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Effects of bulking agents, load size or starter cultures in kitchen-waste composting

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Abstract

Background: To prevent the interruption of the carbon cycle by the disposal of waste to landfills, organic kitchen waste requires proper treatment such as composting to reduce its uncontrolled degradation on disposal sites and subsequent greenhouse gases, odour emissions and nutrient losses. This study investigated the effects of bulking agent, newspaper and onion peels, composting waste load sizes of 2 and 6 kg, or the use of starter culture on kitchen-waste composting consisting of nitrogen-riched substrates, vegetable scraps and fish processing waste in an in-vessel system. The optimised formulation of kitchen waste mixture was used for a 30-day composting study, where the temperature profiles were recorded and the carbon-to-nitrogen ratios were measured as an indication of compost maturity. The kitchen-waste composting process was conducted in parallel in two fabricated kitchen waste composters.

Results: It was found that the onion peels were more suitable in producing matured compost where the carbon-to -nitrogen ratio reduced to 10 within 16 days of composting. A smaller kitchen waste load size of 2 kg gave a shorter composting time by half when compared to the 6 kg. The use of a microbial cocktail consisting seven types of bacteria and eight types of fungi isolated from soils as a starter culture for this kitchen-waste composting did not show advantages in accelerating the composting process.

Conclusions: The results suggest that the in-vessel kitchen-waste composting can be efficient with a minimal load of about 2 kg using onion peels without additional starter culture.

Keywords: Newspaper, Onion peels, Kitchen waste, Composting, Starter culture

Introduction

Disposal of kitchen waste, which contains about 80% of moisture to the landfills, causes various problems like easy putrefaction, offensive odour and pollution of ground and surface water by leachate (Rogoshewski et al. 1983; Wang et al. 2001). Due to interruption of the carbon cycle by disposal of waste to landfills, organic kitchen waste requires proper composting system to reduce its uncontrolled degradation on disposal sites and subsequent greenhouse gases, odour and nutrient emissions (Luostarinen and Rintala 2007). In addition, kitchen waste may be wasted if it is just dumped to landfills as it will break up naturally and never be used directly again, having its nutritious matter lost within the waste. Therefore, a kitchen waste composter was designed to allow the composting process to be conducted in a consistent manner.

While people give attention to recycled inorganic wastes such as plastics, glass and metals, kitchen waste which is rich in organic material and possesses more than 90% of biodegradability can be easily recycled into compost (Veeken and Hamelers 1999). Composting of kitchen waste can be an effective method to reduce waste in landfills while helping conserve the environment. As kitchen waste is produced everyday and everywhere from processed and unprocessed food for human consumption, its composition is quite variable. An optimised kitchen waste formulation and composition involving the use of bulking materials, waste load size and presence of microbes are important in ensuring the commencement of an effective composting process (Fang et al. 2001; Ishii and Takii 2003; Cekmecelioglu et al. 2005; Stabnikova et al. 2005; Cayuela et al. 2006; Chang and Hsu 2008).

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Recognised bulking agents used for composting include sawdust (Sundberg and Jönsson 2005; Kalamdhad et al. 2008), rice hulls and chips of tree cuttings (Chikae et al. 2006), horticultural waste compost (Stabnikova et al. 2005) and mulch hay and wood shavings (Cekmecelioglu et al. 2005). Newspaper contains 9% of moisture content (MC) (Wayman et al. 1992) and 94% of volatile solids with lignin content of the volatile solids ranging from 16% to 22% (Sun and Cheng 2002), while the onion peels contain about 54% of volatile solids (Lubberding et al. 1988) with 1.5% dry weight of lignin (Suutarinen et al. 2003). Both can be suitable bulking materials in the composting of kitchen waste as they contain high carbon contents (Abdullah and Chin 2010). Newspaper is distributed throughout the land, in practically every house and building. The Malaysian Audit Bureau of Circulations reports that newspaper circulations have increased from 2005 to 2009, where the total of publications for the last 6 months of 2009 was 4,100,486 and 576,663 for West and East Malaysia, respectively. Onions are one of the major vegetables consumed in Malaysia (Kamil et al. 2010) and onion peels are the most common waste disposed in almost every kitchen. Among the three important constituents of plant cell wall material, the cellulose, lignin and hemicellulose, lignin is particularly difficult to biodegrade and reduces the bioavailability of the other cell wall constituents (Naik et al. 2012). The domination of different indigenous microorganism population at various stages of composting plays a distinct role in degrading lignin (Raut et al. 2008; Belyaeva and Haynes 2009; Huang et al. 2010).

