treatment with pH value less than 6.0 during food waste composting. Addition of compost and enhancing the aeration rate shorten the period of low pH. Inoculation of Pichia kudriavzevii RB1 was found to accelerate organic acids decomposition and eliminate the initial lag period (Nakasaki et al., 2013).

2.4.2 Odor

Odor emission is a key factor that affects the acceptability of the composting. As mentioned above the change of pH during composting can regulate specific kinds of microorganisms in the system and indirectly affect temperature.

Odorous compounds generated from a composting system can be generally classified into nitrocompounds, sulfides, volatile organic compounds and volatile fatty acids (Louhelainen et al., 2001). Ammonia (NH$_3$) and trimethyl amine ((CH$_3$)$_3$N) are the examples of nitrocompounds which can be produced from aerobic and anaerobic decomposition of proteins and amino acids. NH$_3$ is considered as extremely pungent and (CH$_3$)$_3$N has a fishy odor. Hydrogen sulfide (H$_2$S), dimethyl sulfide ((CH$_3$)$_2$S), and mercaptans (CH$_3$SH) are the examples of sulfide compounds which can be generated in aerobic decomposition of sulfur containing amino acids. Sulfides smell like rotten egg or rotten vegetables. Volatile organic compounds and volatile fatty acids are produced in facultative anaerobic decomposition of proteins and carbohydrates, fats respectively. There are different kinds of fatty acids with varying kinds of smell.

Various technologies have been developed to tackle odor problem during composting, which target to avoid, reduce and eliminate it before being emitted to the atmosphere. Those technologies can be generally summarized as proper control of the
process parameters such as temperature, moisture, pH, aeration, turning frequency and addition of chemical or physical amendments during composting. Some other technologies like building stacks and masking agents were also used to alleviate the odor problem during composting (Schmidt and Jacobson, 1995).

2.4.3 Lipids content

Lipids are triglycerides with straight-chain fatty acids. Food wastes usually contain high level of lipids due to vegetable oils and animal fats used in restaurants or industrial sectors. Food wastes with high lipid contents used in composting pose a problem on decomposition and odor emission (Jakobsen, 1994).

Literature reports that fat content presents only a small fraction of organic matter can be decomposed well. About 96% of lipid content was degraded within 2 months when the food waste with 17.81% lipids was added into fed-batch operational composter daily (Hwang et al., 2002). About 58-82% degradation of fats was observed after 1 week in sewage sludge and floating foams during in-vessel composting (Viel et al., 1987). Some studies reported that there is an upper limit of lipid content for input materials to maintain the composting efficiency. Fernandes et al. (1988) found that if the composting substrates contain more than 20-25% fats would inhibit the composting efficiency. Only 2% of lipids were decomposed when the initial starting composting materials contained 20.01% of lipids.

Acceptable amount of fats in initial composting materials can promote composting such as enhanced heat production, accelerated composting process and production of pathogen-free compost since lipids has higher energy content than carbohydrates and proteins (LaPara and Alleman, 1997). However, the key problems associated with lipids
are low solubility, lack of porosity and low degradability of specific lipids. High lipid content in the composting mass can alter the condition towards anaerobic by covering the surface of all the materials and preventing air passage. A physical barrier between the microbes and the substrates is generated, therefore the decomposition efficiency is retarded and odor is generated in anaerobic condition (Nakasaki et al., 2004).

Inoculation of specific microorganism during composting of lipid-rich wastes have been reported to be an effective tool to enhance lipid degradation. Lemus and Lau (2002) found that inoculating chicken litter or activated sludge to lipid-rich wastes during composting reduced 70% of lipids and shorten the composing period by 10 days. Besides, increase in the amount of bulking agent was also found to be significantly enhanced the decomposition of fat and proteins (Bergesen et al., 2009).

2.4.4 Loss of nutrients

Loss of nutrients during composting is inevitable due to intensive decomposition of organic matter. Loss of nutrients and poorly managed composting not only create the problem of odor emission but also reduce the nutrient value of the final compost. A significant amount of nitrogen can be lost by three possible pathways (gaseous emissions, leaching, and denitrification) during composting. The main pathway of nitrogen loss is gaseous emission. About 47 to 77% of initial nitrogen was lost through gaseous emission. The key of these emissions are ammonia (NH$_3$), and small portion of nitrous oxide (N$_2$O) during straw mixtures and different kinds of liquid manure co-composting processes (Martins and Dewes, 1992). Hansen et al. (1993) found that the treatment of starting materials with C/N ratio of 15 had three times higher ammonia lost than the treatment with C/N ratio of 20. The emission of NH$_3$ can be promoted by high temperature, low
Apart from gaseous emissions, nitrogen can be lost as ammonium ions (NH$_4^+$) and nitrates (NO$_3^-$) by leaching. Martins and Dewes (1992) reported that there were 9.6 to 19.6% of nitrogen lost by leaching of which 76.5-97.8% was NH$_4^+$ and 0.1-2.2% was NO$_3^-$. Leaching problems can be promoted if the process starts with nitrogen-rich materials. Denitrification can also contribute to nitrogen loss during composting but contribution is very minor. Nitrate is converted to nitrous oxide (N$_2$O) or nitrogen (N$_2$) gas by facultative anaerobic bacteria. Generally, physical and chemical strategies were employed in the past to control the nitrogen loss. Nitrogen loss as ammonia in composting process is influenced by the C/N ratio of the starting materials, aeration, pH, moisture and temperature. Therefore nitrogen loss can be reduced by controlling these parameters. Physical method involves the addition of material that can adsorb the ammonia and prevent the loss. Zeolite was demonstrated to be a good adsorbent of nitrogen during composting (Kithome et al., 1999). A lot of chemicals have been reported to reduce the nitrogen loss. Addition of alum and phosphoric acids reduced NH$_3$ emission by 76 and 54%, respectively, during poultry litter composting (DeLaune et al., 2004). Fukumoto et al. (2011) found that addition of struvite salts during swine manure composting not only significantly reduced (25-43%) NH$_3$ loss but also other nitrogenous emission. The detailed function of zeolite and struvite is presented in Section 2.6.1 of this review.

2.5 Factors affecting food waste composting process

In an optimized food waste composting process, many factors are strictly monitored and controlled. The critical problems like emission of odor, poor decomposition and loss
of nutrients are due to improper control. The factors affecting the composting process are the properties of raw materials such as carbon to nitrogen ratio, moisture, particle size, temperature, pH, EC and oxygen level.

2.5.1 Properties of raw materials
2.5.1.1 Carbon to nitrogen ratio

Substrate serves as an energy source to sustain the microorganisms. Carbon is mainly to serve as an energy source for microbes to decompose organic matter while nitrogen (N) is important for the synthesis of proteins, enzymes and other structural components. In an optimal composting process, the ratio of carbon to nitrogen (C/N ratio) should be balanced and the preferred range is 25 to 30 to facilitate the microbial decomposition (Fong et al., 1999). If there is too much of carbon-rich substrate of composting process, the decomposition efficiency would slow down while the nitrogen is used up to cause the organisms death. In contrast, if there is high nitrogen substrate of starting materials but not enough carbon, excess nitrogen will emit as NH3 that cannot be used to finish the nitrogen cycle. In order to adjust an optimal C/N ratio for composting, substrate property should be known. Generally, juicy and animal origin (manure, blood meal etc.) are high in nitrogen and dried plants tissues, woody vegetables are high in carbon. Many studies have been carried out to evaluate the effect of substrate C/N ratio on decomposition efficiency and other consequences.

Huang et al. (2004) reported that co-composting of pig manure and sawdust with initial low C/N ratio prolonged the composting period and resulted in high salinity of the final compost which would pose a negative effect on plant growth. Eiland et al. (2001) studied the influence of different initial C/N ratio (11, 35, 47, 50 and 54) on chemical and microbial composition during straw composting. There was a significant correlation of
heat generation and C/N ratio during the whole composting process. In a low C/N ratio, degradation of fibers was rapid and microbial activities were higher than high initial C/N during the first three months. After 12 months, the above condition was reversed that there was no easily available carbon to sustain the high microbial activities in low C/N treatment. DeLaune et al. (2004) reported that low C/N of initial composting substrates was found as a critical factor to cause loss of ammonia because of excessive availability of nitrogen in the system.

Generally, food waste is considered as a nitrogen rich substrate. Therefore it is often essential to mix with carbon-rich substrates such as sawdust, green wastes to achieve the optimal C/N ratio. Adhikari et al. (2009) used three bulking agents to co-compost with food waste to evaluate the composting effectiveness. Results indicated that food wastes co-compost with chopped wheat straw and chopped hay had better decomposition and no recognizable substrate particles of the finished compost compared to food wastes co-compost with wood shavings. Kumar et al. (2010) suggested that co-composting of food wastes with green waste and rice husk at low C/N ratio can produce a good quality compost free of phyto-toxicants that can reduce the usage of bulking agent to adjust C/N ratio. However, the loss of nitrogen was not clearly presented.

2.5.1.2 Moisture

Sufficient moisture is needed to maintain the growth and survival of the microorganisms during composting. Water not only is a by-product but also is a reactant for microbial reactions. In composting process, moisture content should be maintained in a range of 50 to 60%. Moisture can greatly influence the diffusivity of gas through the substrates during composting. The microbial reactions can be suppressed under low
moisture condition during composting, and dry composting mass is considered physically stable but biologically unstable (Bertoldi et al., 1983). In contrast, composting mass with high moisture content prevent air movement, thereby the oxygen is not able to diffuse without enough pore spaces resulting in the anaerobic condition. Pore spaces are important in a composting system to provide sufficient oxygen for the aerobic microorganisms.

Optimal moisture should be maintained during a composting system to facilitate the microbial decomposition. Frequency of turning the composting materials can redistribute the moisture evenly and dry out the wet materials. Increasing the aeration rate in composting system is a potential approach to control the moisture content of the composting mass. Addition of the carbon-rich material like leaves, straw, wood chip, and sawdust can soak up the excessive moisture.

2.5.1.3 Particle size

Particle size is one of the physical factors that can influence composting efficiency. Cutting, shredding or grinding of raw materials are beneficial to promote the decomposition efficiency by increasing the total surface area to allow more microbial invasion. Besides, it can make the particles in uniform size, improve the aeration, retain the moisture and increase the value of the final product. However, the particle size cannot be too small because it is likely to compact the whole composting mass. In this case, the pore spaces are drastically reduced and insufficient spaces do not allow oxygen movement which leads to anaerobic condition. Rynk (1992) suggested that the maintenance of void space is important during the whole composting process because this can affect the oxygen and water circulation throughout the materials. Microbial activity,
heat and mass transport processes are greatly influenced by porosity and free air spaces (FAS) of the composting materials (Agnew and Leonard, 2003).

2.5.1.4 Temperature

There is an obvious temperature transition at different phases of a composting process (Figure 1), so that specific microorganisms dominate each phase (Miller, 1996). Each group of microorganisms in a particular phase of composting process can bring out different functions under varied temperatures (Golueke, 1991). Thermophilic phase is considered as the highest degradation phase because the complex organic compounds e.g. lignin would be degraded by thermophilic microfungi and actinomycetes (Tuomela et al., 2000).

High temperature is important for destroying pathogenic organisms like eggs of parasites, cysts, flies in a composting process (Hoitink et al., 1997). The optimal composting temperature should range from 52 to 60°C (MacGregor et al., 1981). If a composting started with a low C:N initially, under the high temperature condition, large amount of nitrogen are mineralized and volatilized as ammonia, as a result the nutrient value of final compost is reduced. Pagans et al. (2006) found that ammonia volatilization was strongly depended on temperature during composting process. A serious ammonia loss was observed while composting N-rich poultry with pig-straw mixtures under thermophilic temperature (Martins and Dewes, 1992).

Apart from loss of nutrients, microbial activities can be suppressed under the high temperature. Miller (1996) reported that a significant retardation of thermophilic bacteria can be observed while the temperature increased above 60°C. Supplementary aeration and increase of turning frequencies would be adopted to prevent overheating of the
composting mass. Generally, the optimized composting condition should facilitate the elimination of pathogenic microbes with minimum loss of nitrogen. Therefore, temperature is a critical factor to influence the efficiency of composting; a good-insulation of composting system is a prerequisite for preventing heat loss.

2.5.1.5 pH

pH is a critical factor influencing the microbial activities during composting, a neutral pH condition is considered favorable (Wong et al. 2009). Low pH condition could suppress microbial activity thus retard the biodegradation (Nakasaki et al., 1993). In a normal composting process, large amount of short chain organic acids like lactic and acetic acid are generated when the easily degradable organic matters are intensively decomposed during the early phase of composting (Sundberg and Jönsson, 2005). The generation of large quantities of acids and subsequently their accumulation cause the pH to drop very low (<4.0) that significantly affecting the composting process. These organic acids are used up by microbes as energy sources eventually and the pH increases. Nakasaki et al. (2013) reported that significant reduction of pH during the early stage is a characteristic feature of the food waste composting due to the higher fraction of readily degradable organic matter in the food waste when compared to other substrates. To alleviate this acidic environment, different physical, chemical and biological measures have been developed and reported previously.

2.5.1.6 Oxygen level

Oxygen is an indispensable element for the aerobes microorganisms to perform respiration and decomposition. In a normal composting process, oxygen consumption rate is proportional to the CO$_2$ evolution rate, and oxygen level can influence the efficiency of
the biodegradation during composting. Low oxygen level is one of the common problems of food waste composting since high moisture content of food waste materials are packed together that reduce the free air spaces. To alleviate this problem, addition of bulking agents like sawdust can reduce the bulk density and increase the free air space of the substrate. Haug (1993) reported that oxygen level of <5% could suppress the aerobic activities. However, higher rate of aeration will dry up the composting mass. Therefore, bulk density, free air space and the aeration rate should be considered in a collective manner.

2.6 Enhancing food waste composting

Challenges of food waste composting includes acidity, loss of nitrogen, poor decomposition and odor emission. In the past, many studies have been conducted to alleviate these problems, and those measures can be classified as physical, chemical and biological. Physical method includes adjusting the composting condition like aeration rate, turning frequency, insulation materials. Besides, addition of inert materials could improve the physical properties of composting mix eventually enhancing the composting efficiency. Chemicals are added to the composting mix to alleviate the low pH and enhance the composting efficiency. In general, the response of adding chemical additive is much faster than other type of amendments due to the fast chemical reactions. Addition of lime during food waste composting is known to have a strong neutralizing capacity. Inoculation of bacterial strains into a composting mix is a biological method to effectively improve degradation efficiency.

2.6.1 Zeolite

Zeolite is a microporous aluminosilicate mineral. So far, around 40 kinds of natural
zeolite have been discovered and zeolite can also be synthesized artificially by the process of slow crystallization (Davis and Lobo, 1992). Zeolite has a porous structure with negative charge which can accommodate varying cations like sodium, potassium, calcium, magnesium, ammonium and it also acts as a molecular sieve to allow specific ions to pass through but exclude those ions with larger sizes (Mumpton, 1992). Based on the specific morphological structure of zeolite, it has been widely applied in industrial and environmental fields such as colour removal from wastewater (Chang et al., 2002), remove the mercury ions from industrial effluent (Chojnacki et al., 2002). Addition of zeolite during composting process is mainly to reduce heavy metal availability (Zorpas et al., 2002), reduce N loss (Bautista et al., 2011, Villaseñor et al., 2011), and salinity (Turan, 2008) with other substrates while the reports of food waste composting are very limited.

2.6.2 Lime

Lime (calcium oxide) is a white, caustic and crystalline solid at room temperature, and has a strong acid neutralizing capacity. Lime can release heat when reacting with water. Based on the specific characteristics, lime also has been widely used in composting process. Fang and Wong (1999; 2000) reported that liming reduced the heavy metal availability in sewage sludge compost. Singh and Kalamdhad (2013) found that the bioavailability and leachability of heavy metals were significantly reduced when supplemented with 2% lime during water hyacinth, cattle manure and sawdust composting. Besides, the composting temperature and decomposition efficiency were enhanced in the lime amended treatment.

Addition of 2.25% lime was reported to alleviate the low pH during co-composting of food waste, sawdust and Chinese medicinal herbal residues (Zhou et al., 2014). Wang
et al. (2013) found that addition of 2.25% lime effectively buffered the low pH but caused serious nitrogen loss. Addition of 1.88% of lime with coal fly ash during food waste composting successfully buffered the low pH and provided an optimal environment for microbial decomposition and shortened the composting period by 35% (Wong et al., 2009).

Despite the advantages of applying lime during composting, some researchers observed that high dosage of lime can inhibit the microbial activity at higher concentrations. Besides, ammonia emission can be promoted under the high pH and temperature causing odor emission and nutrient loss. Wong and Fang (2000) found that microbial respiration, populations, and enzyme activities were reduced when high concentration of lime was applied during sewage sludge composting. Witter (1988) reported that more than 60% of nitrogen lost as ammonia during the composting of lime conditioned sludge with a higher initial nitrogen content. Wang et al. (2013) observed 57% nitrogen loss with the addition of lime during the food waste composting. Therefore, application dose of lime must be optimized for composting in order to eliminate the problems of bacterial inhibition and nitrogen loss.

2.6.3 Struvite

Struvite (magnesium ammonium phosphate) is a mineral with the chemical formula: $\text{NH}_4\text{MgPO}_4\cdot 6\text{H}_2\text{O}$. The requirements of struvite formation are the presence of magnesium, ammonium and phosphorous ions under optimal molar ratio, pH, temperature (Doyle and Parsons, 2002). The general chemical reaction of struvite formation is: $\text{Mg}^{2+} + \text{PO}_4^{3-} + \text{NH}_4 \rightarrow 6\text{H}_2\text{O} + \text{MgNH}_4\text{PO}_4 + 6\text{H}_2\text{O}$. Struvite deposition in water treatment works was considered as a nuisance because of clogging and equipment
damage. Recently, people tried to recover the struvite because of its slow releasing ability, which can be of immense importance in the agriculture.

Loss of nitrogen is inevitable during a composting. Addition of struvite salts during composting was reported as an effective strategy to conserve the nitrogen (Ren et al., 2010, Fukumoto et al., 2011, Li et al., 2011). A few studies attempted to optimize the concentration of struvite salts to enhance the composting efficiency and reducing the nitrogen loss. Uludag-Demirer et al. (2005) recommended that magnesium chloride is a good amendment to induce struvite formation during composting because of its high solubility. Ren et al. (2010) reported that addition of magnesium hydroxide (Mg(OH)$_2$) and phosphoric acid (H$_3$PO$_4$) during co-composting of pig manure and cornstalk significantly reduced the nitrogen loss through struvite crystallization.

There are some negative impacts of using struvite salts in composting such as increased salinity when high quantities of salts were added. Jeong and Hwang (2005) observed that addition of Mg and P salts increased the total salinity of final compost and the microbial activities were inhibited, thus the decomposition efficiency of organic matter was reduced. Lee et al. (2009) found that organic matter decomposition was inhibited during swine manure composting, when the concentration of supplemented magnesium and phosphate salts exceeded 0.05 M. However, these findings obtained cannot be directly applicable to food waste composting. Food wastes is considered as highly decomposable but low pH is a key issue, therefore selection of an alkaline struvite salts to co-compost with food waste can alleviate the acidity and reduce the nitrogen loss simultaneously. Therefore, selection of suitable struvite salts optimum concentration need to be examined for efficient composting.
Wang et al. (2013) reported that addition of 0.1 M dipotassium hydrogen phosphate was suitable to buffer the acidity during food waste composting but 0.05 M was not sufficient to overcome the acidity and the microbial activities was inhibited. Struvite formation and 57% reduction in nitrogen loss (when compared with lime treatment) were observed when Mg and P salts were used at 0.05 M and 0.1 M, respectively. Jeong and Hwang (2005) suggested that the actual concentration of Mg and P salts to promote ammonia precipitation into struvite crystals during food waste composting should be 20% of the initial nitrogen which was significantly lower than the usual nitrogen loss experienced.

2.6.4 Microbial inoculums

Composting is a biological decomposition process which involves different kinds of bacteria and fungi in different stages under specific environmental conditions. Addition of yeast in the food waste composting mix was reported to reduce the organic acids thus the acidic pH could be alleviated (Choi and Park, 1998). Similarly, inoculation of three Bacillus species (B. brevis, B. coagulans, and B. licheniformis) in ash-amended sludge composting mass enhanced the organic matter decomposition (Fang et al., 2001). Thus it is clear that addition of appropriate inoculum can remove the organic acids, thus create an environment suitable for other microbes and speed up the entire composting process, especially if the substrates have specific compounds to be degraded.

Food wastes containing high content of lipids can physically block the microbe-substrate contact and limit oxygen diffusion. In such case, addition of specific oil degrading inoculum is an alternative method to enhance the food waste composting. Addition of activated sludge or chicken litter as inoculum to lipid-rich synthetic food
waste could remove 70% of lipids and the process period reduced by 10 days (Lemus and Lau, 2002). Thermophilic and lipolytic Brevibacillus borstelensis SH168 could reduce the crude fat from 4.88 to 1.34% in about 28 days (Tsai et al., 2007). Inoculation of thermophilic fungal consortium improved humification and decomposition during municipal organic waste composting (Awasthi et al., 2014).

2.7 Compost maturity evaluation

Compost can be used as a natural soil conditioner or fertilizer. If the compost is not mature, the application poses negative influence on the plant growth. Therefore the compost must be analyzed carefully to ensure that the organics are well-stabilized. Mature compost should be free of pathogens and phyto-inhibitory compounds like organic acids, ammonia, and ammonium. Immature compost is not only harmful to plants but causes environmental hygiene problems like attraction of insects or rodents, odor emission and pose a possible health threat to the users. Compost maturity tests can be mainly classified into physical (including sensory), chemical and biological. Test Methods for the Examination of Composting and Compost (TMECC) provides detailed testing protocols for the composting industry to ensure the product safety and market claims (Table 2.1).

2.7.1 Physical tests

Physical properties relevant to the composting and compost include moisture content, bulk density, porosity, particle size, morphology, odor and temperature. Use of physical test to evaluate the compost maturity is considered as rapid, direct and easy. A decline of temperature, i.e., the end of the thermophilic phase, indicates that the biomass is reaching stability. Monitoring the temperature is a simple, cheap, and rapid method to assess the state of composting mass rather than an evidence of the maturity. Often other
maturity parameters should be analyzed to confirm the maturity (Inbar et al., 1993; Chefetz et al., 1996). Sometimes the temperature drop could be due to other factors such as low moisture content and acidity (Li et al., 2004).

Table 2.1 Classification of compost maturity tests (Wichuk and McCartney, 2010)

<table>
<thead>
<tr>
<th>Test category</th>
<th>Different compost maturity tests</th>
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</thead>
<tbody>
<tr>
<td>Physical (sensory included)</td>
<td>Temperature of biomass</td>
</tr>
<tr>
<td></td>
<td>Sensory indicators (color, odor and texture)</td>
</tr>
<tr>
<td>Chemical</td>
<td>pH</td>
</tr>
<tr>
<td></td>
<td>Electrical conductivity</td>
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<tr>
<td></td>
<td>Ammonium and nitrite</td>
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<tr>
<td></td>
<td>Soluble organic carbon</td>
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<tr>
<td></td>
<td>Carbon to nitrogen ratio</td>
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<tr>
<td></td>
<td>Organic matter reduction</td>
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<td></td>
<td>Humic acids</td>
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<tr>
<td>Biological</td>
<td>Oxygen level</td>
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<tr>
<td></td>
<td>Carbon dioxide evolution</td>
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<td></td>
<td>Enzyme activity</td>
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<td></td>
<td>Phytotoxicity</td>
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</table>

Similarly, assessing the colour and texture of the compost is a rough estimation to evaluate the compost maturity because the level of sensitivity is subject to each person. The smell, color and texture of compost mass change along the composting process. During the onset of composting, intensive mineralization of organic nitrogen would produce a strong smell of ammonia as significant loss of N as ammonia occurs in this phase (Martin and Dewes, 1992). For the appearance, the immature compost may contain recognizable pieces of substrate and appear in pale brown color. When the compost mass is approaching maturity, the ammonia smell is strongly reduced and the compost is dark brown or black color with lose and fine structure. The odor should be changed from ammonia-smell to earthy smell. Although these physical parameters provide an easy
assessment of the maturity, as said above, other chemical and biological parameters are often necessary to confirm the maturity.

2.7.2 Chemical tests

A large amount of studies have been conducted to find the suitable chemical parameters to evaluate the compost maturity. During composting, significant changes in the chemical properties such as C/N ratio of solid and water extracts, pH, electrical conductivity, ammonium, nitrate and nitrite occurs that can be used to assess the compost maturity. These properties are discussed briefly in the following sections.

2.7.2.1 pH

The pH of mature compost should be slightly alkaline to neutral (Go´mez-Brando´n et al. 2008). pH can vary with different stages of composting. During the onset of composting, pH is decreased since microbes intensively degrade the organic materials leading to the generation of large amounts of organic acids. During the thermophile phase, pH is sharply increased to ~8.0 since large amount of ammonium is produced during intensive decomposition of readily soluble compounds. Ammonium is an alkali and it is the major cause of pH increase. When the compost becomes mature, ammonium is nitrified and the pH is reduced subsequently. Therefore, high quantities of ammonium indicate the immature state of the compost. Brewer and Sullivan (2003) suggested that the pH can be a sole parameter to indicate the compost maturity based on the observations of pH changes from ~5 to 6.5-7.0 of the mature yard waste compost. However, Cayuela et al. (2008) observed that the pH of stabilized olive mill waste compost was ~9.5 which did not fulfill the ideal requirement.

The final pH of matured compost should depend on the properties of starting
materials. Grebus et al. (1994) found only a slight change of pH from initial 7.5 to final 8.1 during the composting of grass clippings. Khan et al. (2009) did not find a significant change in pH during co-composting of green tea and rice bran waste. pH alone was rarely used to assess the compost stability and maturity.

