Influence of Microbial Inoculant on Composting of Biodegradable Domestic Solid Wastes

Hai Quang Dang (dqhai@dut.udn.vn)
The University of Danang
Cuong Phuoc Le
The University of Danang

Research Article

Keywords: Domestic solid waste, Microbial inoculant, Composting, Chemical and physical parameters, Compost quality

Posted Date: May 6th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-475430/v1

Abstract

This study investigated the effect of microbial inoculant (Emuniv) on composting of biodegradable domestic solid wastes for over 30 days. Three different types of treatments were used for the composting of source separated domestic solid waste. The results showed that the use of microbial inoculant in the composting of domestic solid wastes enhanced the biodegradation of composted organic material, which is evident from the considerable changes in temperature, moisture content and volume reduction with time. The compost treatments with Emuniv inoculant recorded higher temperature for the duration of composting phases, compared to treatment without Emuniv inoculant. Whereas, the moisture content and volume reduction of all treatments was showed a decreasing trend during the composting process. The larger reduction was seen in the treatments with Emuniv inoculant. Additionally, according to the results of analysis of variance (ANOVA), there was a statistically significant difference in temperature, moisture content and volume reduction between treatments. Moreover, the utilisation of microbial inoculant in composting was also can improve the quality of final compost product as reflected by the total nitrogen and available phosphorus contents in the compost product were higher than in the control.

1. Introduction

The increasing level of domestic solid waste has been a serious problem over the last few decades due to the increase in population and urbanization, as well as the toxic components of this waste has become a threat to human beings and the environment. The domestic solid waste generally includes degradable (paper, food waste, straw and yard waste), partially degradable (wood, and sludge) and non-degradable materials (leather, plastics, metals, glass, electronics) [1]. Among these, the biodegradable wastes that constitute the major fraction of domestic solid waste load in developing countries, typically characterized by high water content (> 60%) requires greater operating cost and lesser chances of material recovery. Therefore, to establish a sustainable waste management system, it is essential to separate and recycle biodegradable organic material from the domestic waste stream. Of all the recycling methods, composting is recommended due to its environmental and economic benefits [2].

Composting is one of the best known processes for biological stabilization of solid organic wastes by transforming them into a safer and more stabilized material that can be used as a source of nutrients and soil conditioner in agricultural applications [3, 4]. Composting involves the accelerated degradation of organic matter by microorganisms under controlled conditions, in which the organic material undergoes a characteristic thermophilic stage that allows sanitization of the waste by elimination of pathogenic microorganisms [5]. Successful composting generally depends on some factors that influence the activities of the microorganism. These including the type of composted raw material, the composition of nutrients, temperature, moisture content, alkalinity, bulk density, porosity, particle size, etc. [6].

Temperature as well stimulates the growth and metabolic activity of the microbial community within compost mass. It can directly affect the biodegradation rate of the organic matter during composting [7].

Under optimal conditions, composting process through the different temperature phases required for effective sanitization of the feedstock and efficiency of the process. A mesophilic phase, characterized by the proliferation of the microbiota, a thermophilic phase where a high rate of biodegradation, the growth of thermophilic organisms and the inhibition of non-thermotolerant organisms occur and the final phase that includes a period of cooling, stabilization and maturation, characterized by the growth of mesophilic organisms and the humification of the compost [8, 9]. It is interesting to note that the moisture conditions essentially impinge microbial activity, oxygen uptake rate, temperature and the porosity level within composting [10]. An inverse relation exists between moisture content and temperature, exhibiting an increase in temperature as the moisture content drops [11]. During composting, the microorganism's succession is the key for an effective management of the process. The appearances of certain microorganisms influence the rate of biodegradation and compost maturity, reflected by the quality of the generated compost [12]. Furthermore, microbial inoculants influence the process of composting by altering the cellulose, hemicellulose and lignocellulose breakdown process, causing alterations to the temperature and nitrogen levels throughout the composting process [13].

Although several studies have addressed the optimization of composting of various organic wastes [7, 10, 11, 14–17], information on composting of biodegradable domestic solid wastes using effective microorganism inoculants as an accelerator to speed up the composting process and increased nutrients in the compost has not been well documented. Therefore, it is essential to study the effect of microbial inoculant on the composting process.

The objectives of the current work are to study the effect of microbial inoculant application on the composting process of biodegradable domestic solid wastes and also to evaluate the nutrient at the end of composting. This study is based on the hypothesis that the application of microbial inoculant on biodegradable domestic solid wastes will increase the microbial activity and thus, increase the composting rate. To test these hypotheses, compost from biodegradable domestic solid wastes was produced with applications of microbial inoculant and compared to non-microbial inoculant treatment. The results enable the evaluation of the role of microbial inoculant on the composting process.

2. Materials And Methods

2.1. Materials

Domestic solid waste and other substances:

Biodegradable domestic solid wastes (food waste, green waste,…) were collected from waste transfer station in Hai Chau District, Da Nang City, Vietnam.

$Ca(OH)_2$ and Superphosphate ($Ca(H_2PO_4)_2$) were purchased from Kim Nam High Technology Material Joint Stock Company (Ha Noi, Vietnam) and Supe phosphate and Lam Thao chemicals Joint Stock Company (Phu Tho, Vietnam), respectively.