Waste load size influences the temperature development during a composting process (Cayuela et al. 2006). It affects the achievement of the thermophilic phase where it is an essential stage for sanitation and killing all pathogens. Small heap sizes may not produce enough heat to reach the thermophilic phase, while too large heap sizes may prevent air passage into the centre which will paralyse the composting process (Cayuela et al. 2006). The windrow system requires a large heap to achieve the thermophilic stage. This fact is supported by Cekmecelioglu et al. (2005) who performed a composting process using about 11-m long, 2.5-m wide and 1.2-m high heap using conventional layering and mixing methods. Elsewhere, Sellami et al. (2008) have developed cone-shaped heap of 2-m high with a 3-m wide base for co-composting of exhausted olive cake, poultry manure and sesame bark. The other composting method using the in-vessel system requires a closed container, which is also known as a reactor to perform the composting process in small volume. This system can be placed inside or outside the building, as long as the substrates are protected from environmental effects and the process is under controlled conditions. Ishii and Takii (2003) found that smaller stacks are better for food-waste composting. A smaller scale of food waste progresses faster as food waste contains much more easily degradable compounds, and it takes a shorter time to turn into compost.

The application of starter culture has been found advantageous in composting especially for cellulosic waste, which is difficult to be broken down into smaller pieces (Volchatova et al. 2002). Its use is not a new practice for composting, where Wang et al. (2003) added a starter bacterial culture of *Bacillus thermoamylovorans* SW25 in composting mixtures of anaerobic dewatered sewage sludge and vegetable food waste. Although Fang et al. (2001) suggested that starter culture might assist in the composting process, Stabnikova et al. (2005) found that starter cultures are useless in food waste aerobic thermophilic bioconversion as sufficient air and thermophilic temperature ensure a quick composting process. The starter culture governs the process by reducing the accumulation of actinomycetes and fungi, which discharge allergenic spores into the air, and lowering the risk of harmful microorganism growth in the end product (Wang et al. 2003). Previous researchers have used *B. thermoamylovorans* SW25 (Wang et al. 2003; Stabnikova et al. 2005), cultures of three *Bacillus* species (such as *B. brevis*, *B. coagulans* and *B. licheniformis* (Fang et al. 2001)), and a specially developed association of microorganism (Volchatova et al. 2002) in their composting studies.

The objectives of this work are to study the effects of two common bulking media, newspaper or onion peels with compost load sizes of 2 and 6 kg and the use of starter culture in kitchen-waste composting consisting of vegetable scraps and fish processing waste using an optimised formulation using the in-vessel system.

Methods

Composting material preparation

The main composting substrates were vegetable scraps from spinach (*Spinacia oleracea* L.) and fish processing waste of Indian mackerels (*Rastrelliger kanagurta* C.). Newspaper and onion peels were chosen as they are easily available bulking agents, can act as moisture adjuster due to their low moisture content and have high cellulose content, which can be a good source of carbon. The characteristics of both waste and bulking agents in terms of its percentage of moisture, carbon and nitrogen contents, and the values of the carbon-to-nitrogen (CN) ratio have been measured in an earlier study (Abdullah and Chin 2010) and are given in Table 1.

Kitchen waste composter design

As kitchen waste which contains very high moisture is difficult to be self-heated up to 45°C, two self-designed

Table 1 Percentage (%) of moisture, carbon and nitrogen content, and CN ratio (Abdullah and Chin 2010)

Substrates	Moisture content (%)	Carbon content (%)	Nitrogen content (%)	CN ratio
Vegetable scraps	93.32 ± 0.33	37.87 ± 1.14	2.94 ± 0.14	12.87 ± 0.24
Fish processing waste	75.83 ± 0.43	42.60 ± 1.73	8.14 ± 1.24	5.30 ± 0.61
Newspaper	6.50 ± 0.32	50.56 ± 0.02	0.18 ± 0.01	288.15 ± 13.36
Onion peels	11.69 ± 0.22	50.27 ± 0.63	0.83 ± 0.01	60.91 ± 1.82

Percentage and CN ratio are in mean and standard deviation.

kitchen waste composters which included features for temperature and moisture content control were fabricated to allow parallel experiments to be conducted consistently (Figure 1). The kitchen composter consists of three parts, which are the perforated cover, the body and a collector of water and end product. All parts were made from stainless steel 304, except for its transparent window made of polycarbonate that is a heat-resistant plastic for convenient viewing of the waste inside the composter. The external part of body and the perforated cover were insulated using cloth to minimise heat loss. A 25-W bulb was attached to the perforated cover to provide heat internally. The opening at the top allows feeding of fresh waste, and the small holes in the perforated cover allow air movement to maintain an aerobic process. The long L-shaped handle on the top is for manual turning of the mixer blade to aerate and homogenise the sample. The blades were slanted 5° in opposite directions to keep a good blending by moving the mixture up and down. The two side handles at the body of the composter aid the rotation of the body up to 360° when collecting end products. A collector tray was inserted below the body to collect the leachate water or end product. Between the body and the collector, there was a medium hole to collect the end product and many tiny holes to allow excessive water draining.

