Aerobic Composting and Vermicomposting of Durian Shell and Citrus Peel Wastes

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Aerobic composting and vermicomposting processes were compared in the co-composting of durian shells and citrus peels. For decomposers, the microorganism catalyst from the Land Development Department, *i.e.*, the LDD1 catalyst, and earthworms were used. The moisture contents of the durian shells and citrus peels were 84.6% and 77.3%, respectively, and the pH of the shells and peels were relatively low, as these are sources of potassium. The experiments utilized four different reactors: durian shells (100%) in reactor 1; durian shells and citrus peels (50% to 50% ratio) in reactors 2 through 4; with the LDD1 catalysts in reactor 3 and the earthworms in reactor 4. The temperature, pH, moisture content, electrical conductivity, NaCl, organic matter, organic carbon, C to N ratio, nutrients (nitrogen, phosphorus, and potassium), germination index, and size of the compost were analyzed according to the standards of the Land Development department (2013). Throughout the composting process, the pH tended to increase, although citrus peels, with a low pH of 3.95, were used as a raw material. At the end of the composting process, reactor 4, which used earthworms as decomposers, passed the standard criteria, yielding a germination index of 90%.

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INTRODUCTION

Presently, there is a great deal of waste generated by daily consumption associated with an increasing population, economic expansion, as well as household and agricultural augmentation. These wastes in Thailand include durian shells, citrus peels, mangosteen peels, *etc.* Thailand's Agriculture Economics office reported that the durian fruit production of Thailand in 2020 was 1,111,928 tons. It is expected, based on information of the economic fruit crops from the eastern and southern parts of the country in 2021, that the durian production will increase by 13.48% in 2021 (Rueangrit *et al*. 2020). Problems caused by fruit shells and peels during the crop season from May to June can be seen, with abundant amounts of durian shells headed for disposal in landfills, while some are left discarded without proper further attention. Ways to extract various valuable products from durian shell waste have been investigated. Durian shell waste has been recycled into food products, fertilizer, and biopesticides (Kusumaningtyas and Syah 2020). Composting of material into a fertilizer is used to eliminate organic waste and, of course, such technology must be environmentally friendly. Wang and Geng (2015) revealed that, when waste is either sanitarily dumped or non-sanitarily dumped in landfills, or incinerated, 1 kg of waste can release 1.16, 0.79, or 0.51 kg of carbon, respectively. There is also the release of 0.30

kg of carbon from composting the waste, which is below the above methods. In fact, composting of waste is an optimal method for Thailand, as this is an agricultural country, and the use of the compost can reduce the import of chemical fertilizers (Rungsisuriyachai and Saricheewin 2018). A popular method is aerobic composting, which has the following advantages: the organic materials do not create bad smells, and the fertilizer obtained is of good quality, as it contains nitrate (NO_3^-) and sulfate (SO_4^{2-}) (Ebertseder and Gutser 2001). Fauzi and Puspitawati (2017) reported that durian shell compost fertilizer had 1.69% N, 0.16% P_2O_5, and 1.20% K_2O. However, Tudsanaton *et al.* (2021) studied the composting of durian shells *via* aerobic degradation with normal flora bacteria and found that the compost from durian shells did not meet the National organic fertilizer guidelines of Thailand.

The composting process can depend on the bacteria in the organic decomposed material, but decomposers can be added to increase the efficiency. One study reported the efficiency of using LDD1 catalyst (a microbial activator from Land Development Department (2014), in Thailand) to decompose 3 materials, *i.e.*, fresh oil palm empty fruit bunches (EFB), decanter sludge, and red soil. The catalyst shortened the processing time by speeding up the organic degradation rate (Kananam *et al*. 2011). However, earthworms are another option used in vermicomposting, where the earthworm manure contributes to the product, while the worms also ventilate the high moisture content raw materials (Angima *et al.* 2011). This has become an organic waste elimination process and technology that not only has reasonable cost but is also environmentally friendly. Vermicomposting enriches the nutrients in the organic waste compost (Pattnaik and Reddy 2009; Askari *et al.* 2020; Musyoka *et al.* 2020; Singh *et al*. 2020). However, the species of earthworm used is crucial to this process. Tropical earthworm species, *i.e.*, *Eudrilus eugeniae* (Kinberg), *Perionyx excavates* (Perrier), *Eisenia andrei* (Bouche), and *Eisenia fetida* (Savigny) are extensively used in vermicomposting. High-quality vermicast can be produced by red wrigglers (*E. fetida*) (Kaur 2020). The composting process depends upon the activity of the microorganisms, which must be provided a suitable environment and sources of nutrients.

The major sources of nutrients in composting are organic waste materials (Willson 1989). Tudsanaton *et al*. (2021) recommended adding a nitrogen source with durian shells to promote degradation in the compost. As such, citrus peel waste is an interesting nitrogen source. Pathak *et al*. (2017) reported that citrus peels had 0.64% to 1.27% N, while Wang *et al*. (2019) reported the N level as 1.27%. Citrus fruits are seasonal, and Thailand produced 213,743 tons in 2019, meaning that citrus peels are commonly found around fresh markets or orange juice vendors.

Durian shells and citrus peels were employed for composting in this study, in order to sustainably manage fruit shell/peel elimination, to gain maximum benefits from the waste, and to ultimately reduce environmental pollution. The aerobic composting experiments combined organic raw materials with LDD1 catalyst or with earthworms as decomposers. The co-composting of durian shells with citrus peels was compared between aerobic and vermicomposting alternatives.

EXPERIMENTAL

Raw Materials

There were two primary organic waste materials used in composting, *i.e.*, durian shells and citrus peels. The durian shells were collected from the fresh market in the Muang District, Surat Thani Province (Thailand), and were cut to small chips of about 5.0 to 8.0 cm length and 0.5 to 0.7 cm thickness (Fig. 1a) and then milled into a fine-grained state (Fig. 1b). The citrus peel waste came from fruit juice vendors (Fig. 1(c)) at the Diamond Market, Muang district, Surat Thani province (Thailand) and was cut from 2.0 cm to 5.0 cm sized pieces (Fig. 1d).