Microbial inoculant:

An Emuniv inoculant was selected for this investigation. It is a composition in powder form, this is a product of Applied Microbiology Joint Stock Company, Vietnam, which contains a mixture of effective microorganisms that strong decompose organic waste. The composition of Emuniv inoculant is shown in Table 1.

Table 1
The composition of Emuniv inoculant

The composition of Emuniv inoculant	
Bacillus licheniformis	10^8 CFU/g
Lactobacillus plantarum	10^8 CFU/g
Saccharomyces cerevisiae	10^7 CFU/g
Pseudomonas	10^7 CFU/g
Trichoderma viride	10^8 CFU/g
Bacillus subtilis	10^8 CFU/g
Streptomyces murinus	10^8 CFU/g
Metarhizium anisopliae	10^7 CFU/g

2.2. Experimental design

All experiments were performed in rectangular boxes with foam insulation 2.5 cm thickness. The dimensions of each box were as follows: 30 cm height x 30 cm width x 42 cm length.

Experimental design included three treatments and they were replicated two times. The treatments were: Treatment 1 (E1) was composted only from biodegradable domestic solid wastes (5 kg) and is acted as a control, treatment 2 (E2) was biodegradable domestic solid wastes (5 kg) with Emuniv inoculant (1 g), treatment 3 (E3) was biodegradable domestic solid wastes (5 kg) were chopped at approximately 3 to 5 cm length with Emuniv inoculant (1 g).

A certain amount of 100 g of $Ca(OH)_2$ and 150 g of $Ca(H_2PO_4)_2$ was added each treatment to reduce the nitrogen loss and improve the NH_3 recovery during composting. The treatments were conducted under semi aerobic conditions for 30 days. During the composting process, the temperature, moisture content and volume reduction of the compost was determined regularly at 3 days interval. Maturity of the compost was estimated by colour and texture changes observed. When the compost was assumed well matured, homogenized compost samples were taken to determine the compost chemical properties. Samples were placed in polyethylene bags and transferred to the laboratory for analysis.

2.3. Analysis of chemical and physical parameters of the compost

Chemical and physical parameters of the compost were determined according to the Vietnamese National Standards (TCVN). The temperature was monitored throughout the composting period using digital thermometers. The temperature at different locations of each treatment was measured and the average temperature was reported. Heights, lengths and widths of the compost were measured at specific times to calculate surface area, volume and volume reduction of the compost [18]. Moisture content was determined following the method of dry to constant mass (TCVN 9297:2012, Fertilizers – Method for determination of moisture) [19]. Organic carbon (OC) and organic matter (OM) content were determined using the Walkley - Black method (TCVN 9294:2012, Fertilizers - Determination of total organic carbon by Walkley - Black method) [20]. Total nitrogen (TN) was determined by Kjeldhal method (TCVN 8557:2010, Fertilizers - Method for determination of total nitrogen) [21]. Available phosphorus (TP) was analysed using Photometric method (TCVN 8559:2010, Fertilizers - Method for determination of available phosphorus) [22].

2.4. Statistical analysis

Analysis of variance (ANOVA) was used to identify whether there was significant difference among treatments. Statistical analyses were performed with Microsoft Excel 2013 and statistical mean differences were considered significant at $p < 0.05$.

3. Results And Discussion

3.1. Temperature

Temperature is one of the key indicators for active microbial biomass and may be considerable affecting the composting process [6]. Figure 1 shows variation of temperature in each treatment during the composting process.

Table 2
ANOVA of temperature (Two-Factor With Replication)

Source of Variation	**Sum of squares (SS)**	**Degrees of freedom (df)**	**Mean square (MS)**	**F value**	**P value**	**F critical value**
Sample (Time)	1494.623	10	149.4623	70.78945	2.3E-19	2.132504
Columns (Temperature)	30.30576	2	15.15288	7.176821	0.002583	3.284918
Interaction	19.92091	20	0.996045	0.471755	0.960025	1.897669
Within	69.675	33	2.111364			
Total	1614.524	65				

With F_s = 70.78945 > $F_{0.05}$ = 2.132504 (Reject hypothesis H_0 (null hypothesis) is the Time); F_c = 7.176821 > $F_{0.05}$ = 3.284918 (Reject hypothesis H_0 is the Temperature).

Three phases in relation to temperature changes were observed in all the treatments of the present study, consisting of the first as mesophilic phase (ranging from 28.0 to 38.7°C, 28.0 to 39.9°C and 28.0 to 40.8°C for the treatments E1, E2 and E3, respectively), second as thermophilic phase (ranging from 39.0 to 42.5°C, 40.0 to 43.2°C and 41.0 to 45.6°C for the treatments E1, E2 and E3, respectively), and cooling phase. The temperature pattern showed that there is a rapid progress from the initial mesophilic phase to the thermophilic phase for three these treatments, which points to a high proportion of readily degradable substances. The change in temperature pattern observed in this study is in accord with other composting studies [14, 15, 23].

