Effect of initial material bulk density and easily-degraded organic matter content on temperature changes during composting of cucumber stalk

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A B S T R A C T

To inactivate the potentially pathogenic microorganisms and safely utilize vegetable waste compost, ultra-high temperatures (≥70°C) should be maintained during the composting without having an inhibitory effect on maturity. This study investigated the influence of bulk density (part 1) and easily-degraded organic matter content (EDOMC, part 2) on temperature evolution during vegetable waste composting: Part 1: corn straw with different particle sizes was used to achieve different bulk densities in the composting material (BD1–BD3); Part 2: partial or total substitution of the corn straw by corn starch was carried out to obtain different EDOMC (ED1–ED4). The composting experiments were conducted in a lab-scale reactor (1.75 kg material) and lasted for 30 d. Temperature and CO₂ emission were recorded daily, and the organic matter, lignocellulose, microbial activity, germination index (GI) and C/N of the samples were measured at different stages. The highest temperature (65.7°C) in part 1 occurred in the treatment with the bulk density of 0.35 g/cm³, which also had the longest thermophilic phase. Bulk density was found to seriously influence the utilization efficiency of O₂ and heat transfer through materials, rather than heat production from organic matter degradation. In experiment part 2, the highest temperature was obtained with EDOMC of 45% (71.4°C). Therefore, adjusting the bulk density to 0.35 g/cm³ and the easily-degraded organic matter content of the initial material to 45% was the best combination for reaching temperatures above 70°C during composting, with no inhibitory effect on the maturity of the compost product.

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Introduction

According to FAO reports, both the cultivated area and production of vegetables in China are higher in comparison with other countries in the world. In China, the vegetable production was 760 million tons in 2014 (National Bureau of Statistics of China, 2015), which kept rapidly increasing year by year. It was estimated that more than 350 million tons of vegetable wastes are produced during the process of plant growth, harvest, production and sale, according to the ratio of grain to straw (Xi et al., 2010). These wastes could help to control soil erosion and replenish soil nutrients when left on the soil, but could also be...
harmful for the environment if used without proper treatment. Composting is such a proper treatment (McMahon et al., 2008; Huang et al., 2010), which can form a stabilized final product, free of phytotoxicity and pathogens and with certain humic properties, through an economical and environment-friendly biological process of aerobic thermophilic microbial degradation of wastes (Albrecht et al., 2010; Wei et al., 2014; Zhao et al., 2017). Composted organic wastes can also be utilized as soil amendments, and are fully compatible with sustainable agriculture. Because recycling of vegetable wastes through composting technology for agricultural utilization can improve the quality of crops (Eusuf Zai et al., 2009; Das et al., 2011), it has become a strong trend in most countries recently. However, vegetable wastes normally have high moisture content, low C/N ratio and many potential pathogens such as fungal pathogens (like Botrytis cinerea), bacterial disease (like black rot) (Wang et al., 2014), or viral diseases (like Cucumber mosaic virus) (Bhargava, 1951). In order to inactivate the pathogenic microorganisms in the vegetable wastes, especially viral pathogens like cucumber mosaic virus, which might cause great damage for many plants (Bhargava, 1951), the temperature for vegetable waste should be ≥70°C for more than 25 min (Bhargava, 1951; Day and Shaw, 2001). To resolve these problems, different sources of organic carbon (such as rice straw, sawdust and branches) have been used to increase the C/N ratio and to provide suitable free air space (FAS) for proper aeration of the compost (Chang and Chen, 2010; Iqbal et al., 2010), due to FAS being closely related to the bulk density (Agnew and Leonard, 2003; Ahn et al., 2008; Mohee and Mudhoo, 2005), in some cases establishing empirical equations for FAS calculation. However, to reach the goal of ultra-high temperature in the composting process, sufficient biodegradable organic matter is also needed for heat production by microbes, so that the easily-degraded organic matter content should also be considered. Even lignocellulose has presented more advantages than inconveniences: for example it does not produce odors, and usually has good physical properties and low concentrations of potentially toxic elements and other pollutants (Mondini et al., 2006).

The objective of this study is to examine the influence of the bulk density and easily-degraded organic matter content of material consisting of cucumber stalk mixed with carbon conditioners on temperature changes during the composting process, and to verify the influence of ultra-high temperature on compost maturity.

