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Co-composting of Food Waste and Green Waste in Pilot-Scale Systems: In-vessel and Windrow Investigations

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ABSTRACT

The two largest constituents of municipal solid waste are food waste and green waste. These two wastes have enormous quantity of nutrients and other resources; this can be used for plant growth/land application after some degree of treatment. This study discusses the adept schemes for successful co-composting of food waste and green waste in pilot-scale systems via in-vessel and windrow systems. At the end of composting, a TVS reduction ratio of around 31.5% and germination index of 60% for white radish were observed in the in-vessel system. Furthermore, this study describes the effect of moisture content and controlled seeding of microorganisms on the windrow composting system. At controlled moisture content, the temperature was maintained over 55°C for 14 days. Moreover, final NH_4^+-N concentration observed at controlled moisture condition was 37 mg/L, which shows that the compost obtained in this condition is the best suitable for agricultural purposes compared to uncontrolled moisture and seeding conditions.

Keywords: composting, food waste, green waste, in-vessel, windrow piles
Abbreviations: C/N, carbon to nitrogen ratio; **GI**, germination index; **MSW**, municipal solid waste; **TOC_W**, water-soluble total organic carbon; **TKN_W**, water-soluble total Kjeldahl nitrogen; **TVS**, total volatile solids; **WAS**, waste activated sludge

INTRODUCTION

Municipal solid waste (MSW) includes durable goods, non-durable goods, containers and packaging, food waste and yard trimmings, and miscellaneous inorganic wastes. Due to the increase in population density, high economic development and the rising standards of living, the requirement of food materials and the corresponding waste generation ratios are growing substantially. In Taiwan, food waste constitutes around 18 to 38% of the garbage (EPA Statistics 2006). On the other hand, environmental awareness has made the conception of "Green City" more of a trend in the recent years. Simultaneously, huge quantities of fertilizer are used for vegetation, which reduces the fertility of soil. Both the concept of green city and the enormous utilization of fertilizer produce large amount of green waste, accounting about 2 to 6% of the total trash weight in Taiwan over the past 10 years. Therefore, food waste (i.e. cooking wastes and food residuals) and green waste (i.e. pruning yard wastes and fallen leaves) make up the largest amount of organic wastes of MSW in Taiwan.

Conventional MSW disposal methods include physical, chemical and biological treatments. Land-filling or dumping is a common way for solid wastes treatment/removal. However, large numbers of dumpsites were closed down in recent years due to its leachate and other associated problems. Besides, land disposal is not preferred in several countries including Taiwan due to the confined land availability. On the other hand, incineration of wastes reduces its volume and rectifies its harmfulness. However, the organic matter and nutrients present in the waste become unusable after incineration. The presence of high moisture in organic waste can damage the incinerator as well as the process performance. Besides, incineration may results secondary pollutants such as particulate matter and dioxins. Biological treatment for MSW is mostly preferred in the recent years owing to the lower energy cost and less-technology demand.

Composting is a controlled biological process, which decomposes the organic matter by microorganisms. Microorganisms use organic matter as their substrate and transform it into stable products (Barrington *et al*. 2003). Composting is an environmentally- friendly treatment process that makes the organic wastes stable and harmless without secondary pollution. In addition, the end products can be reused as soil amendments or organic fertilizer for land application as well as for agricultural purposes after proper treatment. In other words, composting represents a strategy of organic waste treatment that is fully compatible with sustainable agriculture (Adbrecht *et al*. 2011). Therefore, composting has become a viable treatment process for the treatment and disposal of organic wastes (Lemus and Lau 2002). Although composting has the aforementioned advantages, traditional composting still has several problems including the requirement of longer treatment time.

Composting is carried out in many ways; however, the most popular composting techniques are windrow, aerated static-pile and in-vessel composting. Windrow composting, the most traditional composting technique, involves piling the composting materials at an open space and aerating without forces; thus, combining mesophilic and thermophilic phases due to the decomposition of organic matter by microorganisms to generate heat (Satisha and Devarajan 2007). The large handling capacity of organic wastes, low energy cost and low technique demand make windrow composting the most popular composting method. However, windrow composting requires a large space and a long time to reach maturity and stability. Aerated static-pile composting is similar to windrow composting but uses forced aeration instead of unforced natural aeration. Smaller space is required for aerated static-pile composting compared with windrow composting (Hassouneh *et al*. 1999). On the other hand, in-vessel composting is an enclosed aerated static-pile composting, in which composting factors such as moisture and aeration are easily controlled in the closed system. The

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Table 1 Characteristics of the composting feed stocks.

Parameter	Food waste	Green waste	Rice husk
Moisture content (%)	70-80	7-15	8-11
pH	3.8-6.5	5.8-6.6	7.1-7.3
C (%)	47.35	41.76	41.66
N (%)	5.35	0.8	1.22
H (%)	7.31	5.76	5.22

aeration efficiency is improved by forced aeration or agitation; as a result, the microbial activity and organic matter decomposition rate enhanced by many folds (Diaz *et al.* 2003). Although in-vessel composting overcomes many disadvantages of traditional composting methods such as sanitation and odor problems, normally not designed for treating huge quantities of solid waste (or) in-vessel systems are designed where intensive treatment is required prior to solid waste disposal.