The temperature profile in the treatments E2 and E3 were similar as temperatures had risen to maximum temperatures of 43.2°C and 45.6°C, respectively on day 12 and remained within the thermophilic range with narrow fluctuations until day 18. The treatment E1 followed the same trend of changes like treatments E2 and E3 but only reached a maximum temperature of 42.5°C. In general, treatments E2 and E3 with Emuniv inoculant recorded higher temperature for the duration of mesophilic and thermophilic phases, compared to treatment E1 without Emuniv inoculant. This can be attributed to the fact that the increase in temperature during the composting phases was caused by the heat generated from the respiration and decomposition of the biodegradable material by the population of microorganisms. The increment in temperature is a good indicator that there is microbial activity in the compost pile, as a higher temperature denotes greater microbial activity [23]. Furthermore, the high temperature is the results of the accumulation of microbial metabolic warmth and indicating the occurrence of degradation where organic matter was being transformed [4]. Even though no microbial test was done on the sample, it can be assumed that the compost treatment with Emuniv inoculant (E2 and E3) has higher microbial activity compared to E1 based on the high temperature achieved. It was already reported in the previous investigations that the increase of temperature in the early phases of composting may be the result of mesophilic and thermophilic phases of composting. The temperature rises as a consequence of the rapid breakdown of organic matter by microbial metabolism. The decrease in temperature indicates that the microbial activities started to slow down due to the low amount of organic material available. Hence the microbial activity stopped and reached the cooling phase [16, 24, 25].

On the other hand, the highest temperature was recorded for the treatment E3, as reflected by the fact that the particle size of composted organic material also influence on the microbial activity during the composting process. An appropriate particle size (3–5 cm) can ensure a more available surface area for better microbial activity during composting, resulting in speedy degradation [13, 26].

In addition, based on the Anova test (Table 2), it is apparent that the changes in temperature were significant gradual change during the composting process in the individual units of E1, E2, and E3. The difference in temperature between treatments E1, E2, and E3 was also statistically significant indicating the effect of Emuniv inoculant on the process of composting.

3.2. Moisture content

Moisture content is an essential parameter that influences the changes in physical, chemical, and biological properties of waste materials during the advancement of decomposition of organic matter. Huerta-Pujol et al. [27] reported the moisture content of the waste mix significantly influences biological activity. According to Norbu et al. [28], the optimum moisture content for an effective decomposition significantly depends on the waste nature. However, a moisture content between 50–60% during composting is crucial for microbial activity [4, 29].

In the present study, the amount of moisture in each the treatment was showing a decreasing trend with time. Initial moisture content of treatments E1, E2, and E3 were 60.80%, 62.44%, 60.30% and reduced to 58.44%, 54.01%, 52.92% after 30 days of the composting process, respectively (Fig. 2). This phenomenon could be attributed to the changes in temperature and microbial activity. Moisture content affects microbial activity as well as temperature in the composting process, and thus has a central influence on the biodegradation of organic materials. The high temperatures as mentioned previously contribute to the reduction of moisture content during composting phase due to the evaporation of water from the compost. Treatments E2 and E3 with Emuniv inoculant which enhances microbial activity resulting in increasing the temperature and the rate of degradation of organic matter, and therefore moisture content of these treatments reduced greater than treatments E1 without Emuniv inoculant.

Table 3
ANOVA of moisture content (Two-Factor With Replication)

Source of Variation	Sum of squares (SS)	Degrees of freedom (df)	Mean square (MS)	F value	P value	F critical value
Sample (Time)	308.4752	10	30.84752	44.02843	3.39E-16	2.132504
Columns (Moisture content)	88.44715	2	44.22357	63.11997	5.27E-12	3.284918
Interaction	53.81218	20	2.690609	3.840286	0.000313	1.897669
Within	23.1207	33	0.700627			
Total	473.8552	65				
With F_s = 44.02843 > $F_{0.05}$ = 2.132504 (Reject hypothesis H_0 (null hypothesis) is the Time); F_c = 63.11997 > $F_{0.05}$ = 3.284918 (Reject hypothesis H_0 is the Moisture content).						

Moreover, according to the results of variance analysis of moisture content in Table 3, there was a statistically significant difference in moisture content among treatments E1, E2, and E3 and the decrease in moisture content also indicated significant differences in each the treatment during the composting time.

These results and interpretation are consistent with the previous observations in the literature. According to Beck-Friis et al. [30] and Raj and Antil [31], moisture content of the composting blend is an important environmental variable as it provides a medium for the transport of dissolved nutrients required for the physiological activities of microorganisms. The main factor of moisture content loss is due to the rising in compost temperature. This is because the heat generated from the microorganisms activity. Gajalakshmi and Abbasi [29] reported that in addition to normal water loss caused by the difference in moisture content between the substrate and air, the high temperatures during the thermophilic phase contribute to the reduction of moisture content during composting.