2.7.2.2 Electrical conductivity

Electrical conductivity (EC) is one of the monitoring parameters of the composting since large amount of complex organic compounds are decomposed into soluble components such as ammonium, short chain organic acids. Increase of EC at the high-rate degradation phase is unavoidable but high EC of the compost product is considered phytotoxic because high salts content can inhibit seed germination, damage the root, influence the nutrient uptake (Hakim et al., 2010). Decrease of EC can be observed at the later stage of composting which may due to the decomposition of organic acids and precipitation of soluble salts.

Avnimelech et al. (1996) suggested that the stabilizing trend of EC at the later stage of composting can be correlated with compost maturity. Similarly, Wang et al., (2004) also suggested that measurement of EC can be a simple on-site method to monitor the quality of compost. However, the EC value of matured compost can vary greatly and it should depend on type of starting materials and any amendment during the process. Amendment of struvite salts during food waste composting enhanced the EC value of the matured compost (Wang et al., 2013). Therefore, there is no standard EC value can be found for matured compost which can be entirely applied to all kind of composting processes. Walker and Bernal (2008) found that the EC of poultry manure compost have relatively high salt content than other feedstock. EC can only be used to evaluate the
compost maturity when the compost are produced from similar organic materials (Wu et al., 2002). In short, EC cannot be a reliable parameter to assess the stability and maturity of compost because the salts content can greatly vary with different feedstock.

2.7.2.3 Ammonium, nitrite and nitrate

Mineralization of organic nitrogen during composting process can generate large amount of ammonium ions. The ammonium level is proportional to the rate of biodegradation. At the later stage of composting, most of the ammonium are transformed to nitrate through nitrification process. Therefore, reduction of ammonium and enhancement of nitrate are the potential indicators of compost maturity. The NO$_3$ to NH$_4^+$ ratio below 2:1 indicates the immaturity of the final compost (ASCP, 2001). Sullivan and Miller (2001) considered the ratio of NO$_3$:NH$_4^+$ as a useful tool to assess the compost maturity only if the content of available nitrogen contains at least 50 mg/kg NO$_3$ in fresh weight basis.

Apart from NO$_3$:NH$_4^+$ ratio, literature reported that either nitrate or ammonium alone can be used to appraise the stability or maturity of final compost. Khan et al. (2009) found increased nitrate level under the intensive nitrification corresponded to the stabilization. ASCP (2001) and HKORC (2005) recommend that the ammonium level should be <300 mg/kg FW or ≤700 mg/kg DW as the maximum limit for the stabilized compost, respectively.

In contrast, few researchers did not agree to use either ammonium or nitrate concentration to assess the compost stability or maturity since they can provide the information about compost quality only (Brewer and Sullivan, 2003). Sometimes, the level of ammonium and nitrate changed irregularly and did not follow the expected trend
hindering its use as a sole indicator of compost maturity (Go´mez-Brando´n et al., 2008). Therefore, using NO3:NH4+ might not be reliable parameter to evaluate the maturity of compost. Besides, Brewer and Sullivan (2003) recommended that the ratio of NO3:NH4+ should be monitored frequently during different stages of composting including initial, after high-rate degradation and after curing rather than the final product that could enhance the reliability of using this parameter to assess the maturity.

2.7.2.4 Soluble organic carbon

Low level of extractable organic carbon can be observed in stabilized or matured compost since most of the dissolved nutrients are being used up at the final stage of composting process. In other words, low level of dissolved organic carbon can indicate the stability and maturity of final compost. The mass specific absorbance of soluble organic carbon correlated with the phyto-inhibitory effect since the seed germination rate was increased when the level of soluble organic carbon decreased. Zmora-Nahum et al. (2005) suggested that the SOC content of stable or mature compost should be below 4 g/kg (dry weight basis) and Hue and Liu (1995) suggested a value of <10 g/kg dry weight.

SOC can be separated into hydrophobic (resistant to degradation) and hydrophilic (readily-degradable) fractions and a ratio of these two portions higher than 1 indicate compost is stable (Said-Pullicino et al., 2007). On the contrary, some studies found that SOC is a poor indicator of compost maturity. Benito et al. (2009) found the SOC content was detected below the standard limit during onset of horse manure and pruning co-composting process which indicated a clear limit of SOC need to be developed for different feedstock. There was no obvious decreasing tread of SOC during animal manure
and food waste co-composting (Cooperband et al., 2003), therefore, did not provide evidence of compost maturity.

2.7.2.5 Carbon to nitrogen (C/N) ratio

A decreasing trend of C/N ratio is observed during composting since organic carbon and nitrogen are intensively mineralized which leads to emission of variety of gases and reduction of carbon and nitrogen content. The composts quality standards of HKROC and TMECC indicated a final C/N ratio of compost should be $\leq 25$. Many composting studies observed a significant decrease of C/N ratio and also correlated to other maturity parameters.

Zhu (2007) found a drastic reduction of C/N, from 20.16 to 15.02 and 24.94 to 14.16, during the co-composting of swine manure and rice straw respectively. C/N ratio was also correlated with other parameters such as soluble C/N ratio, ammonium, nitrite and nitrate. During co-composting of pig manure with sawdust, the C/N solid ratio significantly decreased from 28.8 to 20.5 during the first 35 days and less sharply reduced to 16.4 after 63 days (Huang et al., 2006). However, some studies found that C/N ratio cannot be an absolute parameter to determine the compost maturity and it can mislead the user if it is used alone.

Huang et al. (2004) reported that solid C/N ratio cannot be considered as an accurate indicator to evaluate compost maturity because the C/N ratio did not show any correlation with the seed germination index, and the initial C/N ratio varied greatly depending on the properties of the substrate. Hirai et al. (1983) found that the C/N solid ratio of final compost is below or equal to 20, which can be considered as an acceptable value of maturity while the optimal initial starting C/N ratio is within 20 to 30 of the
composting mix. Therefore, use of solid C/N ratio as a compost stability or maturity indicator has some limitations. For instance, if the composted feedstock is rich in nitrogen content, the C/N ratio of composting mix during the process may be low even before the compost is matured (Goyal et al., 2005). A serious reduction of C/N ratio to 15:1 was found during the thermophilic phase while the organic matter was still actively decomposing (Jiménez and Pérez García, 1991). These limitations indicated that C/N ratio cannot be an absolute indicator of compost maturity.

2.7.2.6 Organic matter reduction

Substrates that are used for composting contains a variety of organic compounds such as carbohydrates, lipids, proteins and lignins. Those organic substances are continuously degraded during the composting by microbes and converted to a variety of metabolites simultaneously releasing the heat and gases like carbon dioxide and ammonia until the decomposition is stabilized, and the stability can be evaluated by the quantity of available organic matter remaining.

Organic matter reduction may not be a good indicator to measure the compost stability because the inorganic carbon e.g. carbonates or plastic materials presented in the system might contribute to the determination of organic matter, eventually give a false value (Benito et al., 2009). TMECC (2002c) suggested that the composition of composting feedstocks and operational conditions greatly influence the organic matter reduction.

2.7.2.7 Humic acids

Large amount of readily available organic substances are used up and part of it are converted to humic substances and accumulated until the end of the composting cycle.
During composting, fulvic acids are generated which are ultimately take part in the synthesis of humic substances. Therefore, humic acids are the main contributor to the total organic matter of matured compost (Mathur et al., 1993). The increase of humic acids concentration is closely linked to the compost maturity. Ko et al. (2008) found that the HA level increased while FA level reduced during composting and the HA:FA ratio of the matured composts were higher than 1.6:1. However, not all the researchers have identical views to HA:FA ratio as a good indicator to assess the compost maturity. Benito et al., (2005) observed the content of humic acids decreased initially but subsequently increased at the later phase in their study which was an unexpected result. Another study had similar result that the content of humic acids decreased along the process (Adani et al. 1999).

The possible reasons of increase in humic acids during the initial stage are inconsistent extraction efficiency due to extractability of humus or some interference such as carbohydrates, fats and proteins are extracted unexpectedly. Moreover, there is no universal threshold value of humic acids of stabilized or matured compost since different feedstock materials could have different humus contents. Moreover high lignin content material has high content of humus relatively. To summarize, the extractable humus may not be an accurate parameter to evaluate compost maturity.

2.7.3 Biological tests

Biological parameters such as oxygen uptake, CO₂ evolution, enzyme activities and seed germination are used to evaluate the compost stability (Lasaridi and Stentiford, 1988a). The rationales of using these parameters are the strong demand of oxygen and high generation rate of CO₂ of the microorganisms during intensive decomposition of
organic matter. The oxygen demand and \( \text{CO}_2 \) production would be reduced when the available organic matters are used up during the later phase of composting. Moreover, enzymes play a critical role during degradation since they are involved at both biochemical and biological processes; and can be used as an indicator of the microbial activities. Immature comports consist high amount of phyto-toxicants such as ammonium ions, ammonia, ethylene oxide, organic acids, etc., which can greatly affect the seed germination and plant growth. Each of the biological test will be discussed in details as below.

2.7.3.1 Oxygen uptake

Oxygen uptake is a direct parameter to evaluate the microbial activity of a composting mass since compost with high microbial activity would uptake more oxygen. Thus, matured compost with low microbial activity can be assessed by low level of oxygen uptake. Oxygen uptake can be determined using solid substrates or aqueous compost suspension, however, aqueous compost suspension was reported to accurately indicate the compost stability (Iannotti et al., 1993). On the contrary, immature compost contains many toxic intermediates such as organic acids and ammonium which could suppress the microbial activity. In such a situation, the oxygen demand cannot reflect the actual stability of the composting mass. Besides, as Mathur et al. (1993) observed, the microbes of different kind of compost could have different oxygen demand; therefore it is difficult to set an acceptable limit of stabilized compost.

2.7.3.2 Carbon dioxide evolution

Carbon dioxide evolution test is similar as oxygen uptake to directly evaluate the microbial activity since the high microbial activity could cause high rate of \( \text{CO}_2 \)
evolution. Therefore, low CO$_2$ evolution rate is an indication of matured compost with low microbial activity. The advantages of CO$_2$ evolution test over oxygen uptakes are simpler, less expensive and much accurate and it is also suitable to assess the maturity of composts from varied feedstock materials (Brinton, 2000). Low CO$_2$ evolution correlated well with the cress seed germination test and could be useful to assess the compost maturity (Aslam and Van der Gheynst, 2008). However, some researchers did not agree CO$_2$ evolution is a useful parameter in assessing compost stability and maturity. Similar to oxygen, immature compost with suppressed microbial activity can provide a low CO$_2$ evolution rate but that may not reflect the actual stability.

2.7.3.3. Enzymatic activity

Microbes release enzymes which catalyze the biochemical reactions and involve in the depolymerization of different constituents of organic wastes during composting. Many important enzymes such as proteases, phosphatases, dehydrogenases, cellulases, lipases, hemicellulases, etc., are involved in different stages of composting (Goyal et al., 2005). Enzymatic activity can be used to evaluate the microbial activities of a composting mass and it is considered as rapid, easy and cheap method. For instance, high concentration of dehydrogenases indicates the presence of a high quantity of readily available organic matter. Studies found that the content of dehydrogenases correlated well with the maturity parameters like oxygen uptake, carbon dioxide evolution and humic acids. Forster et al. (1993) suggested that the dehydrogenase activities can be used along with ammonium analysis, and it showed an obvious correlation with HA:FA ratio. However, not all the researchers obtained similar results, indicating the importance of analyzing the routine maturity and stability parameters.
2.7.3.4 Phytotoxicity

Immature compost is still in an active decomposition state; therefore many intermediates produced like short-chain organic acids, and ammonium are phytotoxic and hinder the seed germination, retard plant growth and cause plant death. Chen and Inbar, (1993) mentioned that phytotoxicity test is an ultimate test to evaluate the compost maturity; particularly when the compost is intended to be used for organic farming or horticulture. Since the tolerance of different plant species vary, phytotoxicity test cannot be used alone but may be combined with other parameters to evaluate compost maturity (TMECC 2002e).

Seed germination test and plant growth evaluation using compost suspensions or compost mixture under a controlled environment is a direct test assessing the phytotoxicity of the composts. Mixture of 25% and 50% of compost with standard base soil mix should be prepared for conducting barley test in Germany (Brinton 2000). The sensitivity of cress is higher than radish, lettuce and cabbage (Aslam and Vander-Gheynst, 2008). Despite that it is difficult to select the best plant for the test because so many standards are developed by different sources; however, cress and barley tests are comparatively validated over other plant species.

Plant assays do not provide evidence about the nature of the phytotoxicants such as organic acids, ammonium, salinity or herbicide effect but only express symptoms on plant (Mathur et al. 1993). Also, the duration of plant assay is several days which are considered as time consuming method over those physical and chemical compost maturity tests (Rynk, 2003).

2.8 Compost application

Compost can generally classified as “Good Quality” and “Pass” after evaluating the
maturity, quality, nutrient and seed germination tests (HKORC, 2005). Manser and Keeling (1996) suggested that compost with poor quality containing many impurities and does not fulfill the stability and maturity requirements, can be applied on “Hard” landscaping to cover surfacing of the landfills, road construction, motor way edges, etc. Compost with good quality that fulfills all stability and maturity requirements with desired amount of nutrients can be applied in organic farming, vegetation regions like parks, golf courses.

2.8.1 Effect of compost on soil properties

Effects of compost application on soil can be divided into three aspects. They are physical, chemical and biological effects. In general, compost can improve the physical properties of soil by reducing the bulk density, increasing water holding capacity and enhancing the aggregate stability which make more favorable conditions for the plant growth (Giusquiani et al., 1995). Those chemical effects that commonly observed are pH buffering of acidic soil (Zhu et al., 2013), increase of cation exchange capacity (Karak et al., 2013), and increase in the nutrient content and organic matter (Cortellini et al., 1996).

Besides, there can be some negative impacts of compost application on soil such as increase of salinity, total and extractable trace metals that may affect the plant growth; however, it is influenced by the tolerance and speciation of particular nutrient in the soil environment.

2.8.2 Effect of compost on plants

Enhanced physical and chemical properties will improve the plant growth and biomass production. Bevacqua and Mellano (1993) observed that crop yields were significantly increased in sludge compost amended sandy calcareous soil compared to
soil only over two years. Smith et al. (1992) found that higher yields of cabbage and onion on 25% compost amended treatment when compared with soil amended with NH$_4$NO$_3$ only having similar total nitrogen content. High nitrogen and phosphorus content of inorganic fertilizer applied to soil is often utilized by the plants poorly and leaching is a common phenomenon. However, a controlled release of nutrients from the compost provides an excellent environment for the plant growth and a vibrant plant rhizosphere (Buchanan and Gliessman, 1991).

2.9 Introduction of community composters

Community composters are often small compared to large-scale composing facility, and are designed to handle 1-300 kg/day of food wastes and installed in the backyard of restaurants, hospitals, institutes, housing estates, for on-site composting. This kind of composters are operated in fed-batch mode which mean the food wastes are added into the machine daily and decomposed for a certain period, simultaneously compost can be produced (Sundberg and Jönsson, 2005). There are some advantages of using this kind of composters to handle the organic wastes generated from the community. Through the activities of food wastes separation and recycling, people take responsibility to handle their own waste and build up their consciousness on wastes reduction simultaneously. Cost of transportation and concern of environmental contamination are reduced by diverting part of food wastes to composters instead of landfilling. Moreover, recycling the food wastes to useful resources such as biological fertilizer or soil conditioner can reduce the usage of chemical fertilizer. However, the immature development of this kind of composters can bring about a lot of operational problems such as odor emission, poor decomposition, poor quality of final compost.
There are different kinds of community composters available in the market and they are varied in designs, constituents and operating principles (Plate 2.1). In general, there are some necessary ingredients are required in a basic composter design. They are mainly include heater, agitating device, aeration system, air filter device, indication panel etc. Heater is mainly used to dry the excessive moisture of the composting materials and prevent the heat loss. Agitating device is used to mix the fresh food wastes with the original materials completely in a designated time period. Aeration system is to provide sufficient air for microbes to decompose the organic matters and prevent overheating. Air filter usually is a separated device but connected with the air flow outlet of the machine to clean the air before released to the atmosphere. Indication panel is installed at the surface of the machine to indicate the biomass and heater temperature; also it allows the user to adjust the operations of machine. Inappropriate design and program setting are the critical reasons to cause those operational problems as described below:

Plate 2.1 Food waste composter

2.9.1 Poor decomposition

Poor decomposition is a common problem encountered in batch and fed-batch food
waste composter. The reasons are acidity and lipids problems similar to the batch composter. Although the cause of these problems is similar, the influencing level are different between and fed-batch composting systems. In batch composting, acidity and lipid problems can be alleviated and self-decomposed after a period of time if no additional food wastes are added into the system because the amount of organic acids and lipids are fixed and not accumulated. However, this problem can be serious if new substrates are added continuously without complete decomposition. Beck-Friis et al. (2003) reported that accumulation of organic acids in fed-batch food waste composting inhibited the microbial activity. Recycling of adequate amounts of starting culture consisting of active compost prevented the low pH and microbial inhibition (Sundberg and Jönsson, 2005). Nakasaki and Nagasaki (2004) found that inhibition of organic matter decomposition was negligible until the lard mixing ratio with organic waste was higher than 33.3% during fed-batch composter.

### 2.9.2 Odor emission

Odor emission can be a major problem to cause shut down of the composting facility. Both batch scale and fed-batch scale composters can suffer from odor problem. The main reason of odor generation is due to poor decomposition which was described in previous section. Volatile fatty acid is one kind of odor commonly emitted from a composting process in acidity and limited oxygen conditions. Ammonia is another kind of odor emitted from a composting with high pH and temperature conditions. To tackle the odor problems, different physical, chemical and biological amendments can be supplemented during composting to improve the decomposition efficiency which has been explained in section 2.6. Apart from the addition of amendments in composting material, installation
of biofilter is a popular measure to handle the outlet air that comes out from the composters. Schlegelmilch et al. (2005) proved that the screened compost in biofilter was effective to degrade odor compared to coke-compost mixture. Charles et al. (2013) found that addition of zeolite and coir in biofilter was effective to adsorb non-polar volatile organic carbon substances (monoterpenes) and reduce the total odor level of a composting facility.

2.9.3 Production of immature compost

The reason of production of immature compost in fed-batch compost is because the organic matter does not completely decompose in the machine. Poor decomposition of food waste composting process is due to acidity and lipids which have been explained in previous sections. Due to the fed-batch mode of operation, large amount of immature compost can be produced daily but it cannot be used directly resulting in creating another kind of solid waste problem. The compost consists of phyto-toxicants needing further time to stabilize, therefore a large area of land and labors are needed to accommodate and manage it. If the composting facility operator or the compost user inhales the fungal spores continuously from those immature compost, they can be suffered from disease (Chung and Sugui, 2013). Therefore, optimizing the food waste composting process in fed-batch composter is important to produce completely sanitized, nutrient-rich and eco-friendly compost.
Chapter 3 - Effect of Zeolite on Food Waste Composting in Laboratory Scale Batch Composters

3.1 Introduction

In Hong Kong, about 9,278 tonnes of MSW was landfilled in 2012; of which ~41.7% were putrescibles (HKEPD, 2014). Till now, landfillsing is the major disposal method for food wastes. These organic resources landfilled cause negative environmental impacts and lock the nutrients unavailable for the nutrient recycling in the ecosystem.

Composting is a mature and robust biological treatment technology that can convert food waste into soil conditioner or organic fertilizer. However, food waste composting is always hampered by the onset of acidity due to production of large amount of short chain organic acids during intensive decomposition. Under this acidic condition, microbial activity is inhibited and overall decomposition efficiency is reduced, and odor is also generated (Cheung et al., 2010).

Scientists strived for identifying measures to alleviate the acidity problem during composting and addition of alkaline substances such as sodium acetate (Yu and Huang, 2009), coal fly ash and lime (Wong et al., 2009), bauxite residue (red mud) (Snars et al., 2004), etc is a common approach in dealing with acidity issues. Addition of lime has been demonstrated as an effective method to adjust the initial acidity of composting but high dosage of lime can be harmful to the microbial activity and eventually slow down the efficiency of decomposition (Wong and Fang, 2000). A significant loss of ammonia and reduction in nitrogen content of the final product were also the result of lime addition.

About 57% nitrogen was lost when lime was used to control the pH during food waste composting (Wang et al., 2013). Wong and Fang (2000) reported that addition
0.63% of lime could shorten the time of stabilization by entering the cooling phase earlier than the control. However, 0.63% lime amendment was not sufficient to buffer the acidity generated during food waste composting; instead 2.25% of liming was found effective for food waste composting in earlier study (Wong et al., 2009). However, 2.25% of liming induced a significantly loss of nitrogen as ammonia and reduced the nitrogen value of final product during food waste composting even through the acidity problem was tackled (Wang et al., 2013). Therefore a method to control the acidity and simultaneously reduce the loss of nitrogen is of importance for food waste composting.

Zeolite is a mineral with specific morphological characteristics that allows it to have high adsorption capacity and would be a good candidate to be considered in composting. Zeolite has been amended with soil to reduce heavy metal availability in sludge compost (Zorpas et al., 2008). A layer of zeolite with soil was placed on the composting pile showed strong ability to adsorb the volatilized ammonia and raised the Kjeldahl nitrogen content to 2.5% of final product (Witter and Lopez-Real, 1988). Turan and Ergun (2007) observed that ammonia uptake efficiencies increased from 74.94% to 87.98% when 5% of zeolite application was increased to 10%. Other literature found that zeolite had pH buffering (Mahimairaja et al., 1994), reducing the salinity of the compost (Turan, 2008) and high affinity of ammonium adsorption (Liu and Lo, 2001). Singh and Kalamdhat (2014) observed that addition of optimal concentration of zeolites (clinoptilolite) during rotary drum composting of water hyacinth significantly reduced the bioavailability of heavy metals. Addition of zeolite during grain residue composting on the other hand reduced nitrogen loss by 84% compared to control and reduced the ammonium content of the final product (Čepanko and Baltrėnas, 2011).
However, results obtained from different studies are inconsistent that could arise from the differences in the feedstock materials. Addition of zeolite to food wastes during composting has never been reported before but warrants investigation considering the ammonia adsorption and pH buffering effects. Therefore, the aim of this work was to evaluate the effect of zeolite on food waste composting and to compare its efficiency with lime.

3.2 Materials and Methods

3.2.1 Feedstock Preparation

Artificial food waste was used in the present study to minimize the heterogeneity of food wastes facilitating the comparison of results from different experiments. Bread, rice, cabbage and boiled pork were mixed in a ratio of 13:10:10:5 as a preparation of synthetic food waste which was identical to the previous experiments (Wang et al., 2013, Wong et al., 2009). All the food waste components were cut into 1 cm³ size to ensure easy mixing. General physicochemical parameters such as pH, EC, moisture content, total carbon and nitrogen contents and carbon to nitrogen ratio of mixed synthetic food waste, sawdust and initial composting mixture were analyzed prior starting the experiment. The physicochemical characteristics were presented in Table 3.1.

Sawdust was purchased from a saw mill located in the New Territories in Hong Kong. Clinoptilolite, a synthetic zeolite for agricultural use, was purchased from Zhejiang Shenshi Mining Industry Co., Ltd., PR China. The detailed composition and characteristics of the zeolite are listed in Table 3.2. Lime (calcium oxide) was purchased from Fisher Scientific Chemical Laboratory.

Food wastes and sawdust were mixed thoroughly with different inorganic amendments in dry weight proportion accorded to treatment requirement. The initial C/N
ratio of the mixture was adjusted to ~30 by addition of ~1.5 kg of sawdust of each treatment and initial moisture to ~55%. About 500 g of plastic spheres was added in each treatment to reduce the bulk density of the composting mix to ~0.5 kg/L. The size of each plastic sphere was ~1 cm$^3$. In total, 7 kg of compost was put into each compost reactor.

Table 3.1 The physiochemical characteristics of synthetic food waste, sawdust and initial composting mixture in this experiment

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Food waste</th>
<th>Sawdust</th>
<th>Composting Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.79 ± 0.04</td>
<td>4.99 ± 0.03</td>
<td>5.45 ± 0.05</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>4.87 ± 0.02</td>
<td>0.04 ± 0.01</td>
<td>4.02 ± 0.01</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>57.52 ± 0.03</td>
<td>7.05 ± 0.01</td>
<td>55.98 ± 1.89</td>
</tr>
<tr>
<td>Total organic carbon (%)</td>
<td>46.78 ± 0.20</td>
<td>53.6 ± 0.02</td>
<td>47.82 ± 2.64</td>
</tr>
<tr>
<td>Total organic nitrogen (%)</td>
<td>3.21 ± 0.05</td>
<td>0.62 ± 0.10</td>
<td>1.58 ± 1.02</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>14.57 ± 0.37</td>
<td>86.45 ± 3.98</td>
<td>30.27 ± 2.75</td>
</tr>
</tbody>
</table>

Means and standard deviation are presented (n=3).

