Asia-Pacific Journal of Science and Technology :Volume :31 Issue :02 Article ID :APST-31-02-13 Research Article

APST

Asia-Pacific Journal of Science and Technology

https//:www.tci-thaijo.org/index.php/APST/index

Published by Research and Innovation Department,
Khon Kaen University, Thailand

Accelerating Paper Waste Decomposition in Home Composting, Promoting Sustainable Resource Circulation

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Received 3 April 2025
Revised 3 November 2025
Accepted 7 January 2026

Abstract

The increase in global consumption has led to a significant increase in the amount of paper waste, one of the major components of municipal solid waste. As a cellulose-based material, paper can undergo biological degradation through composting. In this study, the biodegradation of five commercial paper-based packaging materials in a home composting system under ambient conditions was evaluated. Test samples (2.5 × 2.5 cm) were composted with synthetic organic waste from three microbial sources: dairy cow manure (DCM), microbial activator super LDD1 (LDD1), and photosynthetic bacteria (PSB). The results indicate that LDD1 and PSB, combined with DCM, significantly accelerated degradation, achieving visible decomposition within 2 weeks. However, nonbiodegradable plastic coatings on paper food boxes hindered complete degradation. Scanning electron microscopy confirmed progressive fiber decomposition, while germination index values exceeding 60% indicated compost maturity. These findings contribute to a deeper understanding of paper waste biodegradation, thus informing waste management strategies and promoting sustainable organic waste treatment.

Keywords: Degradation, Germination index, Microorganisms, Municipal solid waste, Packaging

1. Introduction

Owing to growing environmental awareness, consumers are now avoiding the use of plastic products and switching to paper products made from natural materials. Plastic products can persist for hundreds of years, whereas paper products can degrade in various environments. Currently, paper waste has become one of the major constituents of municipal solid waste (MSW) owing to global population growth and changing consumption habits [1-3]. According to reports, the amount of nonrecyclable paper waste produced by households, such as sanitary paper, wrapping paper, paper bags, and paper trays, has been increasing continuously. Most of this waste is directly dumped into landfills or incinerated in open areas, leading to severe environmental pollution, including greenhouse gas emissions and air quality deterioration. For instance, the United States alone generated more than 67 million tons of paper waste in 2017, of which 18.4 million tons ended up in landfills [4]. According to one report, 110 million tons of paper and cardboard waste were generated in 2019. Landfilling handled approximately 56% of this waste, while only 38% underwent recycling [5]. In Thailand, the primary components of MSW are food, paper, and plastics, which are commonly disposed of in open dumpsites or landfills. However, improper handling and treatment of most dumpsites or landfills

in Thailand can have detrimental effects on human health and the environment [6,7]. To reduce the amount of paper waste for disposal, numerous approaches for paper waste management have been implemented, such as reuse and recycling, waste recovery, incineration, anaerobic methanation, and composting.

Composting process been recognized as an eco-friendly method for handling the solid organic component of MSW. Home composting is a sustainable alternative for treating household biowaste, offering numerous benefits at the household level. This method reduces the amount of compostable waste that would otherwise end up in landfills, produces mature compost containing essential nutrients for plant growth, and improves the ability of the soil to retain moisture. Moreover, it has a positive effect on the economy and society by reducing the costs of garbage collection, transportation, and disposal [8-11].

Previous studies have focused on the degradation of paper during the composting process. Saludes et al. investigated the application of wallboard paper scraps as a bulking agent in the composting of dairy cattle manure in a 481-L reactor with vacuum-type aeration [12]. Farrell and Jones conducted a study on the cocomposting of catering waste, green waste, and shredded paper in a 1.5 m diameter in-vessel composter under an aerated system for 112 days [13]. In accordance with the relevant literature, most related studies have employed an aerated composting system for paper composting. However, for a typical household, this system is not only prohibitively expensive but also excessively large and unnecessary. Furthermore, research on the use of small-scale or household composters for treating organic waste at the household level is lacking.

The aim of this study was to investigate the degradation behavior of different types of paper-based packaging under home composting conditions. We evaluated the physical and chemical properties of the final composts and assessed their phytotoxicity by determining the germination index (GI) of *Vigna radiata* and *Sorghum bicolor*. The knowledge gained from this study can be used as a guideline for the disposal of paper waste generated by households that are contaminated with other organic waste and not commonly recycled. Furthermore, this study constitutes applied research aimed at reducing waste at its source, aligning with the principles of a circular economy and promoting sustainable, safe, and environmentally friendly waste management practices.