3.3. Volume reduction

The volume reduction behaviour of organic solid waste over 30 days of composting of treatments E1, E2, and E3 is shown in Fig. 3. It was observed that the volume reduction of all treatments was showed a sharp reduction during the composting process. The largest reduction of 72.23% was seen in the treatment E3 with Emuniv inoculant. The lowest reduction of 58.09 % was seen in the treatment E1 without Emuniv inoculant, followed by the treatment E2, with a reduction of 67.68 %. This fact can be explained by the high degradability of the wastes used in this study. The reduction in the volume of compost due to the degradation of organic matter during composting may be due not only to weight loss but also the existence of the smaller particles as a result of the deterioration of the structure of organic compounds.

Table 4
ANOVA of volume reduction (Two-Factor With Replication)

Source of Variation	**Sum of squares (SS)**	**Degrees of freedom (df)**	**Mean square (MS)**	**F value**	**P value**	**F critical value**
Sample (Time)	33054.59	10	3305.459	2693.101	4.76E-45	2.132504
Columns (Volume reduction)	833.4532	2	416.7266	339.5253	9.75E-23	3.284918
Interaction	287.3967	20	14.36983	11.70773	8.6E-10	1.897669
Within	40.50355	33	1.22738			
Total	34215.95	65				
With F_s = 2693.101 > $F_{0.05}$ = 2.132504 (Reject hypothesis H_0 (null hypothesis) is the Time); F_c = 339.5253 > $F_{0.05}$ = 3.284918 (Reject hypothesis H_0 is the Volume reduction).						

Findings in this study also show clearly that composting of organic waste with effective microbial inoculant led to an increase in decomposition of organic waste, and consequently to a greater volume reduction. These results are also confirmed by a variance analysis (Table 4). There are significant differences in volume reduction between treatments E1, E2, and E3 as well as the decrease in volume reduction of each the treatment with increasing time of composting. It may therefore be concluded that microbial inoculant considerably affected the volume reduction of compost materials.

The volume reduction is a result of the organic matter degradation by microbial activity during the composting process has also been pointed out by several investigators [10, 32]. Additionally, previous studies investigating the change of physical properties of organic wastes during the composting phase have demonstrated that high levels of biodegradable organic matter increased the capacity of the microorganisms to oxidise the material, and consequently reduced the volume [17, 33].

3.4. The quality of compost product

By the 30th day of composting, except for the control sample, the composting materials showed temperature stability, fine texture, much darker brown or black colours and homogeneity of materials. The composting process was, therefore, halted and samples collected for compost analysis. The compost product quality are listed in Table 5.

Table 5
Quality parameters of final compost product

Treatments	OC (%)	OM (%)	TN (%)	TP (P_2O_5, %)
E1	38.82 ± 1.01	85.39 ± 2.22	1.06 ± 0.13	0.05 ± 0.010
E2	24.89 ± 0.83	54.75 ± 1.82	1.37 ± 0.09	0.07 ± 0.004
E3	21.57 ± 0.81	47.45 ± 1.77	1.46 ± 0.10	0.08 ± 0.004

It is apparent that organic carbon content in treatments E2 and E3 were significantly lower than that of treatment E1, while the total nitrogen and available phosphorus contents of these treatments were higher than in the control (E1). Treatment E3 recorded the lowest mean OC of 21.57%, and the highest mean TN and TP of 1.46 and 0.08%, respectively. The low OC after composting might be as a result of microbial decomposition of organic substrates, which was evident of temperature increases during composting as microorganism consume carbon for energy [4]. Furthermore, the low OC was served as an indicator of compost maturity and stability [34]. The high level of the total nitrogen in final compost product could be attributed to the Emuniv inoculant effect as a result of substantial degradation of organic carbon compounds to nitrogen component, and the contribution of nitrogen-fixing bacteria [35, 36]. The high level of the available phosphorus is probably due to mobilization and mineralization and mobilization of phosphorus due to microbial activities of Emuniv inoculant.

These results are similar to those obtained by several other previous investigations. According to Teshome and Amza [37] and Tibu et al. [15], the OC values of the matured composts for all the treatments were found to be in between 19–33%. Benito et al. [38] found that the total nitrogen rate in the compost product ranged from 0.99 to 2.01%. Similar trends were observed by Dessalegn et al. [39] who indicated the total nitrogen content of the matured compost was between 1.05 and 1.13 %. Therefore, it can be concluded that composting of organic solid wastes using microbial inoculants (Emuniv) was not only can enhance composting rate, but also can improve the quality of final compost greatly.

4. Conclusions

The results indicated that microbial inoculant Emuniv had a significant impact on the composting of biodegradable domestic solid wastes and the quality of final compost product. The temperature in the treatments E2 and E3 with Emuniv inoculant increased to maximum temperatures of 43.2°C and 45.6°C, respectively, while the treatment E1 without Emuniv inoculant only reached a maximum temperature of 42.5°C. Initial moisture content of treatments E1, E2, and E3 were 60.80%, 62.44%, 60.30% and decreased to 58.44%, 54.01%, 52.92% after 30 days of the composting process, respectively. The volume reduction of all treatments was showed a considerable reduction during the composting process. The largest reduction of 72.23% was observed in the treatment E3. The lowest reduction of 58.09% was observed in the treatment E1, followed by the treatment E2, with a reduction of 67.68%. Moreover, the results of

ANOVA demonstrated that the relationship between the chemical and physical parameters such as temperature, moisture content and volume reduction of treatments was statistically significant difference. In addition, composting of organic solid wastes using microbial inoculants improved the quality of final compost greatly, which is evident from the considerable higher in the total nitrogen and available phosphorus contents of treatments E2 and E3, compared to treatment E1. Overall, the results obtained revealed that composting with microbial inoculant is a promising method for domestic organic waste treatment.