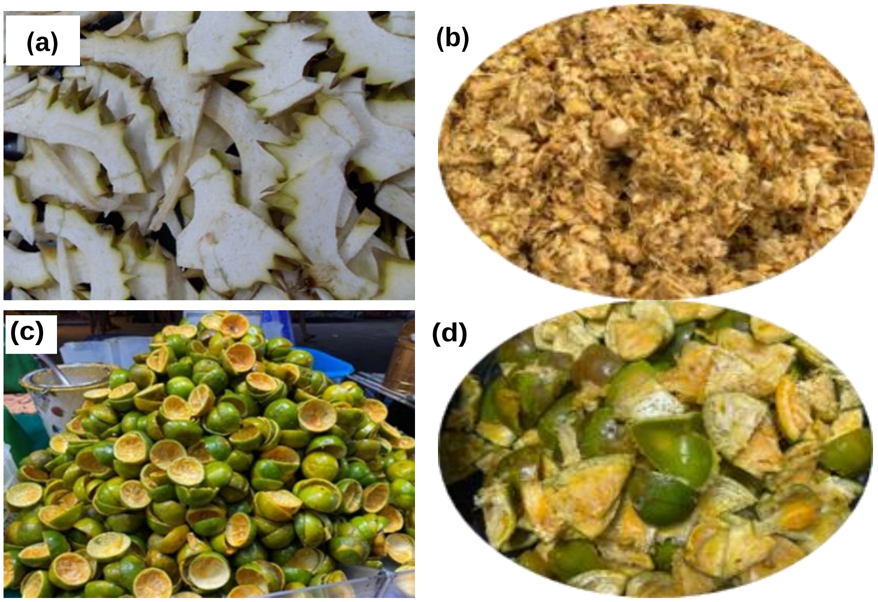

Fig. 1. (a) Durian shell chips; (b) milled durian shells; (c) as received citrus peels; and (d) citrus peels cut to a smaller size

Decomposers

The experiment on co-composting durian shells with citrus peels was conducted by combining natural microorganism decomposers with the microbial activator super LDD1 from Land Development Department (2014) of Thailand (called LDD1 for short). The microorganisms in LDD1 consisted of 4 cellulolytic fungal species, *i.e.*, *Scytalidium thermophilum*, *Chaetomium thermophilum*, *Corynascus verrucosus*, and *Scopulariopsis brevicaulis*, 2 *Streptomyces* species, and 2 *Bacillus subtilis* species. Earthworms of species *Eudrilus eugeniae*, and *Perionyx excavates* (Fig. 2a) were received from Boonjaroen Farm, Muang District, Surat Thani Province. In addition, 3.5 kg of dry cow dung (Fig. 2b) was bought from a flower shop for use in adjusting the environment to suit the live earthworms in the vermicomposting process. A bulking agent was also used for physical adjustment to add volume to the composted material.

Aerobic Composting and Vermicomposting Processes

The experiment was set by arranging 4 reactors for the co-composting of durian shells with citrus peels, each with a total volume of 50 L, *via* either aerobic or vermicomposting processes. The composting reactors were made from plastic buckets with lids, with a 66 L capacity, with air ventilation holes around the sides, and a plastic nylon net placed inside the reactor to prevent the compost from entering the aeration holes.

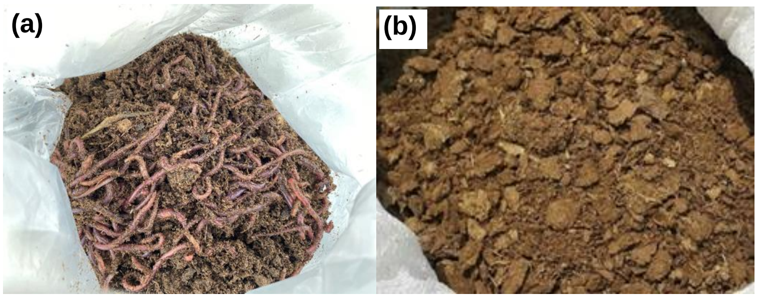

Fig. 2. (a) Earthworms *E. eugeniae* mixed with *P. excavates* species; (b) dry cow dung

Reactor 1 contained solely durian shell waste (control case) and reactors 2 through 4 had durian shells and citrus peels mixed in a 1 to 1 ratio by fresh weight. A LDD1 aliquot of 5 g was mixed with 200 mL of distilled water and added to reactor 3 (once weekly). Reactor 4, which was for vermicomposting, had 100 g of *Eudrilus eugeniae* and 100 g of *Perionyx excavates* earthworms added after the fourth week, together with cow dung. Table 1 summarizes the composting materials and decomposers in each reactor. Once a week, each compost batch was turned upside down in its reactor. The initial moisture contents of the 4 composting reactors were in the range 78 to 84%.