During composting, the organic matter present in the waste is converted into hygienic and bio-stable products by aerobic microorganisms through thermophilic phase (Agnew and Leonard 2003). The main aims of the composting studies are to produce mature compost, which is environmental friendly and can support the plant growth without any phytotoxicity. The application of immature compost may cause pathogen propagation and decrease the oxygen concentration around the plant's root to possibly produce phytotoxicity (Chikae *et al*. 2007). Although composting is well recognized for treating sewage sludge (de Guardia *et al*. 2007), green waste (Benito *et al*. 2006; Hernández *et al.* 2007) and food waste (Chang *et al*. 2006; Kim *et al*. 2008), the physical/chemical properties of a single material may not be always suitable for composting. For example, the high moisture content of food waste and the low nitrogen source in green waste result in a long treatment time or low degradation efficiency. Therefore, co-composting, composting of several types of residual matters altogether such as municipal solid wastes and sewage sludge (Fourti *et al.* 2010), bio-solids and spent active clays (Ho *et al*. 2010), olive solid residue and olive mill waste water (Zorpas and Costa 2010), physic nut deoiled cake with rice straw (Das *et al*. 2011), very often investigated to reduce the composting time and also to increase the efficiency of composting process.

This study was focused to investigate the conversion of green waste and food waste together, i.e. co-composting, into stable products by both in-vessel composting and windrow composting. Besides, the results obtained from both in-vessel and windrow composting systems are analyzed and discussed.

MATERIALS AND METHODS

Composting feedstocks

Food waste (consists of served rice, noodles, vegetables, meats and seafood) was collected from restaurants in Hsinchu and the green waste (consists of raked leaves and grass clippings) was provided by the National Chiao Tung University. The bulking agent, i.e. rice husk, was purchased from Hsinchu Farmers' Association, Taiwan. Besides, the waste activated sludge (WAS) is used as the microbial seed for windrow composting, which is collected from Nei-Hu wastewater treatment plant, Taiwan. Before running the actual composting experiments, the food waste and green waste were composted without the addition of any external seed(s). These trials gave unfavorable results (results not shown). Based on the results, homogeneous compost was added as the seed for in-vessel composting experiment and WAS is added as the seed for windrow composting. All the feedstock's were collected in bulk and used for the experiments. The properties of the composting feedstocks are shown in **Table 1**. Our preliminary investigation revealed no significant variation in carbon to nitrogen ratio (C/N) of these feedstocks with different sampling periods in a calendar year.

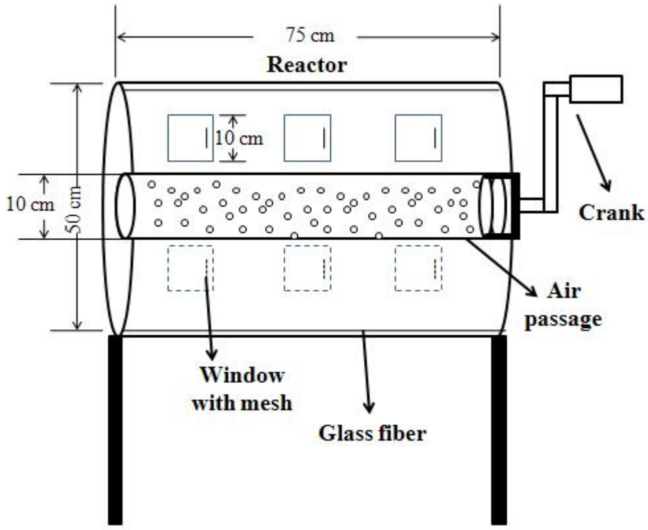

Fig. 1 Schematic diagram of the in-vessel composting reactor.

In-vessel composting experiments

A cylindrical reactor with 147 L capacity, 75 cm length and 50 cm diameter was constructed for in-vessel composting experiments. The reactor was constructed of double layer stainless steel with a glass fiber layer inside to prevent heat loss. A crank was designed to roll the reactor for agitation as an alternative to an auto agitator. **Fig. 1** shows the schematic diagram of the in-vessel composting reactor. In order to maintain the aerobic condition inside the reactor, a 10 cm diameter cylindrical air passage with apertures was provided on the surface. Moreover, six windows with meshes of 2 mm pore diameter were also equipped to increase the air flow while agitating the reactor. As a precursor to in-vessel composting experiment, the food waste was ground-up using a food processor and the green waste was shredded with a pestle to get a homogenous feedstocks with 5 mm particles. Subsequently, food waste, green waste, bulking agent and the compost seed were mixed together to obtain the required C/N, i.e. 19-20. For calculating the mixture's C/N, the weight percentage of the green waste and food waste was used (excluding the weight of seeding materials and bulking agent). The ratio of food waste to green waste and bulking agent under in-vessel and windrow composting systems are shown in **Table 2**. Consequently, tap water was added to adjust the moisture content of the feed stocks to 60% and the feedstocks were placed in the reactor. The feedstocks in the reactor were mixed thoroughly using the crank twice per day for 5 minutes. At regular intervals, samples were withdrawn from the in-vessel composting system and analyzed for various physical/chemical factors. Besides, the decrease in the moisture content of composting mixture as a result of biologically produced heat was adjusted by sprinkling tap water on the surface of the composting mixture.