1. Material and methods

1.1. Compost material and experimental design

The experiment was conducted in the lab of China Agricultural University. The bench-scale compost system (Fig. 1) used in this study was designed to simulate the temperature (50°C), moisture (60% wet weight basis), and forced ventilation (0.1 L/min) of the composting process, which could be vulnerable to external effects (e.g., heat loss) (Michel and Reddy, 1998; Meng et al., 2016). Temperature probes were set inside the tanks, connected with a temperature recorder (Type: L93-4L, Shanghaihuatai Equipment Company, China). The experiment, consisting of two parts (part 1 and part 2), was carried out in a temperature controlled incubator set at 50°C, using composting reactors (capacity 5 L, material weight 1.75 kg), and the experiment lasted for 1 month. Part 1: three treatments were carried out with mixtures of cucumber stalk and corn straw (the corn straw was broken into different particle sizes and then mixed with the cucumber stalk), to provide a range of bulk density (BD1: 0.30 g/cm³; BD 2 :0.35 g/cm³; BD 3 :0.4 g/cm³) by controlling the material weight and volume; Part 2 investigated carbon conditioner mixtures of corn straw and starch at different proportions (1:2, 2:1 and only starch), to provide a range of easily-degraded organic matter content (ED1: 27%; ED2: 36%; ED3: 45%; ED4: 51%) with the same bulk density (0.35 g/cm³) that had been proven to be most useful for cucumber stalk composting. The characteristics of different materials are presented in Table 1.

1.2. Sampling and chemical analysis

For the gas samples, CO₂ produced during composting was trapped by bubbling the exit gas through a solution of NaOH; the amount of CO₂ in the traps was determined by titration with standard H₂SO₄ as described by Michel and Reddy (1998). Samples were collected at 0, 1, 3, 6, 10, 15, 21, and 30 days of the composting process. The material in each reactor was
mixed well prior to sampling. For each sampling procedure, approximately 100 g of material was collected from each reactor. The samples were thoroughly mixed and then divided into two parts: one part of the samples was air-dried for determination of physicochemical characteristics: total organic matter, total carbon, total N and lignocellulose. Total organic matter was determined by weight loss on ignition of dried ground samples at 450°C. The total C and N were calculated with the methods described in Chinese national standard NY 525–2012. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were analyzed using an ANKOM 200 fiber analyzer (Ankom Technology, United States).

The proportion of hemicellulose was calculated from the difference between NDF and ADF, and lignin was calculated from the difference between ADF and cellulose. The data were expressed with respect to ash content, to avoid the effect of weight loss during composting on the relative concentrations.

The other part of the samples was stored in the refrigerator at −20°C for determination of biological parameters: germination index (GI) and microbial activity.

The germination test was run using seeds of Raphanus sativus L., and the GI was calculated as described by Zucconi and De Bertoldi (1987):

\[
GI = 100 \times \left( \frac{G \times L}{G_C \times L_C} \right)
\]  

where G (%) and L (cm) are the germination and root growth of the samples, and G_C (%) and L_C (cm) are the germination and root growth of the control (distilled water), respectively.

Bacterial microbial activity was determined using Polymerase Chain Reaction-Denaturing Gradient Gel Electrophoresis (PCR-DGGE) technology: (1) DNA Extraction: The UltraClean sludge DNA Kit (MoBio Laboratories, Inc., Solana Beach, California) was used with M-NDA Marker from Clean sludge DNA Kit (MoBio Laboratories, Inc., Solana Beach, California) was used with M-NDA Marker from Clean sludge DNA Kit (MoBio Laboratories, Inc., Solana Beach, California) was used with M-NDA Marker from Clean sludge DNA Kit (MoBio Laboratories, Inc., Solana Beach, California) was used with M-NDA Marker from Clean sludge DNA Kit (MoBio Laboratories, Inc., Solana Beach, California) was used with M-NDA Marker from Clean sludge DNA Kit (MoBio Laboratories, Inc., Solana Beach, California) was used with M-NDA Marker from Clean sludge DNA Kit (MoBio Laboratories, Inc., Solana Beach, California) was used with M-NDA Marker from Clean sludge DNA Kit (MoBio Laboratories, Inc., Solana Beach, California) was used with 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and sufficient biodegradable organic matter were essential (Mason, 2006) to increase the temperature. Bulk density, which is closely related with FAS (Iqbal et al., 2010), was important for vegetable waste because of its perishable character. The temperature evolution during composting for the different bulk densities (part 1) is shown in Fig. 2a. The highest temperature (65.7°C) occurred in treatment BD2, and a longer duration of temperature over 60°C was also shown in BD2. In BD1, the temperature was always lower than 60°C, which may have three reasons resulting from the overly high porosity. First of all, having the same amount of material in a larger volume than BD2 must have an influence on the amount of O2 in contact with the material, which would influence O2 utilization efficiency; then, because of the lower bulk density, the heat production in the same volume must be lower than BD2 and BD3, resulting in a lower temperature when the same amount of organic matter is degraded in the composting system; the last reason was the high rate of natural convection caused by the overly high porosity (Veeken et al., 2002). For BD3, however, the temperature was increased to 65°C because of the more rapid organic matter biodegradation. However, the temperature decreased to under 55°C quickly, caused by the natural convection initiated, and the aerobic degradation failed (Veeken et al., 2002). Therefore, the highest temperature was observed at a density of 0.35 g/cm³ for the raw material in this experiment. A similar result was found in the experiment of Veeken et al. (2002), during composting of straw-rich pig manure: the optimal density was proved to be 700 kg/m³, compared to 1100 and 560 kg/m³. The difference in the optimal densities should be due to the different types of composting materials (De Guardia et al., 2010). Therefore, the density should be optimized before a composting process begins, when composting with a new material.