Table 1. Composting Materials and Decomposers for Each Reactor

Reactor	Durian Shell (kg)*	Citrus Peel (kg)	Decomposer	Remark
Reactor 1 (Control reactor)	31	-	Natural	Aerobic composting
Reactor 2	15.5	15.5	Natural	Aerobic composting
Reactor 3	15.5	15.5	LDD1	Aerobic composting
Reactor 4	15.5	15.5	Natural + Earthworms	Vermicomposting (After 4th week)

Physicochemical Parameters

The physicochemical analysis of the as-received durian shells, citrus peels, and cow dung included determination of the pH, moisture content, electrical conductivity, organic carbon (OC), organic matter (OM), nitrogen, phosphorus (total P_2O_5), and potassium (total K_2O). The daily measured composting parameters were pH, temperature, and electrical conductivity. Weekly analysis was conducted on moisture content, organic carbon (OC), organic matter (OM), and nitrogen. The phosphorus (total P_2O_5) and potassium (total K_2O) contents were analyzed on the 0th, 4th, and 9th weeks. In addition, on the ninth week, the total compost size and decomposition status were analyzed based on the organic compost analysis manual (Land Development Department 2010). The pH was determined using a pH meter (pH,700 Eutech, Waltham, MA). The electrical conductivity (EC) and NaCl were determined using a conductivity meter (Con,150 Eutech, Waltham, MA), with which different probes were applied for EC and NaCl measurement. To prepare samples for pH, EC, and NaCl measurements, compost sample of 5 g was diluted with 50 ml deionized water. Then, the suspension was shaken for 30 minutes and filtered through No. 1 filter paper. The moisture content was determined *via* the oven-drying method (FD,115 Binder, Tuttlingen, Germany). The organic carbon (OC) and organic matter (OM) contents were determined *via* the Walkley & Black method and the nitrogen content was determined *via* the Kjeldahl method. The phosphorus (total P_2O_5) content was examined *via* the vanadomolybdate method (TBO UV/VIS spectrometer, PG Instruments Ltd., Wibtoft, United Kingdom) and the potassium (Total K_2O) content was examined using an atomic absorption spectrophotometer (iCE 3000series, Thermo Scientific, Waltham, MA)

Germination Index (GI)

The phytotoxicity of the composts was evaluated in terms of the GI of seeds, following the procedure outlined by Zhou *et al*. (2014). Green cabbage seeds with a GI greater than or equal to 95% were used. The compost suspension was prepared by mixing 10 g of compost into 100 mL of water in a flask and agitating at 180 rpm for 1 h, then filtering to collect the extract. Ten seeds were placed on filter paper moistened with 3 mL of water extract from the compost. After incubation at a temperature of 25 to 30 °C for 48 h, the seed germination percentage and root length of the seedlings were determined. The seed germination and root length of the plants moistened with 3 mL of distilled water were also measured as the control treatment. Forty seeds were used for each composting condition. The GI was calculated according to Eq. 1,

$$\%\,GI = (\%SGR_t \times RT_T) \times \frac{100}{(\%SGR_c \times RT_c)} \qquad (1)$$

where SGR_t is the seed germination root of the treatment, RT_T is the root length of the treatment (cm), SGR_C is the seed germination root of the control, and RT_C is the root length of the control (cm).

Statistical Analysis

One-way analysis of variance (ANOVA) was carried out to compare the composting treatments, and significant differences were confirmed by the least significant difference (LSD) test (requiring *p*-value less than 0.05 for significance) for multiple comparisons. These statistical analyses used Microsoft Excel 2016.

RESULTS AND DISCUSSION

Initial Physicochemical State of the Composting Materials

This study is on recycling organic waste, specifically durian shells and citrus peels, which are wastes from seasonal fruits, seeking to convert these waste products into fertilizer used to improve soil. The initial physicochemical states of the composting materials are shown in Table 2. The durian shells had excellent nutrient values, with nitrogen, phosphorous, and potassium contents of 60.0%, 74.0% and 60.3%, respectively. However, a previous study revealed that composted durian shell has an excessive C to N ratio and the total nitrogen is below guidelines (Tudsanaton *et al.* 2021). The citrus peels also had useful nutrient contents for plants, with nitrogen, phosphorus, and potassium contents of 1.50%, 0.27%, and 1.75%, respectively. The vermicomposting of the shells and peels with earthworms required cow dung as the habitat for the worms, and further adjusting of the pH to a medium level. Wani *et al.* (2000) reported that cow dung has a pH of 8.1 and a nitrogen content of 1.97%. The nitrogen, phosphorus, and potassium of the cow dung were at higher levels than in common kitchen and garden wastes. The data without superscript ‘a’ are experimental results, while data with superscript ‘a’ are literature data (Land Development Department, 2016).

Table 2. Physicochemical Characteristics of the As-received Composting Materials

Parameter	Durian Shell	Citrus Peel	Dry Cow Dung
pH	4.00	3.95	7.50
Organic matter (% dry wt)	63.68	60.56	39.83
Organic carbon (% dry wt)	36.94	35.13	23.10
C to N ratio	49.92	23.42	14.44
Total N (% dry wt)	0.74	1.50	1.95
Total P_2O_5 (% dry wt)	0.60	0.27	2.00[a]
Total K_2O (% dry wt)	3.60	1.75	0.70[a]
Moisture content (%)	84.64	77.32	84.9
Electrical conductivity (dS/m)	2.15	5.72	2.89
Remarks: [a] Land Development Department (2016)			

Physicochemical Parameters during Aerobic Composting and Vermicomposting

There were four reactors in the experiments, and the monitored parameters were as follows: temperature, moisture content, pH, electrical conductivity, NaCl (salt), organic carbon and organic matter, ratio of carbon to nitrogen, total nutrient contents (total N, total P_2O_5, and total K_2O), and volume of the compost. In reactor 4, earthworms were added on the fourth week, and cow dung was added on the fifth week, for vermicomposting.