Table 2 Initial properties of the composting mixture in in-vessel and windrow systems.

Parameter	In-vessel composting	Windrow composting		
		Run-1	Run-2	Run-3
Ratio of Food waste: Green waste: Rice husk	1.5 : 1: 1[a]		1 : 1 : 1[b]	
Temperature (°C)	30	29	27	29
pH	6.5	4.7	4.4	4.5
Moisture content (%)	60	62	58	60
TOC_W (mg/L)	2400	902	1172	918
TKN_W (mg/L)	220	144	278	71
NH_4^+-N (mg/L)	*	40	16	17
C/N	19.6	30	49	36

* NH_4^+-N concentration was not measured
[a] Seed sludge was added at 10% of the total feed stocks
[b] Sewage sludge (SS) was added as the seed at 5% (one time addition in the beginning) in Run-1 and 1% at frequent intervals in Run-2 and Run-3 (no SS addition in the beginning).

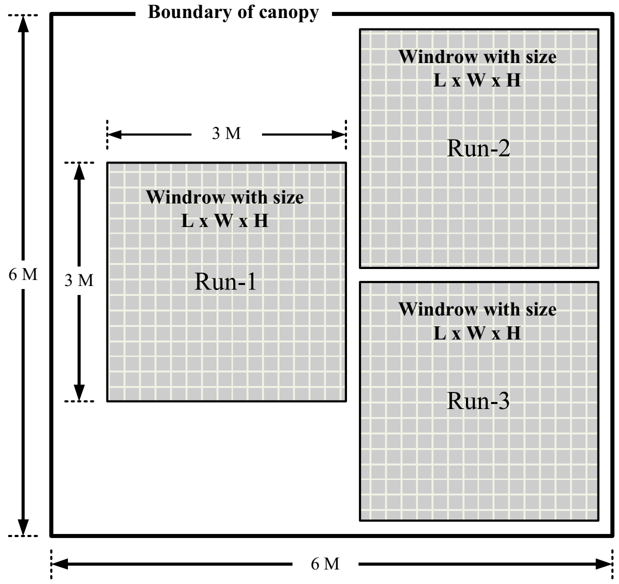

Fig. 2 Arrangement for windrow composting experiments.

Windrow composting experiments

To start with, a canopy was set-up using stainless steel (length: width: height, 6:6:2 m) to cover the entire size of the windrow. The floor of the canopy was made by wooden stands (length: width: height, 3:3:0.6 m) with perforations. These perforations were also capable of supplying the air/ventilation for the windrow piles. The wood stands were covered by fishing net (with 1 mm perforation) to avoid falling and clogging of the perforations in the wooden stands by the compost.

To obtain the composting mixture, the feedstocks (without grounding and shredding), bulking agent and WAS were placed on a dry concrete floor in required proportion and mixed thoroughly using a shovel. Subsequently, the moisture content of the mix was adjusted to 60% by the addition of tap water. After mixing, the contents were formed as 2.1:2.1:0.75 m (length: width: height) windrow piles. Totally, three windrow composting experiments were conducted as per the conditions reported in **Table 2**, i.e. Run-1, Run-2 and Run-3. The arrangement for the windrow composting experiments is shown in **Fig. 2**. In Run 1, 5% WAS was added before starting the windrow composting. On the other hand, 1% WAS was added in Runs 2 and 3 while a decrease in temperature profile was observed. All the windrows were turned at the same frequency (after adding the WAS). Although no WAS seeding was done in Run-1, turning of the feedstocks of Run-1 was also done along with the other Runs. Besides, the moisture content was not allowed to decrease below 40% at any point of time in Run-3 whereas no moisture adjustment was done in Run-2. In both the in-vessel and windrow composting systems, temperature was used to evaluate the performance of the system. The operation of the systems were discontinued when the temperature in these systems persist at 30°C for 2 to 3 days.

Analytical techniques

About 200 g of sample was collected every 12 h interval and analyzed for moisture content, pH, temperature, volatile solids, water soluble total organic carbon (TOC_W), and water soluble total Kjeldahl nitrogen (TKN_W). The collected sample was oven-dried at 105°C for 24 h and the loss of weight was taken as the moisture content. For the determination of volatile solids, the oven-dried sample was further heated at 550°C for 4 h and loss is weight was measured as per the procedures reported in the Standard Methods. For measuring the compost pH, raw samples were mixed with deionized water at a weight ratio of 1:10. The mixture was shaken for 1 h, allowed to settle under quiescent conditions and the pH of the clear supernatant was measured in the top clear liquid with a pH meter. The quantity of TOC_W and TKN_W in the samples were measured using TOC analyzer (OI Analytical model 1010) and TKN analyzer (Gerhardt Vap 50), respectively, on samples that had been centrifuged at 2000 rpm for 20 min and filtered through a 0.45 μm filter paper.