Once the optimal density for the composting raw material for the achievement of the ultra-high temperature target was determined, the content of biodegradable organic matter was considered next, because the temperature increase depends not only on the nature and properties of the waste, but also on the organic matter mineralization (De Guardia et al., 2010). The temperature increase at the beginning of the composting process was positively related with the amount of rapidly biodegradable organic matter (De Guardia et al., 2010).

The temperature evolution for part 2 is shown in Fig. 2b and Fig. 2c. The highest temperature was reached in treatment ED3 (71.4°C), while the time duration for temperature over 70°C was more than 25 min, which could help inactivate potential pathogens in this kind of composting process. The temperature in ED3 after reaching its highest temperature (71.4°C) was always lower than in treatments ED1 and ED4, which may be due to the thermal inhibition of microbiological activities and the decrease in readily soluble nutrients (Viel et al., 1987). A similar inhibitory situation could be seen in the work of Wong and Fang (2000), which was a composting process with sewage sludge, and the inhibitory effect was shown at day 7 of the process. The time was later in their case because the simulated composting process done here was carried out in a temperature-controlled incubator, which may make the temperature increase more rapidly. The fact that the temperature in ED1 and ED2 was lower than that in ED3 may be caused by the shortage of rapidly biodegradable organic matter, while the temperature in ED4 was not increased with the increase of easily-degraded organic matter content, because the increase of easily-degraded organic matter content changed the density and porosity, which influenced the oxygen consumption and heat production, and even led to some of the material degrading without oxygen. Therefore, according to the temperature target, the treatment ED3, in which the ratio of easily-degraded organic matter content was 45%, was better than the other treatments.

2.2. Cumulative CO₂-C mineralization

During the composting process, the thermophilic bacteria were active, causing the degradation of the organic matter and leading to the production of CO₂. The rapid increase of the cumulative amount of CO₂ coincided with the rise in temperature and the beginning of the incubation, as usually occurs during composting (Wong and Fang, 2000). The cumulative levels of CO₂-C mineralized from the mixed materials during the 30-day incubation in parts 1 and 2 are shown in Fig. 3. The results were expressed in terms of the percentage of total carbon in the mixed material, and mineralization curves were constructed. The cumulative CO₂-C curves for the two experiments were fitted to first-order kinetics \( C_t = C_0 \left(1 - \exp(-k \times t)\right) \), with high coefficients of determination, which are shown in Table 2. The values for the mineralized fraction of C₀ in part 1 followed the order BD1 (5.77%) > BD3 (4.81%) > BD2 (4.66%), while the rate constants k followed the order BD1 (0.11%) > BD2 (0.093%) > BD3 (0.09%). Differences between BD2 and BD3 were not significant. Thus, the decrease of bulk density could decrease the mineralized fraction and rate constant at the beginning of the process. The results

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**Fig. 2** – Changes in temperature during co-composting of cucumber waste with different bulk densities (a) and different easily-degraded organic matter contents (b). BD1: density 0.30 g/cm³; BD2: density 0.35 g/cm³; BD3: density 0.4 g/cm³; ED1: Easily-degraded organic matter content: 27%; ED2: Easily-degraded organic matter content: 36%; ED3: Easily-degraded organic matter content: 45%; ED4: Easily-degraded organic matter content: 51%. BD: bulk density; ED: easily degraded.
indicated that the material density would change the labile and stable fraction ratio of organic matter in the material, resulting from the size of the composting cell and differences in O2 consumption caused by density difference. Thus, the density difference would influence the organic matter mineralization and rise of material temperature.