Temperature

Temperature is an important factor in composting because it is an indicator of metabolism by microorganisms (Zhou 2017). Figure 3a shows that the initial temperatures in all reactors were 28 °C to 30 °C, which matched ambient temperature. The changes in temperature tended to be similar across the reactors, while the ambient temperature varied in the range from 28 °C to 33°C during the composting process (the dashed line in Fig. 3a). The temperatures during the first week were high in every reactor. The heat was produced by microorganism activity (Castillo-González *et al*. 2021). The highest temperature in reactors 2, 3, and 4 was approximately 41 °C, while it was approximately 39 °C in reactor 1; these reactors did not reach thermophilic temperatures, *i.e.*, greater than 55 °C (Li *et al.* 2018). It is possible that there were large heat losses, as mentioned by Castillo-González *et al*. (2021). In addition, the elevated temperature may have eliminated some diseases. Effective pathogen elimination requires temperatures greater than 55 °C for at least 5 d (Zhang *et al.* 2016). In addition, the moisture content was high, which could potentially contribute to the low temperatures (Tudsanaton *et al.* 2021). Low temperature has been observed to be caused by less frequent turning (Zhou 2017). However, the initial co-composting materials affected temperature *via* biodegradable organic wastes and their nutrient balance (Lashermes *et al*. 2012). After a week, the temperature in reactor 1 steadily decreased, while the temperatures in reactors 2, 3, and 4 decreased after two weeks. Reactor

4 had been pre-composting for four weeks prior to adding the earthworms to start vermicomposting. Pre-composting prior to vermicomposting is recommended for mass reduction, waste stabilization, and pathogen reduction (Nair *et al.* 2006; Frederickson *et al.* 2007). Upon turning the contents of each reactor upside down every week, only reactor 4 had a temperature increase, which indicated that decomposition was ongoing, but after 52 d, the temperature was slightly below ambient. This indicated that the process was completed. On the last day of the run, the temperatures in reactors 1, 2, 3, and 4 were 29.0, 28.0, 28.0, and 27.5 °C, respectively, as shown in Table 3. The ANOVA indicated that the composting temperatures did not differ significantly among the four reactors (p-value greater than 0.05).

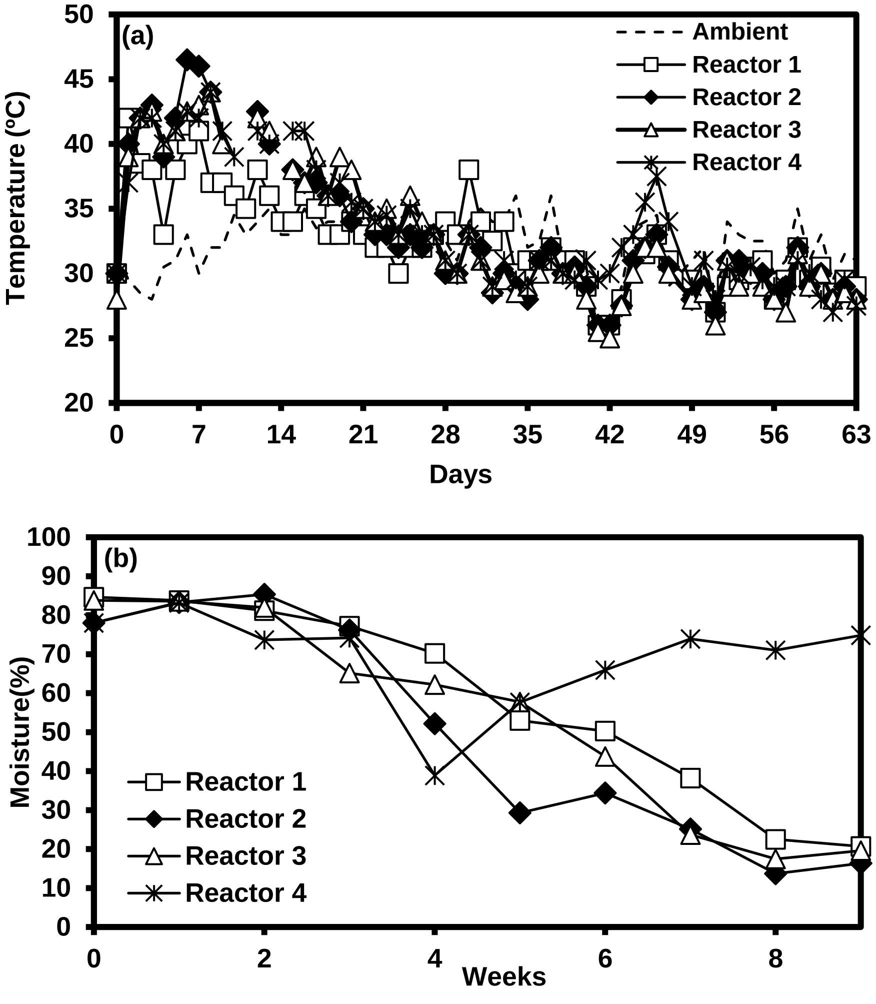

Fig. 3. (a) Temperature and (b) moisture content during the composting process

Moisture content

Moisture in the compost is necessary for the survival and growth of microorganisms. The proper moisture content of compost is approximately 40% to 60% for microbial survival (Hamzah *et al.* 2018). In the experiments, the initial moisture content in every reactor was higher than this proper level (Fig. 3b) *i.e.* 78.0% to 84.6%, because both raw materials had high moisture contents. Nevertheless, by the fourth week, the moisture had decreased to an optimal range, *i.e.*, 38.39% to 70.22%. From then on, the moisture content in all reactors tended to consistently decrease every week until the end of the run (see Table 3), reaching 20.68%, 16.36%, and 19.60% in reactors 1, 2, and 3, respectively, which was consistent with not exceeding 30% as set by the standard of the Land Development Department (2013). In contrast, the moisture content in reactor 4 was not consistent with that standard, as it was 74.84% due to the water added during the fifth week in order to adjust the content to 50% to 90% for the survival of the earthworms (Castillo-González *et al*. 2021). This moisture range was maintained until after the worms were collected at end of the run, and the compost was dried by the wind to a moisture content of 21.48%. However, the composting moisture in reactor 4 had a significant difference from reactors 1, 2, and 3 (p-value less than 0.05).