Germination test

The germination test is usually conducted to measure the quality of compost and also to assure the applicability of the compost for agricultural purposes. For germination test, the compost samples collected at the end of the in-vessel and windrow composting experiments were mixed with deionized water at a weight ratio of 1:10 and shaken for 1 h. Subsequently, the supernatant (compost extract) was centrifuged at 2000 rpm for 20 min and filtered through a 0.45 μm filter paper. The germination test was performed for 48 h at 25°C in the dark with 20 radish seeds (*Raphanus sativus*) placed on a 9 mm filter paper (Whatman #1) soaked with 4 mL of compost extract (Bertran *et al*. 2004), and placed in a Petri dish. The test was also repeated with deionized water (as a control) and with the commercial compost (obtained from local market) extract. The following equations were used to calculate the relative seed germination (RSG (%); Eq. 1), relative root growth (RRG (%); Eq. 2), and germination index (GI; Eq. 3) (Tiquia *et al*. 1996; Zucconi *et al*. 1981).

$$\mathrm{RSG} = \frac{\text{Number of seeds germinated in compost extract}}{\text{Number of seeds germinated in control}} \times 100 \quad (1)$$

$$\mathrm{RRG} = \frac{\text{Mean root length in compost extract}}{\sqrt{\text{Mean root length in control}}} \times 100 \quad (2)$$

$$\mathrm{GI} = \frac{(\text{Relative seed germination}) \times (\text{Relative root growth})}{100} \quad (3)$$

RESULTS AND DISCUSSION

In-vessel composting

Generally, in-vessel composting is conducted with forced aeration or an agitation system (Leth *et al*. 2001; Leiva *et al*. 2003; Cheng *et al*. 2008; Kim *et al*. 2008; Lu *et al*. 2008). The scale-up of these forced aeration in-vessel reactors for the field application typically requires a huge quantity of electrical power considering the huge quantity of food waste and green waste generated in a day. Therefore, to avoid electrical power usage and to take advantage of using natural wind, a specially designed reactor was fabricated in this study. Besides, most of the previous composting experiments were conducted at higher C/N (25 to 35); thus, huge quantity of bulking agent is required for maintaining higher C/N. In some cases, the bulking agent is also used to maintain/provide the required porosity for the composting feedstocks. In case of co-composting green waste and food waste, the required porosity could be achieved by green waste itself. Under this circumstance, the addition of bulking agent is required only for adjusting the C/N. Therefore, a successful composting experiment under low C/N should be developed. To achieve this goal, the in-vessel co-composting experiment was carried out under C/N 19-20 and 60% moisture content.

1. Temperature and pH profiles

The temperature and pH profiles in the in-vessel composting reactor are shown in **Figs. 3A** and **3B**, respectively. The thermophilic phase was reached after 2 d and maintained for more than 70 h. The temperature in the field-scale reactor increased to more than 70°C, indicating that the heat insulation of the field-scale composting reactor was sufficient in maintaining the thermophilic phase. The increase in temperature of the reactor in the initial stage of composting increased the production of organic acids, which subsequently decreased the pH of the composting mixture. During the thermophilic phase, the pH of the system increased from 4.5 to over 8.5 in 2 d, and thereafter attained a steady state.