3.2.2 Experimental Design and compost reactor operation

Food waste compost was amended separately with 0, 2, 5, and 10% of zeolite to check its effect on composting process. An additional treatment with 2.25% lime amendment with food waste compost was also prepared to compare the buffering capacity of zeolite (Table 3.3). The composting materials of each treatment was composted in a bench-scale composter for 56 days. A thermocouple coil was placed around each composter in order to prevent heat loss and the temperature was controlled by a feed back-controlled programme. The heater was turned on when the temperature difference of inner (inside the reactor) and the outer sensor (reference) was less than 1 $^\circ$C.
when the biomass temperature was >35°C. Temperature was monitored continuously and recorded by a data logger. Excessive heat up of the composting mass was prevented during thermophilic phase by switching on the supplementary aeration pump when the temperature was higher than 65°C. An aeration pump was used to provide a constant air supply of 1 L/kg dry weight min⁻¹ (Haug, 1993). The schematic diagram of the reactor is illustrated in Figure 3.1. During the whole composting process, compost temperature was monitored by a temperature sensor in the core area of reactor. Concentrations of carbon dioxide emitted from the reactors were continuously measured by an on-line infrared gas analyzer (WMA-3, PP Systems, UK). Air emitted from the reactors was absorbed by boric acid for 1 h, and then titrated against hydrochloric acid to quantify the ammonia emission (Meeker and Wagner, 1933).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical properties (%)</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>68.43 ± 1.92</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.14 ± 0.01</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>11.41 ± 0.68</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.64 ± 0.48</td>
</tr>
<tr>
<td>FeO</td>
<td>0.11 ± 0.01</td>
</tr>
<tr>
<td>MnO</td>
<td>0.06 ± 0.02</td>
</tr>
<tr>
<td>MgO</td>
<td>0.26 ± 0.23</td>
</tr>
<tr>
<td>CaO</td>
<td>2.72 ± 0.23</td>
</tr>
<tr>
<td>K₂O</td>
<td>1.08 ± 0.14</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.60 ± 0.37</td>
</tr>
<tr>
<td>Cation exchange capacity (CEC) (meq/100 g)</td>
<td>120–160</td>
</tr>
<tr>
<td>Physical properties</td>
<td></td>
</tr>
<tr>
<td>Proportion</td>
<td>2.16</td>
</tr>
<tr>
<td>Hardness</td>
<td>3 - 4</td>
</tr>
<tr>
<td>Diameter (Ai)</td>
<td>3.5 – 4.0</td>
</tr>
<tr>
<td>Than surface product (g m⁻¹)</td>
<td>230 - 320</td>
</tr>
<tr>
<td>Thermal stability (°C)</td>
<td>750</td>
</tr>
<tr>
<td>Silicon to aluminum ratio</td>
<td>4.25 - 5.25</td>
</tr>
</tbody>
</table>

Source: Zhejiang Shenshi Mining Industry Co., Ltd research center. The error bars
represents the standard deviation calculated from three replicates.

### Table 3.3 Dosage of different inorganic amendments in different treatments (on dry weight basis)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Zeolite (%)</th>
<th>Lime (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (C)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Zeolite 2% (Z2)</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Zeolite 5% (Z5)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Zeolite 10% (Z10)</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Lime 2.25% (L2.25)</td>
<td>0</td>
<td>2.25</td>
</tr>
</tbody>
</table>

**Figure 3.1** Schematic diagram of the food waste composting system

The composting mass in each reactor was mixed to reduce compaction periodically at Day 3, 7, 10, 14, 17, 21, 28, 35, 42, 49 and 56 and moisture was adjusted after each
mixing cycle. The weight of the composting mass was recorded for each composter before mixing and sampling. About 200 g of samples were collected after mixing for physicochemical analysis. 50 g of samples were oven-dried at 105°C for 24 h to determine the moisture content; then oven-dried samples were ignited at 550º C in a muffle furnaces for 16h to determine total organic matter (TOM). Twenty gram of fresh samples were extracted with deionized water at 1:5 ratio in dry weight basis (w/v) for 1 h, then suspensions was used to measure pH and electrical conductivity (EC) by using Orion 920 ISE pH meter and Orion 160 conductivity meter, respectively. Then, the suspensions were centrifuged at 13,000 rpm for 10 min and filtered through 0.45 µm membrane filter for the determination of extractable ammonium (NH₄⁺-N) and seed germination index (GI). Total nitrogen (TN) and total phosphorus (TP) were extracted by Kjeldahl digestion method (Bradstreet, 1965), following the contents of NH₄-N was determined by indophenol blue method and the contents of PO₄-P was determined by Molybdenum-blue method (Page et al., 1982). Total organic carbon (TOC) was determined by Walkey-Black method (Walkey and Black, 1934). For the determination of Total potassium (TK), compost was subjected to microwave digestion method by using concentrated nitric acid (HNO₃) and analyzed through atomic absorption spectrophotometer (Varian Techtron Model AA-10). For the test of GI, 5 ml of each testing solution was pipetted to a sterilized petri-dish placed with a Whatman #1 filter paper. Ten cress seeds (Lepidium sativum) were put in each petri-dish and incubated in a dark condition for 48 h at 20-25°C. Seed germination index was evaluated by counting the number of germinated seeds and the length of the root radical. Germination Index can be calculated by the following formulation (Zucconi et al., 1981).
3.3 Statistical analysis

Three replicates were used for the analysis and the mean and standard deviations are presented in the tables and figures. Test of one way ANOVA was used to compare the means among the treatments and significant F values were obtained, differences among the individual means were tested using the Least Significant Difference Tests at 95% confidence interval using SPSS version 16.

3.4 Results and discussion

3.4.1 Changes of temperature

Temperature is an important indicator to ensure a good decomposition and sufficient sanitation of the composting mass. Pathogens can be effectively eliminated when the temperature is above 55°C during composting (Strauch and Ballaini, 1994). Temperature of treatment Z2, Z5, Z10 and L2.25 reached around 55°C within two days and remained thermophilic for about two weeks (Figure 3.2). C and Z2 showed a maximum of ~50 °C initially at day 2, then temperature immediately declined which could be attributed to the unfavorable conditions posed by the low pH as discussed later.

Treatment of L2.25 maintained the highest temperature for a longer period indicating that the dosage of lime was optimum and able to neutralize the acids effectively (Wong and Fang, 2000). Treatments Z5 and Z10 also maintained high temperature during the first two weeks and the profiles were almost comparable to that of L2.25 indicating that the zeolite at 5 and 10% can provide adequate buffering (Venglovsky et al., 2005). The periodical fluctuation pattern in the temperature profile
reflected mixing of the composting mass that can redistribute the moisture content and activate the microbial activities.

![Temperature profile graph](image)

**Figure 3.2** Changes of temperature during the composting of food waste amended with 0, 2, 5 and 10% of zeolite and 2.25% of lime

### 3.4.2 Carbon dioxide evolution

Carbon dioxide evolution is one of the important parameters to evaluate the microbial activities of composting process. High CO₂ evolution rate of composting system indicates the intensive microbial activity. CO₂ evolution profile, as presented in Figure 3.3a, followed that of the temperature profile but the trend of CO₂ emission declined. Furthermore, small peaks observed in the treatments C and Z2 during the later stage of composting process which was due to initial slow incomplete decomposition. As presented in Figure 3.3.b, the cumulative CO₂ emission of the treatments C was significantly lower than the other treatments because the microbial activities were
retarded due to an acidic environment. Zeolite amendment increased the cumulative CO₂ emission with an increase in levels of amendment but 10% amendment was only marginally higher than 5% level. The cumulative CO₂ of compost with lime amendment was only slightly lower than that of 5 and 10% zeolite amendment.

Figure 3.3 Changes of carbon dioxide evolution (a) and cumulative carbon dioxide emission (b) during the composting of food waste amended with 0, 2, 5 and 10% of zeolite and 2.25% of lime.

3.4.3 Changes of pH

During the early stages of the food waste composting, large quantities of short-chain organic acids are produced due to the rapid decomposition of the readily
available organic matters. In a normal condition, the trend of pH profile should decline initially and increase afterwards because the acids are consumed/degraded eventually (Sundberg and Jönsson, 2005). Nakasaki et al. (1993) found that pH in a range of 7-8 is optimal for the growth and protein decomposition while a pH range of 6-9 is optimal for glucose decomposition.

The changes in the pH of the different treatments are presented in Figure 3.4. During the first week, the pH was significantly decreased due to production of the organic acids. The pH of the control treatment was in acidic condition (4.5 to 5.0) for the whole composting period, indicating that the organic acids were not degraded successfully and the microbial activity was severely inhibited. The initial pH of Z2, Z5 and Z10 were slightly increased due to addition of zeolite because of the buffering effect as well as a minor dilution effect. Then pH decreased slightly in the first week with a lower decrease as an increase in amendment. Following the decline pH increased with an increase in time of composting but with a decrease in amendment level there was a longer lag period before reaching the common alkaline pH of 8 after 3 weeks, indicating the higher zeolite amendment had a positive effect on the decomposition process. When compared Z5 and Z10, there was no significant difference in their pH profile. On the other hand, addition of 2.25% lime increased the pH to 10.74 initially and then dropped to 7.5 at day 7 because of the production of organic acids. Lime demonstrated an effective pH buffering over zeolite because of its instantaneous neutralizing capability of acids.
3.4.4 Changes of EC

EC is one of the indicative parameter to evaluate the amount of soluble salts in the composting mass. Final compost with a high quantity of soluble salts is considered potentially phytotoxic (Nawaz et al., 2010). In a composting process, EC is unavoidably increased due to the weight loss from decomposition of organic matter. The EC profiles of the food waste composting with zeolite and lime addition are presented in Figure 3.5. EC of treatment C and Z2 slightly increased along the composting from 4 to 5 mS/cm during the whole composting period. EC of treatments Z5, Z10 and L2.25 have increased during the first week to more than 6 to 8 mS/cm and declined sharply afterwards to <5 mS/cm within 14 d. However, treatment with 5 and 10% zeolite amendment showed significantly lower EC values compared with lime treatment due to the molecular sieving property of zeolite facilitating adsorbing ions that reduced the EC. Turan (2008) observed...
that a reduction in salinity when zeolite application rate was increased, also the characteristics of product was improved with low salinity, ammonium concentration and desirable nitrogen content. Similarly, a soluble salt content of pig manure compost was significantly reduced with the addition of 5% and 10% zeolite (Hu et al., 2010).

![Figure 3.5](image)

**Figure 3.5** Change of EC during the composting of food waste amended with 0, 2, 5 and 10% of zeolite and 2.25% of lime.

### 3.4.5 Ammonia emission

Ammonia (NH$_3$) emission is unavoidable during composting when the organic matter started to mineralize. Severe loss of NH$_3$ is not only cause odor emission but also reduce the nutrient value of final composting product. Kithome et al. (1999) estimated that 47 to 62% of total nitrogen was lost as ammonia during poultry manure composting. The total NH$_3$ loss can amount to 50% of the total initial nitrogen during co-composting of sewage and straw mixtures (Witter and Lopez-Real, 1988).

High temperature, pH>7.5, low C/N ratio and mixing and turning or increased
aeration rate can enhance the loss of NH\textsubscript{3} during composting (Witter and Lopez-Real, 1988; Jeong and Kim, 2001). According to the NH\textsubscript{3} emission profile (Figure 3.6a), the five treatments showed different emission peaks because of varied ammonification rate of organic nitrogen. Treatments Z5, Z10 and L2.25 showed earlier emission peaks than C and Z2 indicating that the composting conditions were more favorable for microbes to decompose the organic matter. Treatments C and Z2 were not favorable for NH\textsubscript{3} emission due to the low pH that prevented ammonia volatilization.

From the cumulative NH\textsubscript{3} emission profile presented in Figure 3.6b, Treatment C and Z2 showed significantly lower NH\textsubscript{3} emission due to the poor decomposition and the acidic pH as mentioned earlier. The NH\textsubscript{3} emission of L2.25 was significantly higher than treatments Z5 and Z10 since the increase in the pH facilitates volatilization of ammonia resulting in more loss as reported in previous studies (Witter and Lopez-Real 1988, Wong et al., 2009; Tran et al., 2011).

NH\textsubscript{3} emission of treatments Z5 and Z10 were significantly lower than L2.25 demonstrating that zeolite had a great affinity to adsorb the NH\textsubscript{3}. Bautista et al. (2011) observed that addition of alum and zeolite during swine manure composting could reduce the ammonia loss by 85-92%, and improved the nitrogen content of final compost. Combined zeolite and yeast addition during poultry litter composting enhanced the degradation and reduced the odor concentration by reducing the ammonia emission by 50% (Zhang and Lau, 2011). Wang et al., (2014) reported addition of zeolite and reed straw during duck manure pre-composting and vermicomposting significantly reduced the emission of NH\textsubscript{3}, N\textsubscript{2}O, and CH\textsubscript{4}. Kučić et al.,(2013) reported that zeolite adsorbed 31% of the emitted CO\textsubscript{2} and all of the NH\textsubscript{3} while the potting soil adsorbed 3% of CO\textsubscript{2}.
and 49% of NH$_3$ during co-composting of grape and tobacco waste.

**Figure 3.6** Change of ammonia emission (a) and cumulative ammonia emission (b) during the composting of food waste amended with 0, 2, 5 and 10% of zeolite and 2.25% of lime.

**3.4.6 Changes of extractable ammonium**

During high-rate degradation of protein, high level of ammonium is generated ammonification process but the level can be reduced at the later stage when the ammonium ions are converted to nitrate through nitrification. High ammonium content in
compost indicates immature status of the compost which needs further composting time. High ammonium in compost can hamper the seed germination and soil fauna (Barker, 1997). As presented in Figure 3.7, NH$_4^+$-N of all the treatments increased at the first week because of the intensive degradation of organic matter. A peak NH$_4^+$-N concentration of 4653 mg/kg was observed in treatment L2.25 after 7 d and the concentration was significantly higher than all other treatments. The NH$_4^+$-N concentration declined thereafter through volatilization. NH$_4^+$-N volatilization was promoted under high pH and high temperature as observed by Wang et al. (2013). Treatment Z10 showed a good decomposition similar to L2.25 as evidenced from the cumulative CO$_2$ emission (Figure 3.3b) but the extractable NH$_4^+$-N content of Z10 was significantly lower than that of L2.25 due to great affinity of zeolite to the ammonium ions (Sarioglu, 2005; Wang and Peng, 2010). After 56 days of composting, the NH$_4^+$-N content of Z5 (723 mg/kg) was comparatively higher than L2.25 and Z10, and marginally higher than the standard values (700 mg kg) indicating the requirement of longer curing period.

There is no obvious change of ammonium content of treatment C and Z2 during the whole process due to poor decomposition and acidic condition. Composts from these two treatments contained lot of soluble organic compounds on Day 56 indicating the immaturity of the composting mass.
3.4.7 Loss of total organic matter, total organic carbon and total organic nitrogen during food waste composting

As presented in Table 3.4, treatments C and Z2 had significantly lower decomposition rate than other treatments due to the acidic environment that suppressed the activity of microbes and 2% zeolite (dry weight basis) was not sufficient to buffer the acidity generated. The nitrogen loss of treatments C and Z2 were 17.5% and 22.65% respectively which correspond well with TOM and TOC since NH₃ was not able to emit under low pH condition thus the nitrogen loss was reduced.

Treatment Z5 had significantly lower TOM and TOC decomposition rate than Z10 and L2.25 due to inadequate dosage of zeolite was not able to provide sufficient dilution effect. However, the total nitrogen loss of treatment Z5 was lower than L2.25, indicating that 5% zeolite addition could reduce the loss of nitrogen and the nitrogen loss can be...
reduced further by increasing the zeolite concentration to 10%.

**Table 3.4** Loss of total organic matter (TOM), total organic carbon (TOC) and total nitrogen (TN) during food waste composting

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Loss of TOM (%)</th>
<th>Loss of TOC (%)</th>
<th>Loss of TN (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>25.8 ± 0.3d</td>
<td>29.6 ± 0.3d</td>
<td>17.5 ± 0.3e</td>
</tr>
<tr>
<td>Z2</td>
<td>32.4 ± 1.15c</td>
<td>37.7 ± 1.02c</td>
<td>22.7 ± 1.26d</td>
</tr>
<tr>
<td>Z5</td>
<td>50.9 ± 0.02b</td>
<td>48.8 ± 0.02b</td>
<td>40.8 ± 0.03c</td>
</tr>
<tr>
<td>Z10</td>
<td>60.1 ± 0.13a</td>
<td>59.0 ± 1.42a</td>
<td>34.2 ± 0.20b</td>
</tr>
<tr>
<td>L2.25</td>
<td>59.6 ± 0.26a</td>
<td>58.6 ± 0.89a</td>
<td>44.0 ± 0.03a</td>
</tr>
</tbody>
</table>

The loss of TOM, TOC and TN were calculated as described by Paredes et al. (1996). TOM loss (%) = 1-[X1/100(1-X2/100)]/[X2/100(1-X1/100)], where X1 and X2 means the initial and final ash content. TOC loss (%) = 100-100[(X1Y2)/(X2Y1)] and N-loss (%) = 100-100[(X1Y2)/(X2Y1)], where Y1 and Y2 means the initial and final of total organic carbon and total nitrogen respectively.

There were no significant differences in TOM and TOC decomposition rates of treatments Z10 and L2.25 because both treatments showed good decomposition efficiency under optimal condition to facilitate the microbial degradation. Nevertheless, 43.97% of initial total nitrogen was lost resulted in 2.25% lime treatment due to the initial high pH. In contrast, nitrogen loss of 10% zeolite treatment was 34.15% demonstrating the ability of zeolite to conserve the nitrogen during composting.

**3.4.8 Compost Quality**

Evaluation of compost maturity is important to ensure that the compost do not contain any phytotoxic substances before application on plants. The properties of the composts from the various treatments after 56 days of composting are summarized in Table 3.5.

**3.4.8.1 Compost Maturity**

According to the Compost Quality Standards of HKORC and TMECC, the
ammonium content of mature compost should be $\leq 700$ mg/kg and 75-500 mg/kg, respectively. Addition of zeolite significantly reduced the NH$_4$-N content especially at 5% and 10% amendment level, with 5% level only marginally met the HKORC criteria. The NH$_4$-N content of lime amended compost also below both criteria. Carbon dioxide evolution rate can directly assess the microbial activity of compost. Carbon dioxide evolution rate of $>2$ g C/kg VS/day is considered to have high microbial activity with unstable organic matters. With an increase in zeolite amendment rate, there was a reduction in carbon dioxide evolution but only at 10% amendment rate the level was below 2 g C/kg VS/day, similar to that of the lime amended compost. Only these treatments, their compost could be considered as mature and non-active state of microbial activities. Another parameter for indication of compost maturity is C/N ratio and a value of less than 25 can be classified as mature but it should depend on the starting materials. As expected C/N ratio decreased with an increase in zeolite amendment and both 5% and 10% amendments met the maturity requirement while lime amendment was marginally higher than the requirement value. It can be concluded that a zeolite amendment level of 10% is required to achieve compost maturity within 56 days of composting.

3.4.8.2 Seed Germination Index

Seed germination index is a biological indication of any adverse effect on plant growth following the application on compost on soil. Immature compost with a high decomposition activity can present a lot of phytotoxic substances such as soluble ammonia and organic acids (Huang et al., 2004). If the germination index (GI) of compost is $>80\%$ under a 1:5 compost:water extraction (dry wt basis), the compost can be considered mature and phytotoxic-free. In this experiment, treatment C had a
significantly lower GI than the other treatments (Table 3.5) because of the persistent low pH condition during the 56 days of composting (Figure 3.4). GI value increased with an increase in zeolite amendment level indicating the beneficial effect of zeolite on compost decomposition process. Compost with lime amendment also had a high GI but lower than that of 10% zeolite supplementation, indicating that at this amendment rate the compost product quality could be enhanced by reducing the amount of phytotoxic substances such as ammonium.

3.4.8.3 Nutrient contents

A good quality compost should be free of phyto-toxicants and contains a desirable amount of nutrients. Nitrogen is one of the essential nutrients to promote the plant growth and prevent the leaves become yellow, wither or die. Phosphorus is to maintain the plant growth and reproduction. Plants deficiency in phosphorus can cause purple leaves delayed maturity, reduced disease resistance and reduced quality of crop (Liu et al., 2004). Potassium is to regulate the growth of plant by providing a suitable ionic environment for metabolic processes in the cytosol (Leigh and Jones, 1984). The indication of plants deficiency in potassium are production of purple spots at the underside of leaf, curling of leaf tip and retardation of plant growth, root extension and fruit production etc.

A total nutrient content of ≥4% (including nitrogen, phosphorus and potassium) is suggested by HKORC (2005) comparable to that of the Chinese Agriculture Ministry Standard. In this experiment, the total N, P, K contents of all the treatments after 56 days of composting were well above 4% considering of the total nitrogen content, treatment amended with 10% zeolite had significantly higher content than the other treatments because the high adsorption capacity of zeolite could reduce the ammonia and
ammonium lost during the whole composting process, and hence it could conserve more N resulting in higher N content.

3.5 Conclusions

Zeolite was demonstrated in the present study as a good candidate to co-compost with food waste while compared to lime in terms of nitrogen conservation and improvement of the final compost characteristics. 10% is an optimal amendment rate of zeolite compared to lower dosage of zeolite (2% & 5%) with stronger pH buffering capacity and greater decomposition efficiency. Addition of 2.25% Lime during food waste composting buffered the pH efficiently but increased the ammonia loss significantly which eventually reduced the nitrogen content of final product and posed odor emission problem. When compared with 2.25% lime, 10% zeolite demonstrated a higher adsorption affinity on ammonia resulting in higher conservation of N in the final compost. Also, a significantly higher seed germination was found in compost amended with 10% zeolite because of low ammonium content of product. Overall, 5% zeolite did not provide as good a composting condition as 10% because of less pH buffering capacity and slight dilution effect. To conclude, compost with high seed germination rate and desirable amount of nutrients can be produced under supplementation of 10% zeolite during food-waste composting. However, the only concerns at such a high application rate of zeolite are the cost and also reduce in treatment percentage of food waste.
<table>
<thead>
<tr>
<th>Parameters</th>
<th>HKORC</th>
<th>TMECC / CCME*</th>
<th>Control (C)</th>
<th>Zeolite 2% (Z2)</th>
<th>Zeolite 5% (Z5)</th>
<th>Zeolite 10% (Z10)</th>
<th>Lime 2.25% (L2.25)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compost Maturity:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium (mg/kg dw)</td>
<td>≤700</td>
<td>75-500</td>
<td>1498 ± 50.91a</td>
<td>1295 ± 59.61b</td>
<td>723 ± 16.97c</td>
<td>63 ± 7.96e</td>
<td>346 ± 41.01d</td>
</tr>
<tr>
<td>Carbon dioxide evolution rate (- g C/kg VS/day)</td>
<td>≤2</td>
<td>--</td>
<td>8.0 ± 0.88b</td>
<td>11.5 ± 0.95a</td>
<td>5.2 ± 0.74c</td>
<td>2.1 ± 1.12d</td>
<td>2.0 ± 1.12d</td>
</tr>
<tr>
<td>Carbon to nitrogen ratio</td>
<td>≤25</td>
<td>--</td>
<td>26.3 ± 0.71a</td>
<td>24.2 ± 0.42b</td>
<td>20.3 ± 0.67c</td>
<td>18.1 ± 0.04d</td>
<td>21.7 ± 0.95c</td>
</tr>
<tr>
<td><strong>Physicochemical Properties:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH value</td>
<td>5.5-8.5</td>
<td>--</td>
<td>4.6 ± 0.42c</td>
<td>8.1 ± 0.03ab</td>
<td>7.6 ± 0.20b</td>
<td>8.0 ± 0.10ab</td>
<td>8.3 ± 0.11a</td>
</tr>
<tr>
<td>Organic matter (% dw)</td>
<td>≥20</td>
<td>≤40</td>
<td>98.0 ± 0.28a</td>
<td>95.7 ± 0.10b</td>
<td>89.2 ± 0.10c</td>
<td>75.7 ± 1.00e</td>
<td>87.2 ± 0.20d</td>
</tr>
<tr>
<td><strong>Seed Germination Index:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed germination index (%)</td>
<td>≥80</td>
<td>80-90</td>
<td>40.2 ± 3.11d</td>
<td>98.2 ± 3.05c</td>
<td>136.9 ± 2.43b</td>
<td>150.2 ± 4.47a</td>
<td>135.2 ± 2.97b</td>
</tr>
<tr>
<td><strong>Nutrient Contents:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nitrogen (% dw)</td>
<td></td>
<td></td>
<td></td>
<td>1.67 ± 0.01d</td>
<td>1.73 ± 0.03c</td>
<td>1.86 ± 0.03b</td>
<td>2.05 ± 0.01a</td>
</tr>
<tr>
<td>Total phosphorus (as P2O5 % dw)</td>
<td>≥4%</td>
<td>≥4%</td>
<td>1.25 ± 0.01a</td>
<td>1.37 ± 0.03a</td>
<td>1.18 ± 0.08a</td>
<td>1.23 ± 0.05a</td>
<td>1.16 ± 0.04a</td>
</tr>
<tr>
<td>Total potassium (as K2O %dw)</td>
<td></td>
<td></td>
<td></td>
<td>1.98 ± 0.07b</td>
<td>2.10 ± 0.08b</td>
<td>1.96 ± 0.09b</td>
<td>2.56 ± 0.17a</td>
</tr>
</tbody>
</table>

@: Compost and Soil Conditioner Quality Standards for General Agricultural Use, HKORC (2005); # TMECC (2002): Test Methods for the Examination of Compost and Composting; * CCME (2005): Guidelines for Grade A Compost Quality. Data with the same letter among the treatments for parameter are not significantly different (p <0.05).
Chapter 4 - Feasibility of Co-composting Food Waste Composting With Zeolite and Struvite Salts

4.1 Introduction

Acidity is a critical problem of food waste composting since high quantity of organic acids are produced during intensive decomposition of readily soluble organic compounds. The acidic condition retards the composting efficiency and generates nuisance odor, and eventually results in poor quality compost. Therefore, it is necessary to include some neutralizing agents to compost mixture prior to the composting to avoid the acidic conditions during composting. In the previous experiment (Chapter 3), addition of zeolite at 10%, helped to alleviate the acidic pH, and improved the decomposition efficiency, significantly reduced the nitrogen loss and EC content. Considering under fed batch composting condition, daily addition of 10% zeolite to composting mixture based on the total dry weight might be too high even though the cost of zeolite is cheap. Alternatively, less zeolite could be used for the composting mixture. Since addition of 5% zeolite only marginally met the mature compost requirements and also the nitrogen conservation was lower than 10% zeolite amendment. To compensate that, struvite may be an alternative additive that can be used to work with zeolite further increase the nitrogen conservation during composting. Formation of struvite as a strategy to conserve ammonium and neutralize the acidity in the composting mass has received much attention in recent years. Sodium acetate (NaC2H3O2) is a kind of buffer salt which has been demonstrated to buffer the acidity and enhance the organic matter degradation efficiency during food waste composting (Yu and Huang, 2009). Li et al. (2013) observed that treatment supplemented with K2HPO4 and MgSO4 additives had high oxygen uptake and total organic matter degradation rate during food
waste composting. However, the final compost supplemented with struvite had significantly high EC value, which reduced the seed germination. Addition of calcium superphosphate during swine manure composting, the nitrogen content of final compost was increased by reducing evaporation of ammonia but the EC of the final product was significantly enhanced to 6.2 mS/cm which might be due to ammonium ions reacted with calcium superphosphate to form ammonium phosphate (Jiang et al., 2014). This EC value was higher than the limit of >4 mS/cm, which only allows for the growth of saline tolerant crops (Richard, 1954). Therefore, high salinity may affect the general acceptability of using struvite formation as a means to conserve nitrogen during composting as well as reduce the acceptability of composting applications.