Table 3. Physicochemical Characteristics of the Composts on the 9th Week

Parameters	Standard Requirement	Reactors			
		1	2	3	4
Moisture (%)	≤30	20.68	16.36	19.60	21.48
Temperature(°C)	-	29.0	28.0	28.0	27.5
OM (%wt.)	≥20%	48.30	56.60	58.10	42.90
pH	5.5 - 8.5	10.90	10.70	10.80	8.44
OC(%wt.)	-	28.0	32.2	29.9	24.9
C/N ratio	≤ 20:1	11.21	9.93	9.28	10.03
EC (dS/m)	≤10	22.80	15.88	17.29	7.15
Total N (%wt.)	≥1.0	2.50	3.24	3.21	2.48

Electrical conductivity

The electrical conductivity indicated that composting released soluble inorganic salts (Zhou 2016). The conductivity should not exceed 10 dS/m, because if it is higher, it will have an effect on the water absorption as well as the growth of plants (Kaewmorakot 2014). However, the experiments demonstrated that the conductivity generally tended to increase in each reactor, but they still had differences between them. In the beginning, the electrical conductivity ranged between 2.15 dS/m and 2.92 dS/m, and then it increased throughout the entire process to a final value of 17 dS/m to 22 dS/m (Fig. 4a), which is not in line with the standard set by Land Development Department (2013). The EC of reactors on the 9th week is shown in Table 3. Reactor 1 had the highest EC (22 dS/m), which indicated that composting durian shells alone with natural microorganisms produced more soluble inorganic salts than co-composting it with citrus peels. The EC was similar for reactors 2 and 3 during composting, reaching 17 dS/m on the 9th week. This indicated that the LDD1 decomposer did not affect the formation of soluble salts. For approximately six weeks, the EC of reactor 4 was similar to the EC of reactors 2 and 3. After adding earthworms on the 4th week and adding dry cow dung on the 5th week, the EC sharply decreased from 13 to 6 dS/m in the 6th week. At the end of composting run, reactor 4 had an EC of 7.15 dS/m, which complies with the department set standards, *i.e.*, does not exceed 10 dS/m. In addition, the EC in reactor 1 was significantly different ($p < 0.05$) from the EC in reactors 2, 3, or 4. The EC in reactor 4 was also significantly different ($p < 0.05$) from either reactor 2 or reactor 3.