2. Materials and methods

2.1 Materials

Five commercially available paper-based packaging materials were selected to evaluate their degradation behavior under home composting conditions: (i) paper food boxes (code A), (ii) parcel wrapping paper (code B), (iii) paper bags (code C), (iv) snack trays (code D), and (v) egg trays (code E). Test samples were cut into 2.5 × 2.5 cm pieces in accordance with the ISO 20200:2023 standard [14]. Before the composting test, the characteristics of all the test samples were assessed. The moisture content and total dry solid content were determined by drying paper samples at 105 °C in an oven (model FED 720, Binder, Tuttlingen, Germany) until a constant weight was reached. The volatile solid content was assessed at 550 °C for 8 hours. The thickness was measured with a digimatic thickness gauge (model Film Master, Mitutoyo, Osaka, Japan) for parcel wrapping paper and paper bags and with a digimatic caliper (model no. CD-8, Mitutoyo, Osaka, Japan) for paper food boxes, snack trays, and egg trays. The grammage, which refers to the mass of a unit area of paper measured in grams per square meter (g/m^2), and the density (kg/m^3) were assessed using the ISO 536:2019 method [15].

2.2 Sources of microorganisms and viable plate count

Three sources of microorganisms were used in this study: dairy cow manure (DCM), the microbial activator super LDD1 (LDD1), and photosynthetic bacteria (PSB). DCM was purchased from Sukjaroen999 Co., Ltd. (Nonthaburi, Thailand). LDD1 was produced by the Land Development Department of Thailand. PSB was prepared in the laboratory according to the preparation method outlined by the Office of the Permanent Secretary for the Ministry of Agriculture and Cooperatives, Thailand. Briefly, one tablespoon of beaten eggs was mixed with 1 liter of water and poured into a polyethylene terephthalate (PET) plastic bottle. The bottle was placed under direct sunlight and shaken once a day for 2–3 weeks until the mixture turned red.

Microbial quantification was conducted on all sources of microorganisms using the spread plate technique with serial dilutions. The quantities of microorganisms in DCM and LDD1 were quantified as colony-forming units per gram (CFU/g), whereas PSB were measured in colony-forming units per milliliter (CFU/mL). For the enumeration process, 10 g of DCM, 10 g of LDD1, and 10 mL of PSB were transferred into 250-mL flasks with 90 mL of 0.85% NaCl. The mixtures were agitated at 150 rpm for 10 minutes and subsequently allowed to stand for approximately 15 minutes for precipitation. Each supernatant was subjected to tenfold serial dilution, and 100 µL of each dilution was

spread on selective agar media. In this study, nutrient agar (HiMedia Laboratories Pvt. Ltd., Mumbai, India) supplemented with cycloheximide (50 mg/mL) was used for the enumeration of general bacteria. Potato dextrose agar (HiMedia Laboratories Pvt. Ltd., Mumbai, India) supplemented with penicillin–streptomycin (5,000 U/mL) was used for fungal counts.

2.3 Composting experiment setup

The home composting experiment was conducted using 10-liter composting bins. The composting bins were designed with 0.5-cm diameter perforations for optimal aeration and water drainage. There were 5 holes per row across 10 rows on the bin body, 12 holes on the lid, and 6 holes at the bottom. A three-dimensional model of the compost bin used in this experiment is shown in Figure 1.

The synthetic organic biowaste for compost production comprised12 kg of wood chips as a bulking agent, 12 kg of DCM as the primary source of microorganisms, 9 kg of cooked rice, 12 kg of fruit, and 12 kg of vegetable waste, all of which represent food waste. The combination was thoroughly mixed and used as the base for composting. Each bin was filled with 3.5 kg of synthetic biowaste, 300 samples of each paper type, and 200 mL of water as the control. In Treatment 1 and Treatment 2, 200 mL of water was replaced with either 200 mL of LDD1 or 200 ml of PSB, respectively. All the experiments were coded as shown in Table 1. A total of 15 bins were established at ambient temperatures over 8 weeks throughout the home composting process.

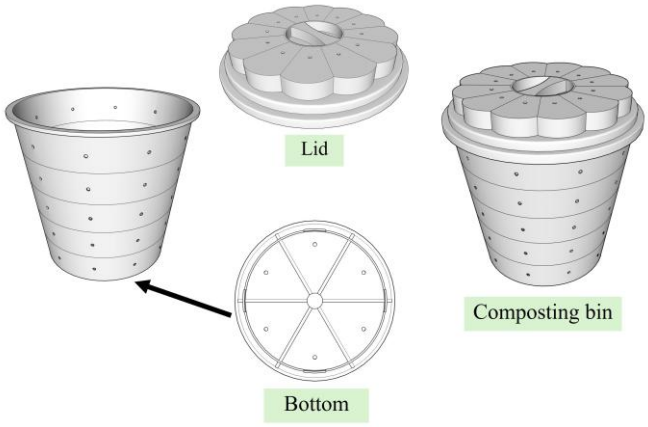


Figure 1 The composting bin used in this study.

Table 1 Composition and code of all experiments.