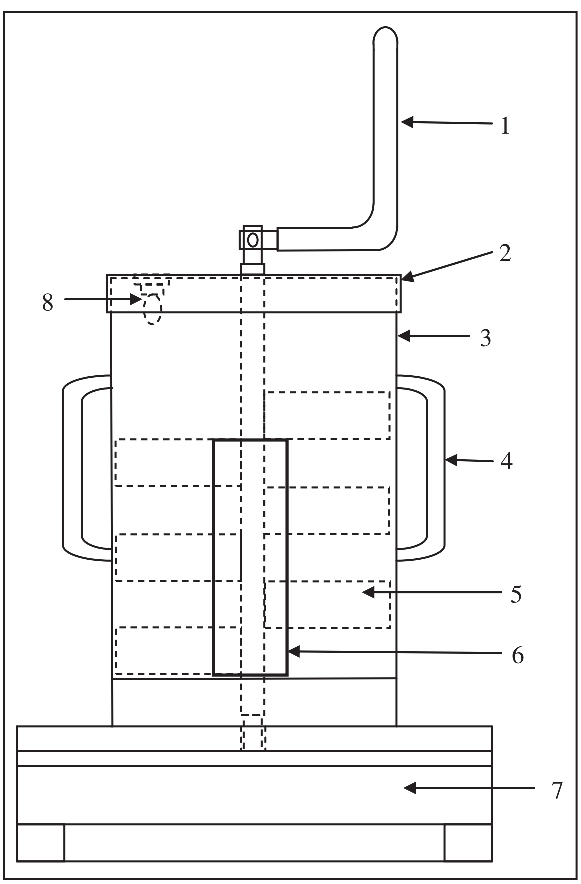

Figure 1 Schematic diagram of the designed kitchen waste composter. 1 = Turner's handle, 2 = perforated cover, 3 = body, 4 = handle, 5 = blade, 6 = window, 7 = tray, 8 = light.

Composting and sampling

The optimised mixture formulation for kitchen-waste composting was referred from Abdullah and Chin (2010) following the fixed CN ratio of 30 and MC of 60%. Table 2 shows the amounts of substrate compositions for investigations on bulking agents, load size and use of starter culture. All substrates were weighed using a scale (SSB12001, Mettler Toledo, Switzerland), then mixed manually in a basin before loading into the composter.

Table 2 Amount of substrate compositions used in each experiment

Substrates	Amount (g)	
	Composter 1	Composter 2
Bulking agents	Newspaper	Onion peels
Vegetable scraps	971	880
Fish processing waste	355	395
Newspaper	675	0
Onion peels	0	725
Load size	2 kg	6 kg
Vegetable scraps	880	2,641
Fish processing waste	395	1,185
Onion peels	725	2,174
Starter culture	With	Without (control)
Vegetable scraps	2,641	2,641
Fish processing waste	1,185	1,185
Onion peels	2,174	2,174

The composting was conducted simultaneously using two composters for each experiment. The first experiment was the comparison of the effectiveness of the bulking media, i.e. between the newspaper and onion peels at 2-kg load size. After finding that the onion peels were more effective in composting, they were used at two load sizes, 2 and 6 kg, before further investigation on the effect of presence of starter cultures using 6 kg of kitchen waste. Each compost cycle was for 30-days, and the composters were placed in a laboratory at 27 ± 5°C. The composts were also turned and mixed in the composters each time after sampling to prevent shortage of oxygen pore required for aerobic composting. The pipe water sprayed onto the composting substrates inside the composters to maintain an MC of 60% was left overnight before use to reduce its chlorine content. Samples were taken on days 0, 1, 4, 8, 10, 16, 23 and 30 of the composting period. The bulb in the composter was switched on to help the composting material to achieve the thermophilic temperature of 45°C and until the compost temperature stabilised towards the end of the composting process where the CN ratio reduced to less than 15 or the compost reached the matured stage.

For composting with added starter culture, a solution of bacteria from *Aeromonas* sp., *Azotobacter* sp., *Bacillus* sp., *Clostridium* sp., *Pseudomonas* sp., *Thermomonaspora* sp. and *Trichurus* sp., and eight plates of fungi from *Aspergillus* sp., *Cellulomonas* sp., *Chaetomium* sp., *Coprinus* sp., *Microbispora* sp., *Penicillium* sp., *Thermoactinomyces* sp. and *Trichoderma* sp. were provided by the Biotechnology Research Centre, Malaysian Agricultural Research and Development Institute. This microbe cocktail was formulated after considering the functions of each microorganism isolated from soil. The *Bacillus* sp., *Clostridium* sp., *Pseudomonas* sp., *Aspergillus* sp., *Cellulomonas* sp., *Chaetomium* sp., *Penicillium* sp. and *Trichoderma* sp. play important roles in degrading cellulose and other carbohydrates (Bhatt and Kausadikar 2010). Proteins are degraded to individual amino acids mainly by fungi, *Actinomycetes*, *Bacillus* sp., *Clostridium* sp. and *Pseudomonas* sp. (Bhatt and Kausadikar 2010). Bacteria like the *Pseudomonas* sp., *Clostridium* sp. and *Bacillus* sp. and fungi like *Trichoderma* sp., *Penicillium* sp. and *Aspergillus* sp. help degrade toxic chemicals and pesticides into non-toxic substances, thus minimising any damage caused by harmful chemicals to the ecosystem (Bhatt and Kausadikar 2010). Both bacteria and fungi were mixed using a kitchen blender (PB-323 T, Pensonic, Malaysia) before being sprayed onto the waste in composter 1 on day 1 of composting. This is to allow the waste inside the kitchen waste composter to stabilise and so that the starter culture could easily adapt to the surroundings inside the kitchen waste composter and perform good composting activities.