According to our previous study, addition of 1:2 molar ratio of magnesium oxide (MgO) and potassium hydrogen phosphate (K₂HPO₄) during food waste composting effectively alleviated the acidity and reduced the nitrogen loss (Wang et al., 2013). However, the struvite-based compost reduced the seed germination because of high EC. Therefore, it would be potentially advantageous to investigate whether the supplementation of zeolite with struvite enables the synergistic achievement of both pH and EC buffering, and N conservation during food waste composting and the possibility to reduce the usage of zeolite; that has not yet been investigated. Besides, the presence of zeolite in the compost could also be useful in controlling nutrient release upon soil application. Thus, developing a good composting process to overcome the intensive acidification and to reduce odor and nutrient loss during food waste composting is necessary. The aim of this chapter was to investigate the effect of combined zeolite and struvite additives on food waste composting in order to alleviate the problems mentioned above.

4.2 Materials and Methods

4.2.1 Feedstock preparation

The preparation procedures of food wastes, sawdust, zeolite and plastic spheres were similar to
the procedures described in Chapter 3 (section 3.2.1).

4.2.1 Struvite formation
Magnesium oxide (MgO) and di-potassium hydrogen phosphate (K₂HPO₄) in 1:2 molar ratio were used in this experiment as the sources of Mg and P salts to induce struvite formation.

All the initial adjustments after mixing with all kinds of feedstock were followed as described in Chapter 3 (section 3.2.1). The physicochemical characteristics of different substrates and composting mix are presented in Table 4.1.

4.2.2 Composter and operation
Composter used in this experiment and all the operational procedures were same as described in Chapter 3 (section 3.2.2).

4.2.3 Sampling
Sampling and mixing dates were identical as described in Chapter 3 (section 3.2.4). At each sampling the biomass was mixed well, weighed, and then triplicate samples were taken for subsequent physicochemical analysis.

Table 4.1 Physicochemical characteristics of different substrates and initial composting mix used in this experiment

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Food waste</th>
<th>Sawdust</th>
<th>Composting Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.98 ± 0.10</td>
<td>4.60 ± 0.12</td>
<td>5.30 ± 0.08</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>5.12 ± 0.05</td>
<td>0.02 ± 0.01</td>
<td>4.16 ± 0.23</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>58.7 ± 0.35</td>
<td>9.6 ± 0.04</td>
<td>56.1 ± 1.22</td>
</tr>
<tr>
<td>Total organic carbon (%)</td>
<td>47.1 ± 0.5</td>
<td>54.8 ± 0.1</td>
<td>48.6 ± 3.04</td>
</tr>
<tr>
<td>Total nitrogen (%)</td>
<td>2.96 ± 0.14</td>
<td>0.60 ± 0.14</td>
<td>1.63 ± 0.13</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>15.9 ± 0.23</td>
<td>91.5 ± 4.1</td>
<td>29.8 ± 3.16</td>
</tr>
</tbody>
</table>

Values represent mean and standard deviation (n=3).
### Table 4.2 Dosage of different inorganic amendments in the four treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Zeolite (%)</th>
<th>MgO (M/kg)</th>
<th>K$_2$HPO$_4$ (M/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (C)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Struvite (Mg:P)</td>
<td>0</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Zeolite 5% plus struvite (5% Z + Mg:P)</td>
<td>5</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Zeolite 10% plus struvite (10% Z + Mg:P)</td>
<td>10</td>
<td>0.05</td>
<td>0.10</td>
</tr>
</tbody>
</table>

### 4.2.4 Treatments

A total of four treatments were designed in this experiment including (1) control without any amendment (C), (2) struvite amendment at 1:2 molar ratio of 0.013% MgO and 0.055% K$_2$HPO$_4$ (Mg:P), (3) struvite amendment with 5% zeolite at 1:2 molar ratio of 0.013% MgO and 0.055% K$_2$HPO$_4$ (5% Z + Mg:P) and (4) struvite amendment with 10% zeolite at 1:2 molar ratio of 0.013% MgO and 0.055% K$_2$HPO$_4$ (10% Z + Mg:P). The dosages of different inorganic amendments of these four treatments are shown in (Table 4.2).

### 4.2.5 Composting samples analysis

The measurement and determination methods of CO$_2$ emission, NH$_3$ emission, moisture content, TOM, pH, EC, NH$_4^+$-N, GI, TKN and TOC were followed the methodology given in Chapter 3.

### 4.3 Results and Discussion

#### 4.3.1 Change of temperature and carbon dioxide evolution

In a successful composting process, thermophilic phase should be maintained for a period of 1 to 2 weeks to achieve a good removal of pathogenic organisms. If the compost does not accomplish the disinfection, it is not only harmful to plants but also not hygienically safe for the users. Strauch and Ballaini (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 treatment, the temperature dropped drastically after three days (Figure 4.1a) due to the large amount of organic acids produced during intensive degradation which lowered the pH and made the environment unfavorable for microbial activity. In the treatments with inorganic additives, there was no obvious differences in temperature profiles of the 5% Z + Mg:P, 10% Z + Mg:P and Mg:P treatments, and the thermophilic phase lasted for about 2 weeks, longer than the control which was sufficient to destroy the pathogenic microorganisms. The results also indicated that zeolite in combination with struvite salts did not cause any negative effects during food waste composting.

Rate of CO$_2$ evolution directly reflects the microbial activity in the composting process with high population of bacteria at the thermophilic phase resulting in high evolution of CO$_2$. As presented in (Figure 4.1b), the profiles of CO$_2$ evolution in the control and treatments followed the same trend of temperature profiles (Figure 4.1a); but CO$_2$ evolutions decreased much faster than temperature due to the insulation of composters that can prevent the rapid heat loss from system efficiently as observed previously (Wang et al., 2013). There were no significant difference ($P<0.05$) in cumulative CO$_2$ emission among all treatments except for the control, which had a significant lower cumulative CO$_2$ evolution (Figure 4.1c), because the acidic condition did not provide a favorable condition for microbial activities (Wong et al., 2009; Wang et al., 2013).
Figure 4. Change of temperature (a), carbon dioxide evolution (b) and cumulative carbon dioxide evolution (c) during the composting of food waste without amendment, amended with 0.013% MgO and 0.055% K₂HPO₄, 5% zeolite with 0.013% MgO and 0.055% K₂HPO₄ and 10% zeolite with 0.013% MgO and 0.055% K₂HPO₄.
4.3.2 Changes in pH profile

pH is a critical factor influencing the microbial activities and microbial community during composting. Under optimal conditions, pH should increase from acidic to neutral range after an initial reduction. If the organic acids are decomposed successfully and a range of 7-8 is reported optimum for composting (Smars et al., 2002). As shown in Figure 4.2a, the pH of the control decreased from 6.37 to 4.67 during the first week and then remained stable around 4.5 until the end of experiment. This is likely due to the accumulation of organic acids, which might inhibit the microbial activities and thus the microbial population responsible for the degradation of the organic acids were reduced creating a circular effect. In contrast, the pH increased from ~6.0 to 8.5 during the first two weeks in other treatments. Addition of K₂HPO₄ could successfully buffer the pH by neutralizing the organic acids, in agreement with a previous report (Wang et al., 2013). Addition of 5 and 10% zeolite with struvite salts did not show any additional pH enhancement. Although, zeolite did not show a direct influence on pH values under the supplement of struvite, which can act as an adsorbent for H⁺ competing with NH₄⁺ under acidic condition (Koon and Kaufmann, 1975). The adsorption ability of zeolite can be changed according to the pH. Kithome et al. (1998) observed that the ammonium adsorption was maximized while the pH adjusted to 7 compared to acidic environment. Therefore, the pH buffering function of zeolite is depending on soluble ions available in the system. Singh et al. (2014) observed that the zeolite amended treatments had slightly higher pH compared with 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 the control, and this observation was linked to the adsorption of ammonium onto zeolite. Even though, zeolite might not affect the pH, its adsorption property can be greatly varied under a pH changing condition.
4.3.3 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 enhanced due to the degradation of complex organic matter. As shown in Figure 4.2b, the initial EC of the treatments ranged between 1.9 dS/m for the control and 2.6 dS/m for those receiving inorganic amendments. Subsequently in the treatment with struvite only, EC rapidly increased from 2.86 dS/m to 6.85 dS/m during the first two weeks and was stable between 6 to 7 dS/m until 56 days. On the other hand, the addition of zeolite significantly (P<0.05) reduced the EC, which was almost stable between 3 and 4 dS/m below the salinity limit of 4 dS/m (Richard, 1954). In the control, without the addition of inorganic salts, the EC was very low and in the range similar to that of zeolite added treatments. Due to molecular sieve structure of zeolite, it can accommodate and allow the ions exchange freely on its surface. The affinity of the adsorbed ions can vary with type of zeolite, grain size, pH, temperature etc. (Hedstrom, 2001). In a composting process, a wide variety of soluble ions are released because of biodegradation; and zeolite can provide sites for complexation of the released ions.
Figure 4. 2 Change of pH (a) and EC (b) during the composting of food waste without amendment, amended with 0.013% MgO and 0.055% K$_2$HPO$_4$, 5% zeolite with 0.013% MgO and 0.055% K$_2$HPO$_4$ and 10% zeolite with 0.013% MgO and 0.055% K$_2$HPO$_4$.

4.3.4 Changes in extractable ammonium nitrogen (NH$_4^+$-N) and ammonia (NH$_3$) emission

Treatments amended with zeolite had a lower concentration of NH$_4^+$-N during the whole experimental period compared to treatment with struvite salts only demonstrating a great affinity of zeolite for NH$_4^+$-N; and the pH is a crucial factor affecting this affinity. In an acidic condition, NH$_4^+$ had to compete with H$^+$ for the adsorption sites; however, in an alkaline condition, the
NH$_4^+$-N would be transformed to NH$_3$. Thus when the pH is neutral the ammonium adsorption onto zeolite will be higher as the optimum pH is 6-7 for adsorption (Kithome et al., 1988). Therefore, relatively high affinity of NH$_4^+$-N to zeolite during the first week might have existed in the zeolite amended treatments (Figure 4.3a): however, NH$_3$ emissions among the treatments are almost similar as evidenced from the cumulative NH$_3$ emission (Figure 4.3c). But the peak concentrations for the zeolite amended treatments were not as high as that observed in the Struvite treatment (Figure 4.3b) implying that the odor emission derived from ammonia could be reduced by zeolite, although the exact mechanism is not clear and further study is required. After the first week, the concentrations of NH$_4^+$-N decreased due to volatilization and nitrification. Obviously, zeolite exhibited a great affinity to ammonium ions, as also reported previously for soil and wastewater matrices (Kithome et al., 1998; Widiastuti et al., 2008).

NH$_3$ emission is inevitable during composting because of the high pH and temperature during the active mineralization of organic matter. Loss of NH$_3$ from the composting mass poses serious odor problem and results in low nutrient compost. Komilis and Ham (2006) reported that ~65% of initial nitrogen of food waste can be volatized as NH$_3$. In the present study, the nitrogen loss was reduced to 25% in treatment with struvite only (Figure 4.3b), and a similar value of 23% was reported previously (Wang et al., 2013). From the NH$_3$ emission profile, an obvious NH$_3$ emission peak in Mg:P treatment around Day 7 can be observed.

Figure 4.3c shows that the cumulative NH$_3$ loss of the TKN in the 10%Z + Mg:P (17.96%) was significantly lower than the 5%Z + Mg:P (26.98%) and Mg:P (25.02%) treatments, while no significant difference was noted between the two latter treatments (P>0.05). Comparing the results of NH$_3$ loss with our previous experiment, supplemented 5 and 10% of zeolite with struvite salts could further reduce the NH$_3$ loss as compared to treatment with addition of zeolite.
only. The results also clearly showed that zeolite amendment could significantly reduced NH$_3$ loss as compared to the treatment with struvite only.

In the control, the low pH prevented the volatilization of NH$_4^+$-N into NH$_3$; thus a very low emission was observed. The influence of zeolite on the NH$_4$/NH$_3$ is proven as seen in Figure 4.3; however, whether it is the main reason for the control of EC remains to be investigated even the results demonstrated that zeolite amended treatments had high buffering capacity for EC.
Figure 4.3 Changes of extractable NH$_4$-N (a), NH$_3$-N emission (b) and cumulative NH$_3$-N emission (c) during the composting of food waste without amendment, amended with 0.013% MgO and 0.055% K$_2$HPO$_4$, 5% zeolite with 0.013% MgO and 0.055% K$_2$HPO$_4$ and 10% zeolite with 0.013% MgO and 0.055% K$_2$HPO$_4$. 
4.3.5 Changes in total organic carbon (TOC), total nitrogen (TN) and C/N ratio

As shown in Figure 4.4a, the contents of organic carbon in all treatments decreased along the composting process except the control treatment since the acidified environment did not favor the microbial decomposition, while the ‘struvite’ treatments showed higher decomposition rate. Although the TOC content of the final compost of treatment Z10 + Mg:P was lower than that of other struvite amended treatments. The low initial TOC can be explained by the dilution effect of the addition of 10% inorganic materials. Therefore, the actual loss of TOC of each treatment needs to be expressed as the actual amount of organic carbon in the sample as presented in (Table 4.3).

During the initial stage of composting, due to the significant organic decomposition, the composting mass is reduced; however, the nitrogen will not be consumed in the same rate as that of carbon; thus the TKN increased mainly as a concentration effect. However, the increase was not significant (Figure 4.4b). Treatments amended with struvite salts are expected to enhance the nitrogen content in the final compost because of ammonium conservation through struvite formation.

Results showed that the TKN concentration of 10% Z + Mg:P (2.15%) after 56 days composting was slightly higher than treatments of Mg:P (2.09%) and 5% Z + Mg:P (2.00%), indicating that the zeolite might have provided nitrogen conservation function along with struvite. However, the N content of the 5% zeolite supplemented treatment was lower than that of the Mg:P treatment indicating that zeolite at 10% is required to achieve high N conservation. Addition of 10% zeolite altered the physical structure of the composting mass significantly different from 5% zeolite supplementation and Mg:P treatments, and facilitated the aerobic bacteria involved in nitrification, N immobilization and conservation. However, further studies are required to comprehensively reveal this complex interaction.
C/N ratio is one of the parameters to evaluate compost maturity, compost with C/N ratio less than 20 C/N is considered as satisfactory level of mature compost which has been mentioned in our previous publication (Zhou et al., 2014). A significant reduction of C/N can be observed in all the treatments during the first week of composting, which was mainly due to the reduction of total carbon and concentration effect of total nitrogen. Afterwards, C/N ratio of all the treatments reduced except control compost. The poor reduction of C/N in the control compost was due to poor decomposition efficiency under unfavorable conditions such as stable acidic condition. Treatment of Z10 + Mg: P had the lowest C/N ratio among all the treatments indicating the highest decomposition efficiency and nitrogen conservation.

Comparing the final TN content of treatment amended with 10% zeolite and 10% zeolite with struvite, there was no significant difference between these two values even though the ammonia loss was further reduced from 34.2% to 17.96% with the supplementary of struvite.
Figure 4.4 Changes of Total organic carbon (a), Total nitrogen (b) and Carbon to nitrogen ratio (c) during the composting of food waste without amendment, amended with 0.013% MgO and 0.055% $K_2$HPO$_4$, 5% zeolite with 0.013% MgO and 0.055% $K_2$HPO$_4$ and 10% zeolite with 0.013% MgO and 0.055% $K_2$HPO$_4$. 
4.3.6 Loss of TOM, TOC and TN

Table 4.3 presents the total loss of TOM, TOC and TN after 56 days composting. Results indicate that control (C) had the lowest decomposition rate of TOM and TOC compare to other treatments because of decreased microbial activity under acidic environment. As acidic condition is unfavorable for release of ammonia, the nitrogen loss was reduced in control compost. In contrast, in struvite and zeolite additives amended treatments, the loss of TOM and TOC was higher and insignificant.

Table 4.3 Loss of total organic matter (TOM), total organic carbon (TOC) and total nitrogen (TN) during food waste composting

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Loss of TOM (% dw)</th>
<th>Loss of TOC (% dw)</th>
<th>Loss of TN (% dw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>24.17 + 1.23b</td>
<td>28.93 + 1.44b</td>
<td>17.50 + 2.16b</td>
</tr>
<tr>
<td>Mg:P</td>
<td>59.87 + 1.09a</td>
<td>58.63 + 0.35a</td>
<td>25.02 + 0.65a</td>
</tr>
<tr>
<td>Z5 + Mg:P</td>
<td>59.74 + 1.75a</td>
<td>57.49 + 1.03a</td>
<td>26.98 + 1.60a</td>
</tr>
<tr>
<td>Z10 + Mg:P</td>
<td>58.54 +2.46a</td>
<td>55.47 + 1.72a</td>
<td>17.96 + 0.81b</td>
</tr>
</tbody>
</table>

The loss of TOM, TOC and TN were calculated as described by Paredes et al. (1996). TOM loss (%) = 1-{X1/100(1-X2/100)}/[X2/100(1-X1/100)], where X1 and X2 means the initial and final ash content. TOC loss (%) = 100-100[(X1Y2)/(X2Y1)] and N-loss (%) = 100-100[(X1Y2)/(X2Y1)], where Y1 and Y2 means the initial and final of total organic carbon and total nitrogen respectively.

Differences were noted among the treatments. The improved reduction of TOC and TOM in treatments might be due to the adsorption of hydrogen ions and reduction of acidity, which could facilitate the decomposition efficiency. Apart from the organic matter decomposition, treatment supplemented 10% zeolite and struvite salts significantly reduced the TN loss compared to Z5% + Mg:P and Mg:P alone. This further indicated the benefit of the combination of zeolite and struvite amendment to the food waste.
4.3.7 Seed germination index (GI)

Germination index is a text indicating compost maturity by evaluating the phytotoxicity level of final compost using seed germination and root growth as an indication. A minimum value of 80% GI is considered to indicate the compost maturity (TMECC, 2002; HKORC, 2005). The GI profiles of compost samples indicate (Figure 4.5) that the final compost products of the treatments Mg:P, Z5%+Mg:P and Z10%+Mg:P were sufficiently mature; proving that compost maturity can be accelerated with the addition of zeolite. Due to the low organic degradation, high ammonium concentrations and possibly high organic acids, the compost from control did not achieve maturity after 56 days. Treatment Z10%+Mg:P reached 80% GI on Day 35 and which was much faster than the other treatments receiving struvite amendment, which might be due to that the 10% of zeolite amendment providing a good physical structure, good buffering, and adsorption sites for ammonium.

Lin et al., (1998) reported that increasing the zeolite application rate on acidic soil could stabilize and reduce the amount of toxic substance which were leached from the soil. Treatments with 5 and 10% zeolite amendment showed significantly (P<0.05) higher GI than the treatment with struvite salts amendment only on Day 56. It is interesting that despite the high EC, the Mg:P treatment exhibited a GI of 85.6%, indicating that the struvite indeed could control the release of ions, especially the ammonium ions; thus caution should be exercised when interpreting the standards when struvite based composts are analyzed. However, Wang et al., (2013) observed an inhibition on GI 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 EC. Linking the current results with the previous experiment, supplemented of 10% zeolite alone enhanced the GI to 150.16% and only took 28 days to reach the standard requirement which significantly higher than 136.4% and 35 days of
supplemented 10% zeolite with struvite.

4.3.8 Final compost characteristics

In this experiment, treatments of Mg: P, Z5 + Mg: P and Z10 + Mg: P had fulfilled all the requirements of compost quality standards (HKORC, 2005, TMECC, CCME) which were considered as mature compost. Only control treatment failed

![Figure 4.5 Changes of seed germination index during the composting of food waste without amendment, amended with 0.013% MgO and 0.055% K2HPO4, 5% zeolite with 0.013% MgO and 0.055% K2HPO4 and 10% zeolite with 0.013% MgO and 0.055% K2HPO4.](image)

most of the compost quality standard’s requirements such as high ammonium ions, >20 total carbon to nitrogen ratio, high concentration of incompletely decomposed organic matter and less than 80% seed germination. Besides, low pH and carbon dioxide evolution characteristics of final compost indicated the product still contained high quantities of organic acids which will suppress microbial activities. Treatments amended with struvite salts successfully buffered the pH and promoted the microbial activities to facilitate the organic matter decomposition. Results
indicated that supplemented struvite salts with zeolite had further improved the compost characteristics.

Treatment amended with 5 and 10% zeolite with struvite had further reduced the ammonium contents of final product compared to the treatment Mg:P due to increased adsorption effect which significantly improved the compost’s quality. Treatment of Z10+Mg:P with the lowest ammonium contents had the highest seed germination rate among all treatments which demonstrated that seed germination can be greatly affected by ammonium content. There were no significant differences in carbon dioxide evolution of all struvite amended treatments due to low microbial activities in stabilized organic substances.

High pH of the final composts in those struvite amended treatments indicated the organic acids were completely decomposed. Compost from treatment Z10 + Mg:P had significantly lower C/N ratio and TOM content compared to that of Z5 + Mg:P and Mg:P because of the dilution effect of 10% zeolite. The actual loss of organic matter was presented in (Table 4.3) and there were no significantly differences of organic matter degradation among all struvite amended treatments.

The total nitrogen content of the final product of the treatment of Z10+ Mg:P had significantly higher nitrogen content (2.15 ± 0.11) than that of other treatments due to the high ammonia adsorption function of 10% zeolite and the formation of struvite crystals. There were no significant differences in total phosphate content of all treatments but struvite amended treatments had slightly higher TP and TK contents than might be due to struvite formation with the addition of K$_2$HPO$_4$.
Table 4.4 Properties of the compost at the end of the composting period of 56 days

<table>
<thead>
<tr>
<th>Parameters</th>
<th>HKORC®</th>
<th>TMECC®/CCME*</th>
<th>Control (C)</th>
<th>Mg:P</th>
<th>Z5+Mg:P</th>
<th>Z10+Mg:P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compost Maturity:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium (mg/kg dw)</td>
<td>≤700</td>
<td>75-500</td>
<td>1467±8.94a</td>
<td>896±6.59b</td>
<td>126±5.36c</td>
<td>62±3.26d</td>
</tr>
<tr>
<td>Carbon dioxide evolution rate (g C/kg VS/day)</td>
<td>≤2</td>
<td>--</td>
<td>2.05±0.03a</td>
<td>1.89±0.04a</td>
<td>2.03±0.11a</td>
<td>2.01±0.71a</td>
</tr>
<tr>
<td>Carbon to nitrogen ratio</td>
<td>≤25</td>
<td>--</td>
<td>27.74±0.21a</td>
<td>17.62±0.86b</td>
<td>18.78±0.17b</td>
<td>15.84±0.45c</td>
</tr>
<tr>
<td><strong>Physicochemical Properties:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH value</td>
<td>5.5-8.5</td>
<td>--</td>
<td>4.35±0.14b</td>
<td>8.16±0.01a</td>
<td>8.24±0.03a</td>
<td>8.20±0.01a</td>
</tr>
<tr>
<td>Organic matter (% dw)</td>
<td>≥20</td>
<td>≥40</td>
<td>97.64±0.17a</td>
<td>91.06±0.14b</td>
<td>79.96±0.18c</td>
<td>78.63±0.21d</td>
</tr>
<tr>
<td><strong>Seed Germination Index:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed germination index (%)</td>
<td>≥80</td>
<td>80-90</td>
<td>39.7±0.57d</td>
<td>85.6±4.80c</td>
<td>119.5±0.42b</td>
<td>136.4±2.12a</td>
</tr>
<tr>
<td><strong>Nutrient Contents:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nitrogen (% dw)</td>
<td></td>
<td></td>
<td>1.69±0.24b</td>
<td>2.09±0.21ab</td>
<td>2.00±0.07ab</td>
<td>2.15±0.11a</td>
</tr>
<tr>
<td>Total phosphorus (as P₂O₅ % dw)</td>
<td>≥4%</td>
<td></td>
<td>1.25±0.17a</td>
<td>1.31±0.21a</td>
<td>1.29±0.17a</td>
<td>1.34±0.14a</td>
</tr>
<tr>
<td>Total potassium (as K₂O %dw)</td>
<td></td>
<td></td>
<td>1.86±0.14c</td>
<td>2.11±0.16bc</td>
<td>2.49±0.18ab</td>
<td>2.55±0.13a</td>
</tr>
</tbody>
</table>
4.4 Conclusion

Results showed that 10% zeolite with struvite significantly reduced the ammonia lost and only required 35 days to attain the maturity. However, there was no significant difference of the final nitrogen content and decomposition efficiency compared to other struvite amended treatments. Comparing treatment of 10% zeolite of previous experiment and 10% zeolite with struvite with current experiment, 10% zeolite showed superior performance since better decomposition efficiency, lesser time to require to pass the GI (28 Days) and lower cost because of salts exclusion. Even though, higher ammonia lost was resulted; there was no significant difference in final TN of these two treatments.
Chapter 5 - Influence of Oil Degrading Bacterial Consortium on Food Waste Composting with Zeolite

5.1 Introduction

Using synthetic food waste as the feedstock to conduct the food waste composting experiment can minimize homogeneity and ensure quality control. However, it might underestimate the actual content of fat, oils and grease (FOGs) of the real food waste. Nowadays, many food service establishments and industrial sectors use large amount of animal fats and vegetable oils to prepare their foods (Ho and Beraheim, 2013). Residual FOGs are one of the major sources that cause wastewater pipelines clog because of lipid deposition, operational disturbance and increase the cost of maintenance (Kabouris et al., 2012). Disposal of food wastes in high FOGs content in sanitary landfills can generate serious odor problem due to reduction of oxygen transfer make it turn to anaerobic condition (Grulois et al., 1993). Lipids composed of triglycerides with varying length of fatty acid chains (C\textsubscript{16}-C\textsubscript{32}) and it comprises more energy compared to other organic matters like starch and sugar.