Experiment	Source of microorganisms	Composition	Code
Control	DCM	Organic waste + paper food boxes	Control-A
		Organic waste + parcel wrapping paper	Control-B
		Organic waste + paper bags	Control-C
		Organic waste + snack trays	Control-D
		Organic waste + egg trays	Control-E
Treatment 1	DCM + LDD1	Organic waste + paper food boxes	LDD1-A
		Organic waste + parcel wrapping paper	LDD1-B
		Organic waste + paper bags	LDD1-C
		Organic waste + snack trays	LDD1-D
		Organic waste + egg trays	LDD1-E
Treatment 2	DCM + PSB	Organic waste + paper food boxes	PSB-A
		Organic waste + parcel wrapping paper	PSB-B
		Organic waste + paper bags	PSB-C
		Organic waste + snack trays	PSB-D
		Organic waste + egg trays	PSB-E

2.4 Data analysis

The temperature within each composting bin was monitored every 2 days during the first 2 weeks of the experiment and subsequently measured on a weekly or biweekly basis until the end. The compost was manually stirred, and its

moisture content was maintained on a weekly basis. The moisture content was measured initially and at the end of the experiment using the method described in the materials preparation section, whereas intermediate measurements were performed using the hand squeezing method. The composting material was within the optimal moisture range (approximately 50–60%) when it formed a cohesive ball with a slight amount of moisture visible between the fingers. This technique is widely accepted in household-scale composting systems.

Test samples were collected from each bin every 2 weeks. The samples were cleaned and dried at 40 °C to observe changes in physical appearance through visual inspection. Changes in surface morphology during composting were monitored using a field emission scanning electron microscope (FESEM JSM7800F; JEOL, Tokyo, Japan). After 8 weeks, the physicochemical properties of the compost, including particle size, moisture content, pH, electrical conductivity, and C:N ratio, were analyzed. The pH and electrical conductivity of the compost samples were determined in a 1:5 (w/v) compost-to-deionized water suspension using universal pH paper (Merck, Darmstadt, Germany) and a conductivity meter (Cole-Parmer, Vernon Hills, United States), respectively. The total organic carbon content was analyzed using a total organic carbon analyzer (Shimadzu Corp., Kyoto, Japan), while the total nitrogen content was determined using the Kjeldahl method (Gerhardt Vapodest 45 s, Gerhardt GmbH & Co. KG, Königswinter, Germany).

2.5 Germination test

Numerous studies have extensively utilized the germination index (GI) to evaluate the maturity and phytotoxicity of compost. In this study, compost obtained after 56 days of home composting was extracted with deionized water at a ratio of 1:10 (w/v, dry weight basis) by mechanical shaking at 200 rpm for one hour. Each extract was then separated from the compost particles using a 0.45-µm filter paper. The dicotyledon *Vigna radiata* (mung bean) and monocotyledon *Sorghum bicolor* (sorghum), listed as standard test species in OECD 208:2006 [16], were used as test seeds. Mung bean seeds were purchased from Chia Tai Co., Ltd. (Bangkok, Thailand). Sorghum seeds were purchased from Pacific Seeds (Thai) Ltd. (Saraburi, Thailand). The seed quality was verified prior to the germination index test, which was conducted in the dark for 3 days. The results revealed that more than 95% of the mung bean and sorghum seeds germinated, meeting the OECD 208 standard requirements.

Ten seeds of each species were placed in sterilized plastic Petri dishes lined with seed germination paper. Approximately 5 mL of each compost extract was then added, and the dishes were covered with another layer of germination paper. Controls were prepared by substituting the compost extract with 5 mL of deionized water. Both control and test petri dishes were incubated at 25 ± 2 °C for 72 hours in the dark, with three replicates for each treatment. After incubation, the number of germinated seeds was counted, and the root length was measured. The germination index (GI) was calculated according to Equation (1).

$$\mathrm{GI} = \frac{\text{number of germinated seed in extract}}{\text{number of germinated seed in control}} \times \frac{\text{root length in extract}}{\text{root length in control}} \times 100\% \quad (1)$$

3. Results and discussion

3.1 Basic properties of the samples

The basic properties of the paper samples are summarized in Table 2. The moisture values of all test paper types were similar, ranging from 7.5% to 10%. According to the product specifications, the moisture content of paper products should not exceed 10%. The volatile solid content indicates the amount of organic matter present in the paper samples. In this study, the high content of volatile solids observed in paper food boxes and snack trays could be attributed to the high purity requirements for these paper types, particularly those intended for food contact applications. This high content can be explained by the fact that the main component of these papers, cellulose fibers, decomposes at 550 °C. In the case of the paper food box, the volatile solid content reached 99.4%, which may be attributed to the presence of a plastic coating on the material's surface that is not biodegradable. In contrast, parcel wrapping paper, paper bags, and egg trays may contain additional components that transform into ash upon heating to 550 °C, resulting in slightly lower volatile solid contents than those of paper food boxes and snack trays.