Analytical methods

During the 30-days of kitchen-waste composting, the progression of temperature and MC (Abdullah and Chin 2010) were determined. The temperature was measured at 50% depth from the surface of compost materials at four different positions. In assessing the maturity level of the compost, the CN ratio was determined. The content of the volatile solids was calculated after measuring the ash content using the dry ashing method to obtain the total organic carbon (TOC) content (Abdullah and Chin 2010). The total nitrogen content was measured using the micro-Kjeldahl method (Mohee et al. 2008; Unmar and Mohee 2008), where the digested sample was distilled with 45% sodium hydroxide and 2% boric acid, and titrated with 0.05 N sulphuric acid until neutral; the same procedure was repeated for the blank sample. The CN ratio was calculated by dividing the TOC content with the total nitrogen content. All the analyses were conducted on samples collected using a standard sampling method, except for temperature measurements which were performed *in situ*.

Statistical analyses

All samples were analysed in triplicates, except for the temperature measurements, which were repeated four times. The averages and standard deviation of the means as the error bars were calculated using Microsoft Excel 2007 (Vista Edition, Microsoft Corporation, USA). Statistical analyses were made using statistical analysis software (SAS 9.2, SAS Institute, Inc., USA). The data were subjected to one-way analysis of variance (ANOVA), generalised linear model (GLM) and Duncan's multiple range tests (DMRT) at alpha level, $\alpha = 0.05$. ANOVA was implemented to all parameters, except for those data with unbalanced sample size and missing data using the GLM statistical analyses. Where significant differences were obtained giving $p < 0.05$, individual means were tested using the DMRT to compare the significant difference between the two treatments means, i.e. newspaper blend with the onion peels blend, 2 kg with 6 kg of load size and starter culture with control.

Results and discussion

In general, the MC of the compost increased with time due to vaporisation and the trapped moisture loss inside the composter. The values were still acceptable as long as the air supply in the compost mass is sufficient in keeping the microbes alive (Unmar and Mohee 2008). The pH of the waste mixture for all treatments increased up to 9 from acidic conditions through the 30-days of composting, while the electrical conductivity (EC) increased and was in the range of 3 to 6 dS/m. The EC was low at the thermophilic temperature because a high amount of nutrients that were ingested by the microorganisms made the nutrients insoluble in water and consequently produced a low salinity. With colour measurements, the blend with onion peels became black more rapidly than the blend with newspaper ($p < 0.0001$), showing the colour of matured and stable compost. The waste compost colour changes to black in the 2- and 6-kg load sizes, and both mixtures with and without starter culture were not significantly different with $p = 0.2031$ and $p = 0.8383$, respectively. There were no clear trends in the all microbial numbers due to a diverse microbial community in the organic waste, which comply with the reports by Sundberg et al. (2004) who believed that the temperatures affected the active microbial numbers.

Temperature profiles

Figure 2 illustrates the temperature profiles showing typical phases of a composting process for investigations using bulking agents of newspaper and onion peels, investigations of load sizes at 2 and 6 kg, and use of starter culture during a 30-day kitchen-waste composting process. The temperature profiles displayed quite similar patterns for all composting batches where it increased at the early stage before decreasing gradually. For the first 24 h in Figure 2a, the compost with newspaper was self-heated from 26.7°C to about 39.2°C, while the blend with the onion peels was self-heated from 30.3°C to about 44.9°C. The temperature change in onion peels blend during composting followed a typical pattern displayed by many other composting system, i.e. organic fraction of municipal solid wastes, raw sludge, anaerobically digested sludge, animal by-products from slaughterhouses and partially hydrolysed hair from the leather industry (Pagans et al. 2006), co-composting of exhausted olive-cake with poultry manure and sesame shells (Sellami et al. 2008), green leaves, green branches, grass, brown branches and brown leaves Unmar and Mohee (2008), and co-composting of green tea waste and rice bran (Khan et al. 2009). The newspapers, however, did not assist the compost to achieve thermophilic temperature of 45°C. The temperature of the compost with the onion peels rose to 51.3°C on day 4 and dropped sharply to 44.1°C on day 7. It stayed in the thermophilic phase for about 3 days. The temperature decrease is probably due to the excessive loss of compost volume, and when the compost moves into the cool phase, it produces stable compost. The average temperature of the two composts with different bulking agents, newspaper and onion peels was significantly different at $p < 0.0001$ when compared with ambient temperatures. The DMRT resulted greater mean of temperature in compost with onion peels, followed by compost with newspaper and ambient temperature.