Real food wastes with high lipid content can generate more heat during high temperature disinfection causing a longer thermophilic phase that speed up the chemical reactions (Lemus and Lau, 2002). Correspondingly, the solubility and diffusion of lipids can be increased under thermophilic temperature which makes them more accessible for microbial degradation. About 80% of lipids were degraded at the end of the active phase while co-composting of olive husks with high moisture content (Gigliotti et al., 2012). There were 58-82% of fats degraded in the first week with 8-9% initial fat contents during co-composting of floating foams and sewage sludge (Viel et al., 1987). However, if the oil contents are higher, as found in the
post-consumption food wastes, the fats can completely enclose the raw materials and prevent diffusion of oxygen which limit microorganisms to digest resulting in the prolonged composting period (Nakasaki et al., 2004) or failure of composting. Guo et al., (2014) analyzed the physicochemical properties of food wastes collected from several catering units in Hangzhou, China of different seasons and the results showed that the average fats content of food wastes was ~24.3%. Aikaite-Stanaitiene et al. (2010) observed that the fat degradation was slowed down 3 times when the fat content increased from 5 to 20%. In general, composting of food wastes with high lipids can cause odor emission under anaerobic condition, hamper organic matter decomposition, prolong the composting period and reduce the quality of the final product.

Indigenous microbes in food wastes may not be sufficient to overcome the lipid problem. Therefore, inoculation of specific microbes has been demonstrated to improve the composting efficiency by reducing the lipid content. Strain *Bacillus thermoleovorans* IHI-91 improved biodegradation of olive oil and lipid-rich wool scouring treatment (Becker et al., 1999). Three different species of thermophilic bacteria including *Aeromonas salmonicida*, *Bacillus pantothenticus* and *Stenotrophomonas maltophilia* have been reported to degrade crude oil in soil both individually and in a mixed culture (Nugroho et al., 2010). Sarker et al. (2011) found that addition of bacterial consortia effectively enhanced the degradation of kitchen wastes by secreting different types of enzymes, and eliminated the odor.

Results obtained from the previous experiments indicated that supplementation of 10% zeolite as additive to the synthetic food waste composting effectively reduced the ammonia emission and provided good pH buffering function by adsorption and dilution, therefore the overall decomposition efficiency was enhanced. Zeolite might be a potential candidate to adsorb odorous compounds like fatty acids during post-consumption food waste composting. Therefore,
the objective of this experiment was to investigate the use of thermophilic microbial consortium as inoculum to improve the lipid decomposition and odor reduction during composting of real food waste supplemented with and without 10% zeolite.

5.2 Materials and Methods

5.2.1 Feedstock Preparation

Both pre-consumption and post-consumption food wastes were collected from Chinese and Western style restaurants in Kowloon Tong, Hong Kong. Post-consumption food wastes were leftover of customers and pre-consumption were the leftover of preparation work from kitchen. Food residuals were continuously collected for a week and temporarily stored at 4 °C in cold room. All the inorganic materials such as straw tissues, bones, shell, and plastics were removed and the food particles were cut into ~1 cm³ before analysis and used in the experiment. The preparation procedures of raw materials were similar to that of presented in Chapter 3 (section 3.2.1).

Bacterial strains were isolated from food waste compost, horse manure and oil contaminated soil using enrichment culture on modified basal salt liquid medium with 2% of carboxymethylcellulose (CMC), gelatin, soluble starch, and vegetable oil as specific substrates (Atlas, 1995). Selection of the potential bacterial strains was made on the basis of enzymatic activity (cellulases, protease, amylase and lipases) at a wide range of temperature.

Food waste and sawdust were mixed in a ratio of 4:1 (wet weight basis) and amended with 10% zeolite and inoculated with bacterial consortium. All the initial adjustments after mixing with all kinds of feedstock were followed Chapter 3, moisture of mixing materials was adjusted to ~55% and initial C/N was~ 30 (section 3.2.1). Physicochemical characteristics of different types of food wastes and initial composting mixture are shown in Table 5.1.
5.2.2 Composter and operation

Composters used in this experiment and all the operational parameters are same as Chapter 3 (section 3.2.2). Composting were conducted in computer controlled 20-L bench-scale composters, temperature and aeration were controlled by a computer-controlled programme.

Table 5.1 Physicochemical properties of different types of food wastes and initial composting mix used in this experiment.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Chinese-style food waste</th>
<th>Western-style food waste</th>
<th>Sawdust</th>
<th>Chinese-style food waste composting mixture</th>
<th>Western-style food waste composting mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.34±0.01</td>
<td>4.39±0.01</td>
<td>4.71±0.06</td>
<td>5.17±0.02</td>
<td>5.09±0.01</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>7.68±0.03</td>
<td>6.56±0.17</td>
<td>0.03±0.01</td>
<td>6.32±0.16</td>
<td>6.49±0.05</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>69.1±0.6</td>
<td>72.6±0.23</td>
<td>8.7±0.05</td>
<td>57.6±0.27</td>
<td>58.5±0.11</td>
</tr>
<tr>
<td>Total organic carbon (%)</td>
<td>49.1±0.8</td>
<td>49.9±0.80</td>
<td>55.6±0.88</td>
<td>49.3±1.34</td>
<td>49.9±0.98</td>
</tr>
<tr>
<td>Total nitrogen (%)</td>
<td>2.67±0.02</td>
<td>2.12±0.33</td>
<td>0.68±0.08</td>
<td>1.89±0.02</td>
<td>1.84±0.05</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>18.5±0.1</td>
<td>21.1±3.33</td>
<td>90.8±12.71</td>
<td>26.4±0.41</td>
<td>27.1±0.22</td>
</tr>
<tr>
<td>Total lipid content (%)</td>
<td>20.1±0.04</td>
<td>20.0±0.04</td>
<td>nd</td>
<td>12.7±0.05</td>
<td>13.1±0.15</td>
</tr>
</tbody>
</table>

Values represent means and standard deviation (n=3). (nd) means non detectable.

5.2.3 Sampling

Sampling and mixing dates were identical as described in Chapter 3 (section 3.2.4).

Biomass was weighed after mixing an equal amount of samples were taken during each sampling for physicochemical analysis.
5.2.4 Treatments

There were six treatments in this experiment: (1) Chinese-style food waste (C1), (2) Chinese-style food waste supplemented with 10% zeolite (C1+10%Z), (3) Chinese-style food waste supplemented with 10% zeolite and bacterial inoculum (C1+10%Z+O), (4) Western-style food waste (C2), (5) Western-style food waste supplemented with 10% zeolite (C2+10%Z) and (6) Western-style food waste supplemented with 10% zeolite and microbial inoculum (C2+10%Z+O). The details of the treatments are presented in Table 5.2.

5.2.5 Analyses

Table 5.2 Dosage of different organic and inorganic amendments in the six treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Zeolite (%)</th>
<th>Inoculum (CFU/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinese-style food waste (C1)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Chinese-style food waste and 10% zeolite (C1+10%Z)</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Chinese-style food waste, 10% zeolite and inoculum (C1+10%Z+O)</td>
<td>10</td>
<td>200 ml of 6.8 × 10^6/ml</td>
</tr>
<tr>
<td>Western-style food waste only (C2)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Western-style food waste and 10% zeolite (C2+10%Z)</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Western-style food waste, 10% zeolite and inoculum (C2+10%Z+O)</td>
<td>10</td>
<td>200 ml of 6.8 × 10^6/ml</td>
</tr>
</tbody>
</table>

The CO₂ evolution, NH₃ emission, MC, TOM, pH, EC, NH₄⁺-N, GI, TN, TOC, NO₂-N and NO₃-N were analyzed and the methodologies were presented in Sections 3.2 and 4.2. Aqueous extracts collected from 1:5 ratio of compost: water (w/v) of the fresh composts with deionized water were used for water soluble fatty acids analysis. Compost extracts filtered through 0.45 μm cellulose acetate membrane were analyzed using GC/FID (Cassinelli, 1994) with the operating conditions as presented in Table 5.3. For the determination of total lipids, oven dried (55 °C)
finely ground compost samples were, 20 g, was weighed in a thimble and extracted with n-hexane (1:5 w/v) by Soxhlet extraction apparatus at 110 to 130 "C for 20 - 30 extraction cycles (4-6 h), depending on the nature of sample and solvent. Solvent vessel was continuously heated until all the solvent has been evaporated and condensed in Soxhlet extractor. Container with fat residue was placed in rotary heater at 103 °C to evaporate all the solvent. After the container turn to room temperature, it was weighed (USEPA, 1998).

5.3 Results and Discussions
5.3.1 Change of temperature
Temperature is a critical factor affecting compost quality because low temperature cannot completely kill the pathogens. The temperature profiles during the composting revealed that except the two controls (C1 and C2), in other treatments the temperature reached 65 °C on day 1 and the thermophilic period was observed for about 2 weeks (Figure 5.1). In the controls (C1 and C2), the thermophilic temperature was observed only for a few days then the temperature was sharply dropped to the ambient temperature. This could be linked to the prevailed low pH due to the accumulation of organic acids as reported previously (Wang et al., 2013).

For the other treatments, the organic acids were successfully removed with 10% of zeolite addition as observed in previous experiment. Treatments amended with 10% zeolite and bacterial inoculum showed slightly longer thermophilic periods compared to 10% zeolite alone treatments because there was more energy released under good decomposition of lipids (Lemus and Lau, 2002). Zhang and Lau (2011) found that treatment supplemented with zeolite and ‘bio-additive’ reached the thermophilic temperature much faster and stayed longer than the other treatments similar to our findings.
Table 5.3 Conditions for GC/FID analysis of VFAs in compost extracts.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>1 μL</td>
</tr>
<tr>
<td>Injector temperature</td>
<td>240°C</td>
</tr>
<tr>
<td>Column type</td>
<td>Econo-Cap™ EC-1000, 15 m × 0.53 mm × 1.20 μm</td>
</tr>
<tr>
<td>Column flow</td>
<td>1.9 mL min⁻¹</td>
</tr>
<tr>
<td>Run time per each sample</td>
<td>13 min</td>
</tr>
<tr>
<td>Detector temperature</td>
<td>120°C, 5 °C min⁻¹ to 160 °C and hold for 5 mins</td>
</tr>
</tbody>
</table>

Figure 5.1 Changes of temperature during Chinese and Western-type food waste composting amended with zeolite and bacterial inoculum.

Temperature is a critical factor affecting the degradability of lipids during composting. Ohtaki et al. (1998) reported that treatment at ~50 °C supplemented with inoculum improved the degradation efficiency of poly-ε-caprolactone (PCL) than other lower temperature. Similarly, inoculation of fungal consortium significantly enhanced the degradation and the temperature during composting of municipal solid waste (Awasthi et al., 2014). Besides, rapid decomposition of organic matter was also observed with fungal inoculation in that study. Hachicha et al. (2009)
observed high lipid degradation with long thermophilic period when co-composing olive oil industry wastes with animal manure. In this experiment, treatments amended with 10% zeolite with microbial consortium increased the thermophilic duration compare to 10% zeolite and control (Figure 5.1). In this case, degradation of lipids might be improved with extended period of high temperature which will be further discussed at the later section.

5.3.2 Change of carbon dioxide evolution and cumulative carbon dioxide evolution

During organic matter decomposition, CO$_2$ is emitted and is positively correlates with the microbial activities. As shown in Figure 5.2a, high levels of CO$_2$ evolution was observed during the first week of the treatments except controls. Similar to the temperature profile, CO$_2$ emission rates were also decreased sharply after about two weeks. In contrast, the two control treatments showed faster and drastic drop in CO$_2$ evolution after Day 2 due to suppression of microbial activity under continuous acidified environment. The inhibition is severe when the pH is low and the temperature is high.

As presented in Figure 5.2b, the cumulative CO$_2$ evolution of controls were significantly lower than others (P<0.05) while the two treatments amended with 10% zeolite and bacterial inoculum showed significantly (P<0.05) higher CO$_2$ evolution than 10% zeolite only. These results clearly indicate that zeolite alone can overcome the oil problem but the bacterial inoculum in combination with zeolite can further enhance the microbial activities during food waste composting. The CO$_2$ evolution and oxygen uptake rate in a previous study were observed to be proportional to the dosage of inoculum and degradation efficiency (Xi et al., 2005).
Figure 5.2 Changes of carbon dioxide evolution (a) and cumulative carbon dioxide evolution (b) during Chinese and Western-type food waste composting amended with zeolite and bacterial inoculum.

5.3.3 Changes of pH and electrical conductivity

pH is a critical factor to indirectly influence the ammonification rate and CO₂ evolution. In a typical food waste composting process, reduction of pH at the initial phase is due to generation
a lot of organic acids under high-rate decomposition of organic compounds. However, organic acids can be used up by microorganisms and pH increased subsequently (Sellami et al., 2008).

In this study, pH of two control treatments was in acidic range (4-5) during the whole composting period due to the generation of organic acids and reduced microbial activity. Besides, the inhibition of microbial activities led to further accumulation of organic acids increasing the acidity (Figure 5.3a). The pH of 10% zeolite amended treatments was increased from ~5.0 to ~8.5 within two weeks indicating that the acids were successfully decomposed and a balance was maintained thereafter. Gage (2003) suggested that composting efficiency can be improved if the pH was maintained in neutral condition. Treatments with bacterial inoculum+zeolite did not show any significant pH enhancement effect when compared with 10% zeolite. Papadopoulos et al. (2009) reported that addition of zeolite enhanced the pH of the final household compost to slightly alkaline condition. Similarly, higher pH of the zeolite amended treatment when compared with control was reported by Jiwan et al. (2013) during the green waste composting.

Electrical conductivity (EC) is inevitably increased during the rapid decomposition of organic matter because of production of soluble ions but it would be reduced subsequently when the compost reaching maturity. As shown in Figure 5.3b, increasing trend of EC was observed during the first week of all treatments and decreased gradually afterwards. Treatments with 10% zeolite addition showed a significantly (P<0.05) higher EC during the thermophilic period than controls due to good decomposition.

After the first week, EC of all treatments declined and those treatments amended with 10% zeolite had significantly lower EC than controls in the final products indicating the efficiency of zeolite in controlling the availability of ions similar to the previous experiments. Turan (2008) found that efficiency of salinity reduction was enhanced from 66.64 to 88.91% while the
application rate of zeolite increased from 5 to 10% during poultry litter composting. Zeolite exhibited ion exchange capacity leading to the reduction of EC of final compost during swine manure composting (Bautista et al., 2011). High EC of compost is known to inhibit the seed germination and plant growth.

![Diagram of pH and EC changes](image)

**Figure 5.** Changes of pH (a) and electrical conductivity (b) during Chinese and Western-type food waste composting amended with zeolite and bacterial inoculum.
Comparing the salinity reduction performance of 10% zeolite in synthetic and real food wastes, the initial EC of synthetic food waste composting mixture was \(~4\) mS/cm and real food wastes was \(~6\) mS/cm due to the presence of more salts in the real food waste. During the first week, soluble salts were drastically increased under the conditions of intensive decomposition and the EC value increased to about \(~8\) mS/cm compared with \(6\) mS/cm observed for synthetic food wastes in the previous experiments. Although the EC buffering efficiency of these two kind of food wastes were differed during the composting process, the final EC of matured compost were similar at \(~3\)-\(4\) mS/cm. Therefore, 10% zeolite was proved to buffer the salinity effectively either for the synthetic or real food wastes.

5.3.4 Nitrogen dynamics

During the early phase of composting, high temperature and pH can promote the volatilization of ammonia (Eiland et al., 2001). As shown in Figure 5.4a, most of the ammonia was released during the thermophilic stage under high pH and the patterns of variations among the treatments were due to different ammonification rate of organic matter. Low peak values of ammonia emission were observed in the two control treatments due to low pH conditions that suppressed the microbial activity and inhibit volatilization of ammonia. Lin (2008) reported that there was no ammonia detected when the pH of the composting mixture dropped to 5.4 during food waste composting.

As presented in Figure 5.4b, cumulative ammonia loss of control treatments were significantly lower than others treatments (\(P<0.05\)) mainly due to the poor degradation and the low pH. Treatments amended with zeolite and bacterial inoculum showed significantly (\(P<0.05\)) higher emission of ammonia than zeolite amended treatments that can be attributed to the additional microbial activities resulting in enhanced organic degradation.
Figure 5.4 Changes of ammonia emission (a) and cumulative ammonia emission (b) during Chinese and Western-type food waste composting amended with zeolite and bacterial inoculum.

This result coincides with the observations of enhanced organic decomposition during composting due to the secretion of a range of enzymes required for the decomposition (Naik et al., 2007; Awasthi et al., 2014).
Extractable NH$_4^+$-N content of all treatments increased during the first two weeks during the high-rate degradation phase (Figure 5.5a). After 2 weeks, the NH$_4^+$-N concentrations of the two controls were high and stable due to the slow-rate of nitrification and suppression of ammonia volatilization in an acidic condition. Wong et al. (2009) reported that ammonification
rate was greatly influenced by the pH. In their study, the ammonium content increased up to Day 7, then a steady concentrations until the end of experiment were observed similar to the present study. Similar to the present study, the overall NH$_4^+$-N content of control was significantly lower than alkaline (lime) amended treatments (Wong et al., 2009). In this experiment, the NH$_4^+$-N contents of zeolite amended treatments declined after 2 weeks which might be due to effective nitrification. Also, 10% zeolite demonstrated high affinity to NH$_4^+$-N ions in the previous experiments because of its adsorption property.

Increase of total nitrogen content at the initial stage of composting was observed in all the treatments including control (Figure 5.5b) mainly due to the concentration effect as reported earlier (Wang et al., 2013). Afterwards, the overall total nitrogen contents decreased because of nitrogen loss either by NH$_3$ volatilization or leaching. Since leaching did not occur in this experiment, NH$_3$ volatilization was the main source of N loss. The final total nitrogen content of all zeolite amended treatments were significantly (P<0.05) higher than controls because zeolite demonstrated a nitrogen conservation function by adsorbing NH$_4^+$-N and NH$_3$ during composting. A couple of previous studies also observed that addition of zeolite during composting can reduce the nitrogen loss significantly due to adsorption and enhance the nitrogen content of the final product (Turan and Ergun, 2007, 2008).

**5.3.5 Changes in total organic carbon (TOC) and total organic matter (TOM)**

Different initial TOC and TOM contents among treatments were due to the addition of varying level of inorganic substances. An obvious trend of reduction of TOC and TOM was observed along the composting period that should be contributed to the microbial use of carbon as their energy source. Two control treatments did not show a significant reduction of TOC and TOM during the whole process because the microbial activities were retarded in acidic
conditions that resulted in only 30-35% decomposition of TOM or TOC.

Addition of zeolite with inoculum had increased the decomposition of TOC and TOM to 55% (Figure 5.6), which was higher than ~50% reduction observed in those treatments with zeolite only. This can be attributed to the oil degrading bacteria which enhanced the degradation of lipid and resulting in overall reduction in TOM as well as provided a good environment for the microbial activities. Zhang and Lau (2011) reported that addition of zeolite with 10% (w/w) yeasts resulted in a greater degree of degradation and reduced the ammonia emission by 50%; and reduced the odor emission by 12% during poultry litter composting.

![Figure 5.6 Decomposition of total organic matter and total organic carbon during Chinese and Western-type food waste composting amended with zeolite and bacterial inoculum.](image)

5.3.6 Changes in seed germination index (GI)

Seed germination index directly reflects the availability of phyto-toxic substances such as ammonium and VFAs in the composts. High concentrations of these compounds inhibit the seeds germination. A standard of compost quality specified HKORC (2005) that compost with >80%
of seed germination rate indicates there are very less or no phyto-toxicant exists in the compost. Low germination index of the two control treatments (<50%) clearly indicated that high quantities of phyto-toxic substances were present in the comports. Wang et al. (2014) also observed that control treatment without amendment had relatively low of seed germination rate since high amount of toxicants such as organic acids, ammonium and volatile fatty acids were generated under low pH condition.

![Germination Index Graph](image)

Figure 5.7 Changes of seed germination index during Chinese and Western-type food waste composting amended with zeolite and bacterial inoculum

The GI of other treatments completely complied the Compost Quality Standard of HKORC (2005) and could be considered mature comports. GI of those zeolite+inoculum treatments were significantly (P<0.05) higher than zeolite due to better decomposition and stabilization (Figure 5.7). Jahanshah et al. (2013) reported that addition of bacterial consortium (Bacillus and Streptomyces) during composting speeded up the decomposition, accelerated the stabilization
and reduced the toxicity resulting in enhanced seed germination and root length. Awasthi et al. (2014) found that those treatments supplemented with fungal inoculum had significantly higher seed germination rate than without inoculation. Therefore, considering the load of microbial population in the food wastes, inoculation of specific microbes in consortia is a potential approach, especially the oil degrading microbes when the feedstock contains the post-consumption food waste.

5.3.7 Changes in total lipid contents

Total lipid content of food wastes vary greatly and depends on the sources of food products and the preparation. In this study, the food wastes consist of ~20% total lipid content and after preparing the compost mix, the contents were reduced to ~13%. Lipid-rich food waste is a major obstacle affecting the composting efficiency because it can completely enclose the surface of organic matter and act as an insulator to prevent the oxygen diffusion. Therefore, the microbial activity is seriously retarded under this oxygen limiting condition (Lemus and Lau, 2002). Decomposition efficiency was correspondingly reduced with increased fat contents (Nakasaki and Nagasaki, 2004).

As shown in Figure 5.8, reduction of lipid content was observed in all the treatments along the whole process but with varying efficiency. A drastic reduction of lipids during the first two weeks was observed in the zeolite amended treatments and the degradation efficiency was enhanced under thermophilic temperature. Of the zeolite treatments, treatments having supplementary microbial inoculum showed significantly higher lipid reduction than the zeolite alone treatments. Considering the controls, the low levels of reduction could be attributed to the very short thermophilic period and the inhibition of microbes under low pH.

Lipids degradation rate was calculated and presented in Figure 5.9. About 45-48% of lipids
were degraded in the control treatments which were significantly lower than other treatments (P<0.05). About 70-80% of lipids were decomposed in the 10% zeolite amended treatments, while in the zeolite+inoculum treatments, ~91-93% of lipid was degraded and this range was significantly higher than the zeolite alone treatments indicating the importance of supplementing competent microbial inoculum.

![Figure 5.8 Changes of total lipid content during Chinese and Western-type food waste composting amended with zeolite and bacterial inoculum.](image)

The period of thermophilic phase was longer for the zeolite + inoculum amended treatments which also an indirect evidence for the effective lipid degradation and higher heat released. Agamuthu (1994) reported that the physical properties of lipids such as solubility, dispersion and melting point are altered under thermophilic phase, therefore food wastes with considerable lipid content is a good source for composting provided an effective thermophilic was maintained.
5.3.8 Changes of water soluble fatty acids (VFAs)

Volatile fatty acids are the by-products of organic matter mineralization and has high odor potential (Lan et al., 1996). Generation and transformation between aqueous and gaseous VFAs are controlled by pH during composting (Paul and Beauchamp, 1989). High-rate degradation, thermophilic temperature and an acidic pH can promote volatilization of VFAs leading to odor emission, which is often a major cause of closing a composting facility in the urban setups. In this study, fatty acids of acetic acid, butyric acid and iso-butyric acid which are considered as most commonly found during composting were analyzed. The profiles of these VFAs are presented in Figure 5.10.

Acetic acid has a sour smell and is a common intermediate product of biodegradation process. The detection limit of the acetic acid is usually higher than other VFAs, therefore it can generate less severe odor problem compared to the other VFAs. All the treatments showed an increasing trend of acetic acid during the first week because due to the rapid degradation of
easily degradable organic matter; and this increase has a good correlation with the reduction in the pH (Figure 5.3a). The levels of acetic acid decreased thereafter in the zeolite and zeolite+inoculum treatments. In the control also, after the initial increase the acetic acid concentrations decreased but the rate of decrease was significantly lower than the zeolite or zeolite+inoculum treatments. Even after 56 days of composting, significant quantities of acetic acid was observed in the control treatments that showed a good correlation with the low pH observed in the control treatments. Treatments with 10% zeolite amendment had significant (P<0.05) lower levels of acetic acid which demonstrated a great affinity of zeolite to absorb the VFAs. Zeolite adsorption process is regulated by molecular sieving properties and electrostatic field strengths of the exchange actions. However, treatments amended with zeolite and inoculum did not show any further reduction of VFAs than the zeolite implying the dominant role of the zeolite. Further, the zeolite fundamentally facilitated a good environment for the microbial activity thus exerted a dominant effect.

Butyric acid has a rancid smell and commonly emitted during composting but has a lower detection limit when compared with acetic acids. The trend of extractable butric acid was similar to that of acetic acid. Generally, the butric acid concentrations increased for the first two weeks and decreased gradually thereafter. However, in the control, the levels were almost stable for about 5 weeks indicating the accumulation. Decomposition of VFAs was retarded due to the inhibition of microbial activity due to acidic condition. Zeolite amended treatments had significantly lower levels of butyric acids due mainly to the good environment and the adsorption sites provided by the zeolite. However, the adsorption mechanisms of zeolite on VFAs need to be further investigated.