5. Declarations

Availability of data and material

All data generated or analyzed during this study are available upon request.

Competing interests

The authors declare they have no competing interests.

Funding

This research was supported by The University of Danang - University of Science and Technology.

Authors' contributions

Hai Quang Dang contributed: Conceptualization, Methodology, Investigation, Writing - Review & Editing, Cuong Phuoc Le contributed: Validation, Resources. The author(s) read and approved the final manuscript.

Acknowledgements

The authors are grateful to Faculty of Environment, The University of Danang - University of Science and Technology for the support of the laboratory for this study.

6. References

1. Jha MK, Sondhi OAK, Pansare M. Solid waste management - A case study. Indian J. Environ. Prot. 2003;23:1153-60.
2. Wei Y, Li J, Shi D, Liu G, Zhao Y, Shimaoka T. Environmental challenges impeding the composting of biodegradable municipal solid waste: a critical review. Resour Conserv Recycl. 2017;122:51-65.
3. Lazcano C, Gómez-Brandón M, Domínguez J. Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. Chemosphere. 2008;72:1013-19.
4. Bernal MP, Alburquerque JA, Moral R. Composting of animal manures and chemical criteria for compost maturity assessment: A review. Bioresour. Technol. 2009;100:5444-53.

5. Lung AJ, Lin CM, Kim J, Marshall MR, Nordstedt R, Thompson NP, et al. Destruction of Escherichia coli O157:H7 and Salmonella enteritidis in cow manure composting. J. Food Prot. 2001;64:1309-14.
6. Jain MS, Daga M, Kalamdhad AS. Variation in the key indicators during composting of municipal solid organic wastes. Sustain. Environ. Res. 2019;29:1-8.
7. Waszkielis KM, Wronowski R, Chlebus W, Białobrzewski I, Dach J, Pilarski K, et al. The effect of temperature, composition and phase of the composting process on the thermal conductivity of the substrate. Ecol. Eng. 2013;61:354-57.
8. Ryckeboer J, Mergaert J, Vaes K, Klammer S, De Clercq D, Coosemans J, et al. A survey of bacteria and fungi occurring during composting and self-heating processes. Ann. Microbiol. 2003;53:349-410.
9. Eusufzai MK, Deb SK, Maeda T, Fujii K. Mass loss and C and N release from decomposing fresh and composted residues as affected by cold climate conditions. Environ. Nat. Resour. J. 2013;3:116-27.
10. Petric I, Avdihodžić E, Ibrić N. Numerical simulation of composting process for mixture of organic fraction of municipal solid waste and poultry manure. Ecol. Eng. 2015;75:242-49.
11. Varma VS , Kalamdhad AS. Evolution of chemical and biological characterization during thermophilic composting of vegetable waste using rotary drum composter. Int. J. Environ. Sci. Technol. 2015;12:2015-24.
12. Jurado M, López MJ, Suárez-Estrella F, Vargas-García MC, López-González JA, Moreno J. Exploiting composting biodiversity: study of the persistent and biotechnologically relevant microorganisms from lignocellulose-based composting. Bioresour. Technol. 2014;162:283-93.
13. Rastogi M, Nandal M, Khosla B. Microbes as vital additives for solid waste composting. Heliyon. 2020;6:1-11.
14. Tognetti C, Mazzarino MJ, Laos F. Improving the quality of municipal organic waste compost. Bioresour. Technol. 2007;98:1067-76.
15. Tibu C, Annang TY, Solomon N, Yirenya-Tawiah D. Effect of the composting process on physicochemical properties and concentration of heavy metals in market waste with additive materials in the Ga West Municipality, Ghana. Int.J. Recycl. Org. Waste Agric. 2019;8:393-403.
16. Mengistu T, Gebrekidan H, Kibret K, Woldetsadik K, Shimelis B, Yadav H. Comparative effectiveness of different composting methods on the stabilization, maturation and sanitization of municipal organic solid wastes and dried faecal sludge mixtures. Environ. Syst. Res. 2018;6:1-16.
17. Jalalipour H, Jaafarzadeh N, Morscheck G, Narra S, Nelles M. Potential of Producing Compost from Source-Separated Municipal Organic Waste (A Case Study in Shiraz, Iran). Sustainability. 2020;12:1-17.
18. Breitenbeck GA , Schellinger D. Calculating the reduction in material mass and volume during composting. Compost Sci. Util. 2013;12:365-71.
19. Vietnam Ministry of Agriculture and Rural Development. TCVN 9297:2012, Fertilizers – Method for determination of moisture; 2012.