The thickness of the paper samples varied depending on the paper type. The thinnest samples were parcel-wrapped paper and paper bags (0.18 mm). The paper food box and snack tray were slightly thicker, at 0.38 mm and 0.51 mm, respectively. The egg tray exhibited the greatest thickness at 0.96 mm, which provides adequate structural integrity to support the weight of the eggs.

Grammage, defined as the weight per unit area (g/m²), generally correlates with paper thickness. In contrast, the density of the paper samples, which reflects the compactness of the fibers, was relatively consistent, ranging from 611.2 to 710.1 kg/m³, except for the egg tray, which exhibited the lowest density of 387.0 kg/m³. These findings suggest that the egg tray consists of loosely bonded fibers, resulting in a more porous and less compact structure.

Table 2 Basic properties of paper samples.

Properties	Paper samples				
	Paper food box	Parcel wrapping paper	Paper bag	Snack tray	Egg tray
Moisture content (% wt.)	7.5 ± 0.4	10.0 ± 0.3	8.6 ± 0.2	9.4 ± 0.1	9.4 ± 0.1
Total dry solid content (TS, % wt.)	92.5 ± 0.4	90.0 ± 0.3	91.4 ± 0.2	90.6 ± 0.1	90.6 ± 0.1
Volatile solid content (VS, % wt. on TS)	99.4 ± 0.0	90.5 ± 0.1	87.5 ± 0.0	99.1 ± 0.0	87.5 ± 0.1
Thickness (mm)	0.38 ± 0.02	0.18 ± 0.00	0.18 ± 0.00	0.51 ± 0.01	0.96 ± 0.02
Grammage (g/m^2)	269.4 ± 5.0	117.1 ± 0.5	127.1 ± 1.0	311.7 ± 3.9	371.5 ± 18.6
Density (kg/m^3)	709.1 ± 13.2	643.5 ± 2.9	710.1 ± 5.9	611.2 ± 7.7	387.0 ± 19.3

3.2 Viable plate count

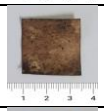
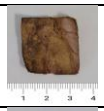
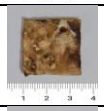
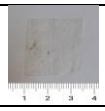
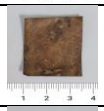
The viable plate count method was employed to quantify the number of microorganisms. A comparable quantity of bacteria was observed to grow on nutrient agar in DCM, LDD1, and PSB. The DCM concentration was 1.2×10^7 CFU/g, and the LDD1 concentration was slightly greater (2.0×10^7 CFU/g), whereas the PSB concentration was 2.0×10^7 CFU/mL. Fungal quantification on potato dextrose agar revealed that PSB had the highest fungal concentration, at 1.7×10^7 CFU/mL, while DCM and LDD1 had comparable fungal concentrations, at 3.5×10^5 CFU/g and 3.0×10^5 CFU/g, respectively. In this study, the enhancement of paper degradation was investigated using a combination of DCM and the microbial inoculants LDD1 and PSB, which contain various strains of bacteria and fungi. Previous research has shown that LDD1 and PSB can accelerate organic waste biodegradation in household composting systems. For example, Karnchanawong and Nissaikla applied LDD1 in a 200-liter aerated composting bin, with daily additions of 0.16 g, simulating typical household composting [17]. In contrast, in this study, a single high-concentration dose of 200 mL was applied to a 10-liter composting bin, providing approximately 2.0×10^7 CFU/g, which is higher than the microbial load used in the previous study. Furthermore, Li et al. reported that applying a commercial effective microorganism (EM) inoculant at 0.5% w/w, with a concentration of 1×10^9 CFU/mL and containing photosynthetic bacteria, to 80 kg of green waste compost (pile size 1.0 × 1.0 × 0.75 m) reduced the composting period to 37 days [18].

3.3 Visual observations

The degradation behavior of test paper under home composting is shown in Table 3. All the paper samples completely degraded within 8 weeks in the composting bins, except for the snack tray in Control-D, which exhibited residual pieces beyond this timeframe. The results from Treatments 1 and 2 indicate that combining DCM with LDD1 and PSB accelerated the degradation of paper samples by at least 2 weeks compared with the control group, which used only DCM. This increase could be attributed to an increase in the quantity and diversity of microorganisms in the composting bin, which is a critical factor in composting. The paper food box exhibited 100% degradation in Treatment 1 and was almost completely degraded in Treatment 2 within 4 weeks. In contrast, complete degradation was observed within 6 weeks in the control group. Despite the degradation of the paper component, the plastic film coating remained intact and retained its original square shape across all 3 experiments. Both the paper bag and the parcel wrapping paper exhibited rapid degradation within 4 weeks in Treatments 1 and 2. The thickness and grammage, as reported in Table 2, were lower than those of other paper types, contributing to faster degradation. Conversely, the degradation rates of the snack tray and egg tray were the slowest, with complete degradation occurring within 6 weeks, except in Control-D, which still had residues. In terms of physical properties, the egg tray had the greatest thickness at 0.96 mm; however, its density was approximately 2-fold lower than those of the others. In contrast, the snack tray was thinner than the egg tray; however, it had a greater density. These results indicate that both thickness and paper quality significantly influence the rate of degradation. These findings are consistent with those of previous studies. Dolci et al. investigated the degradation of paper-based boxes under composting conditions. They reported that corrugated cardboard boxes made from bleached and unbleached paper were highly degraded after 4 weeks, demonstrating their high compatibility with biowaste. In contrast, a bleached cartonboard box with a barrier coating against fats and humidity showed slower degradation, requiring 12 weeks for decomposition. These results suggest that the compostability of paper materials may be limited by the presence of the coating [19]. Additionally,