Both compost load sizes at 2 and 6 kg using onion peels as shown in Figure 2b present a quite similar temperature trend with compost using food waste, manure and bulking agent mixture by Cekmecelioglu et al. (2005). The composting started with mesophilic temperature, continued to thermophilic temperature and then drop to ambient temperature. During the first 24 h of composting, the temperature of the waste rose 17.5°C for the 2-kg load and 8°C for the 6 kg. The 6-kg load contained more carbon to be degraded compared to the 2 kg; thus, it was observed that the 2-kg load has entered

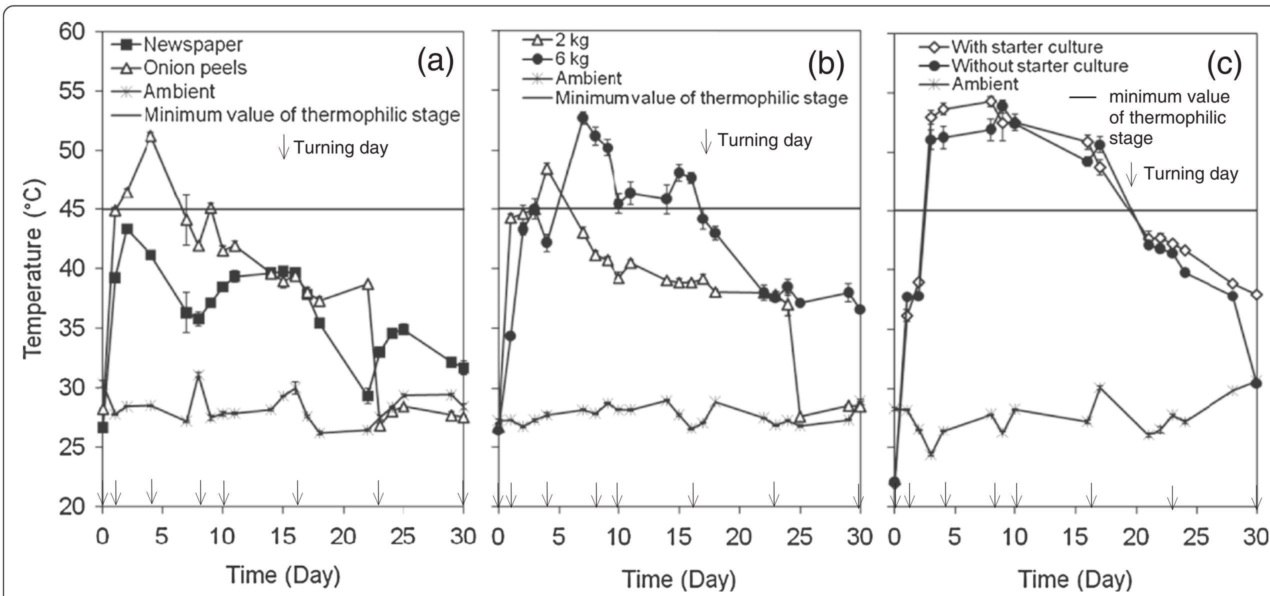

Figure 2 Temperature profiles of the compost. (**a**) With blends of newspaper or onion peels at 2-kg load size, (**b**) at 2- or 6-kg load size both with onion peels, and (**c**) with or without starter culture both at 6-kg load size using onion peels.

the mesophilic stage 10 days earlier than the 6 kg, on day 6 and 16, respectively. The temperature fluctuations observed during the composting process were because of the turning and watering activities. The 6-kg load size has a higher mean of temperature followed by 2-kg load size and ambient temperature.

Figure 2c shows that the temperatures of the composts with added starter culture and control increased quickly to thermophilic temperatures of 53°C and 51.1°C, respectively, on day 3 of composting due to the compost load size. The presence of an active microbial community also helps start the degradation process immediately and reduces the particle size (Sundberg and Jönsson 2005). The thermophilic phase of both composts lasted for a long period of 17 days, probably due to the availability of easily degradable organic matter, energetic compounds (like protein) and large amounts of organic nitrogen in the waste (Pagans et al. 2006). With a large amount of waste, the high thermophilic temperatures worked on breaking down the proteins, fats and complex carbohydrates like cellulose and hemicelluloses. The compost with added starter culture achieved the highest temperature of 54.3°C on day 8, which is slightly higher and one day earlier than the control (53.8°C on day 9). The temperature of the mixtures began to decline on day 8 for mixture with starter culture and day 9 for control, probably due to convective loss (Palmisano et al. 1993) and a higher amount of readily degradable carbon. At the end of the process, heat was released progressively, causing the temperature for both mixtures to decrease and tended to meet the ambient temperature. This tendency was found with composting fish offal in reactors (Laos et al. 2002) and composting of green tea waste and rice bran (Khan et al. 2009), which implied that the rapidly degradable organic matter had been reduced (Sundberg and Jönsson 2005). The average temperatures of the compost with added starter culture and the control were not significantly different from the DMRT results.