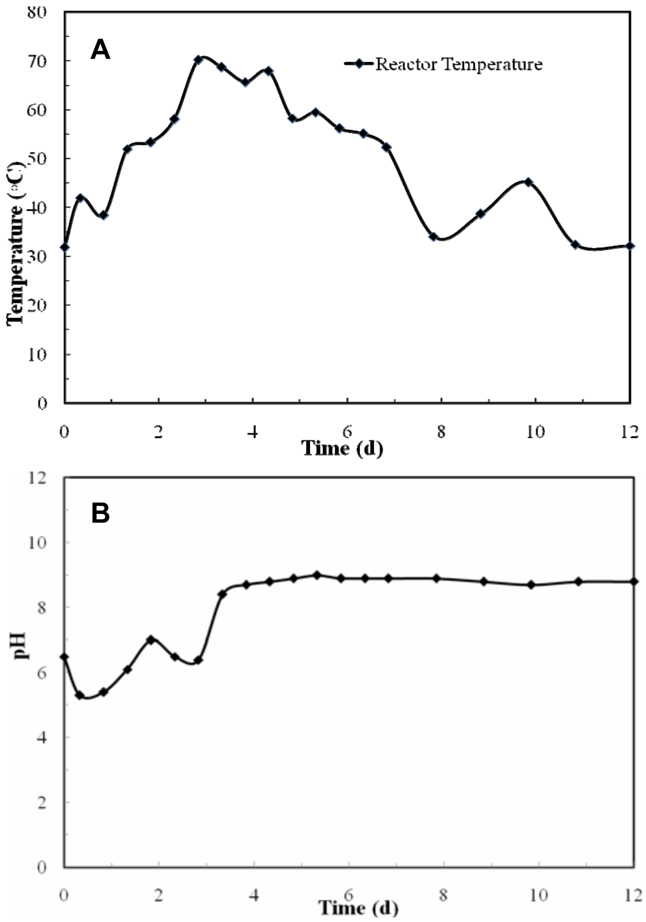

Fig. 3 Profiles of (**A**) temperature and (**B**) pH in the in-vessel reactor.

2. TOC_W, TKN_W and TVS reduction profiles

Figs. 4A and **4B** show the variations of TOC_W and TKN_W concentrations in the in-vessel co-composting reactor, respectively. During the thermophilic phase, the TOC_W concentration decreased steeply then reached pseudo equilibrium at the end of composting. On the other hand, increase in TKN_W concentration was observed during thermophilic phase of the reactor. This could be due to the higher initial total nitrogen content in the composting mixture. However, the values are decreased at the end of composting. The reduction of water soluble organic matter in the reactor shows that a specifically designed reactor can be promising for co-composting of green waste and food waste.

The TVS reduction ratio in the in-vessel co-composting reactor is shown in **Fig. 4C**. At the end of composting, a TVS reduction ratio of around 31.5% was observed. The TVS reduction ratio observed in the present study is compared with other composting studies in **Table 3**. Most researchers experienced a better TVS reduction ratio (>20%) when the moisture content was close to 60%. However, the low initial C/N adopted for this co-composting study has not shown any significant effect on TVS reduction ratio. In **Table 3**, it can also be noticed that the substrates, i.e. food waste and green waste, in this study are composted at a relatively faster rate, i.e. 12 days.

3. Germination test

Several researchers indicate that the compost is mature when the final C/N less than 20 (Bernal *et al*. 1997; Huang *et al*. 2004; Iyengar and Bhave 2006). The C/N of the compost obtained in the in-vessel co-composting reactor was around 12 (**Table 3**), this ensures that the compost is mature and could be applied as soil conditioner or fertilizer. However, maturity of compost is not the only criteria for land application of compost, whereas it needs to pass the germination and heavy metal tests.

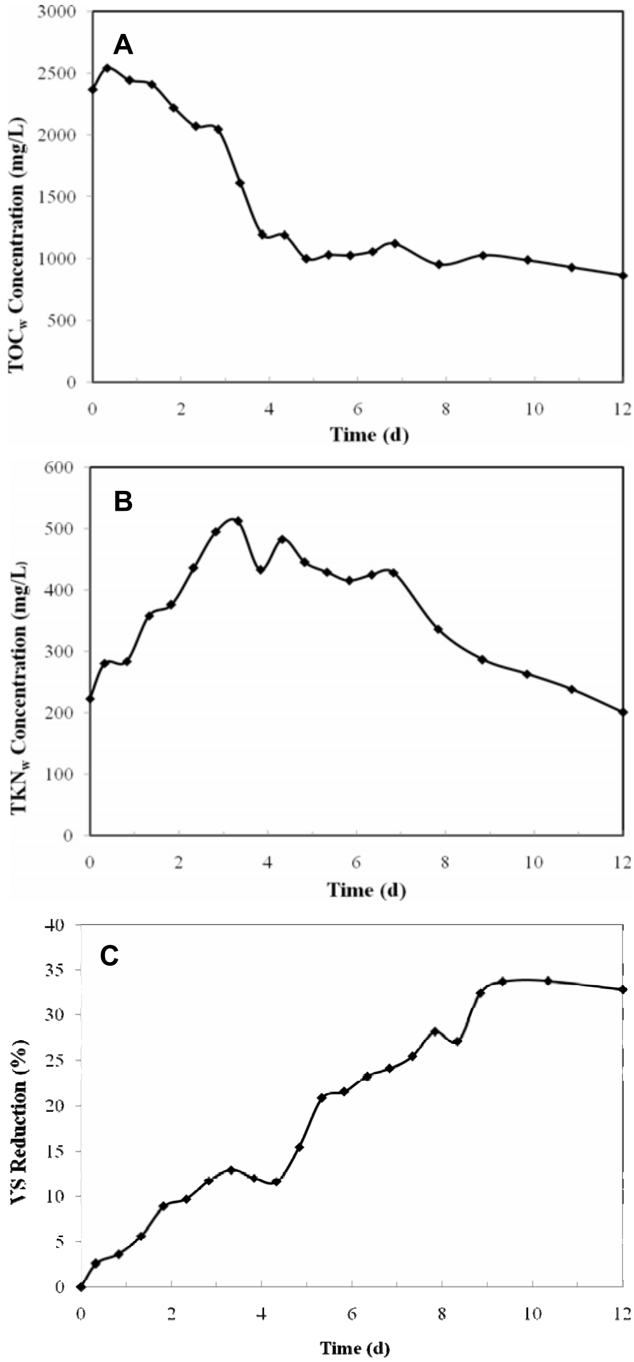

Fig. 4 Profiles of (**A**) TOC_W concentration (**B**) TKN_W concentration and (**C**) TVS reduction in the in-vessel reactor.