Alvarez et al. reported that the biodegradability of 6 groups of paper ranged between 43% and 65% after 45 days under aerobic compost conditions [20].

Table 3 Photographs of residue samples before and after home composting at different degradation times.

Experiment	Code	Samples	Composting time (weeks)				
			0	2	4	6	8
Control	Control-A	Paper food box					
	Control-B	Parcel wrapping paper				-	-
	Control-C	Paper bag			-	-	-
	Control-D	Snack tray					
	Control-E	Egg tray					-
Treatment 1	LDD1-A	Paper food box					
	LDD1-B	Parcel wrapping paper			-	-	-
	LDD1-C	Paper bag			-	-	-
	LDD1-D	Snack tray					-
	LDD1-E	Egg tray					-
Treatment 2	PSB-A	Paper food box					
	PSB-B	Parcel wrapping paper			-	-	-
	PSB-C	Paper bag			-	-	-
	PSB D	Snack tray					-
	PSB-E	Egg tray					-

3.4 Scanning electron microscopy (SEM) results

Table 4 shows SEM micrographs at 500× magnification of the fiber structures on the surfaces of the decomposed paper residues collected after the composting process under the studied conditions. Additionally, the remaining plastic films from the paper food box after 8 weeks were analyzed. SEM micrographs revealed rough surfaces on these films; however, no tears or pores were detected, indicating that the films were nonbiodegradable under the tested conditions. The parcel wrapping paper from the control group after 4 weeks, as well as those from Treatments 1 and 2 after 2 weeks, exhibited comparable characteristics in the SEM micrographs. The presence of degraded and torn fibers suggests that the addition of LDD1 and PSB accelerated the degradation of this paper type within 2 weeks in Treatments 1 and 2. SEM micrographs of the paper bag after 2 weeks revealed decomposed and torn fibers in all the treatments, in contrast to the tightly arranged fibers observed before composting. Similarly, the snack tray exhibited holes and broken fibers in Treatments 1 and 2 after 6 weeks and in the control group after 8 weeks. The slowest degradation of the snack tray suggests that its initial fiber structure was uniform in size, highly ordered, and tightly arranged. This arrangement contributed to its resistance to decomposition. SEM analysis of the egg tray before composting revealed a nonuniform fiber structure with loosely arranged fibers, which facilitated degradation. However, the degradation rate of the egg tray was slower than expected. SEM micrographs revealed visible holes and tears after 6 weeks in all treatments, confirming degradation. The slower degradation of the egg tray was attributed to its greater thickness than that of the other paper samples.