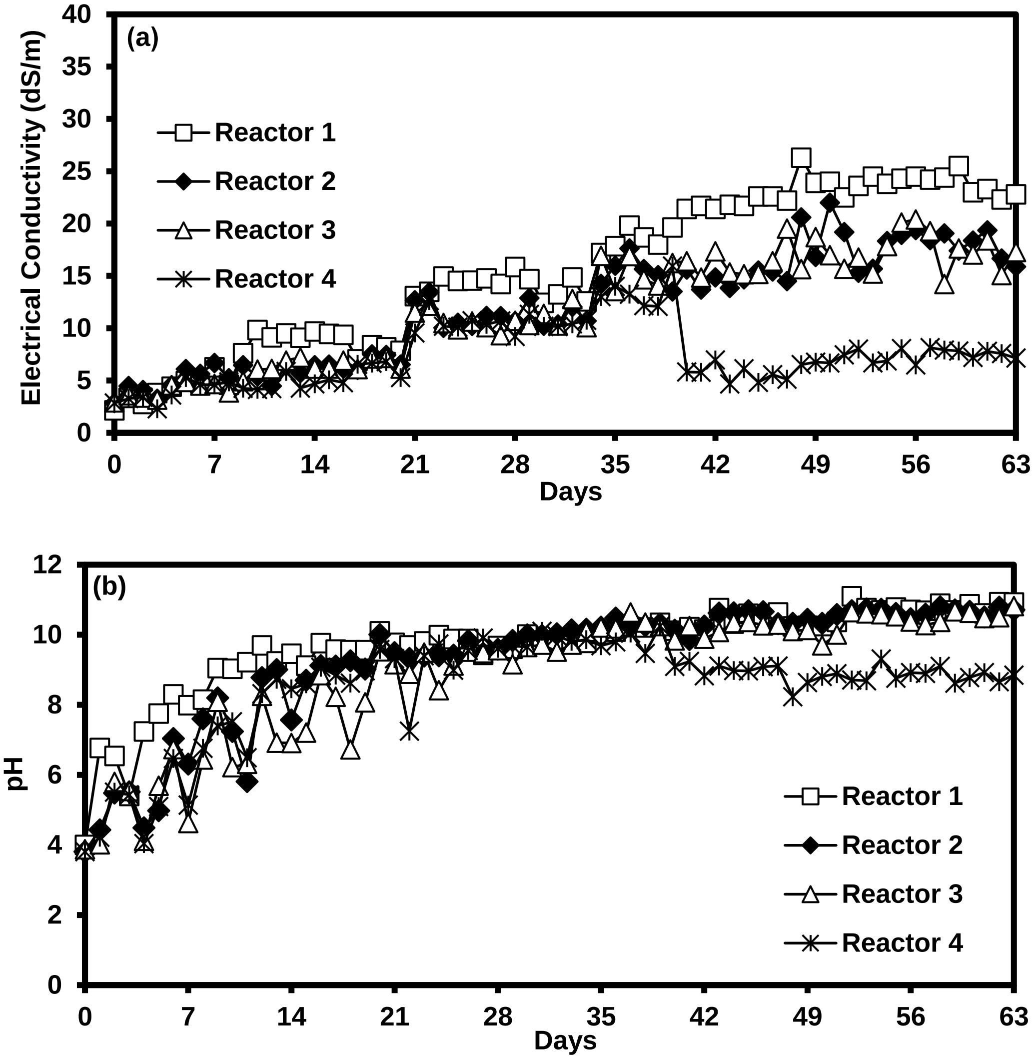

Fig. 4. (a) Electrical conductivity and (b) pH during the composting run

pH

The changes in pH during composting are related to microorganism growth and activities, with organic decomposition being the most intense at pH from 6 to 9 (Pinedo *et al.* 2019). A pH of 5.5 to 8.5 is suitable for vermicomposting (Yadav and Garg 2011). The results of the experiments (Fig. 4b) reveal that the pH was initially acidic, at 3.8 to 4.0. It then increased in every reactor up to the third week. The pH in reactor 1 was higher than in the other reactors during the first two weeks of composting, but the pH changes of the other reactors were similar. The pH of reactors 1, 2, and 3 were consistent during the 4th to 9th weeks, at 10.6. Li *et al.* (2018) found that a high pH corresponded to high ammonia emissions from protein degradation and a loss of organic acids, as can be seen in Table 3. In the case of reactor 4 with vermicomposting, the pH steadily decreased from 9.8 to 8.8 during the 5th to 7th weeks and then it slightly decreased further to 8.4 on the 9th week. The degradation of organic matter produced carbon dioxide, ammonia, nitrates, and volatile fatty acids that decreased the pH (Suthar 2009). In addition, the pH in reactor 4 decreased because it was suitably controlled for the live earthworms by adjusting the pH to between

6.0 and 8.0, where the worms live naturally (Edwards *et al*. 2011). The pH 4.8 of reactor 4 was consistent with the 5.5 to 8.5 range set by the standards of the Land Development Department (2013). The pH in reactor 1 was significantly different from reactors 3 or 4 ($p < 0.05$), and reactors 2 and 4 also differed.

NaCl content

Table salt (NaCl) at suitable levels can have a positive impact on the root system of plants, but in excess it may hinder the growth of the root system (Epron *et al.* 1999). The experimental results revealed that the salt contents were quite low (as shown in Fig. 5a), especially the initial ranged was between 0.13% and 0.17%, but it increased during the third week to 0.39% to 0.46%, and at the end of the runs it was from 0.15% to 0.53%, as seen in Table 3. This range complied with the standard set by the Land Development Department (2013) by not exceeding 1% by weight. However, the NaCl content in reactor 1 had a significant difference to reactors 2, 3, and 4 ($p < 0.05$). The NaCl content in reactor 4 also significantly differed ($p < 0.05$) from either reactor 2 or reactor 3.

Organic carbon

Figure 5b shows that the organic carbon (OC) content was between 33.2% and 38.0% at the beginning of the run, and then it tended to decrease in all cases. The OC final range was 24% to 32%, as shown in Table 3. The largest difference between the initial and final OC contents was in reactor 4 (34.5%), followed by reactor 1 (24.1%), whereas the smallest change was in reactor 3 (10.2%). The OC reduction can be attributed to microorganisms using the OC as a source of energy for metabolic activities and for the synthesis of cellular constituents (Castillo-González *et al*. 2021). The metabolic activities changed the carbon into organic acids and some parts were emitted as carbon dioxide into the atmosphere. The OC differences when comparing reactors 1 and 2, or reactors 3 and 2, were significant ($p < 0.05$).

Organic matter

Figure 6a shows that the organic matter was quite similar to the OC, as it decreased in every reactor as the OC was decomposed and used as an energy source by the bacteria. Once the OC decreased, the organic matter was similarly affected. The compost obtained from the experiments should contain at least 20% organic matter by weight, and initially its level was between 57.1% and 65.5%, by dry weight. After the fourth week it was reduced to 56.2% to 60.4%. At the ninth week (end of the experimental runs), it ranged between 42.9% and 55.5% (see Table 3); the reactor with the highest reduction from the initial organic matter content was reactor 4 (34.5%), whereas reactor 3 had the least reduction, *i.e.*, 10.06% (similar to the OC). The loss of organic matter was due to mineralization and loss as carbon dioxide (Castillo-González *et al*. 2021). Nevertheless, the organic matter content in every reactor was not less than 20% by weight, which is the standard set by the Land Development Department (2013). In addition, the organic matter contents of reactors 2 and 3 had a significant difference ($p < 0.05$).

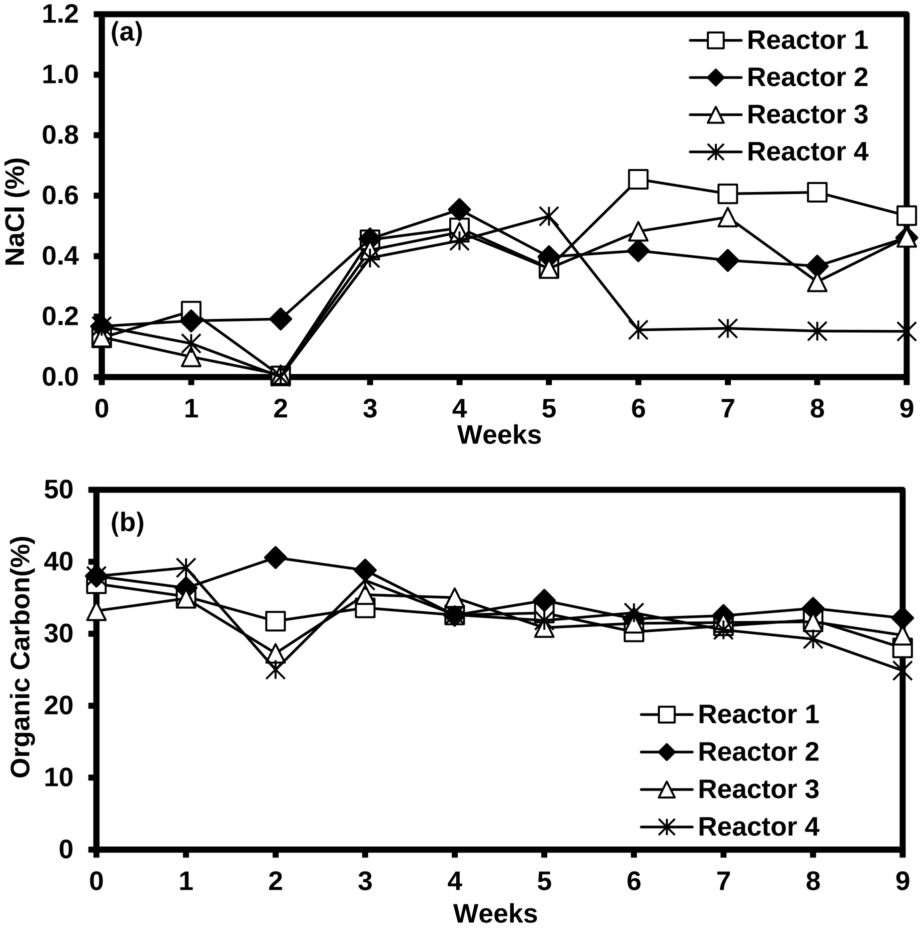

Fig. 5. (a) NaCl and (b) organic carbon during the composting process

Total nitrogen (*total N*)