The values for the mineralized fraction of C0 in part 2 (Table 2) followed the order ED1 (4.66%) > ED3 (4.52%) > ED2 (3.92%) > ED4 (3.77%), while the rate constants followed the order ED3 (0.13%) > ED4 (0.11%) > ED1 (0.09%) > ED2 (0.07%). No positive or negative relationship could be observed between the parameters and the easily-degraded organic matter content. These results suggested that the increase of easily degradable organic matter contents could influence the mineralized fraction and rate constant at the beginning of the process, and it could also influence the material density and simultaneously influence the organic matter mineralization and the rise in the material temperature. Thus, it is important to determine the optimal material density and organic matter fraction ratio for a given raw material before starting the composting process.

2.3. Organic matter

The organic matter decreased throughout the composting process in all piles, from initial values of 72%–81% of the dry matter to values of 43%–55%, illustrating the organic matter (OM) mineralization process. As Fig. 4a and Fig. 4b show, the OM losses in all piles were significant during the bio-oxidative phase of composting, which lasted for nearly 5 days, corresponding to the rapid CO2-C mineralization shown in Fig. 3a and Fig. 3b. At the end of the process, all piles showed different OM losses, in the order: BD1 (67.15%) > BD2 (59.87%) > BD3 (50.98%) and ED4 (82.57%) > ED2 (70.25%) > ED3 (63.96%) > ED1 (59.87%). This suggested that the increase of material density would decrease the OM loss, while the opposite occurred when the easily-degraded organic matter content in the material increased. However, the OM concentrations in all the treatments of both experiments were between 60%–65% (dry weight basis).

The OM degradation profile in part 1 during composting, according to the OM losses, followed a first-order kinetic equation \( \text{OM}_{\text{min}} = A \times (1 - \exp(-k \times t)) \) in all piles. Curve fitting of the experimental data gave the following parameter values:

- BD1: \( A = 34.5569 \) (2.7770), \( k = 0.4178 \) (0.1566) \( R^2 = 0.8294, F = 35.0262^{**} \).
- BD2: \( A = 32.3031 \) (2.9643), \( k = 0.2664 \) (0.0955) \( R^2 = 0.8170, F = 32.2513^{**} \).
- BD3: \( A = 30.4854 \) (1.1099), \( k = 0.6051 \) (0.1174) \( R^2 = 0.9546, F = 148.0833^{***} \).

where, \( \text{OM}_{\text{min}} \) is the mineralized OM (%) at composting time t (day), A is the potentially mineralizable OM (%).

Therefore, an increase in the material density significantly decreased the concentration of degradable OM. The product of \( A \times k \) indicates that the initial OM mineralization rate was faster for BD3 (18.45% OM/day) and BD1 (14.44% OM/day), than BD2 (8.61% OM/day), showing quick mineralization in the first several days. However, BD3 showed a slower OM mineralization rate, stabilizing after 5 days, which was associated with low degradation, as observed in the temperature (Fig. 1a) and CO2 emission (Fig. 2a), as a consequence of the decreased oxygen consumption because of high material density. In BD1, the higher amount of OM loss was consistent with the higher CO2 emission, while lower temperature was observed, which suggested that the loss of heat transfer from the OM degradation was the highest in BD1.
The OM degradation profile in part 2 during composting, according to the OM losses, also followed a first-order kinetic equation (\(\text{OM}_{\text{min}} = A \times (1 - \exp(-k \times t))\)) in all piles. Curve fitting of the experimental data gave the following parameter values:

**ED1:**
- \(A = 32.3031 (2.9643)\)
- \(k = 0.2664 (0.0955)\)
- \(R^2 = 0.8170\)
- \(F = 32.2513^{***}\)

**ED2:**
- \(A = 41.5444 (1.4468)\)
- \(k = 0.3963 (0.0631)\)
- \(R^2 = 0.9666\)
- \(F = 203.2907^{**}\)

**ED3:**
- \(A = 50.9351 (2.5983)\)
- \(k = 0.8933 (0.2769)\)
- \(R^2 = 0.8988\)
- \(F = 63.1851^{***}\)

**ED4:**
- \(A = 59.8464 (1.8872)\)
- \(k = 1.1166 (0.2316)\)
- \(R^2 = 0.9574\)
- \(F = 158.3592^{***}\)

The increase of easily-degraded organic matter content significantly increased the concentration of degradable OM and the degradation rate, the same as observed for the product of \(A \times k\). This indicated that the initial OM mineralization rate would rise along with the increase of easily-degraded organic matter content at the beginning of the process, followed by a slowing of the increase trend. This may be a consequence of high microbial activity due to the high amount of biodegradable OM in the material, and the high temperature shown in Fig. 1b. However, we found no association between OM degradation and CO2 emission. This implied that the OM in ED2 and ED4 was not fully degraded, resulting from the inhibitory effect on microbial activity caused by the ultra-high temperature shown in Fig. 2, and on the oxygen consumption shown in Fig. 3 caused by the increase in the dry bulk density of the composting matrix (Larney et al., 2000; Mohee and Mudhoo, 2005).

**2.4. Lignocellulose**

The OM concentration changes were not only influenced by the biodegradable fractions, but also by the lignocellulose degradation. The concentrations of lignocellulose (lignin, hemicellulose and cellulose), expressed with respect to ash content, in all the treatments of both experiments are shown in Table 3 (part 1) and Table 4 (part 2); little change in lignin concentration was observed between the treatments, while different degradation amounts were shown for cellulose and hemicellulose in different treatments. More lignocellulose was degraded in BD2 (28.78%), as compared with BD1 (23.10%) and BD3 (22.13%), in part 1. That may be one of the reasons for the high temperature reached in BD2, because the OM losses in the three treatments were not significantly different. The percentage of lignocellulose degraded was from hemicellulose and cellulose degradation, which can be seen in Table 3. The results indicated or implied that more organic matter could be degraded with better material density, not only the easily-degraded parts, so that more hemicellulose and cellulose were degraded for the same amount of organic matter as well as the easily-degraded part. The hemicellulose and cellulose degraded in the material were transformed into CO2.
emission or humic-like substances, which may help increase the temperature and improve the compost quality during future use.

The degradation of lignocellulose in part 2 followed the order: ED1 (28.78%) > ED2 (17.58%) > ED3 (8.10%) > ED4 (6.11%), and the changes in degradation percent were caused by the hemicellulose and cellulose degradation. However, increase in the easily degraded OM may contribute to more CO₂ emission and heat loss during the composting process.

2.5. Microbial activity

On the basis of the analysis on organic matter degradation in different treatments, the optimal initial conditions for the beginning of the composting process were chosen. Microbes play a vital role in this process. They could be able to produce extracellular enzymes to degrade a wide range of polymers that may be used as a carbon source during composting, thus they obtain a nutritional advantage (Jurado et al., 2014). It is generally known that composting is a dynamic process and can be divided into three stages by temperature (Zhao et al., 2016), the initial stage (temperature rising stage, day 1), high temperature stage (thermophilic stage, day 3) and cooling stage (mesothermal stage, day 15), so the microbial activity was analyzed for these three stages. DGGE profiles of 16S rRNA genes of microbial activity in different stages of the composting process are shown in Fig. 5. In our analysis, the number of DGGE bands was treated as an indication of the species in each sample. Numbers of Bands (N), H and E are shown in Table 5. For the series of treatments BD1–BD3, the most microbial bands were always observed in treatment BD2, which may suggest that more microbial degradation took place during the BD2 composting process than in the other two treatments. However, the high temperature reached on day 1 may heavily influence the microbial activity (N and H, respectively), and nearly half of the species were lost because of the rise in temperature in the material pile (López-González et al., 2013). For the other series of treatments, the lower part of Table 5, an inhibitory effect on microbial activity was shown in treatments ED3 and ED4, for N and H, which could be a main reason for the rapid decrease of

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**Table 4** – Lignocellulose degradation during the simulated composting process in different treatments in experiment 2.

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<th>ED1</th>
<th>ED2</th>
<th>ED3</th>
<th>ED4</th>
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</thead>
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<tr>
<td></td>
<td>L</td>
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<td>C</td>
<td>LC</td>
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The data in the table are percent of the total dry weight; L: Lignin; H: Hemicellulose; C: Cellulose; LC: lignocellulose; ED1: Easily-degraded organic matter content: 27%; ED2: Easily-degraded organic matter content: 36%; ED3: Easily-degraded organic matter content: 45%; ED4: Easily-degraded organic matter content: 51%.