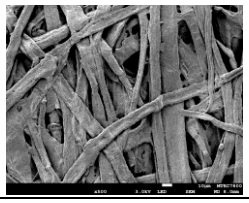
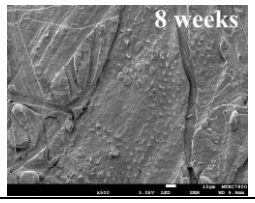
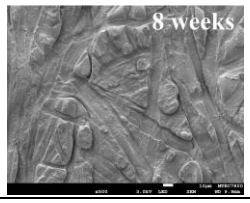
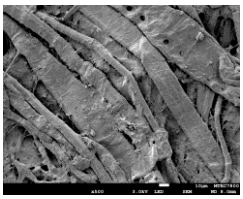
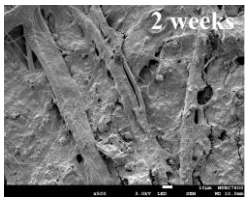
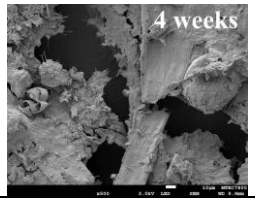
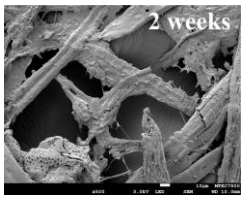
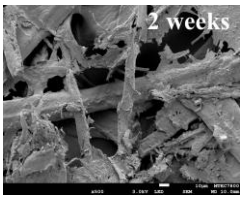
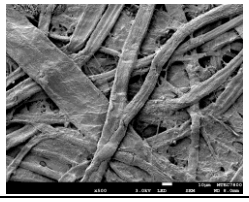
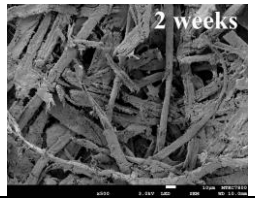
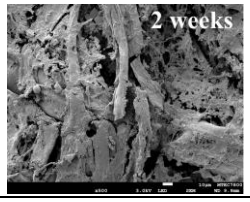
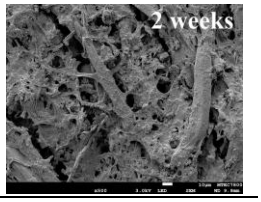
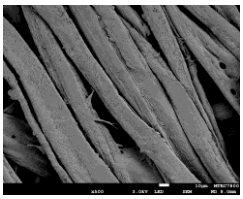
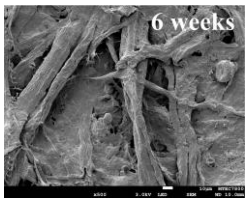
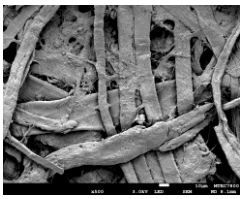
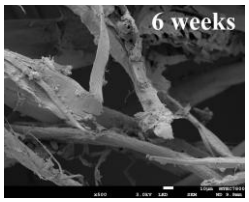
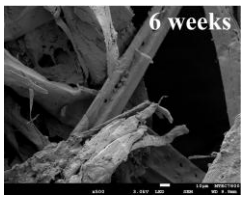
3.5 Temperature profiles

The environmental temperature patterns during composting are shown in Figure 2. The ambient temperature remained stable throughout the experiment, ranging from 30.5 to 34.1 °C, with an average of 32.2 °C. The temperature trends during composting were similar across all the treatments. On the first day, the temperature in all the treatments exceeded 50 °C. The highest temperature was approximately 57 °C in control-C and control-D, whereas the lowest temperature, approximately 50 °C, was observed in treatment LDD1-E. The mean temperature of all the treatments on the first day was 22.3 °C above the average ambient temperature.

The thermophilic phase of home composting in this study occurred within the first 3 days, with temperatures ranging between 45 and 70 °C. During this phase, thermophilic microorganisms actively decomposed organic compounds, specifically cellulose and lignin [21,22]. After the peak temperature occurred during the thermophilic phase, the temperatures in all the treatments decreased until day 6 but subsequently increased again on day 11. The second step of rising temperatures was probably due to the degradation of bioavailable organic matter after the thermophilic phase [23].

After 15 days of composting, the temperatures in all the treatments decreased to approximately 29 to 35 °C, which was identified as the mesophilic phase. During this period, mesophilic microorganisms continuously decomposed polymeric substances and minor constituents [21,22]. The temperatures in all the treatments over the last 2 weeks gradually decreased to levels close to the ambient temperature. This was considered the maturation phase. This temperature profile reflects the characteristic microbial succession and organic matter transformation typical of composting processes. These results are consistent with the findings of Dolci et al., who reported similar temperature profiles during the degradation of paper-based boxes [19].

Table 4 SEM micrographs (500×) of paper samples before and after home composting at different degradation times.

Samples	Before	After home composting		
		Control	Treatment 1	Treatment 2
Paper food box				
Parcel wrapping paper		 		
Paper bag				
Snack tray		 		
Egg tray				