Iso-butyric acid showed a similar profile that of butric acid. A sharp increase during the
first week, gradual increase or stable for about two weeks and gradual decrease thereafter was the trend in the zeolite and zeolite+inoculum amended treatments. In contrast, after the initial raise, the concentrations were almost stable for about 5 weeks in the controls and the concentrations were almost more than two-fold than that of the zeolite treatments (Figure 5.10c) during Chinese and Western-type food waste composting amended with zeolite and bacterial inoculum. Cai et al. (2007) reported that application of 10% zeolite was the most effective to control VOCs and odor emissions during simulated poultry manure storage and the reduction rate of acetic acid, butanoic acid, isovaleric acid, indole, and skatole were proportional to the zeolite application rate.

5.4 Conclusion
Addition of 10% zeolite was proved to reduce the ammonia emission and total volatile fatty acids level in the composting mass during the composting of real-food wastes, thus the total odor emission level can be reduced. Supplementing 10% zeolite with bacterial consortium further improved the lipid degradation and also the overall decomposition efficiency.
Figure 5. Changes of extractable acetic acid (a), butyric acid (b) and iso-butyric acid (c)
Chapter 6 - Optimization Food Waste Composting in Fed-Batch community-composters: Influence of Zeolite and Bacterial Inoculation

6.1 Introduction

Composting is a robust technology to handle organic waste in terms of volume reduction, sanitation and recycling and it can be generally classified into batch and fed-batch operation. For batch operation, it may not make good use of the composter volume due to reduction in composting mass resulting in loss of capacity. Whereas in fed-batch operation, the raw materials are added regularly and treated for a period of time without discharging the products (Kwon and Lee, 2004). This is the reason why fed-batch is the most-common operation mode resembling that of continuous operation.

Decentralized food waste composter under fed-batch mode of operation is gaining momentum and providing alternative for large-scale centralized operation, which is widely installed in restaurants, hospitals, institutions and housing estates recently. Decentralized composting has several advantages such as reduced transportation cost, reduced environmental contamination, reduced demand for landfill space, and encouraging the community to participate in food waste separation and collection. Hogland et al. (2003) reported that ~20% of the original transportation cost can be reduced through employing decentralized composter to handle the organic wastes.

Despite these advantages, there are some operational problems when using this kind of composter. The major problems are the design inadequacy and inappropriate feeding mix. Poor decomposition, acidity problem, odor emission, incapable of handling oily waste are the
common symptoms of poor composting in these systems, especially for the food wastes. Consequently, large amount of immature composts are produced that cannot be applied directly due to the presence of phytotoxic substances and unstable organic matter. Therefore, additional space and process are required to complete the organic stabilization and curing to obtain mature composts. Sundberg and Jönsson (2005) reported that decomposition was inhibited when organic acids accumulated in fed-batch food waste composter. Hwang et al. (2002) reported that the final stabilization step of compost is important but the on-site composting machine usually has short retention time and limited space.

In the past, many theoretical composting studies have been conducted using synthetic food wastes in lab-scale composters. Those research were targeted to tackle the common problems encountered in food waste composting such as acidity (Yu and Huang, 2009, Cheung et al., 2010), loss of nutrients (Jiang et al., 2011, Wang et al., 2013), poor decomposition (Clottey et al., 2006), odor emission (Hanajima et al., 2010). Many organic or inorganic amendments were identified to alleviate these problems. Lime, coal fly ash (Wong et al., 2009), sodium hydroxide (Sundberg et al., 2004) and sodium acetate have been reported as effective chemical amendments to alleviate the acidity to improve organic matter decomposition during food waste composting. Addition of struvite salts during composting was demonstrated to conserve nitrogen by precipitation (Li et al., 2011) and partly alleviated the acidity (Wang et al., 2013). Inoculation of “effective microorganisms” reduced the odor emission in a composting plant (Kulig and Barczak, 2010).

However, the performance of these amendments may be over-estimated if applied in an actual real-food waste in a fed batch composter. The level of pH adjustment achieved in batch composters was not evident when applied to the fed-batch composters in our preliminary study.
With this constraint, a practical study is needed to assess the applicability of these additives in commercial fed-batch composter using locally generated food wastes. Effectiveness of lime, zeolite and oil degrading inoculum were evaluated in the previous experiments under batch mode of composting and were applied and assessed in fed-batch composter in this experiment.

6.2 Materials and Methods

6.2.1 Food wastes separation and collection

The food wastes used in this experiment were collected from Student Hall Canteen in Hong Kong Baptist University (HKBU). The source-separated food wastes were collected daily in 120-L bins, brought to the composting site and loaded to the composter by an automatic loader. Pre- and post-consumption wastes were collected separately. A flow chart of food wastes separation, collection and composting at the food waste composter is presented as Figure 6.1.

6.2.2 Food waste composter

Two commercial composters with 50 kg/day feeding capacity were used in this experiment. Composters were made of stainless steel and consists of two chambers (A and B). The volume of chamber A was 0.365 m³ and chamber B was 0.243 m³. According to manufacturing design, Chamber A was a mixing and high-rate degradation chamber that receives the fresh organic wastes; subsequently composting mixture was gradually transferred to chamber B for curing for a period of time. Heating coil was installed at the bottom of chamber A to prevent heat loss and to evaporate excessive water in the fresh food wastes. Heater temperature was set as 65°C maximum and the cut off temperature was 55°C. The composter mixed the composting material continuously with an internal rotary mechanism and with continuous air supply through an aeration vacuum. A schematic diagram of the internal structure of composter is presented in Figure 6.2, while the actual images of composter and the composting facility are presented in Plate 6.1 and 6.2.
Figure 6.1 Composting process flow diagram of food waste composting used in this experiment.

Figure 6.2 Schematic diagram of commercial food waste composter used in this experiment.
Plate 6.1 A close-up view of food waste compost used in this experiment.

Plate 6.2 A picture of the two food waste composters and the composting facility

6.2.3 Preparation of the starting culture

Starting culture was prepared to provide diverse microbes and dilute the effect on fresh organic matter to activate the fed-batch composting process. Food wastes and horse manure compost were mixed at a ratio of 1:4 (wet weight basis) as a starting culture. Food waste was collected from the Student Hall Canteen in HKBU and horse manure compost was collected from the Ngau Tam Mei Animal Waste Composting Plant in New Territories, Hong Kong.
Starting culture was seeded in the composter for 5 days initially before the regular addition of food wastes. The physicochemical properties of the starting culture are showed in Table 6.1.

**Table 6.1 Physicochemical properties of starting culture in fed-batch composter**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Food waste</th>
<th>Horse manure compost</th>
<th>Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.90 ± 0.01</td>
<td>8.69 ± 0.06</td>
<td>7.50 ± 0.08</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>8.20 ± 0.08</td>
<td>5.17 ± 0.09</td>
<td>6.07 ± 0.06</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>75.8 ± 0.5</td>
<td>49.4 ± 1.05</td>
<td>56.1 ± 0.85</td>
</tr>
<tr>
<td>Total organic carbon (%)</td>
<td>49.0 ± 0.7</td>
<td>45.5 ± 0.83</td>
<td>45.9 ± 0.17</td>
</tr>
<tr>
<td>Total organic nitrogen (%)</td>
<td>2.51 ± 0.37</td>
<td>1.72 ± 0.04</td>
<td>1.78 ± 0.03</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>19.7 ± 2.6</td>
<td>26.5 ± 0.06</td>
<td>25.8 ± 0.31</td>
</tr>
</tbody>
</table>

Values represent means and standard deviation (n=3).

**6.2.4 Preparation of composting mix input**

Post-consumption and pre-consumption food wastes were collected for a week to obtain representative samples and analyzed for physicochemical properties. Composting mixture was prepared by mixing post-consumption and pre-consumption wastes at 1:1 ratio, and food wastes to sawdust (wet weight basis) at 4:1 ratio. The C/N ratio and moisture content of feedstock mix were adjusted to ~25 and ~57%, respectively. Subsequently, 2.25% lime or 10% zeolite was mixed with the composting mix at each feeding day on dry weight basis. About 2-L of an oil-degrading bacterial consortium (6.8 x 10^6 CFU/ml) was added once at the beginning for the treatment with bacterial consortium. These bacterial strains were isolated from food waste compost, horse manure and oil contaminated soil. The total input of composting mix is 35 kg/d. The physicochemical properties of the feedstock materials are presented in Table 6.2. Plate 6.3 shows the operation of the food waste composter.
Table 6.2 Physicochemical properties of substrate in the composting mix

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Post-consumption wastes</th>
<th>Pre-consumption wastes</th>
<th>Sawdust</th>
<th>Composting Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.65 ± 0.04</td>
<td>5.46 ± 0.08</td>
<td>4.94 ± 0.07</td>
<td>5.13 ± 0.03</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>8.41 ± 0.21</td>
<td>8.02 ± 0.12</td>
<td>0.13 ± 0.01</td>
<td>6.17 ± 0.04</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>74.7 ± 0.6</td>
<td>67.9 ± 0.78</td>
<td>8.4 ± 0.36</td>
<td>57.2 ± 0.84</td>
</tr>
<tr>
<td>Total organic carbon (%)</td>
<td>48.8 ± 0.5</td>
<td>47.7 ± 0.70</td>
<td>50.5 ± 0.52</td>
<td>49.6 ± 0.40</td>
</tr>
<tr>
<td>Total organic nitrogen (%)</td>
<td>2.28 ± 0.04</td>
<td>2.68 ± 0.05</td>
<td>0.06 ± 0.01</td>
<td>1.73 ± 0.04</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>21.5 ± 0.1</td>
<td>17.8 ± 0.07</td>
<td>804.6 ± 38.09</td>
<td>28.7 ± 0.47</td>
</tr>
<tr>
<td>Bulk density (kg/l)</td>
<td>0.78 ± 0.03</td>
<td>0.70 ± 0.02</td>
<td>0.21 ± 0.04</td>
<td>0.57 ± 0.03</td>
</tr>
<tr>
<td>Total lipid content (%)</td>
<td>19.9 ± 0.1</td>
<td>4.8 ± 0.04</td>
<td>0</td>
<td>13.7 ± 0.13</td>
</tr>
</tbody>
</table>

Values represent means and standard deviation (n=3).

Plate 6.3 Operation of food waste composter

6.2.5 Treatments

There were four treatments in this experiment, with a control without amendment (C), a treatment with 2.25% lime (L2.25) and another two treatments with 10% zeolite with (Z10+O) or without bacterial inoculum (Z10) (Table 6.3).
Table 6.3 Dosage of different organic and inorganic amendments applied in the four treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Lime (%)</th>
<th>Zeolite (%)</th>
<th>Inoculum (CFU/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (C)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.25% lime (L2.25)</td>
<td>2.25</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10% zeolite (Z10)</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>10% zeolite + bacterial consortium (Z10+O)</td>
<td>0</td>
<td>10</td>
<td>$6.8 \times 10^6$</td>
</tr>
</tbody>
</table>

6.2.6 Sampling

Samples were collected daily for monitoring of moisture content (MC), pH and electrical conductivity (EC) to evaluate the composting performance. Samples collected on Day 0, 3, 7, 10, 14, 17, 21, 28 and 42 were used to determine extractable ammonium ($\text{NH}_4^+$-N), total Kjeldahl nitrogen (TKN), total organic carbon (TOC), carbon to nitrogen (C/N) ratio, total lipid content and total bacteria count. Food wastes were fed into the composters daily after 5 days incubation period, composts produced from the composter’s outlet was collected at day 28 to evaluate the maturity.

6.2.7 Analyses

Temperature of the composting biomass was monitored using portable temperature probe daily. Ammonia gas in the outlet was trapped in boric acid and the concentration was determined by titration method (Soil Sci. Soc. Am. 1986). Analytical details of MC, pH, EC, extractable $\text{NH}_4^+-\text{N}$, TKN, TOC were as described in Chapter 3. For total bacteria count, 1 g of fresh sample was extracted with 99 ml of 0.9% sterile sodium chloride solution for 1 h, then the extracts were spread on nutrient agar plates after serial dilution and incubated at 37°C. The colonies grew on the plate were counted after 48 h incubation and expressed as colony forming units (CFU/g) dry
compost mass (Wong et al., 2009). Analytical methods of total lipid content and water soluble fatty acids were as earlier described in Chapter 5. Cress seed germination, carbon dioxide evolution and nutrient availability (N, P, and K) tests to assess the compost maturity were presented in the previous chapters.

6.3 Results and Discussion

6.3.1 Changes of temperature, moisture, pH and EC

Temperature, MC, pH and EC were the daily monitoring parameters in this experiment since those parameters could provide a direct and mediate reflection of composting efficiency of biomass in the composters. Temperature decreases after thermophile stage in a batch composting process because of the exhaustion of the readily available organic matter. In contrast, temperature profile of fed batch composting is different due to regular addition of fresh food wastes every day. High temperature should be maintained during the continuous feeding process to ensure complete sterilization of pathogenic organisms and to accelerate organic degradation. As shown in Figure 6.3a, temperature increased sharply during the initial five days of all treatments due to the start-up procedures that activated the microbial activity. Afterwards, a drastic drop of temperature was observed in the control due to the acidic environment resulted under the continuous addition of the food wastes. Sundberg and Jönsson (2004) observed that the fed-batch composting process failed when the daily feeding rate was higher than 48% of the starting culture that resulted in pH of biomass reduced to less than 6.0, and low temperature and carbon dioxide evolution. In this study, the daily feeding rate of food wastes was less than 48% of the total amount of starting culture. Nakasaki et al. (2000) found that the temperature and carbon dioxide evolution profile in fed-batch operation was different from batch operation during composting due to the short time available for the microbes to proliferate.

Addition of 2.25% lime along with food wastes provided a good buffering against the
release of acid for the composting which enhanced the temperature initially. However, temperature decreased subsequently since frequent addition of lime had a deterrent effect to the microbial activities. Wong and Fang, (2000) reported negative effects of high concentrations of lime on all biological parameters, however these influences were only limited to the early stage in batch-scale sewage sludge composting because of just one time lime addition. Kwon and Lee (2004) used lime to adjust the initial pH to a range of 7.8 to 8.5 during food waste composting in fed-batch mode but only used for the first time. In this study, 2.25% lime was added with the food wastes on dry weight basis of each feeding continuously, providing continuous buffering.

Treatment of zeolite with bacterial inoculum sustained the high temperature during the whole composting process because addition of 10% zeolite physically diluted the acids generated and bacterial inoculum effectively degraded the lipids under high temperature to release more energy to enhance the overall degradation efficiency. Compared with 10% zeolite treatment, temperature dropped subsequently similar to that of the lime treatment since zeolite alone might not sufficient to buffer the acidity generated from the decomposition process and tackle the lipids problem under a fed-batch operational mode.

Moisture is a critical parameter to control the microbial activity because low moisture can inhibit decomposition rate of organic matter due to dehydration while excessive moisture can reduce the available oxygen level for the microbes by filling up most of the void spaces. Therefore, maintaining the moisture content at 50-60% is essential in the fed-batch processes. In the first week, moisture content of all treatments was within the optimal range (Figure. 6.3b). A trend of increasing moisture was observed in the control and reached ~65% after 3 weeks of operation. Moisture content of zeolite amended treatments were within the optimal range during the whole process. Zeolite was able to retain the moisture efficiently during composting as
reported in previous studies (Zorpas et al., 2000, Venglovsky et al., 2005).

The pH of the composting mass generally show a decreasing trend after about two weeks except the zeolite+bacterial inoculum treatment. In the control, pH decreased rapidly to ~6.0 in about 8 days while in treatment receiving lime and zeolite amendment, the pH dropped to <6.0 after 3 weeks indicating the both lime and zeolite can provide buffering but seems that the acidity resulting from the continuous addition of food wastes exceeded the buffering capacity of both lime and zeolite amendment. (Figure 6.4a). These same additives, however, adequately buffered against the pH in batch-mode reactor. Only zeolite with inoculum treatment was able to maintain the pH in an optimal range during the whole process since inoculum addition facilitated the decomposition of organic acids. This means lipids in food waste is a key factor affecting in organic decomposition. An optimal pH of composting is ranged from 6.5 to 8.0 (Kalbasi et al., 2005). An irreversible reduction of pH was observed in the control indicating that the composting process failed due to the accumulation of organic acids. Sundberg and Jönsson (2005) found that treatments with 20 and 100 g starting culture could maintain the pH below 6.0 and temperature was below 42 °C throughout the fed-batch composting experiment because of insufficient amount of the starting culture facilitated accumulation of organic acids. Compared to this study, the accumulation of organic acids of those treatments were not due to insufficient of starting culture but due to the effects of different amendment with the same amount of starting culture.

Literatures reported that addition of zeolite during co-digestion of swire manure and olive mill waste water reduced the ammonia toxicity in the anaerobic digestion process (Kougias et al., 2013). Wen et al. (2006) found that addition of yeast and zeolite to poultry manure significantly reduced the odor emission, enhanced the decomposition efficiency and improved the maturation.
Thus it can be concluded that suitable microbial inoculum is required to sustain the successful operation of the fed-batch composters while zeolite and lime could sustain the acidity for about 20 days.

Figure 6. Changes of temperature (a), moisture (b) during food waste composting in fed-batch composter.
During composting, complex organic matter is degraded resulting in the generation of large quantities of soluble compounds such as ammonium and VFA that enhance the EC of the composting biomass. In this experiment, the EC of the control treatment was in the range of 4-6 mS/cm due to the accumulation of the VFAs in the system (Figure 6.4b) that can be attributed to the low pH. However, treatments amended with zeolite had significantly (P<0.05) lower EC ~3.5-4.5 mS/cm than the control due to the ions adsorption onto zeolite as observed in the previous experiment (Chapter 3). Addition of natural zeolite was found to improve the properties
of the final poultry litter compost by reducing the salinity (Turan, 2008). Onat et al., (2008) reported that soluble salt contents were proportionally reduced with increase in zeolite concentration.

Lime treatment showed significantly highest EC than other treatments during the whole composting process, which could be attributed to the continuous addition of inorganic salts to the composting mass. Wang et al. (2013) found that addition of 2.25% lime significantly increased the EC during the initial stage of batch food waste composting process.

6.3.2 Changes of total organic carbon, total Kjeldahl nitrogen and carbon to nitrogen ratio

Reduction of total organic carbon along the composting can be commonly observed in batch composting process because microbes can continuously utilize the carbon as their energy sources. In fed-batch operation, fresh organic matters are being applied daily and hence there was no marked reduction in TOC was observed (Figure 6.5a). All treatments had similar TOC contents because of the same starting materials. TOC contents were maintained in a constant range in the control and lime treatment during the whole process. In contrast, significant reduction of TOC was observed in zeolite and zeolite+bacterial inoculum treatments due to large amount of inorganic materials added into the composter posed a dilution effect.

TN of the control treatment was significantly (P<0.05) higher than the other treatments because of the higher proportion of food waste in the composting mass and the poor ammonification process. A good organic degradation could create a concentration effect, an enhancement of total nitrogen concentration during the first week in a high-rate decomposition condition either in batch or fed-batch composting system (Figure 6.5b). In this study, an increased trend of TN concentration was observed for the treatment with lime, zeolite and zeolite + inoculum treatments which can be attributed to concentration effect during high rate
decomposition. Subsequently, the TN concentration decreased slightly or remained stable after 20 days because of dilution effect with the fresh organic matter addition and the degradation. Reduction of C/N ratio during composting is one of the indicators for compost maturity. The fed-batch composter used in this study contained two chambers (high-rate degradation and curing chamber). Samples taken from the high-rate degradation chamber were mainly used to evaluate the process performance and could not indicate the product maturity.

As presented in Figure 6.5c, the C/N ratio of all treatments reduced drastically in the first week due to rapid decomposition of organic matter. Subsequently, total nitrogen values were slightly increased in steady condition except for the control treatment because the decomposition rate reduced while fresh food wastes were loaded continuously. The control treatment had a continuous decreasing trend for C/N ratio mainly due to the high nitrogen value of the fresh food wastes added while the low decomposition could not reduce the carbon content.
Figure 6.5 Changes of total organic carbon (a), total nitrogen (b), and carbon to nitrogen ratio (c) during food waste composting in fed-batch composter.
6.3.3 Changes of extractable ammonium content during fed-batch food waste composting process

The high concentration of ammonium nitrogen produced coincide with the intensive organic matter degradation during the initial stage of composting (Sánchez-Monedero et al., 2001). In a fed-batch composting process, fresh organic materials are loaded frequently and the decomposition should be maintained in high-rate condition. Wang et al. (2014) found that higher ammonium concentrations were observed in treatments that showed better decomposition efficiency.

As shown in Figure 6.6, the ammonium contents increased to similar level of all treatments at the first week because of the same starting materials. Lime treatment had significantly higher (P<0.05) ammonium content during the whole process than other treatments due to rapid organic matter degradation but reduction was observed after 2 weeks due to microbial activity was retarded under continuous addition of lime.

Treatments amended with zeolite had good decomposition conditions which were reflected by high temperature (Figure 6.3a) and high microbial activity (Figure 6.8) but the ammonium content were significantly lower than the others because of the great affinity of ammonium ions to zeolite. Previous studies have reported the ammonium adsorption function of zeolite during composting (Villaseñor et al., 2011, Bautista et al., 2011). Probably, the high temperature could have contributed to the volatilization of the ammonium but the results indicates that the quantity of zeolite plays a critical role in adsorbing ammonium despite the pH >8.0. Control treatment had relatively low ammonium level during the whole process that was mainly due to poor decomposition under acidic condition.
6.3.4 Changes of total lipid content during fed-batch food waste composting process

High lipid content is a constraint during the initial stage in batch composters, especially treating food waste in fed-batch composting. Nakasaki et al. (2004) reported that the percentage of lard decomposition was reduced when increasing the mixing ratio of lard during composting.

Lipids completely enclose the food waste surface and prevent the oxygen to diffuse and contact with microbes. However, more than 95% of lipids can be degraded under high temperature when the composting is started with low lipids content (Lemus and Lau, 2002). In this experiment, all treatments were started with similar lipid content due to same starting materials (food waste + horse manure compost) (Figure 6.7). The lipids content significantly (P<0.05) increased in all the treatments except treatment amended with zeolite and inoculum.

In the control treatment lipids accumulated during the whole composting period and reached ~22% indicating that lipids may not be degraded effectively under mesophilic
temperature. Biomass of control treatment inside the composter was sticky and formed lumps (Plate 6.4) with severe odor due to incomplete decomposition. In addition, the material came out from the outlet was not loose but was sticky like polymer (Plate 6.5). Unwanted insects and rodents can be attracted when a large quantity of incompletely digested organic matter is retained in the composter.

The content of lipids of lime and zeolite treatment significantly increased at the later stage due to decrease in temperature when the pH were not able to sustain the in the neutral range to promote the microbial activities, however the accumulation were less than control. About 50% lipid contents were degraded in 2.25% lime and 10% zeolite treatments when compared to the control. Treatments amended with zeolite and bacterial inoculum effectively controlled the lipids content in a constant level of ~3-4% during the whole process demonstrating that the lipids were effectively decomposed in a sustained manner. Photo 6.6 shows the material inside the composter of zeolite + inoculum amended treatment. Comparatively, composting mass was loose that enabled effective movement of air through the mass. Addition of microbial consortium effectively improved the lipids degradation similar to the results reported in Chapter 5. Sarker et al. (2011) also observed that addition of bacterial consortia can accelerate degradation and prevent the emission of odor.
Figure 6.7 Changes of total lipid content during food waste composting in fed-batch composter.

Plate 6. 4 Composting mass of control treatment inside the food waste composter
Plate 6.5 Material of control treatment at the outlet of food waste composter

Plate 6.6 Material of zeolite + inoculum treatment inside food waste composter
6.3.5 Changes of total bacteria count during fed-batch food waste composting process

In a batch composting system, the bacterial population varies at different stages. The population of bacteria exponentially increased during the transition from lag phase to thermophilic phase. Subsequently the bacterial populations and temperature are reduced when the nutrient is depleted. However, the nutrient would not be depleted in a fed-batch composting system since the organic matter is added regularly; therefore, a stable level of bacterial population could be maintained.

As shown in Figure 6.8, the total bacteria counts of all treatments increased from 8.04 log CFU/g to 11.47 log CFU/g during the first three days with the same starting materials (horse manure compost + food wastes) but the slightly higher bacteria counts of zeolite + inoculum treatment was due to addition of bacterial inoculum. Afterwards, treatment of zeolite with inoculum had significantly higher bacteria counts than the other three treatments. The addition of specific microbial consortium enhanced the microbial activities and promoted the composting efficiency. Durruty et al. (2011) observed high microbial activity and degradation when supplementing two acclimated bacteria (Pseudomonas aeruginosa and Achromobacter sp.) isolated from soil in a fed-batch system followed by a short period of post-treatment.

The subsequent differences in bacterial population among treatments varied due to the amendments. A significantly lower total bacterial population (P<0.05) was observed in control treatment due to the inhibition posed by the accumulation of organic acids and lipids, and low pH during continuous feeding.

Total bacterial population of 2.25% lime and 10% zeolite amended treatments gradually decreased after two weeks which indicated that the high microbial activity could not be maintained in a sustained manner during continuous feeding. The major reason could be the inhibitory effect of lime to microorganisms and inadequate neutralizing effect of zeolite. Wong
and Fang (2000) reported that increasing the lime concentration posed significant inhibitory effect on microbes during the initial stage of thermophilic phase. Addition of zeolite was reported to have no or slight pH enhancement function during fed batch composting (Papadopoulos et al., 2009, Singh and Kalamdhad, 2014). Therefore, supplementing zeolite only in a continuously feeding mode is not sufficient to maintain the high microbial activity through buffering the acidity.