20. Vietnam Ministry of Agriculture and Rural Development. TCVN 9294:2012, Fertilizers - Determination of total organic carbon by Walkley - Black method; 2012.
21. Vietnam Ministry of Agriculture and Rural Development. TCVN 8557:2010, Fertilizers - Method for determination of total nitrogen; 2010.
22. Vietnam Ministry of Agriculture and Rural Development. TCVN 8559:2010, Fertilizers - Method for determination of available phosphorus; 2010.
23. Jusoh ML, Manaf LA, Abdul Latif P. Composting of rice straw with effective microorganisms (EM) and its influence on compost quality. J. Environ. Health Sci. Eng. 2013;10:1-9.
24. Sundberg C, Smars S, Jonsson H. Low pH as an inhibiting factor in the transition of mesophilic to thermophilic phase in composting. Bioresour. Technol. 2004;95:145-50.
25. Sharma D, Varma VS, Yadav KD, Kalamdhad AS. Evolution of chemical and biological characterization during agitated pile composting of flower waste. Int.J. Recycl. Org. Waste Agric. 2017;6:89-98.
26. Wang Y , Ai P. Integrating particle physical geometry into composting degradation kinetics. Bioresour. Technol. 2016;200:514-20.
27. Huerta-Pujol O, Soliva M, Martinez-Farre FX, Valero J, Lopez M. Bulk density determination as a simple and complementary tool in composting process control. Bioresour. Technol. 2010;101:995-1001.
28. Norbu T, Visvanathan C, Basnayake B. Pretreatment of municipal solid waste prior to landfilling. Waste Manag. 2005;25:997-1003.
29. Gajalakshmi S , Abbasi SA. Solid waste management by composting: State of the art. Crit. Rev. Environ. Sci. Technol. 2008;38:311-400.
30. Beck-Friis B, Smårs S, Jönsson H, Kirchmann H. SE-Structures and Environment: Gaseous Emissions of Carbon Dioxide, Ammonia and Nitrous Oxide from Organic Household Waste in a Compost Reactor under Different Temperature Regimes. J. Agric. Eng. Res. 2001;78:423-30.
31. Raj D , Antil RS. Evaluation of maturity and stability parameters of composts prepared from farm wastes. Arch. Agron. Soil Sci. 2012;58:817-32.
32. Yue B, Chen T, Gao D, Zheng G, Liu B, Lee D. Pile settlement and volume reduction measurement during forced-aeration static composting. Bioresour. Technol. 2008;99:7450-57.
33. Abbassi B, Abubaker S, Al-Manaseer E, Nassour A, Dababneh B, Shqairat W, et al. Optimization of operating parameters of windrow composting of animal manures. J. Solid Waste Technol. Manag. 2015;41:60-67.
34. Inbar Y, Hadar Y, Chen Y. Recycling of cattle manure: the composting process and characterization of maturity. J. Environ. Qual. 1993;22:857-63.
35. Huang GF, Wong JWC, Wu QT, Nagar BB. Effect of C/N on composting of pig manure with sawdust. Waste Manag. 2004;24:805-13.

36. Said-Pullicino D, Erriquens FG, Gigliotti G. Changes in the chemical characteristics of water-extractable organic matter during composting and their influence on compost stability and maturity. Bioresour. Technol. 2007;98:1822-31.
37. Teshome B , Amza J. Evaluating Methods of Composting on Date of Maturity and Quality of Compost in Assosa, Western Ethiopia. Int. J. Waste Resour. 2017;7:1-6.
38. Benito M, Masaguer A, De Antonio R, Moliner A. Use of pruning waste compost as a component in soilless growing media. Bioresour. Technol. 2005;96:597-603.
39. Dessalegn D, Hammed S, Seyoum L. Evaluation of Composting and the Quality of Compost from the Source Separated Municipal Solid Waste. J. Appl. Sci. Environ. Manage. 2012;16:5-10.