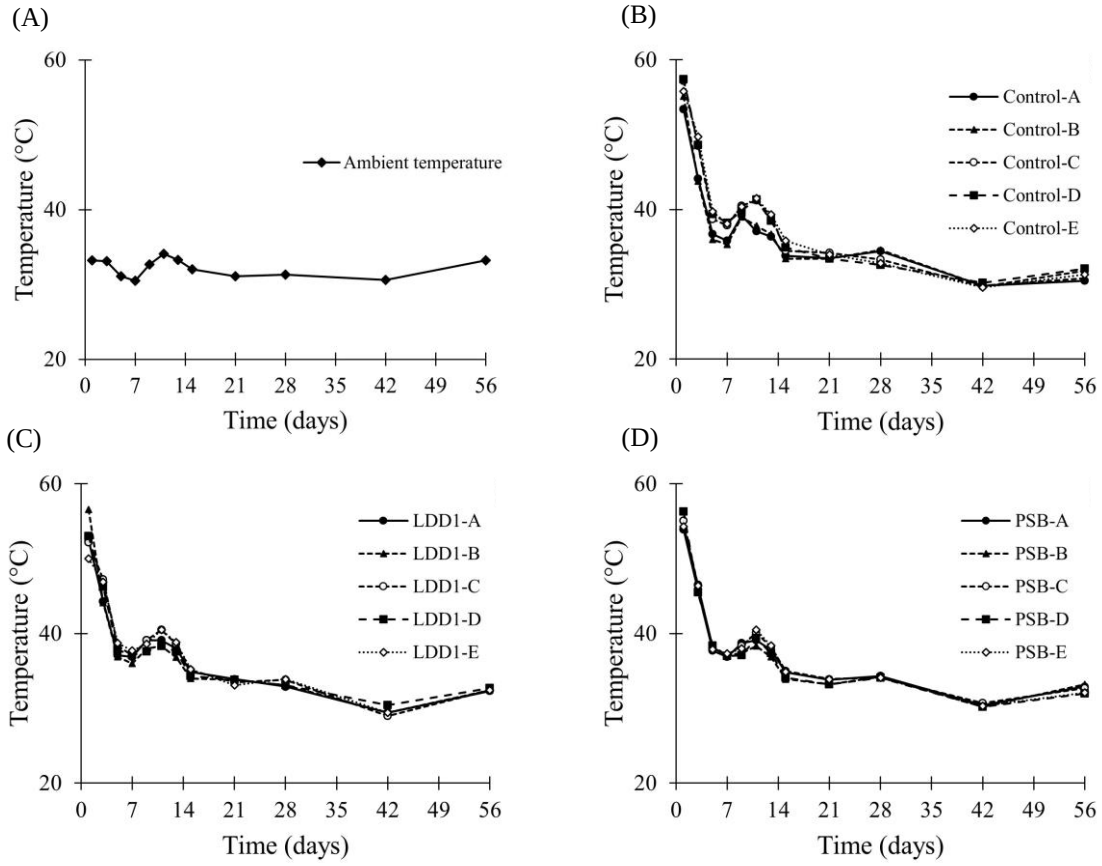


Figure 2 Temperature profile of (A) ambient temperature, (B) control, (C) Treatment 1 and (D) Treatment 2 during home composting.

3.6 Germination assessment

The germination index (GI) is widely used as a biological indicator to evaluate compost maturity and phytotoxicity and has been extensively applied in previous studies [24-26]. Compared with the control, compost is considered mature and nonphytotoxic if the GI value exceeds 60% and 80%, respectively [24,27]. The results of the seed germination tests of mung bean plants (*Vigna radiata*) and sorghum plants (*Sorghum bicolor*) following the home composting test are shown in Figure 3.

Compared with those of the deionized water treatment, the GIs of all the treatments were greater than 60%, indicating that the compost was relatively mature and suitable for use in plant cultivation. In the phytotoxicity test, the GI values for *Vigna radiata* in Control-A (73.5%) and LDD1-D (79.0%) were slightly below the 80% threshold. Similarly, for *Sorghum bicolor*, some treatments (Control-A, Control-B, Control-C, LDD1-A, LDD1-C, and PSB-B) presented GI values ranging from 73.5% to 79.2%, which were also slightly below the threshold. This suggests that transient phytotoxicity occurred because of the high concentration of biodegradable materials introduced into the biowaste. To further enhance compost quality, future studies may consider slightly extending the composting period by 1–2 weeks to achieve more complete decomposition and minimize potential toxicity that could adversely affect plant growth.