**Figure 6.8** Changes of total bacterial count during food waste composting in fed-batch composter.

**6.3.6 Evaluation of ammonia emission (NH₃) during fed-batch food waste composting process**

In a batch composting process, odor level is gradually reduced along the composting period, especially after the intense thermophilic phase. In a fed-batch process, high-rate decomposition is maintained and the odor level is remained high during the whole operation. Emission of strong odor can be a major reason to cause closure of composting plant, therefore
odor level need to be strictly monitored. NH₃ is one of the odorous compounds that are unavoidably generated during organic matter decomposition. NH₃ is generated under mineralization of organic matter and emission can be promoted under high temperature and pH. Furthermore, serious loss of NH₃ can reduce the nutrient value of final compost.

In this experiment, NH₃ gas emission was continuously monitored as presented in Figure 6.9. All the treatments showed strong and similar NH₃ emission levels during the first week due to same starting materials and good decomposition. A significant drop of NH₃ level was observed in control due to the low pH condition which was not favorable for the NH₃ volatilization. A sharp and high peak was observed in lime treatment after Day 10 since NH₃ emission was promoted under high pH and temperature. Wong et al. (2009) reported that about 50% of nitrogen can be lost as NH₃ in a lime amended composting system. Du et al. (2011) also observed that lime enhanced the nitrogen loss during the initial stage of night soil and MSW co-composting.
Figure 6.9 Changes of ammonia emission (a) and cumulative ammonia emission (b) during food waste composter in fed-batch operation.

The other two treatments amended with zeolite had significantly lower (P<0.05) NH$_3$ emission level compared to lime due to NH$_3$ adsorption function of zeolite. However, the NH$_3$ emission of Z10+O was higher than Z10 because of better and higher decomposition. Zeolite has great affinity for NH$_3$ adsorption as reported in previous studies (Ren et al., 2010, Turan and Ergun, 2007, 2008). Villaseñor et al. (2011) investigated the NH$_3$ and NH$_4^+$ adsorption performance using different kind of zeolites and reported that the adsorption efficiency was
proportionally increased to the application rate of zeolite. Inoculation of microbial consortium with zeolite demonstrated a synergistic effect on NH₃ adsorption and improved organic matter decomposition.

6.3.7 Changes of water soluble fatty acids during fed-batch food waste composting process

VFAs can be formed under anaerobic, facultative anaerobic and aerobic conditions by microbial transformation. There are several groups of VFAs significantly contributing to the offensive odor during composting with varied odor intensity. They are acetic, propionic, iso-butyric, butyric, iso-valeric, valeric, iso-caproic, caproic and heptanoic acids. The variation of VFAs content in the composting mass are regulated by the decomposition efficiency of fats and carbohydrate and the utilization of VFAs by microbes as their nutrients. High concentration of undissociated form of VFAs exist under low pH that inhibit the microbial activities (Cherrington et al., 1991). Transformations of VFAs between aqueous and gaseous phases are regulated by pH (Paul and Beauchamp, 1989). Emission of strong odor of a composting mass is attributed to the high concentration of water soluble fatty acids in a composting mass.

Food wastes were added into the fed-batch operational composter daily, therefore odor causing compounds such as fatty acids can be generated continuously in a high-rate degradation condition. In this experiment, frequent samples were taken from each treatment to evaluate the concentration of extractable fatty acids. As mentioned above the existence of fatty acids during composting is strongly depending on the pH and the decomposition efficiency of organic matter. As shown in Figure 6.10, control treatment had significantly higher concentration of water soluble fatty acids (acetic acids, butyric acids and iso-butyric acids) than the other treatments due to the low pH. Accumulation of lipids in control reduced the oxygen level and formed an anaerobic environment which facilitated the growth of anaerobic bacteria to degrade the complex
organic compounds. Microbes hydrolyzed the organic matter first, and were fermented by acidogenic bacteria into fatty acids (Wang et al. 1999). Moreover, high concentrations of acetic acids pose a serious odor problem than other fatty acids due to higher detection threshold.

Lime is an effective amendment to neutralize the acidity in a short time. Lime amended treatment had significantly lower (P<0.05) level of acetic acid, butyric acid and iso-butyric acid than control since the pH was greatly enhanced with 2.25% lime addition, as shown in Figure. 6.10a. Efficiencies of decomposition of the fatty acids were greatly improved under optimal pH. However, lime addition drastically enhanced the emission of NH₃, which is another kind of odor. Wynne (1995) reported that lime addition inactivated the hydrogen sulfide compounds but simultaneously increased the odor emission. Compare the 2.25% lime treatment with zeolite amended treatments, lime treatment had higher concentration of acetic acid since continuous addition of lime retarded the microbial activity and reduced decomposition efficiency. As presented in Figure 6.4a, pH was decreased along the experimental period of lime amended treatment which could be linked to the higher concentration of acetic acids. There was no significant difference of the butyric acids level in lime and zeolite amended treatments. However, concentration of iso-butyric acids in lime treatment was marginally higher than the zeolite amended treatments.

Zeolite amended treatments had significantly (P<0.05) lower levels of water soluble fatty acids than other treatments. The overall fatty acids concentration of Z10 was higher than Z10+O that could be linked to the better decomposition achieved with the addition of microbial consortium. These positive effects can be attributed to the adsorption as well as a good environment for the microbial activities. Zeolite with a high surface area and cationic exchange capacities has demonstrated a great adsorption functions for water soluble fatty acids in this
Figure 6.10 Changes of extractable (a) acetic acid (b) butyric acid and (c) iso-butyric acids during food waste composter in fed-batch operation.
experiment. Cai et al. (2007) reported that emission of VFAs was consistently reduced when increasing the zeolite application rate in simulated poultry manure storage and 83% reduction of total odor emission was reported with 10% zeolite supplement. Similarly, a composite material (fiber web + zeolite) placed on the surface of landfill reduced the emission of odorous gas (Bilodeau et al., 2012).

6.4 Physicochemical properties of compost of different treatments in fed-batch operation

Composting mass was retained in the composter for ~28 days and the compost passed out of the composter was evaluated for maturity. The physicochemical properties of compost from different treatments are presented in Table 6.4. Results indicated that compost from Z10+O treatment completely fulfilled the requirements of compost quality standards (HKORC; TMECC and CCME) and can be considered as a mature product while the composts from other treatments were not stabilized completely.

High ammonium content of the compost is considered to have deterrent effect on seed germination and plant growth. Compost of treatment C and L2.25 had significantly higher amount of ammonium than other two treatments due to incomplete decomposition and possibly low nitrification rate. Treatment of Z10 had marginally higher ammonium concentration (785±7.72) than the 700 mg/kg standard value set by the HKORC (2005). The zeolite with inoculum treatment had significantly lower ammonium concentration because the adsorption potential of zeolite that improved the decomposition effectively. The whole composting process was suppressed in treatment C due to low pH. The pH of the final product of L2.25 and Z10 were significantly higher than C but lower than Z10+O since lime provided a good neutralizing capacity and zeolite provided a dilution effect with acidity buffering at the early stage but did not sustain the buffering with the continuous feeding. Only zeolite with inoculum was able to
maintain the optimal pH during the continuous process and maintained high microbial activities.

Compost with high salinity has multiple negative effects on plants as documented in many reports. Composts of Z10 and Z10+O had significantly lower EC than L2.25 due to high EC buffering capacity of zeolite similar to the previous experiment reported in Chapter 3 (Section 3.4.4). Low EC of the product from control treatment was due to low degradation rate of organic matter in acidic condition and high EC of L2.25 was due to addition of inorganic salts.

Comparatively, composts of treatment C, L2.25 and Z10 had significantly higher total organic matter than Z10+O due to lower decomposition and lower microbial activities. Accumulation of incompletely decomposed organic matter was found in the treatment C which can explain the high moisture in the product and significantly lower moisture of other three treatments.

C/N ratio is one of the parameters to assess the compost maturity. In general, compost with C/N ratio of less than 25 is considered as mature but it should depend on the properties of starting substrates. Treatment Z10+O had significantly lower C/N than the others because of good decomposition, and the C/N of treatment L2.25 and Z10 were marginally close to the standard requirement. Treatment C had the highest C/N ratio among all treatments due to poor decomposition.

Seed germination is a sensible and direct method to evaluate the phyto-toxicity of compost. Compost of Z10+O treatment showed >80% GI indicating the phytotoxic free product. Other treatments showed a significantly low GI due to incomplete decomposition, and the ammonium and soluble ions hindered the seed germination.

Nitrogen (N), Phosphorus (P) and Potassium (K) are the essential elements for the plant’s growth. According to the compost quality standards, compost with ≥4% (NPK) is consider as
organic fertilizer. Compost from treatment C had higher than 4% of NPK nutrients which was mainly attributed to the high nitrogen content of the incompletely decomposed food wastes. The NPK contents of L2.25 and Z10 were significantly higher than Z10+O which were mainly due to the concentration effect similar to that of control treatment. Plant is not able to utilize the organic nitrogen directly and those unstable organic matters would rapidly decompose in the soil to produce phyto-toxic substances. Therefore, the total nitrogen content of compost could not reflect the total amount of available nitrogen to plants. There were no significant differences of total phosphorus content of the final products although higher values were observed in the lime and zeolite amended treatments. The total potassium content of control was significantly higher than the others due to concentration effect of the incomplete decomposition.

6.5 Conclusion

Formulation including 10% zeolite and microbial consortium is suitable for fed-batch food waste composting process. Addition of bacterial consortium enabled to degrade the lipids that enhanced the environment suitable for other microbes while the zeolite provided a better physical environment. Although the pH buffering capacity of the zeolite is not sufficient, the inoculum effectively degraded the organic acids produced thus the pH was effectively controlled. In contrast, lime and zeolite alone treatments could not sustain the optimal pH that led to reduced degradation and stabilization in the later stages of the composting. Besides, continuous addition of lime increased the EC of the compost. Therefore, addition of 10% zeolite and bacteria capable of degrading lipids and organic acids can effectively produce mature compost in fed-batch food waste composters.
<table>
<thead>
<tr>
<th>Parameters/ Treatments</th>
<th>HKROC, 2005*</th>
<th>TMECC**, CCME***</th>
<th>C</th>
<th>L2.25</th>
<th>Z10</th>
<th>Z10+O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium (mg/kg dw)</td>
<td>≤ 700</td>
<td>75-500</td>
<td>1563 ± 22.26 b</td>
<td>1896 ± 15.03a</td>
<td>785 ± 7.72c</td>
<td>456.63 ± 11.24d</td>
</tr>
<tr>
<td>pH</td>
<td>5.5-8.5</td>
<td>--</td>
<td>4.43 ± 0.03c</td>
<td>5.64 ± 0.01b</td>
<td>5.54 ± 0.21b</td>
<td>8.69 ± 0.06a</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>--</td>
<td>--</td>
<td>4.83 ± 0.07b</td>
<td>8.16 ± 0.14a</td>
<td>4.96 ± 0.11b</td>
<td>4.48 ± 0.16c</td>
</tr>
<tr>
<td>Organic matter (% dw)</td>
<td>≥ 20</td>
<td>≤ 40</td>
<td>98.05 ± 1.45a</td>
<td>86.13 ± 1.73b</td>
<td>78.97 ± 0.07c</td>
<td>76.38 ± 2.52d</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>--</td>
<td>--</td>
<td>65.74 ± 1.47a</td>
<td>48.74 ± 0.76b</td>
<td>46.39 ± 1.26b</td>
<td>45.96 ± 0.44b</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>≤ 25</td>
<td>≤ 25</td>
<td>28.22 ± 0.79a</td>
<td>26.14 ± 1.57ab</td>
<td>23.42 ± 1.26bc</td>
<td>20.65 ± 0.92c</td>
</tr>
<tr>
<td>Seed germination index (%)</td>
<td>≥ 80</td>
<td>80-90</td>
<td>4.23 ± 3.88d</td>
<td>40.26 ± 4.96c</td>
<td>56.96 ± 2.98b</td>
<td>85.63 ± 7.28a</td>
</tr>
<tr>
<td>Total nitrogen (as N % dw)</td>
<td></td>
<td>--</td>
<td>2.63 ± 0.08a</td>
<td>1.79 ± 0.14b</td>
<td>1.75 ± 0.07b</td>
<td>1.65 ± 0.04b</td>
</tr>
<tr>
<td>Total phosphorus (as P₂O₅ % dw)</td>
<td></td>
<td>--</td>
<td>0.56 ± 0.07a</td>
<td>0.67 ± 0.21a</td>
<td>0.74 ± 0.11a</td>
<td>0.62 ± 0.14a</td>
</tr>
<tr>
<td>Total potassium (as K₂O % dw)</td>
<td></td>
<td>--</td>
<td>2.56 ± 0.07a</td>
<td>1.88 ± 0.10b</td>
<td>1.91 ± 0.05b</td>
<td>1.86 ± 0.08b</td>
</tr>
</tbody>
</table>


Data with the same letter for the same parameter of different treatments are not significantly different (P<0.05).
Chapter 7 - Influence of food waste composts from community composter on plant growth

7.1 Introduction

Application of organic matter on agricultural farmlands as fertilizer has been a long history. However, along with the technology development, farmers started to utilize synthetic chemical fertilizer because it can release high quantities of readily soluble nutrients to promote plant growth and enhance crop yield in a short time. Besides, practices like intensive cultivation, selective planting of fast growing species and addition of pesticides are of common practice to enhance the plant production.

Varying adverse effects were reported after using intensive cultivation practices. Residual pesticides retained on the crops can accumulate in human body and pose a serious threat. Gilden et al. (2010) reported that pesticide can be harmful to human reproductive system and able to cause other health risks. Moreover, rapid leaching characteristic of chemical fertilizer could contaminate nearby water resources. Cultivation of mono-species of crops can deplete specific nutrients and enhance the chance of pest infection. Savci (2012) summarized the negative impacts of chemical fertilizer, which included pollution of environment by contaminating water resources and eutrophication, discharging toxic substances like heavy metals, radionuclides, and nitrosamines which can accumulate in the food chain and pose health threats to animals.

Organic farming is considered as a sustainable agriculture in terms of production of safe and high quality foods, environmental friendly and reduction of energy consumption during the whole cultivation process. Organic farming emphasize on environmental concern of the whole process of food production. The substances that are considered environmentally harmful, such as chemical fertilizers, pesticides, drugs, etc., are prohibited to use in organic farming (Norton, 2009). Compost is a stabilized organic matter which can be utilized as soil conditioner or
fertilizer. It is the major ingredient in organic farming. The advantages of using compost are including enhancement of the soil physical properties by reducing the bulk density, retaining the moisture, improving oxygen diffusion and enhancing the physicochemical properties by buffering the pH, cations exchange capacity, providing slow-releasing and balanced nutrients in soil (Stoffella et al., 2011). Furthermore, biological properties of the soil can be improved by providing healthy microorganisms such as bacteria, actinobacteria, fungi, protozoa and rotifers to facilitate the organic matter decomposition and nutrients release (Pérez-Piqueres et al., 2006).

The merits of using food waste compost rather than other composts are low concern of pathogen and heavy metal. Food waste compost can be produced from decentralized food waste composter and the operational details of this kind of composter have been reported in the last chapter (Chapter. 6).

Numerous studies were conducted to find out the optimal application rate of compost in soil (Wong et al., 1999, Killi and Kavdr, 2013) but no research are available on the application rate of food waste compost produced from the decentralized food waste composter. Therefore, this study was aimed to examine an optimal application rate of food waste compost produced from the small scale decentralized community composter and compare the effectiveness of organic and chemical fertilizer through plant growth experiment using Brassica chinensis and Lycopersicon esculentum.

7.2 Materials and methods

7.2.1 Plant species

Two commonly found edible plants species, cherry tomato (Lycopersicon esculentum) and Chinese cabbage (Brassica chinensis), were used in the study. The seeds were purchased from the flower market in Mong Kok, Hong Kong.
7.2.2 Soil

Soil used in this experiment was collected from a local agricultural field (Produce Green Foundation) situated at New Territories, Hong Kong. Soil was taken from the top of 15 cm of the soil surface of the field. The collected soil was dried at room temperature, crushed by mortar and pestle, and then passed through the 2-mm sieve to remove the larger particles and stones. Selected physicochemical properties are presented in Table 7.1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.08±0.10</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>0.05±0.02</td>
</tr>
<tr>
<td>Organic matter (% dw)</td>
<td>3.46±0.01</td>
</tr>
<tr>
<td>Organic carbon (% dw)</td>
<td>0.47±0.10</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>2.34±0.12</td>
</tr>
<tr>
<td>Total N (mg kg/dw)</td>
<td>879±0.00</td>
</tr>
<tr>
<td>Soluble N (mg kg/dw)</td>
<td>0.03±0.01</td>
</tr>
<tr>
<td>Total P (mg kg/dw)</td>
<td>3478±87</td>
</tr>
<tr>
<td>Soluble P (mg kg/dw)</td>
<td>0.83±0.21</td>
</tr>
<tr>
<td>Total K (mg kg/dw)</td>
<td>11653±110</td>
</tr>
</tbody>
</table>

**Table 7.1 Physicochemical properties of soil used in the experiment.**

<table>
<thead>
<tr>
<th>Total metal contents</th>
<th>Soil Reference Standard (AFCD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu (mg kg/dw)</td>
<td>≤190</td>
</tr>
<tr>
<td>Zn (mg kg/dw)</td>
<td>≤720</td>
</tr>
<tr>
<td>Pb (mg kg/dw)</td>
<td>≤530</td>
</tr>
<tr>
<td>Cd (mg kg/dw)</td>
<td>≤12</td>
</tr>
</tbody>
</table>

*AFCD: Agriculture Fisheries and Conservation Department - Standard for agriculture soil

7.2.3 Food waste compost

Food waste composts used in this experiment were collected from the decentralized food waste composter operated at Hong Kong Baptist University (HKBU). The food waste was
composted with the supplementation of 10% zeolite and bacterial inoculum as presented in Chapter 6. Physicochemical properties of food wastes compost are presented in Table 7.2.

### Table 7.2 Physicochemical properties of food waste composts collected from HKBU composter

<table>
<thead>
<tr>
<th>Parameters</th>
<th>HKORC*</th>
<th>TMECC#/CCME@</th>
<th>HKBU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium (mg/kg dw)</td>
<td>≤ 700</td>
<td>75-500</td>
<td>456.63±7.95</td>
</tr>
<tr>
<td>pH</td>
<td>5.5-8.5</td>
<td>--</td>
<td>8.69±0.04</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>--</td>
<td>--</td>
<td>4.48±0.11</td>
</tr>
<tr>
<td>Organic matter (% dw)</td>
<td>≥ 20</td>
<td>≤ 40</td>
<td>76.38±1.78</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>--</td>
<td>--</td>
<td>45.96±0.31</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>≤ 25</td>
<td>≤ 25</td>
<td>20.65±0.65</td>
</tr>
<tr>
<td>Seed germination index (%)</td>
<td>≥ 80</td>
<td>80-90</td>
<td>85.63±5.65</td>
</tr>
<tr>
<td>Total nitrogen (as N % dw)</td>
<td>--</td>
<td>--</td>
<td>1.65±0.64</td>
</tr>
<tr>
<td>Total phosphorus (as P₂O₅ % dw)</td>
<td>≥4%</td>
<td>--</td>
<td>0.62±0.10</td>
</tr>
<tr>
<td>Total potassium (% dw)</td>
<td>--</td>
<td>--</td>
<td>1.86±0.08</td>
</tr>
<tr>
<td>Cu (mg kg/dw)</td>
<td>≤300</td>
<td>≤400</td>
<td>26.96±1.56</td>
</tr>
<tr>
<td>Zn (mg kg/dw)</td>
<td>≤600</td>
<td>≤700</td>
<td>19.86±8.6</td>
</tr>
<tr>
<td>Pb (mg kg/dw)</td>
<td>≤100</td>
<td>≤500</td>
<td>56.67±5.9</td>
</tr>
<tr>
<td>Cd (mg kg/dw)</td>
<td>≤1</td>
<td>≤3</td>
<td>nd</td>
</tr>
</tbody>
</table>

* HKORC 2005: Compost and Soil Conditioner Quality Standards 2005
# TMECC 2002: Test Method for the Examination of Composting and Compost
@CCME 2005: Guidelines for Grade A Compost Quality.

#### 7.2.4 Chemical fertilizer

Treatments amended with chemical fertilizer received a complete fertilization and the application rate of fertilizer was 150 kg of nitrogen per hectare (kg/ha). The composition of the added fertilizer included NH₄NO₃, KH₂PO₄,2H₂O, K₂SO₄, MgSO₄, CaCl₂, MnSO₄·H₂O, ZnSO₄·7H₂O, CuSO₄·5H₂O, H₃BO₃ and [NH₄]₆Mo₇O₂₄·4H₂O) as suggested by Wong et al.
7.2.5 Treatments

There were five treatments in this experiment. They are (1) control with soil only (C), (2) soil amended with chemical fertilizer (CF), (3) soil amended with 2.5% compost (ZI-2.5), (4) soil amended with 5% compost (ZI-5) and (5) soil amended with 10% compost (ZI-10). Composts were mixed with soil on dry weight basis. The weight of compost, chemical fertilizer, soil and total nitrogen input of each treatment used for cabbage and cherry tomato plants are presented in (Table 7.3).
Table 7.3 The weight of compost, soil and total nitrogen input of each treatment for planting Chinese cabbage and cherry tomato

<table>
<thead>
<tr>
<th>No.</th>
<th>Treatments</th>
<th>Abbr.</th>
<th>Compost (g/pot)</th>
<th>Soil (g/pot)</th>
<th>Total nitrogen input (mg/kg dw)</th>
<th>Compost (g/pot)</th>
<th>Soil (g/pot)</th>
<th>Total nitrogen input (mg/kg dw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control</td>
<td>C</td>
<td>--</td>
<td>523</td>
<td>900±45d</td>
<td>--</td>
<td>1561</td>
<td>901±17d</td>
</tr>
<tr>
<td>2</td>
<td>Chemical fertilizer</td>
<td>CF</td>
<td>--</td>
<td>523</td>
<td>1471±29c</td>
<td>--</td>
<td>1561</td>
<td>1525±41c</td>
</tr>
<tr>
<td>3</td>
<td>2.5% compost</td>
<td>ZI-2.5</td>
<td>10.46</td>
<td>513</td>
<td>1471±12c</td>
<td>31.22</td>
<td>1530</td>
<td>1525±11c</td>
</tr>
<tr>
<td>4</td>
<td>5% compost</td>
<td>ZI-5</td>
<td>26.15</td>
<td>497</td>
<td>2562±34b</td>
<td>78.05</td>
<td>1483</td>
<td>2632±39b</td>
</tr>
<tr>
<td>5</td>
<td>10% compost</td>
<td>ZI-10</td>
<td>52.30</td>
<td>471</td>
<td>4964±23a</td>
<td>156.10</td>
<td>1405</td>
<td>5080±43a</td>
</tr>
</tbody>
</table>

*All weights are presented in dry weight basis
*Values represent means and standard deviations of four replicates
*Data with the same letter for the same parameter for different treatments are not significantly different at P<0.05.
7.2.6 Experimental setup and preparation

Pots with 4 inch diameter were used to plant Chinese cabbage while 6 inches pots were used for Cherry tomato since plant's size of tomato is larger than cabbage in mature state. Food wastes composts were mixed with soil thoroughly at 0, 2.5, 5 and 10% (v/v) which were equivalent to 0, 10.13, 25.33 and 50.67 tonnes/ha for Chinese cabbage and 0, 17.12, 42.81 and 85.62 tonnes/ha for cherry tomato. Compost and soil were mixed thoroughly and packed into pots. Four replicates were prepared for each treatment. Seeds were washed to remove the impurities before sowing and 10 seeds per pot were sown. After the seedlings emerged, seedlings were removed to keep only one seedling per pot and the seed germination was recorded. Pots were arranged in completely randomized block design at the HKBU greenhouse (Plate 7.1) with constant temperature in a range of 25°C to 35°C and supplemented with artificial light. Pots were watered once or twice per day depending on the requirement using field capacity method. Chinese cabbage and cherry tomato were allowed to grow for 28 and 80 days, respectively.
Plate 7.1 Experimental pots placed on greenhouse benches in randomized block design

7.2.7 Collection of soil and plant samples

About 30 g of soil samples were collected before planting and after harvesting the plant to analyze the physicochemical properties. Chinese cabbage and cherry tomato plant tissues, above-ground and the roots, were carefully removed, washed with tap water for several times and rinsed in deionized water to
eliminate the attached soil particles.

7.2.8 Analytical methods

7.2.8.1 Soil and compost analysis

Soluble N, P, nitrite (NO$_2^-$-N), nitrate (NO$_3^-$-N), pH and EC of the soil samples were determined using 1:2 soil extracts (w/v). The pH and EC were measured in the soil-water paste by using Orion 920 ISE pH meter and Orion 160 conductivity meter, then the soil suspension was centrifuged at 10,000 rpm for 7 minutes, and then filtered through Whatman no.42 filter paper to determine the other soluble nutrients. Soluble NH$_4^+$-N and PO$_4^{3-}$-P were determined by Indophenol blue method and Molybdenum-blue method (Page et al., 1982) respectively. Soluble NO$_3^-$-N and NO$_3^-$-N were determined by Cadmium reduction method followed by sulfanilamide-NAD reaction (Huffman and Barbarick, 1981). Moisture content was obtained by a weight difference after drying the samples in 55°C oven for 16 h, then oven-dried samples were ignited at 550°C for 16 h to determine TOM. Total N, P were extracted by Kjeldahl digestion method (Bradstreet, 1965), then the determination methods were followed soluble N and P. Walkey-Black method (Walkey and Black, 1934) was used to determine TOC. Total metals in soil was extracted by microwave by using concentrated nitric acid (HNO$_3$) and analyzed through atomic absorption spectrophotometer (Varian
Techtron Model AA-10). Compost samples were analyzed as described in Chapters 3 and 4.

7.2.8.2 Plant analysis

Seed germination was recorded after 3 days and 7 days of germination for Chinese cabbage and Cherry tomato, respectively. After that seedlings were thinned to keep only one plant per pot. Shoot and root were dried in an oven at 75 °C for 72 h (until the constant weight) to determine the dry weight and calculate the root to shoot ratio (Thornley, 1972). Dried plant tissues were ground to a powder and digested for the analysis.