Figures

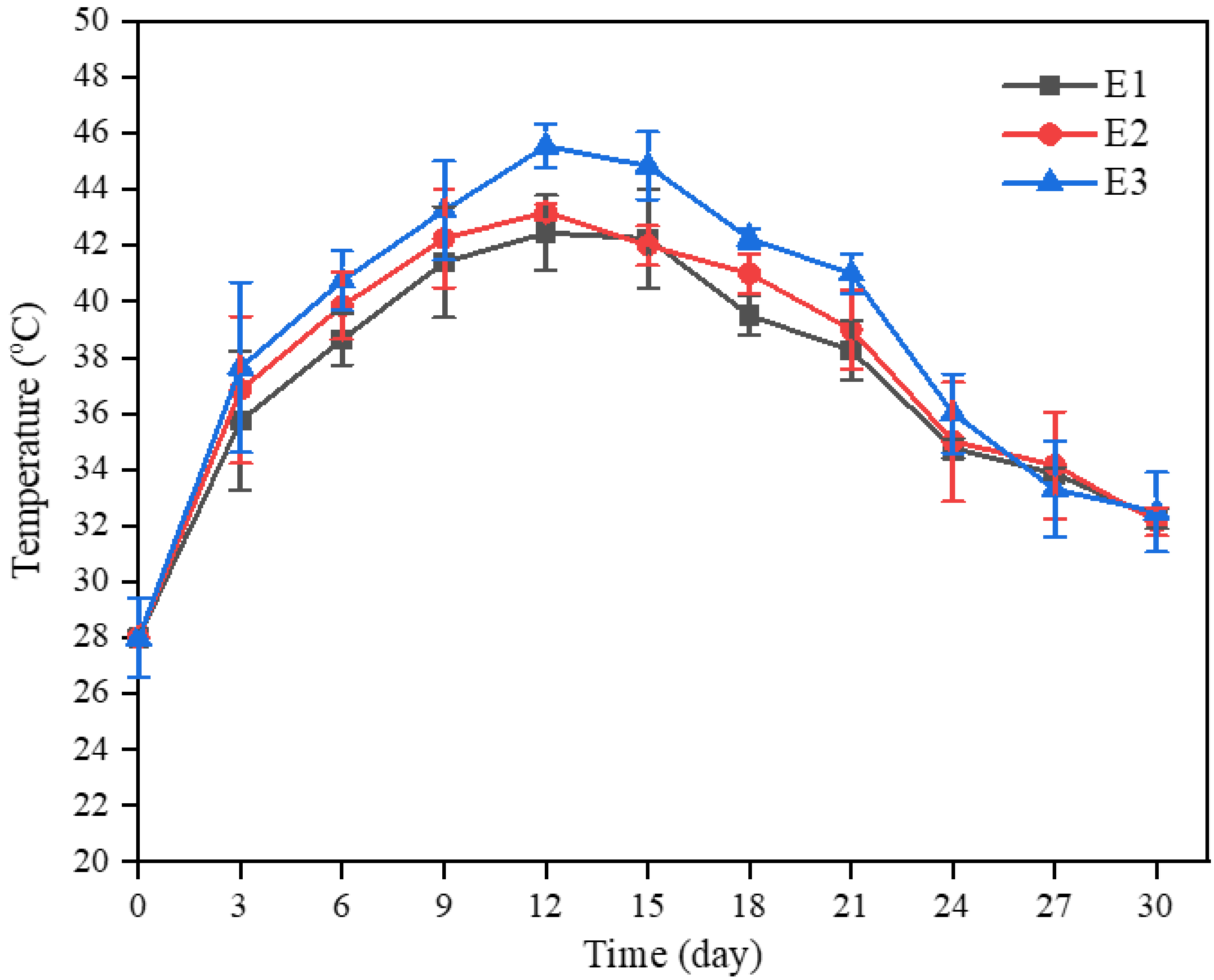

Figure 1

Variation of temperature during the composting period

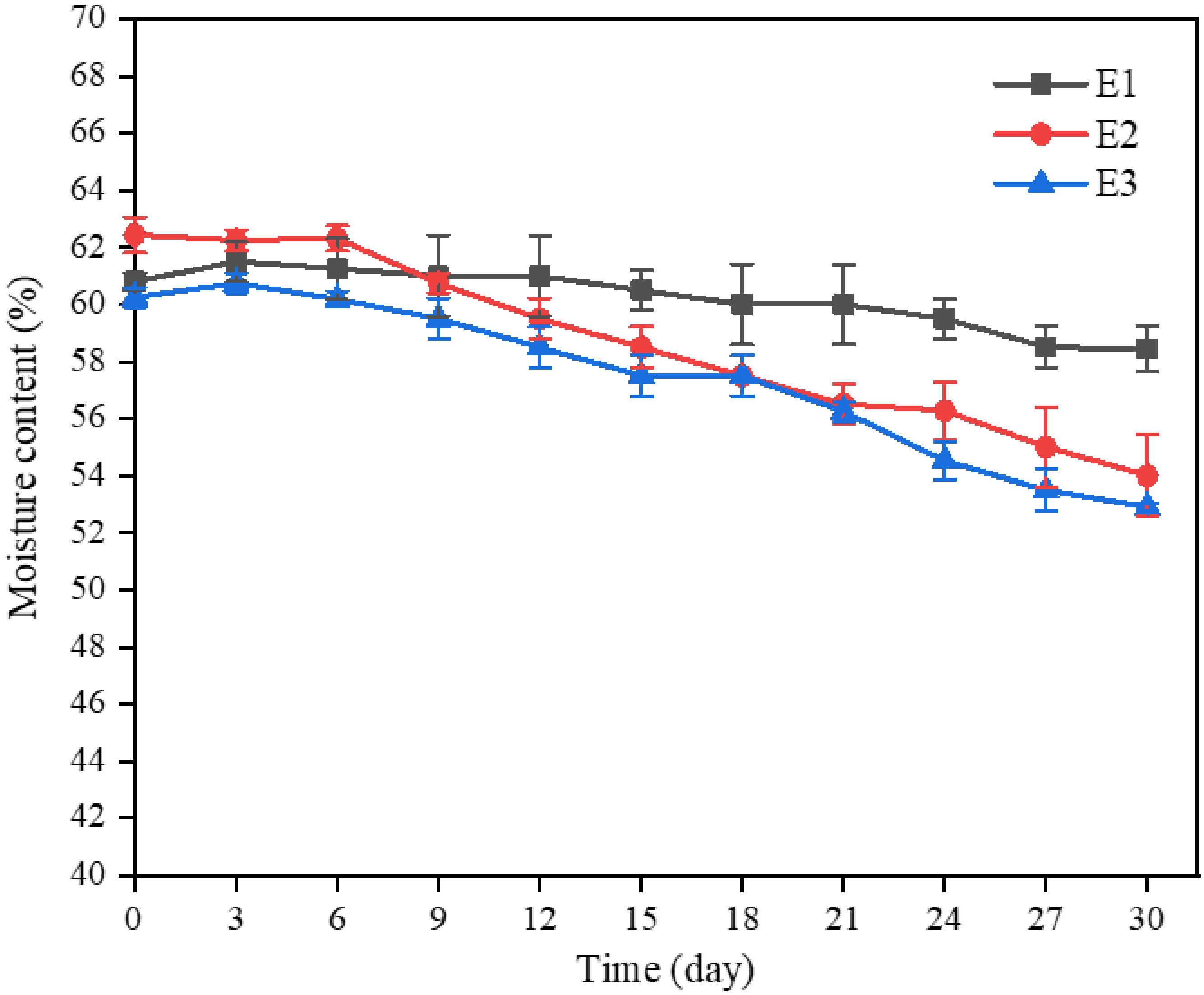