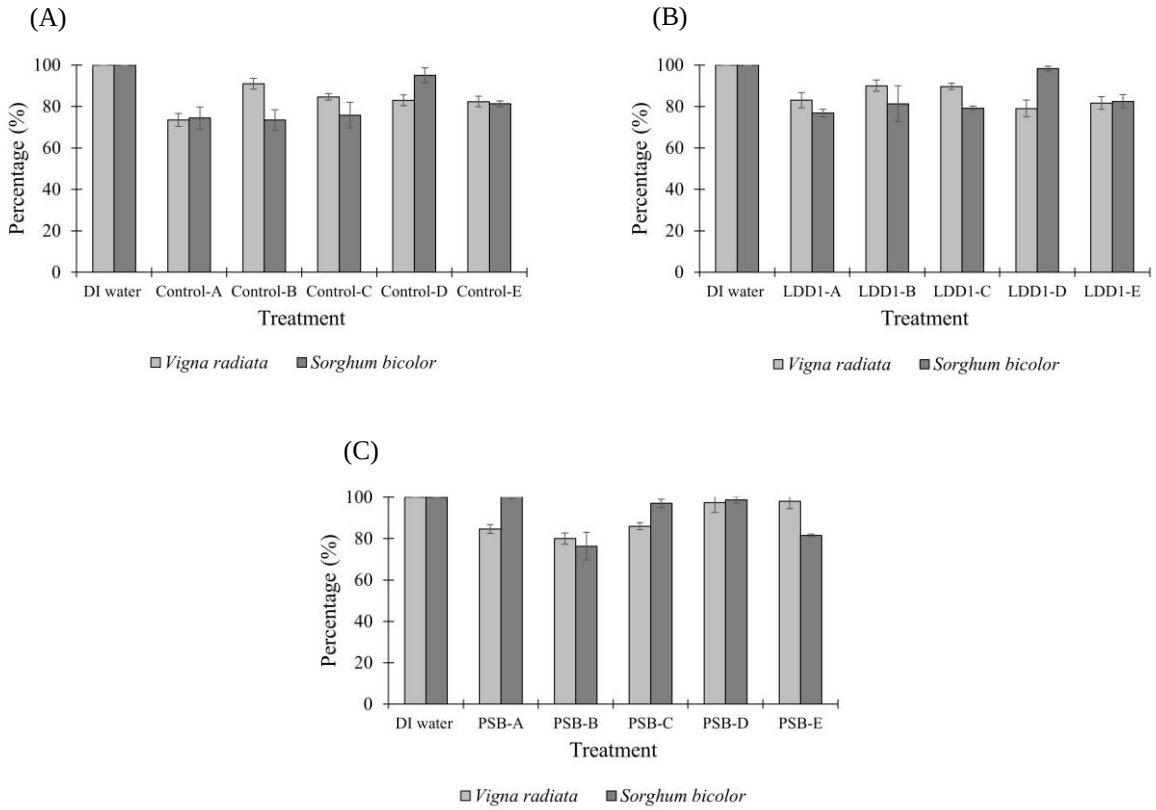


Figure 3 Germination index (GI) of *Vigna radiata* and *Sorghum bicolor* grown with compost from (A) control, (B) Treatment 1 and (C) Treatment 2.

3.7 Properties of the compost

This study examined the fundamental characteristics of the mature compost in accordance with the Thai agricultural standard TAS 9503-2005, which outlines compost specifications [28]. The properties, including the compost particle size, contaminants, moisture content, pH, electrical conductivity, and C:N ratio, are summarized in Table 5. Other parameters, such as primary nutrients, organic matter composition, and heavy metal concentrations, were not analyzed in this study.

The results revealed that the compost obtained from all the experiments had a fine texture, with particle sizes smaller than 12.5 × 12.5 mm. No contamination from rocks, gravel, plastic, glass, or other metal parts was observed, demonstrating compliance with the standard requirements. After 8 weeks of composting, the obtained compost had a low moisture content (< 10%) and maintained its pH, electrical conductivity, and C:N ratio values within the specified acceptable ranges. To evaluate complete decomposition, a GI value exceeding 80% was used as the benchmark. However, some treatments resulted in GI values slightly below this threshold, suggesting that extending the composting duration might be necessary to achieve full decomposition and ensure compost maturity.

Table 5 Quality of compost after 8 weeks under home composting conditions.

Parameters	Thai agricultural standard TAS 9503-2005	Control	Treatment 1	Treatment 2
Compost particles	≤ 12.5 x 12.5 mm	Pass	Pass	Pass
Rocks and gravels	≤ 2 % by weight	Not found	Not found	Not found
Plastic, glass, sharp particles and other metal parts	≤ 0.01 % by weight	Not found	Not found	Not found
Moisture	≤ 35 %	7.17–7.22%	6.71–7.32%	7.18–7.85%
pH	5.5-8.5	7.0	7.0	7.0
Electrical conductivity	≤ 10 dS/m	2.88–6.02	3.06–4.23	4.10–5.40
C:N ratio	≤ 20 : 1	9.69–10.58	10.89–11.23	10.79–11.31

4. Conclusion

This study demonstrated that all the paper samples completely degraded within 8 weeks. Compared with the control treatment, the incorporation of LDD1 and PSB into DCM accelerated degradation by at least 2 weeks. This increase was attributed to increased microbial activity and diversity. Paper thickness and quality were identified as critical factors influencing degradation. Home composting reduced the organic waste weight by approximately 70%, with all the compost samples achieving germination index values above 60%, indicating maturity. While most samples exceeded 80%, some ranged from 73.5% to 79.2%, suggesting that transient phytotoxicity may be mitigated by extending the duration of composting to enhance compost quality.

5. Acknowledgements

This work supported by The Twenty-Fourth Young Scientist Competition (YSC 2022) in the Environmental Science category by NSTDA.

6. Author Contributions

Boonmee, C.: Conceptualization, Methodology, Visualization, Writing – review & editing, Supervision; Chandenduang, T.: Writing – original draft, Data curation, Investigation, Formal analysis; Chandenduang, T.: Writing – original draft, Data curation, Investigation, Formal analysis; Chandenduang, T.: Writing – original draft, Data curation, Investigation, Formal analysis; Methapitaknon, S.: Conceptualization, Methodology, Supervision; Panitanta, P.: Data curation, Investigation; Thongchuentrakool, B.: Investigation, Visualization, Formal analysis.

7. Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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