Degradation rate progression

Figure 3 illustrates the decreasing trends of volatile solids content during the 30-day composting period. All three figures were comparable with the findings of Cekmecelioglu et al. (2005) in terms of volatile solids content. Unmar and Mohee (2008) considered that the volatile solids are a good indicator of how biological degradation occurred over time. Figure 3a shows that the initial volatile solids contents for both blends (onion peels and newspaper) were the same at 85%. The final volatile solids in compost with onion peels then reduced to 60.9% compared to the newspaper at 76.1%, indicating that onion peel compost had a higher degradation as it contained higher amounts of biodegradable matter. The calculated percentage of volatile solids loss for blend with newspaper was only 9.98% compared to 28.3% for blend with onion peels. The volatile solids of both blends were significantly different at $p = 0.0004$, with onion peels having lower means compared to the newspaper. Figure 3b presents that the percentage of volatile solids loss for the 2 kg was higher than that of the 6 kg, at 24.5% and 21.4%, respectively. These findings were lower than those of Cekmecelioglu et al. (2005) who discovered that the percent volatile solids loss of food waste in various windrow systems was in the range of 32.6% to 52.6%. The means of volatile solids content of the two load sizes were significantly different at $p = 0.0427$, where the 2-kg load size contained lower volatile solids than the 6 kg. With the same volatile solids contents of 87%, the compost with added starter culture attained a higher volatile solids loss of 22.5% compared to the control at 21.7% (Figure 3c). The starter culture could have been involved in degrading the materials slightly faster, although the average values between the two types of composts were not significantly different at $p = 0.4511$. This is because the starter culture serves as an inoculum, increasing bacterial density and perhaps reducing lag phase duration.

Compost maturity evaluation

The CN ratio is an accurate indication of compost maturity (Gray et al. 1971; Chanyasak and Kubota 1981; Jimenez and Garcia 1989). In these kitchen-waste composting studies, the TOC content in the compost material reduced arbitrarily higher than the reduction of total nitrogen contents resulting in a corresponding reduction of CN ratio as composting proceeds. The carbon provides the primary energy source for microbial metabolism, and nitrogen is critical for microbial population growth (Stoffella and Kahn 2001).

Figure 4a shows that the TOC content of the onion peel blend decreased to 28%, while the newspaper blend was at 10% over the 30-day period. The reduction of TOC is mainly because of the mineralisation process (Grigatti et al. 2004), a process where microbes employ organic matter and leave behind inorganic substances such as minerals, carbon dioxide and water. The blend with onion peels was prone to a higher mineralisation than the blend with newspaper because newspaper contains cellulose fibres sheathed in lignin, which is a compound found in wood with highly resistant to biological degradation (Trautmann et al. 1996). In addition, the thermophilic bacteria ($p < 0.0001$) and the thermophilic fungi ($p = 0.0002$) were governing the blend with onion peels, as they help accelerate the composting. In the blend with newspaper, the mesophilic fungi ($p < 0.0001$) was dominating the 30-day period of composting, which indicates that the mineralisation is low and takes a longer time for composting. The nitrogen content for the

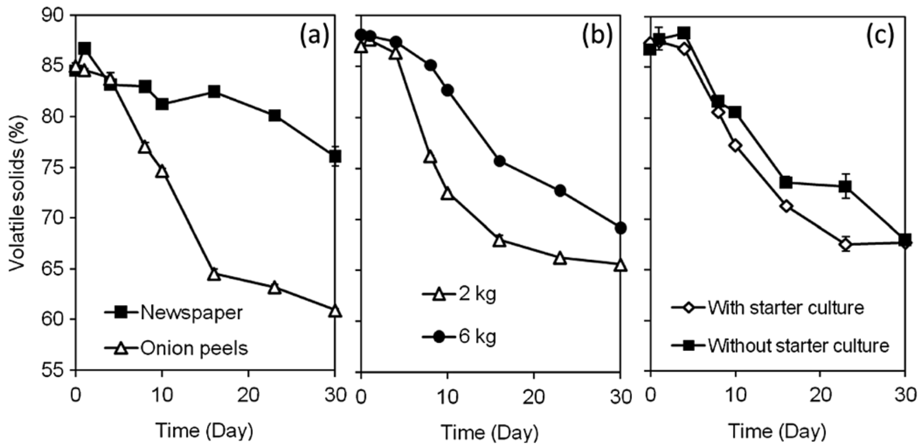

Figure 3 Volatile solids of compost. (**a**) With blends of newspaper or onion peels at 2-kg load size, (**b**) at 2- or 6-kg load size both with onion peels, and (**c**) with or without starter culture both at 6-kg load size using onion peels.