7.3 Statistical analysis

Four replicates were used for the analysis. The mean and standard deviations are presented in the tables and figures. One way ANOVA was used to compare the means among the treatments and significant F values were obtained. Differences among the individual means were tested using the Least Significant Difference Tests at 95% confidence interval using SPSS version 16.

7.4 Results and Discussion

7.4.1 Properties of food waste compost and soil

The pH of the collected soil was slightly acidic with a value of 5.08. Nutrient availability is greatly affected by soil pH. Characteristics like low EC,
organic matter and other soluble nutrients of collected soil indicate the infertility of soil. In addition, the metal concentrations were low. Food waste compost was slightly alkaline (~8.69) and its properties indicated that the compost was matured as per Compost and Soil Conditioner Quality Standards of HKORC (2005).

7.4.2 Seed germination

![Figure 7.1](image_url) Percent seed germination of the five treatments of Chinese cabbage and Cherry tomato. Bars with same lowercase alphabet letters do not differ significantly at 5% level.

Seed germination Index (GI) is a sensitive and direct method to evaluate the phyto-toxicity of soil because seed germination can be retarded if the soil contains high level of toxicants (Mer et al., 2000). As presented in Figure 7.1, there were no significant differences of seed germination rate among all treatments indicating
that the collected soil and food waste compost were free from phytotoxic substances. However, the 10% compost amendment slightly reduced the seed germination of both the plants that can be attributed to the increase in soil salinity. Many reports indicate that high salinity in soil can greatly reduce the seed germination (Guma et al., 2010 and Zhang et al., 2012). Wang et al., (2013) reported that addition of inorganic salts during food waste composting increased the salinity of the final product and significantly reduced the GI. Treatments of C and CF had marginally lower GI compared to ZI-2.5 and ZI-5 since compost mixed with soil enhanced the physical properties by reducing the bulk density.
7.4.3 Changes of pH

Figure 7.2 pH of the soil before planting and after harvesting: (a) soil samples from Chinese cabbage treatments, and (b) soil samples collected from Cherry tomato treatments. Bars with same lowercase alphabet letters do not differ significantly at 5% level.

pH is an important parameter in soil to affect the plant growth performance because it can directly affect the nutrient availability in soil. Nitrogen is an essential macro-element to promote the plant growth and serve as major constituent of plant cells. The availability of nitrogen is greatly depends on pH.
The amount of available nitrogen, the nitrate, is reduced if the soil pH is <5 because of retardation of nitrification rate under low microbial activity. Pandey and Singh (2010) reported the optimal pH range to maximize the available nutrients and maintain the optimal growth of plants is 6.5 - 7.0.

As presented in Figure 7.2, the pH of soil used in the experiment was slightly acidic ~5.08 as reported for treatment C and CF. pH was significantly increased to 6.08 and 6.48 when mixed with compost at 5 and 10%, respectively, in Chinese cabbage experiment. In case of cherry tomato treatments, pH was proportionally increased to 5.5, 6.1 and 6.5 when mixed with 2.5, 5 and 10% food waste compost. After planting, pH did not show much change in control because of low mineralization rate. Marginal decrease of pH was observed in CF treatment because of addition of chemical fertilizer (Barak et al., 1997). Soil acidification is a common problem with the continuous application of chemical fertilizer in agricultural soil since the inputs of the nitrogen fertilizer accelerate acidification through oxidation of NH$_4^+$ to NO$_3^-$, which produce large quantities of H$^+$ and decrease the pH value (Schroder et al., 2011).
### 7.4.4 Changes of EC

**Figure 7.3** EC of the soil before planting and after harvesting: (a) soil samples from Chinese cabbage treatments, and (b) soil samples collected from Cherry tomato treatments. Bars with same lowercase alphabet letters do not differ significantly at 5% level.

Determination of EC is the rapid method to evaluate the total amount of soluble salts in soil. Soil having an EC exceeding 2 dS/m is considered to have
detrimental effect on seed germination and plant growth. Application of compost with high EC on soil can cause plant death due to osmotic effect that would withdraw the water from the plant cell (Zhang, 2014). Moreover, soil EC can be indirectly correlated with physical and chemical properties of soil. An infertile soil should have low conductivity due to lack of soluble nutrients.

As shown in Figure 7.3, control treatment had low EC values of ~0.05 dS m\(^{-1}\) because of infertile soil with low content of soluble nutrients. Treatment of CF has significantly high EC value than control, ZI-2.5, ZI-5 treatments and value was similar to Z10 treatment in cabbage and tomato treatments since the chemical fertilizer contains high quantities of soluble nutrients and readily available in soil after application. EC increased significantly with increase in the compost application rate from 2.5% to 10%. Compost contains large amount of soluble nutrients which can support the growth of plants and increase the EC of mixed soil. After planting cabbage and tomato, EC were drastically reduced in compost amended treatments because most of the soluble nutrients were utilized by plants. Chemical fertilizer is considered as fast releasing fertilizer because it is more water-soluble and makes the nutrient readily available to plants. Comparatively, compost contains lesser nutrients than chemical fertilizer but slow-releasing of nutrients in a balanced way and reduction in bulk density of soil make it effective.
to improve the soil quality.

7.4.5 Changes of extractable ammonium

![Graph showing changes of extractable ammonium](image)

**Figure 7.4** Extractable NH$_4^+$ of the soil before planting and after harvesting: (a) soil samples from Chinese cabbage treatments, and (b) soil samples collected from Cherry tomato treatments. Bars with same lowercase alphabet letters do not differ significantly at 5% level.

Nitrogen is one of the essential nutrients required for the plants. It is the
critical composition of proteins to control the metabolic process and plant growth. Generally, nitrogen can be segregated into organic and inorganic fractions. Plants can utilize the inorganic nitrogen directly; ammonium (NH$_4^+$) and nitrate (NO$_3^-$) are the common forms of inorganic nitrogen being taken up plants. NO$_3^-$ is a nutrient readily available for plant uptake but NH$_4^+$ is fractionally taken by plants or being converted to NO$_3^-$ by soil microorganisms.

As shown in Figure 7.4, control soil contained low level of NH$_4^+$ with low nutrient contents. Significantly higher concentration of NH$_4^+$ was found in CF treatment than control and compost amended treatments since NH$_4^+$ ions was one of the ingredients in the preparation of synthetic chemical fertilizer to serve soluble nitrogen to plants. Composts contain NH$_4^+$ ions because of mineralization of organic nitrogen during decomposition. The NH$_4^+$ concentration proportionally increased with compost application rate. Composts can provide NH$_4^+$ ions to plants continuously because of slow-releasing nature.

After planting, NH$_4^+$ levels of all treatments decreased due to nitrification by microorganisms and plant utilization. Control did not show drastic reduction of NH$_4^+$ compared to compost amended treatments due to low initial NH$_4^+$ levels and low utilization by plants. Treatments with composts improved the physical and chemical properties of soil, therefore indirectly enhanced the plant uptake.
efficiency. Compost amended treatments and CF Treatment had the same nitrogen input but the latter had higher reduction of \( \text{NH}_4^+ \) content than the compost after planting. Chemical fertilizer provided the \( \text{NH}_4^+ \) ions easily and the \( \text{NH}_4^+ \) ions concentration decreased along the plant growth which mainly due to leaching from soil because plant uptake only a small fraction added nitrogen in CF treatments (Table.7.4). In contrast, reduction of \( \text{NH}_4^+ \) ions after planting of compost amended treatments were mainly due to plant uptake which was demonstrated by high nitrogen content of plant tissue (Table.7.4). Varied compost amendment rate affected the \( \text{NH}_4^+ \) uptake efficiency of plants as well. Higher reduction of \( \text{NH}_4^+ \) content was observed for ZI-5 and ZI-10 than ZI-2.5 due to enhanced uptake efficiency with increased compost application rate. After harvesting, plants of ZI-5 had higher nitrogen content compared to other treatments. High nutrient value of plant leaves can directly reflect high nutrient uptake efficiency. Therefore, the uptake efficiency of \( \text{NH}_4^+ \) among the treatments can be ranked from high to low as: ZI-5> ZI-5>ZI-2.5>CF> C.
7.4.6 Changes of nitrate

![Chart showing changes of nitrate](chart.png)

**Figure 7.5** Extractable NO$_3^-$ of the soil before planting and after harvesting: (a) soil samples from Chinese cabbage treatments, and (b) soil samples collected from Cherry tomato treatments. Bars with same lowercase alphabet letters do not differ significantly at 5% level.

As mentioned before, nitrate (NO$_3^-$) is a major form of inorganic nitrogen which could be utilized by plants directly and nitrogen is a key constituent of
proteins and enzymes. NO$_3^-$ can be leached out from soil quickly when compared with NH$_4^+$ since cations can attach to soil particles easily to prevent leaching. In general, the NH$_4^+$ content in soil is higher than NO$_3^-$. 

As presented in Figure 7.5, control soil had low concentration of NO$_3^-$, and the concentrations increased with increasing compost application rate. The stabilized compost should contain low amount of NH$_4^+$ because of mineralization of organic nitrogen during composting and relatively higher concentration of NO$_3^-$ during maturation due to nitrification by microorganisms which can explain the reason of increase in NO$_3^-$ concentration in soil upon compost addition. Treatment of CF had significantly higher concentration of NO$_3^-$ than C, ZI-2.5 and ZI-5 since NO$_3^-$ was included in the fertilizer mix.

After plant growth, the NO$_3^-$ levels of all treatments drastically decreased mainly due to the utilization by the plants. Plant grown in soil amended with composts consumed higher NO$_3^-$ quantities compared with control mainly due to nutrient availability and high nutrient uptake efficiency. Reduction of NO$_3^-$ content of CF after planting was mainly due to fast leaching character (Fang et al., 2006) of chemical fertilizer but not because of plant uptake as evident from the low nutrient contents of plant tissue after harvesting (Table. 7.4).
7.4.7 Changes of extractable phosphorus

Figure 7.6 Extractable phosphorus of the soil before planting and after harvesting: (a) soil samples from Chinese cabbage treatments, and (b) soil samples collected from Cherry tomato treatments. Bars with same lowercase alphabet letters do not differ significantly at 5% level.

Apart from nitrogen, phosphorus also is an essential element and macronutrient as required by plants. Phosphorus is one of constituent of plant...
cells, important for cell division and development. In addition, it can stimulate early plant growth and hasten maturity. The outcomes of phosphorus deficiency are growth retardation, stunted root, greyish-green leaves, etc. (Rouached et al., 2011). In general, phosphorus in soils can exist in three forms: soluble P, solid P and fixed P (Dean, 1938). Most of the soluble P is in the orthophosphate form which is the major form of P taken up by the plants. Normally, the solution P pool is very small compared to the solid P. A growing crop easily use up soluble P if there is no replenishment of P. Solid P is a major source of available P for plants since it can release phosphate to replenish the deficient P in soil. The fixed P portions contain inorganic P which is insoluble and organic P which is resistant to mineralization.

As presented in Figure 7.6, the initial PO$_4^{3-}$ content of soil in control and CF treatments were ~20 mg kg$^{-1}$ and the concentration significantly increased with increasing compost application rate. At the end of the experiment, more than 50% of PO$_4^{3-}$ were decreased in all treatments because the consumption by the plants. Compared with other treatments, 5% compost application showed higher PO$_4^{3-}$ reduction ~80%, indicating more uptake by the plants.
7.4.8 Changes of total nitrogen

![Graph showing changes of total nitrogen in different treatments.](image)

**Figure 7.7** Total nitrogen of the soil before planting and after harvesting: (a) soil samples from Chinese cabbage treatments, and (b) soil samples collected from cherry tomato treatments. Bars with same lowercase alphabet letters do not differ significantly at 5% level.

High concentration of total nitrogen in soil does not indicate high content of available nitrogen for the plants. Major uptake forms of nitrogen by the plants are $\text{NH}_4^+$ and $\text{NO}_3^-$. Generally, more than 95% of nitrogen in soil is in organic form,
only very small fraction is present in inorganic form. Total nitrogen in soil can be varied greatly and depends on microbial activities, weather, and decomposition efficiency.

Total nitrogen content of collected soil is only ~0.1% (Figure 7.7). The initial total nitrogen content of treatment CF was almost similar to ZI2.5 since the N content of the CF was adjusted to match the N of the 2.5% compost addition facilitating the comparison of effects. Total nitrogen content increased significantly with increased in compost application rate.

At the end of the experiment, the total nitrogen contents of all treatments decreased significantly since the nitrogen locked in the organic matter was released by the soil microorganisms and were subsequently absorbed by the plants. Comparatively, reduction is total nitrogen with 5% compost was drastic than other treatments indicating a good mineralization with 5% compost application.
7.4.9 Changes of total organic matter

![Graph of Changes of total organic matter]

**Figure 7.8** Total organic matter of the soil before planting and after harvesting: (a) soil samples from Chinese cabbage treatments, and (b) soil samples collected from cherry tomato treatments. Bars with same lowercase alphabet letters do not differ significantly at 5% level.

Total organic matter (TOM) represents the living and dead organisms and humic substances in soil. TOM can provide nutrients for all living organisms in
soil. Soil with optimal organic matter can maintain good soil structure, retain and prevent the loss of nutrients.

As presented in Figure 7.8, treatments C and CF had comparatively low TOM content. Since the soil was collected from a non-cultivated farmland without fertilization, there was not much organic addition through external application or natural recycling of plant materials. Addition of compost provided stable organic matter to the soil thus the TOM increased with increase in compost application (Sikora and Yakovchenko, 1996). Literature clearly suggests that the compost is an excellent source of organic matter through which the physicochemical and nutrient qualities of the soil are significantly improved. At the end of the experiment, the TOM contents of all treatments decreased due to the mineralization during the plant growth and the trend of TOM contents among the treatments were almost similar to that of the initial values. Compared to the reduction rate of TOM among the treatments, compost amended treatments had higher reduction rate of TOM than CF and C because of organic matter addition.
7.5 Changes of total phosphorus

Figure 7.9 Total phosphate of the soil before planting and after harvesting: (a) soil samples from Chinese cabbage treatments, and (b) soil samples collected from cherry tomato treatments. Bars with same lowercase alphabet letters do not differ significantly at 5% level.

Phosphorus is one of the essential nutrients required by the plants for cellular development and function. Total P is the sum of organic and inorganic
fractions. The contents of total P in soil depend on the quantity of organic matter, soil texture and cultivation. In general, 20-50% of the total P exist as organic P.

As shown in Figure 7.9, the soil contained ~0.06% of total P as observed in C and CF treatments. Mature compost is rich in organic matter, therefore total P content increased proportionally when increasing the compost amendment rate. After harvesting the plants, total P of all treatments decreased due to decomposition, soil microorganisms and utilization by plants. Treatment with 5% compost maximized the P absorption by plants similar to other inorganic nutrients.
7.5.1 Biomass production

![Graph showing biomass production](image)

**Figure 7.10** Biomass production of five treatments of planting Chinese cabbage (a) and cherry tomato (b). Bars with same lowercase alphabet letters do not differ significantly at 5% level.
Biomass production is another direct parameter to reflect the plant growth and nutrient uptake. As presented in Figure 7.10, the biomass yield among all treatments were significantly different for both cabbage and tomato plants. Control treatment had the lowest biomass production because of inadequate nutrient of the infertile soil. Biomass production of CF treatment was higher than C but lower than compost amended treatments because the chemical fertilizer only provided large quantity of nutrients to plant but did not improve the physical properties of soil. Therefore, the nutrient adsorption efficiency and root health were retarded. Treatments amended with compost showed significantly higher biomass production than others. Food waste composts provided a balanced and
sufficient nutrient to promote the plant growth. Moreover, compost mixed with soil can effectively improve the physicochemical and biological properties of soil by reducing the bulk density, retaining the moisture, enhancing the microbial activities, etc. Among the compost amended treatments, 5% compost application resulted in the highest yield of biomass compared to other composting application rates which indicated 5% is the optimal application to increase the biomass production.

7.5.2 Total nitrogen and total phosphorus of plant tissues

Nutrients of plant tissue can directly reflect the nutrient absorption efficiency of the plant. Plants with high nutrient content in their tissue indicate efficient nutrient absorption and suitable soil environment for plant growth. Nitrogen and phosphorus are critical elements to promote the growth of plants. Severe deficiency of either N or P could cause growth inhibition or death. In this experiment, total N and P of plant tissue were selected as indicators to evaluate the nutrient absorption efficiency of each treatment.

Total N and P of plant tissues of different treatments are presented in Table 7.4. At the end of the experiment, there were significant difference of total nitrogen content of plant tissues among CF and compost amended treatments while control had significantly lower total nitrogen content. There was nutrient
Table 7.4 Total nitrogen and phosphorus contents of the *Brassica chinensis* and *Lycopersicon esculentum* plant grown in soil mixed with 0, 2.5, 5, 10% composts.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Cabbage</th>
<th>Tomato</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total nitrogen (% dw)</td>
<td>Total phosphorus (% dw)</td>
</tr>
<tr>
<td>C</td>
<td>1.09±0.18b</td>
<td>0.31±0.30a</td>
</tr>
<tr>
<td>CF</td>
<td>1.51±0.07a</td>
<td>0.36±0.03a</td>
</tr>
<tr>
<td>ZI-2.5</td>
<td>1.46±0.06a</td>
<td>0.42±0.10a</td>
</tr>
<tr>
<td>Z-I5</td>
<td>1.56±0.03a</td>
<td>0.46±0.04a</td>
</tr>
<tr>
<td>ZI-10</td>
<td>1.48±0.13a</td>
<td>0.47±0.17a</td>
</tr>
</tbody>
</table>

*Values are mean ± standard deviation of four replicates.
*Values followed by the same lower case alphabet within a column is not significantly different at 5% level.

deficiency of plants grown in control soil that affected the nutrient content of the plants. Chemical fertilizer and food waste compost provided sufficient nutrients for plants to grow but the final nitrogen content of CF was lower than compost amended treatments which demonstrated the nutrient adsorption efficiency of CF was poor. Compared with CF, compost not only provided sufficient, balanced and slow-releasing nutrients to plant but also improved the physical properties of soil which might be the key to enhance the nutrient adsorption in this study.

There were no significant differences of total P in plant tissues of cabbage although plants grown in compost amended soils showed higher P contents because of greater nutrients adsorption performance. In case of tomato, the tissue
P content of plants grown in compost amended soils were significantly higher than the fertilizer amended treatments. Compost amended treatments had higher P content than treatment C and CF similar to that of total nitrogen.

7.6 Conclusions

Food waste compost can be a good alternative for the chemical fertilizer in terms of providing balanced nutrients and improving physical properties of soil. Results indicated that addition of food waste compost significantly increased the plant available nutrients such as NH$_4^+$, NO$_3^-$, PO$_4^{3-}$ that are essential for the plant growth. Food waste compost provided a buffering effect to resist pH and EC changes in soil. The optimal application rate of compost collected from decentralized food waste composter is 5% for cabbage and tomato. Application of 10% compost showed a slight negative effect due to increased salts content while 2.5% compost did not provide sufficient nutrients for plants. Highest biomass production and nutrient uptake efficiency were observed in 5% compost amended plants than other application rates.
Chapter 8 - General Discussion, Conclusions and Recommendations

8.1 Introduction

Food wastes generation problem is a stern issue in Hong Kong. Food wastes composter in fed-batch mode can be used to handle daily produced food wastes from communities and produce valuable compost product which can be used as a soil conditioner or fertilizer. Therefore, optimize composting condition for food wastes was the major target in this study. Due to complexity characteristics of food wastes like acidic, high moisture and lipids contents that made it poses different challenges that deter the decomposition of organic matter during composting. Numerous constraints were identified during operation of a fed-batch composter such as acidity, loss of nitrogen, poor decomposition and emission of odor that severely inhibited decomposition efficiency and reduced fertilizer value of the final product. Therefore, the aim of this study was to optimize the operation of fed-batch commercial food waste composter by developing a proper compost mix formulation. To achieve this aim, alkaline amendments and oil degradative inoculum were used as co-composting substrates with synthetic food wastes to evaluate their effects on pH buffering, change of nutrients and decomposition efficiency by using computer controlled batch experimental composters.
Subsequently, the information obtained from lab scale experiments were applied to fed-batch composters to study the practicability for developing an ideal composting mix formulation for commercial composters. Lastly, composts produced from the fed-batch composter were put into soil in order to determine the optimal application rate of food waste compost and study the effects of compost on soil and plants.

8.2 Efficiency of Zeolite and Oil-degradative inoculum in batch mode food waste composting

Zeolite was demonstrated as a good candidate to compost with food wastes compared to lime amendment. Ten percent zeolite amendment was found as an optimal amendment rate to co-compost with food waste in a batch composting process as indicated by the stronger pH, EC buffering and higher organic matter decomposition efficiency. A total of 60.2% of TOM was degraded after 56 days in the treatment with 10% zeolite amendment as compared to 50.9 and 32.4% at 2 and 5% zeolite amendment rate respectively. Compared to 10% zeolite amendment, treatment receiving 2.25% lime amendment significantly enhanced ammonia emission and reduced the fertility of the final compost product, although it alleviated acidity effectively. The total nitrogen content of 10% zeolite amended compost was 2.05% while lime amended compost was 1.72%. With further
experimentation, 10% zeolite was used in conjunction with struvite to co-compost with food waste and a further reduction of ammonia loss during composting was achieved but there were no differences of the final nitrogen values for both treatments with zeolite amendment with/without struvite. Besides, compost of 10% zeolite treatment only required 28 days to reach maturity as indicated by the seed germination test while compost of 10% zeolite plus struvite took 35 days. Obviously, 10% zeolite showed superior performance than zeolite plus struvite in terms of compost maturity and lower cost due to exclusion of struvite. Addition of 10% zeolite with oil degradative inoculum improved degradation of lipids significantly during composting of real-food wastes as compared to other treatments without inoculum. About 91 to 93% of total lipids in food waste were degraded in composting mix with zeolite and inoculum while 70-80% of lipids was degraded in treatment with zeolite amendment only. Reduction of total soluble fatty acids level in the composting mass was observed in those treatments with zeolite amendment, which demonstrated zeolite could potentially reduce the emission of volatile fatty acids. To conclude the results obtained from the batch experiments, treatment with 10% zeolite plus inoculum was selected to apply in fed-batch composter for further study because of its superior performance among all treatments.
8.3 Pilot scale application of Zeolite and Oil-degradative inoculum in food waste composting using fed batch composter

Supplementing 10% zeolite and oil-degradative inoculum was suitable to optimize fed-batch food waste composting process compared to those treatments supplemented with zeolite and lime alone. Only 10% zeolite and Oil-degradative inoculum amended treatment could effectively buffered the pH and electrical conductivity, and maintained optimal moisture content and high microbial activity during the whole experimental period. In contrast, lime or zeolite alone were not able to buffer against the pH continuously that led to inhibit or effect on microbial activity and reduction in overall decomposition efficiency. Through the addition of bacterial consortium, lipids were effectively degraded and maintained at around 3-4% constantly along the process; however lipids were accumulated in composting mass of those treatments without inoculation. Therefore, composts produced from the treatment supplemented with 10% zeolite and Oil-degradative inoculum were completely fulfilled compost quality standards requirements in terms of maturity and nutrients availability. The results from the present study provides a solution to the composters available in the market to allow good composting conditions by removing the inhibitory derived from the oil entrained in food waste.
8.4 Influence of zeolite amended compost on soil and plant

Food waste compost was demonstrated as a good alternative for chemical fertilizer because of improved physical properties of soil and nutrients for plants. Food waste compost provided a buffering effect to resist pH and EC changes in soil. 5% amendment rate was an optimal application rate for planting Brassica chinensis and Lycopersicon esculentum which indicated by the highest biomass production and highest nutrient contents in plant tissues among all treatments. Treatments amended with 2.5% compost were not able to provide sufficient nutrients to support plant’s growth while 10% amendment showed slightly inhibition on plant’s growth which might be due to high salts content. Therefore, application of 5% zeolite amended compost produced from fed-batch food waste composter in soil can improve crop yield which might be due to the improved physical properties of soil and enriched soil nutrients facilitating the growth of cabbage and tomato.

8.5 Recommendations for further study

8.5.1 Feasibility of reducing dosage of 10% zeolite

According to the results of batch scale composting study at Phase 1, treatments supplemented with less than 10% zeolite were not sufficient to against the acidity generated which as a result retarded decomposition efficiency by
inhibiting microbial activity. Considering addition of 10% zeolite on dry weight basis in fed-batch composter daily, there would be high quantities of inorganic materials accumulated in composting mass that would significantly dilute food wastes and pose a potential negative effect on microorganisms. This may need further investigation whether we can further reduce the application rate of zeolite. Nevertheless zeolite is being used frequently in agriculture for retaining nutrients in soil, so the application of zeolite can be easily maintained. Using struvite to co-compost with lower dosage of zeolite was not an appropriate approach for reducing the use of zeolite during food waste composting since seed germination rate of the final compost was reduced due to high salts content. Therefore, other potential organic or inorganic amendments are needed to examine their feasibility to compensate the impact by using lower dosage of zeolite during food waste composting. Developing a microbial consortium with multi-purposes is recommended to tackle problems like acidity, decomposition and lipids simultaneously.

8.5.2 Practicability of applying the oil degradative inoculum in large scale composter

In this study, inoculation of oil degradative inoculum in batch experimental composter (20L) and fed-batch commercialized composter (35kg d⁻¹) by using
real food wastes successfully reduced the lipid contents of the composting mass and improved the quality of final product. More and more communities are setting up fed-batch composters in their housing estates to handle their daily generated food wastes and the handling capacity of these composters are commonly in a range of 50 kg d$^{-1}$ to 500 kg d$^{-1}$. Therefore, it is necessary to evaluate oil degrading ability of the inoculum in the large scale composting facility in order to fulfill the market requirement.


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