For the germination test, radish seed was chosen due to its sensitivity to phytotoxicity. The outcomes of germination test are shown in **Table 4**. The relative seed germination and root growth are 99.2% and 49.1%, respectively, and the calculated value of germination index was close to the suggested value of 60% for white radish (Diaz *et al*. 2003). On the other hand, poor relative seed germination (50.9%), root growth (16.4%) and GI (8.3%) values were observed when the germination test was repeated with the commercial compost extract purchased from the local market. In addition, the heavy metal concentrations in the compost were in compliance with the limitation of Taiwan and other countries. Therefore, the composting end product shows no phytotoxicity to plant growth.

Table 3 Comparison of the experiments outcome of this study with previous composting investigations.

Reference	Composting type	Automatic system	Composting materials	Moisture content (%)	Initial C/N	TVS eduction ratio (%)	Composting time (day)	Final C/N
Lu *et al*. 2008	In-vessel	Forced aeration + Agitator	Barley dregs + sewage sludge	55	-	24.0	3	-
Kim *et al*. 2007	In-vessel	Forced aeration	Food waste	58	24	11.0	30	17
Kim *et al*. 2007	In-vessel	Forced aeration	Swine manure	53	12.26	38.5	90	7.2
Chang *et al*. 2006	In-vessel	Forced aeration + Agitator	Food waste	55	35-40	29.0	4	55-60
Hoyos *et al*. 2002	Aerated static pile	Forced aeration	Waste sludge	72	30	20.0	56	20
Bernal *et al*. 1998	Aerated static pile	Forced aeration	Pig slurry + Poultry manure + sweet sorghum bagasse	60-75	24.1	20.0	112	11
This study	In-vessel	None	Food waste + green waste	60	19.6	31.5	12	12
This study	Windrow (Run-3)	None	Food waste + green waste	60	36	26	32	18

Table 4 Outcomes of germination test.

Parameters/Conditions	In-vessel system			Windrow-piles			
	Control	Final compost	Commercial compost	Control	Run-1	Run-2	Run-3
Total seeds	400	400	400	400	400	400	400
Germinated seeds	397	394	202	382	392	394	388
Mean root length (cm)	2.9	0.8	0.3	2.7	4.5	4.8	4.1
Relative seed germination (%)	-	99	51	-	103	103	102
Relative root growth (%)	-	49	16	-	167	178	152
Germination index (%)	-	49	8	-	171	183	154

Windrow composting

The effects of controlled seeding (i.e. fixed initial biomass seeding of 5 and 1% at regular intervals) and controlled watering (i.e. fixed initial moisture content and controlled moisture content over 40%) on co-composting of green waste and food waste were investigated through windrow-piles.

1. Temperature, moisture content and pH profiles

Fig. 5A shows the temperature profiles in the windrow piles. The temperature rose to over 66, 62 and 64°C on day 4 and the temperature decreased to less than 55°C on day 8, 10 and 13 in Run-1, Run-2 and Run-3, respectively. In the whole period of composting, the temperature was more than 55°C for 9, 12 and 14 days in Run-1 to Run-3, respectively. Comparing the temperature profiles of Run-1 to Run-3 demonstrate that the initial addition of WAS in Run-1 reached the highest temperature in a short time and more easily than other runs. The windrow temperature of Run-1, Run-2 and Run-3 at the end of 3 days were 62, 57 and 57°C, respectively. However, the addition of WAS in different intervals at 1% in Run-2 and Run-3 enriched the microorganisms and was also useful in maintaining the temperature above 55°C for a longer period, i.e. 12 days in Run-2 and 14 days in Run-3. Moreover, the windrow piles were turned and mixed at frequent intervals after the addition of WAS and moisture content. Interestingly, it was observed that the windrow pile temperatures dropped to ambient temperature immediately after each turning event; however, it returned to the thermophilic phase (above 55°C) within two subsequent days and maintained for a several days. Carcamo (1997) reported a similar observation while carrying out active and passive composting treatments in the winter season. Moreover, the ambient temperature is one of the important factors affecting the temperature in the windrow piles. The minimum air temperature recorded during the study was 16°C (at day 10); even under this lower temperature, the windrow piles showed a maximum temperature of around 50-55°C.