Figure 2

Variation of moisture content during the composting period

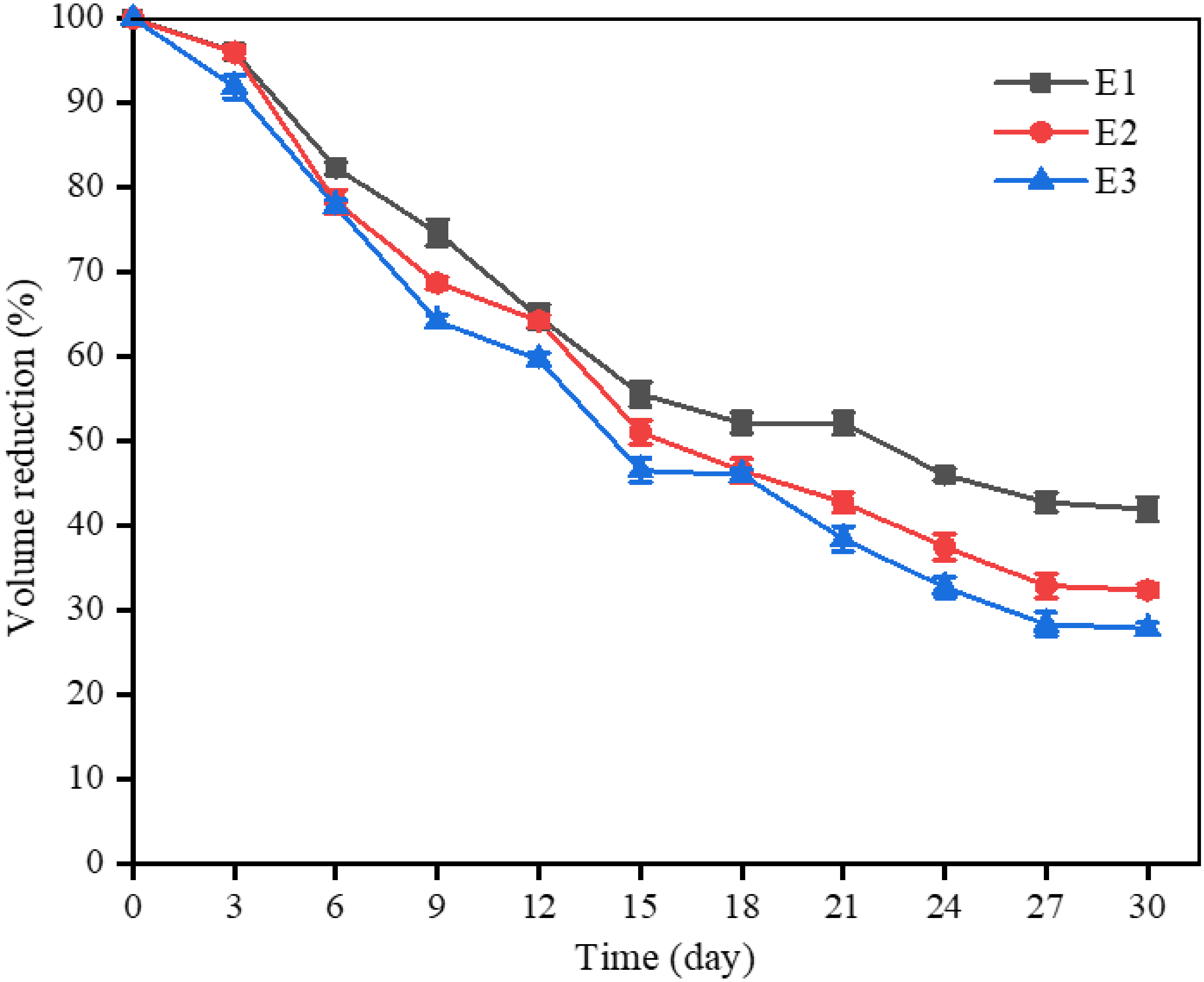

Figure 3

Volume reduction during the composting period