newspaper blend fluctuated at the range of 0.8% to 1.3%, while the onion peels increased to 4.2%. Both average carbon and nitrogen contents were significantly different with $p = 0.0004$ and $p < 0.0001$, respectively, with DMRT results showing lower carbon content and higher nitrogen content for the blend with onion peels. The resulting CN ratio in Figure 4c shows that the blend with newspaper underwent a slow composting process with its CN ratio value reduced to 37.04 compared to the blend with onion peels with a CN ratio of 8.15 after 30 days. Benito et al. (2006) stated that a CN ratio between 14 and 24 would be ideal for ready-to-use compost. For these reasons, the final products compost with onion peels were ready to be used on day 8 due to its CN ratio of 16.2, but the blend with newspaper needed more time for decomposition activity. The means of CN ratio for both blends were significantly different ($p < 0.0001$), with the onion peel blend having lower means of CN ratio than the newspaper. The initial increase in CN ratio of the newspaper blend could be due to the incomplete degradation process, and it did not reach thermophilic temperatures.

For load size studies, the 2-kg compost had lower TOC content and higher nitrogen content than the 6 kg (Figure 5a,b). The CN ratio of the 2-kg load increased slightly after 24 h before dropping rapidly to 10.94 on day 10 as compared to the 6 kg which required 30 days to reach a CN ratio of 10.15 (Figure 5c). The 2-kg load size decomposed more quickly compared to the 6-kg load size. The final CN ratio of the 2- and 6-kg loads was 9.22 and 10.15, respectively. They were considered matured and suitable to be applied to soil based on the study of Shiralipour et al. (1992) who have identified that if the CN ratio is less than 30, it will help crop production with its microbial mobilisation. Molnar and Bartha (1988) believed that a stable and high quality compost has a CN ratio in the range of 15 to 17. Hence, it was suggested that

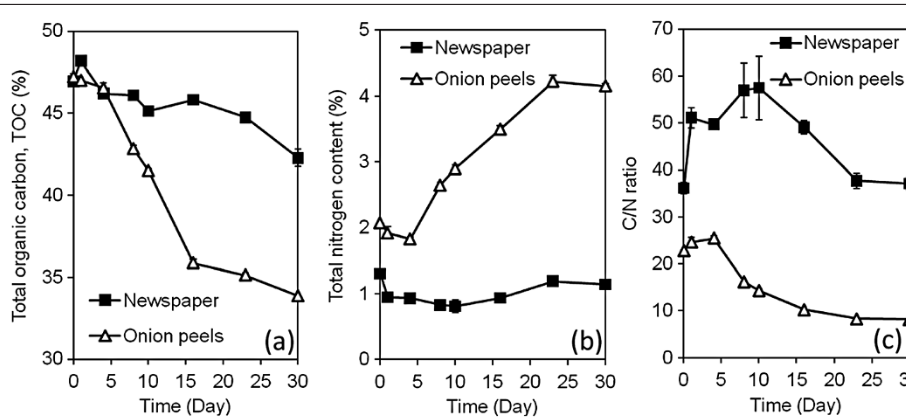

Figure 4 Composting using different blends of bulking media, newspaper or onion peels at 2-kg load size. (**a**) TOC, (**b**) nitrogen content and (**c**) CN ratio profiles.

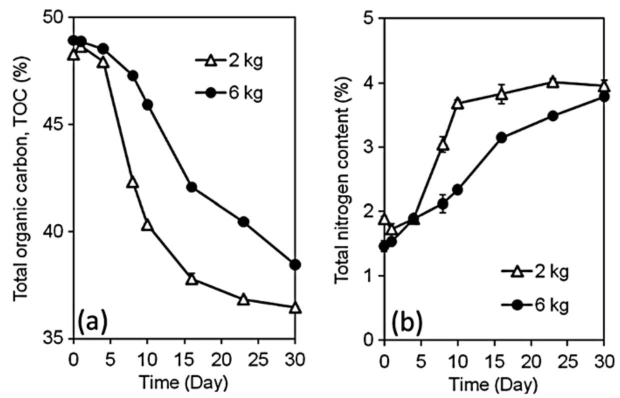

Figure 5 Composting using different load size of 2 or 6 kg with onion peels. (**a**) TOC, (**b**) nitrogen content and (**c**) CN ratio profiles.

the end product of the 2-kg load size can be collected on day 8, half the time of the 6-kg load size on day 16. The means of the TOC content for the 2- and 6-kg load sizes were significantly different with $p = 0.0427$. The means of the total nitrogen content and CN ratio between the 2- and 6-kg load sizes, however, were not significantly different at $p = 0.0533$ and $p = 0.0701$, respectively.