The profiles of pH and moisture content of the windrow piles are shown in **Figs. 5B** and **5C**, respectively. The pH profiles were almost similar in all the windrow piles. On the other hand, the moisture profiles were almost similar in Run-1 and Run-2 owing to the absence of moisture adjustment process. But the moisture content was not allowed to decrease less than 40% in Run-3 and it was adjusted 7 times during the whole composting period by sprinkling water on the surface of the windrow pile. Comparing **Figs. 5A** and **5C** indicate that controlled watering at 40% in Run-3 has increased the windrow performance compared to Run-1 and Run-2 especially in the final stages of composting (between days 20 and 26). The controlled moisture content throughout the study is helpful for easy mass transport of the organic substrates from the solid phase to the liquid phase and making the substrate readily available for the microbial metabolism. As a result of controlled moisture content, the temperature in Run-3 was maintained over 55°C for 14 days.

2. TOC_W, TKN_W and NH_4^+-N concentration profiles

The profiles of TOC_W, TKN_W and NH_4^+-N concentrations are shown in **Fig. 6**. The TOC_W concentration in Run-1 to Run-3 followed similar trends and showed a sharp decrease when the temperature reached the thermophilic phase. During composting, TOC_W loss in Run-1, Run-2 and Run-3 were 39, 76 and 78%, respectively (**Fig. 6A**). On the other hand, slight increase in TKN_W concentration was observed in the initial stage of composting, which could be due to the higher initial total nitrogen content in the composting mixture (**Fig. 6B**). During the thermophilic phase of Run-1 to Run-3, NH_4^+-N concentration increased slightly and then decreased steadily at the maturity stage. Bernal et al. (1997) recommended a maximum NH_4^+-N concentration of 40 mg/L for quality compost. The final NH_4^+-N concentration in Run-1, Run-2 and Run-3 were 117, 83 and 37 mg/L, respectively (**Fig. 6C**). This observation shows that the compost obtained in Run-3 could be applied for agricultural purposes.

3. Germination test

In all windrow-piles, temperature reached mesophilic phase (55°C) within 2 days and maintained over 8 days. Moreover, turning of windrow and the addition of moisture increased the temperature in all windrow-piles to certain extent. However, the windrow system operated at controlled seeding and watering showed better results. The properties of the final compost obtained in Run-3 of the windrow composting system are shown in **Table 3**. Besides, the compost samples collected from the windrow-piles are undergone standard germination test. As like the in-vessel system, white radish seed was chosen for the germination test. The outcomes of germination test are shown in **Table 4**. The

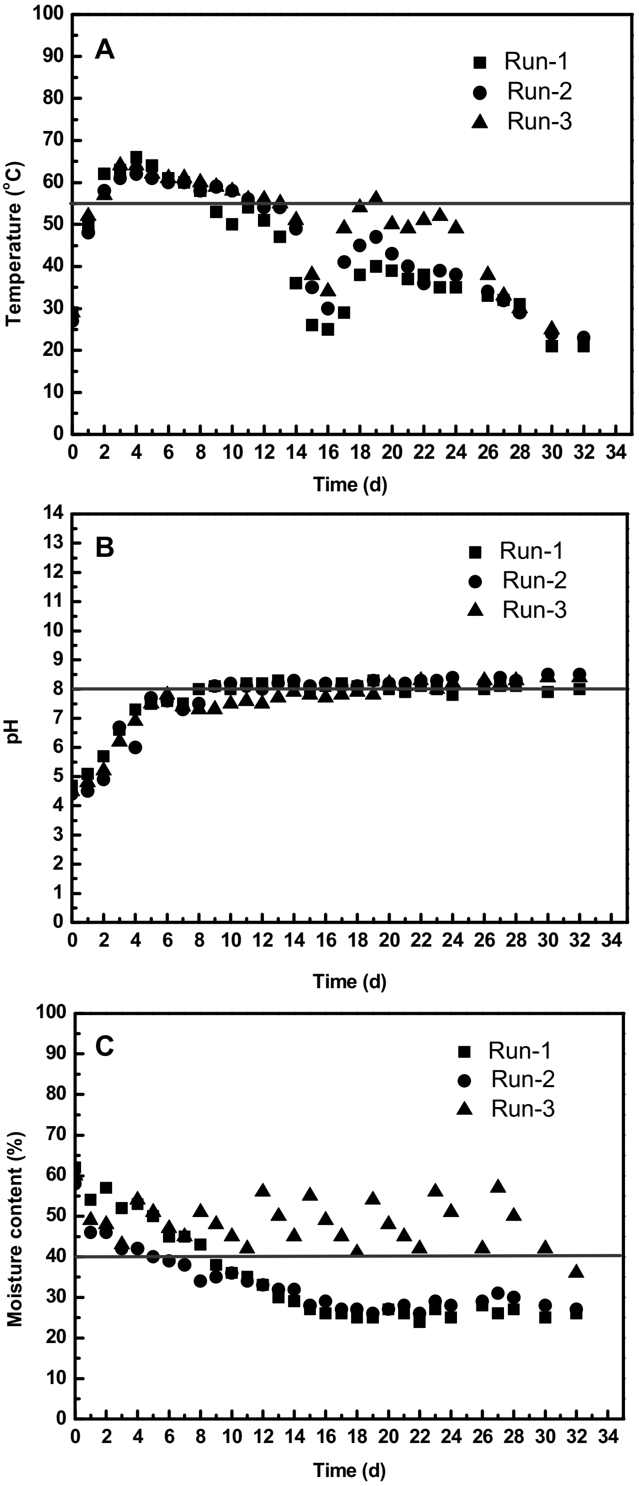

Fig. 5 Profiles of (**A**) temperature, (**B**) pH and (**C**) moisture content in the windrow piles.