Figure 6b shows that at the beginning of the composting process, the nitrogen content ranged between 0.74% and 1.41%. The lowest total nitrogen content was in reactor 1 (with only durian shell), and the content increased to 2% at the ninth week. In the first five weeks, the total N profiles of reactors 2, 3, and 4 were similar, *i.e.*, increasing past 3%. Thereafter, the total N contents in reactors 2 and 3 were rather steady for the last four weeks, while the total N in reactor 4 (vermicomposting) decreased to 2% during the 9th week, as can be seen in Table 3. The increase in the total N was caused by the loss of organic carbon from use in metabolic activities by microorganisms and earthworms; the latter producing additional nitrogen in various forms of mucus, nitrogenous excreted substances, body fluids, and growth-stimulating hormones (Castillo-González *et al*. 2021). Conversely, the loss of total N was a result of excess moisture creating anaerobic conditions, which in turn caused denitrification and ferric ammonium oxidation, producing organic nitrogen emitted as a gas (Tudsanaton *et al.* 2021). However, the total N in all reactors was not less than 1%, as set in the standards of the Land Development Department (2013). Nevertheless, the total N content in both reactors 1 and 4 was significantly different from either reactor 2 or reactor 3 ($p < 0.05$). The total N content differences when comparing reactors 1 and 4, or reactors 2 and 3, were not significant ($p > 0.05$).

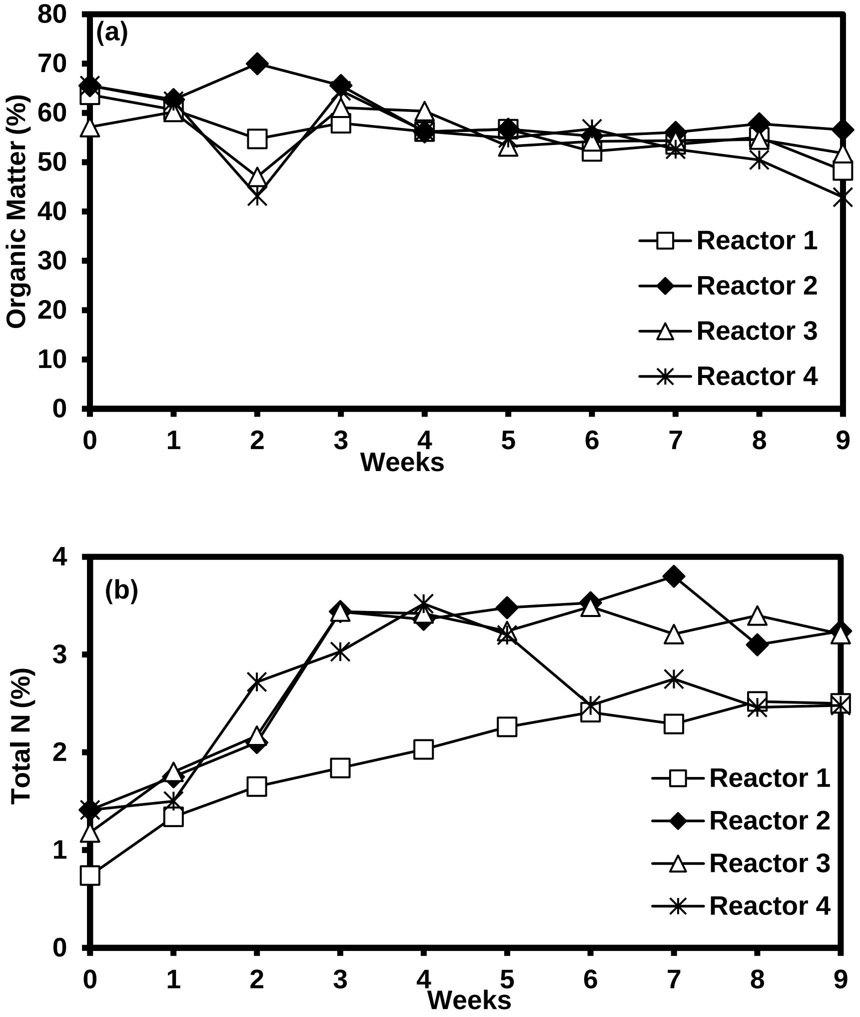

Fig. 6. The (a) organic carbon; and (b) total N during the composting process

Carbon tonitrogen ratio (*C* to *N ratio*)

The proper C to N ratio should be between 25 and 35. It was found that at the beginning of the experiments the C to N ratio in reactor 1 (only durian shell) was higher than the guideline (49.92), while reactors 2 though 4 had 50% citrus peels that not only affected the initial pH but also the C to N ratio (Fig. 7). Later, at end of the run, the C to N ratio in every reactor had decreased to between 9.28 and 11.21 (as can be seen in Table 3), which is in line with the standard set by the Land Development Department (2013), *i.e.*, less than 20. Decrease of the C to N ratio resulted from carbon loss in the form of CO_2 during microbial respiration, and from nitrogen rich excretions (Singh *et al*. 2011). The C to N ratios among the four composting reactors showed no significant differences ($p > 0.05$).