Figure 6 shows that the mixture with added starter culture and control have no significant difference in terms of TOC content ($p = 0.4512$), total nitrogen content ($p = 0.9183$) and CN ratio ($p = 0.8158$). The starter culture has just a slight influence on the reduction of TOC due to the presence of microbial growth, although thermophilic temperatures do increase the level of carbonaceous material (Ginnivan et al. 1981). The microbial growth caused a carbon substrate limited condition even though the thermophilic temperatures could increase the level of carbon. The compost with added starter culture had lower nitrogen contents before day 10 and higher nitrogen contents after day 10 when compared to the control. The presence of microbes could have accelerated the decomposition activities in the beginning of the composting process. At the early composting stage, the mesophilic bacteria dominated the control up to 9 log colony-forming unit (CFU)/g, while the thermophilic bacteria dominated the mixture with added starter culture up to 13 log CFU/g. Both the TOC and nitrogen contents of the compost with added culture and control reached similar values at the end of composting. The decrease in CN ratio generally is explained by the bigger loss of TOC to produce carbon dioxide and smaller increase of nitrogen content as the decomposition progressed. The decreasing pattern of the CN ratio and TOC, and the increasing pattern of nitrogen content were similar to the findings of Goyal et al. (2005) on sugarcane trash, cattle dung, press mud, poultry waste and water hyacinth composting. The slight nitrogen losses of the control on day 10 which caused the slight CN ratio increase was due to nitrogen losses in the form of ammonia. This interpretation is consistent with Goyal et al. (2005) who found that nitrogen losses during ammonia volatilisation caused the increase of the CN ratio. The compost with added

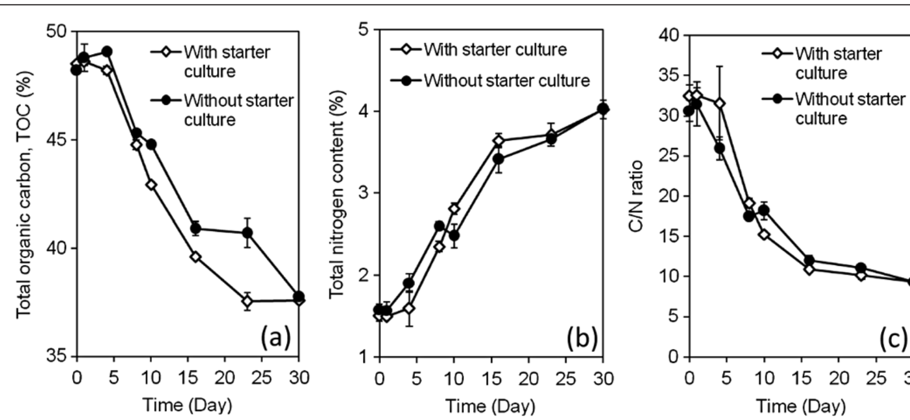

Figure 6 Composting using microbial treatments at 6-kg load size using onion peels. (**a**) TOC, (**b**) nitrogen content and (**c**) CN ratio profiles.

starter culture and control both possessed quite similar CN ratio of 9.33 and 9.35, respectively, which are less than 12 and in the range of acceptable degree of maturation (Bernal et al. 1998; Paredes et al. 2005). The optimum CN ratio of 10 has been suggested by Pöpel and Ohnmacht (1972) for the complete oxidation of the waste by aerobic bacteria.

Conclusions

The onion peels were more suitable; at a smaller waste load, compost maturity with CN ratio below 10 was attained more quickly. The larger compost load size plays a vital role to achieve higher temperature. However, the lack of oxygen may have influenced the loss of volatile solids, and the lack of ventilation certainly influenced the loss of nitrogen by ammonia volatilisation when the maximum volume for the reactor, which is 6-kg load size, was used. No apparent differences were found in compost with added starter culture. The kitchen-waste composting process is said to require no additional microbes as accelerant, although it did help to achieve a slightly higher thermophilic temperature during the early stage of composting.

Abbreviations

ANOVA: analysis of variance; CFU: colony-forming unit; CN: carbon-to-nitrogen ratio; DMRT: Duncan's multiple range tests; EC: electrical conductivity; GLM: generalised linear model; MC: moisture content; TOC: total organic carbon.

Competing interest

The authors declare that they have no competing interests.

Authors' contributions

NA designed and performed the experiments, as well as collected, analysed and interpreted the data. NA also wrote the manuscript and finalised its format. NLC was the leader of the research project, contributed to the conceptual design of the composter and helped improve the content and writing of the manuscript. MNM and FST contributed to the interpretation of data. All authors read and approved the final manuscript.

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