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**Fig. 5** – Denatured gradient gel electrophoresis (DGGE) profiles of 16S rRNA genes of microbial activity in different stages of composting process for different material structures (a) and different easily-degraded organic matter contents (b).
temperature in treatment ED3, even though more easily degradable substances were contained in the material (Yu et al., 2013). A slight recovery could be seen at day 15, but the temperature could not increase because of the rapid organic matter degradation that took place in the first 10 days.

2.6. Germination index (GI)

The stability and maturity of compost are often referred to as compost quality (Moral et al., 2009), and particularly for vegetable waste composting, inactivation of pathogens (ultra-high temperature) is essential for safe utilization. The GI is commonly used to assess the phytotoxicity of compost because phytotoxicity is a problem associated with immature composts. Such composts may contain various heavy metals, ammonia and/or low molecular weight organic compounds that may reduce seed germination and also inhibit root development (Tam and Tiquia, 1994; Brinton, 2000).

The changes in the GI during the composting process are shown in Fig. 6, showing a tendency to increase throughout the process. The material density had little influence on the GI (Fig. 6a); it was over 60% after day 10, which basically indicated maturity. The GI value was better in BD2 at the end of the composting process, while the differences between BD2 and the other two mixtures were not significant. The increase of the easily-degraded organic matter content would slow the organic degradation, resulting from the increase in the dry bulk density of the composting matrix along with the material composition (Larney et al., 2000; Mohee and Mudhoo, 2005).

The more the easily-biodegradable organic matter was turned into CO₂ and water directly, the less humus was produced, and the worse the material structure became. What’s more, the ultra-high temperature also inhibited the microbial activity (Fig. 5). However, the inhibition of the GI had no influence on the realization of thorough decomposition except for ED4, so that it could be concluded that the material structure would not influence the maturity process, while the fractional ratio of organic matter would, even though maturity could finally be reached at the end. Therefore, when composting with vegetable waste, the initial bulk density and the ratio of organic matter in the raw material must be considered firstly.

2.7. C/N ratio

The C/N ratio has been used to indicate compost maturity (Sánchez-Monedero et al., 2001; Bernal et al., 1998) for many years. Until now, however, no specific value has been suggested for the ratio that could be used to evaluate the maturity of different kinds of composts. Previous research showed that a C/N ratio below 20 was assumed to be indicative of mature compost, while 15 or less is preferable (Bernal et al., 2009). On the other hand, some researchers reported that the C/N ratio was not a good indicator of mature compost because it had large variability in the raw materials and often gave a misleading indication of maturity; also, it might not reflect a material that was sufficiently decomposed. In our study with the same raw material, cucumber stalk, the C/N ratio decreased from 25 in the beginning to lower than 15 at the end. The trend of C/N ratio changes in different treatments was similar in both experiments (Fig. 7). Material density differences had little influence on the change in C/N ratio, while different contents of easily-degraded organic matter only influenced the change in the C/N ratio during the composting process. Nevertheless, at the end of the process, all the mixtures reached a similar value (<15, Fig. 7).

This decrease had been observed by many authors in other composting experiments, such as Bustamante et al. (2008, 2013). The consistent final C/N ratios suggested that all the composts had reached an acceptable degree of maturation, since they were all <15 (Mathur et al., 1993).

<table>
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<th>Table 5 – Indexes of microbial activity in different stages of the composting process.</th>
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<td>Day 1</td>
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<td>BD1</td>
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<td>ED4</td>
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Fig. 6 – Germination index (GI) changes for different material structures (a) and different easily-degraded organic matter contents (b).
3. Conclusions

Based on the results above, composting of vegetable wastes (cucumber stalk) with carbon additives (corn stalk and corn starch) was able to transform the waste into mature fertilizer without potential pathogenic risk, by adjusting the initial material bulk density and easily-degraded organic matter content. According to the experiments conducted, the bulk density and ratio of easily-degraded organic matter content should be 0.35 g/cm³ and 45% respectively, to ensure a suitable FAS and enough biodegradable organic matter to produce an ultra-high temperature (>70°C). However, the higher temperature obtained by adjusting the easily-degraded organic matter content of the initial material would inhibit the microbial activity and influence the rotting process, but one month was sufficient to achieve maturity. However, ways to avoid excessive nitrogen loss and microbial inhibition under the ultra-high temperature conditions should be taken into account in future research.

Acknowledgments

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REFERENCES


Fig. 7 – C/N ratio changes for different material structures (a) and different lignocellulose contents (b).

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**Fig. 7** – C/N ratio changes for different material structures (a) and different lignocellulose contents (b).