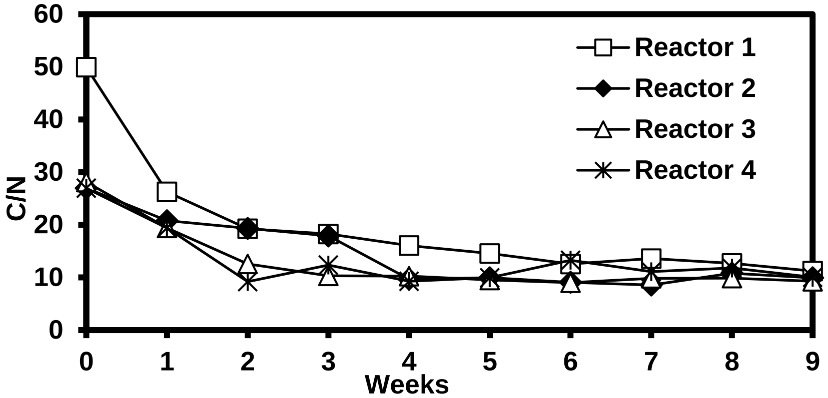

Fig. 7. The C to N ratio during the composting process

Total phosphorus (total P_2O_5) and potassium (Total K_2O)

The phosphorus was bioavailable in the form called diphosphorous penta oxide (P_2O_5). The total P_2O_5 revealed that, in the beginning, the phosphorous content in reactor 1 was 0.60% (Table 2), whereas the phosphorous contents in reactors 2 through 4 were 0.27% (Table 3). In reactor 4, the content was analyzed during the fourth week prior to adding earthworms and cow dung, and the content had increased to 0.84%. After the ninth week, the content became higher in every reactor and ranged between 0.66% and 1.47%. The final phosphorus content (total P_2O_5) in every reactor was consistent with the not-less-than 0.5% by weight required by the Land Development Department (2013).

Table 4. The Total P_2O_5 and Total K_2O Contents, Particle Size Indicated by Size Fraction, and Germination Index

Reactor	Week	Total P_2O_5 (wt.%)	Total K_2O (wt.%)	The fraction of particles less than 12.5 mm [a] (%)	Germination Index (%)
1	9th	0.77 ± 0.00	5.70 ± 0.06	89.10	20.17
2, 3, and 4	0	0.27 ± 0.01	1.96 ± 0.01		
2	9th	0.87 ± 0.01	5.64 ± 0.05	33.4	27.28
3	9th	0.97 ± 0.01	5.83 ± 0.06	44.2	30.00
4	4th	0.84 ± 0.01	5.53 ± 0.04		
4	9th	1.47 ± 0.01	2.71 ± 0.06	94.3	90.00

Note: [a] Percentage of the sample weight with a particle size less than a mesh size of 12.5 mm x 12.5 mm

Potassium is an important substance for physiological and biochemical processes, plant resistance to biotic and abiotic stresses, and contributes to a plant's growth (Wang *et al*. 2013). The experiments showed that initially the potassium content was at 3.60% (as seen in Table 2) in reactor 1 and at 1.96% (Table 3) in reactors 2 through 4. In reactor 4, on the fourth week prior to adding earthworms and cow dung, the potassium content had increased to 5.52%. However, on the ninth week, it ranged from 2.71% to 5.83%, with reactor 3 having the highest level due to the added LDD1 catalyst. The total potassium content in all cases was in line with the standard set by the Land Development Department (2013), *i.e.*, that the total K_2O content should not be less than 0.5% by weight.

Singh *et al*. (2011) stated that microbial enzyme activities in the gut of earthworms increased the P and K contents in vermicomposting, which matched the observed P content in this study. In addition, natural organisms and LDD1 decomposers yield higher K content compared to earthworms when co-composting durian shells with citrus peels.

Particle Size Fractions in the Composts

The compost particle size indicates the extent of decomposition of the raw materials (Kaewmorakot 2014). The compost particle size needs to comply with the standard set by the Land Development Department (2013) in Thailand, which states that it should not exceed a mesh size of 12.5 mm x 12.5 mm (should be less than 12.5 mm). Table 3 shows the fraction of particles less than 12.5 mm in the final compost (on 9th week) presented as a percentage of the sample by weight, and the compost in reactor 4 had the largest fraction pass through such a sieve (94.3%). The fraction of compost particles less than 12.5 mm in reactor 1 was also high (89.1%), while lower fractions of 33.4% and 44.2% were observed for reactors 2 and 3.

Germination Index

An organic compost can be tested for its performance as fertilizer by measuring its germination index to indicate potential toxic or growth promoting effects on plants. The results showed the highest germination index (90%) for reactor 4 (as seen in Table 3), which is consistent with the not-less-than 80% standard set by the Land Development Department (2013). A phytotoxicity-free compost for plants has a GI greater than 80% and a mature compost has a GI greater than 90% (Cunha-Queda *et al*. 2007; Ko *et al*. 2008). The vermicompost from durian shells and citrus peels was not phytotoxic and was far superior to the aerobic composts made with natural microorganisms or with the LDD1 decomposers.

CONCLUSIONS

1. The final product from reactor 4 (durian shells + citrus peels + earthworms) was consistent with the Thai standards set by the Land Development Department (2013).
2. The decomposition by earthworms provided a final product that was more efficient than the compost using the LDD1 catalyst or the one with natural microorganisms, especially in obtaining the highest germination index of 90%.
3. The high moisture that was necessary for vermicomposting (reactor 4) decreased the total nitrogen content, but the final content still satisfied the Thai standards set by the Land Development Department (2013).
4. Compost from durian shells still had a high final pH despite the acidic citrus peels added for 50% of fresh weight. In contrast, with earthworms as decomposers in vermicomposting, the final pH was in the optimum range according to the standard requirements.

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