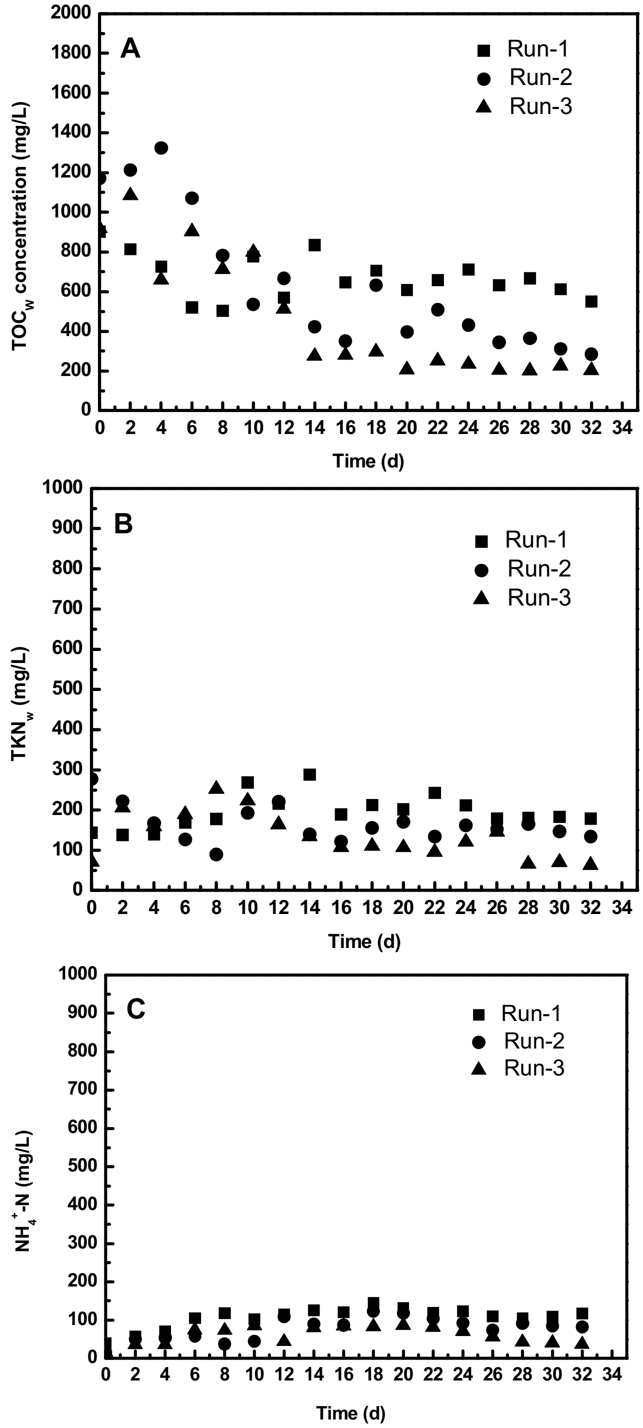

Fig. 6 Profiles of (**A**) TOC$_W$ (**B**) TKN$_W$ and (**C**) NH_4^+-N concentrations in the windrow piles.

relative seed germination of the compost samples from Run-1, Run-2, and Run-3 were 103, 103 and 102%, and root growth were 167, 178, and 152%, respectively. The corresponding values of GI were 171, 183 and 154%, respectively. A GI value of 50% has been used as an indication of phytotoxic-free compost (Zucconi *et al.* 1981), and a GI of more than 80% is considered for mature compost (Tiquia 2005; Kumar *et al.* 2010). Therefore, the compost obtained from all the windrow piles is free from phytotoxicity, which suggests that the compost could be used for agricultural purposes.

CONCLUSIONS

Food waste and green waste were rapidly decomposed in the in-vessel composting under low C/N. Adopting co-composting at low C/N could reduce the requirement of bulking agent for adjusting C/N. A high TVS reduction ratio (>30%) was observed in the in-vessel composting reactor. In windrow composting, the addition of WAS at different intervals was useful in maintaining thermophilic phase for a longer period. In addition, the controlled moisture content of the windrow piles could achieve easy mass transport of the organic substrates and also make the substrates readily available for the microorganisms. The compost obtained from both in-vessel and windrow systems passed the germination test and also in accordance with limits set for compost application in agricultural purposes. Therefore, both in-vessel and windrow composting systems could be adopted to obtain a useful end product from food waste and green waste. However, the choice of treatment is completely based on the size of wastes and the treatment conditions.

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