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Composting of Pineapple Residues and Food Waste: A Pilot-Scale Study

Nguyen M. Thien[a,b], Lam C. Nghiep[a,b], Le T.K. Phung[a,b], Tran T. Viet[a,b], Nguyen T.T. Nga[c], Hoang A. Hoang[a,b,*]

[a]Faculty of Chemical Engineering, Ho Chi Minh City University of Technology (HCMUT), 268 Ly Thuong Kiet, District 10, Ho Chi Minh City, Vietnam
[b]Vietnam National University Ho Chi Minh City, Linh Trung Ward, Thu Duc District, Ho Chi Minh City, Vietnam
[c]Faculty of Economics of Natural Resources and Environment, Ho Chi Minh City University of Natural Resources and Environment, 236B Le Van Sy, Tan Binh District, Ho Chi Minh City, Vietnam
hoang.a.hoang@hcmut.edu.vn

Spraying herbicide, followed by burning, is a common practice for clearing pineapple residues (leaves and stems) and preparing subsequent cultivation crops in the Mekong Delta, Vietnam. This is an unsustainable agricultural practice that causes environmental pollution. In this study, pilot-scale pineapple residue composting was studied at Tan Phuoc district, Tien Giang province. Approximately 5.5 t of pineapple leaves and stems were mixed with 10 wt% food waste and 0.1 % v/w effective microorganisms. Chopped pineapple residues and food waste were distributed in layers in sequence and sprayed with the microorganism solution. Composting was carried out in a pyramid-shaped pile with a bottom diameter of approximately 5 m and a height of about 1.5 m. The composting temperatures were monitored daily using a digital thermometer. The composting mixture was withdrawn, mixed thoroughly and then re-distributed to the composting pile every 3 d. Composting was performed after 45 d when the composting pile temperature almost reached ambient temperature. The compost product was subjected to pH and mesophilic/thermophilic microorganism cell density measurements. Phytotoxicity tests were carried out, and other important parameters such as organic content, useful/harmful microorganisms and heavy metals were determined. Mesophilic and thermophilic microorganism densities were approximately 2×10^8 and 3.8×10^7 CFU/g. The compost pH was 7.3, and the organic matter content reached 32.3 wt%. Heavy metals and harmful microorganisms, such as *E. coli* and *Salmonella*, were also within Vietnamese standards. Root length and number of roots were 372.8 % and 22.6 % higher than controls; stem length and diameter were 137.5 mm and 15.1 mm, and were not significantly different from controls ($p < 0.05$). The seed germination index of 141.56 was higher than the minimum value of 80 %, indicating that the compost was phytotoxic free and matured.

1. Introduction

Pineapple (Ananas cocosus) is one of the most important fruit trees in the world's tropical and subtropical areas. The Mekong Delta is a primary pineapple planting area of Vietnam, comprising an area of approximately 40,000 ha (Hoang et al., 2019). About 90–150 t/ha of pineapple residues (including stems and leaves) are discarded after two fruit harvests (Liu et al., 2013). In some countries, the wastes are shredded and incorporated directly into the soil. This method may take up to 35 weeks to obtain complete pineapple residue decomposition (Tam and Magistad, 1936). In the Mekong Delta, these pineapple residues are sprayed in situ with herbicides and burned prior to the next crop. However, this method pollutes the environment and has potential risks to humans (Heard et al., 2006). Incorporating the ash that remains after burning into the soil does not improve the following crop's yields (Ahmed et al., 2002). With the rapid development of urbanisation, food waste is a significant challenge for management agencies. Food waste may contain approximately 55 % of organic matter (Troschinetz and Mihelcic, 2009). Incomplete waste classification and treatment causes substantial environmental pollution and human disease (Kim et al., 2008). In Vietnam, most food waste is

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disposed of in landfills, resulting in odours and water contamination (Ngoc and Schnitzer, 2009). Both of these wastes must be treated with a more effective, thorough and environmentally friendly solution.

Composting is one of the high promising methods for converting wastes into environmentally friendly organic fertiliser (Sanadi et al., 2018). The composting heap's high temperature destroys pathogenic microorganisms in the waste (Kim et al., 2008). The resulting compost can be used in farming to replace some inorganic fertilisers. More importantly, the compost provides nutrients and useful microorganisms in the soil that will increase plant growth rates, crop quality and yield (Liu et al., 2013). Hoang et al. (2019) were the first to study a pineapple residue/food waste co-composting process at an experimental scale. Their research revealed that adding food waste to pineapple residues at a 1:10 weight ratio enhanced composting efficacy compared to not using food waste. The use of larger composting scales can solve the significant amount of pineapple residues and food waste in the region. With the published studies, there is no study regarding co-composting of pineapple residues and food waste at larger scales. In this work, co-composting of pineapple residues and food waste was initially evaluated at a pilot scale. Composting efficacy was determined by temperature-time course, compost characteristics, germination index and physiological indicators of mung bean.

2. Materials and methods

2.1 Composting location and materials

The composting was carried out at My Phuoc commune, Tan Phuoc district, Tien Giang province, which is one of the 13 provinces in the Mekong Delta, Vietnam. My Phuoc is approximately 60 km from Ho Chi Minh city. The pineapple area in Tan Phuoc district comprises more than 16,000 ha of the 40,000 ha total pineapple area in the Mekong Delta. Pineapple is the most important fruit tree in this area because the region is covered by acid sulphate soil.

Roughly 5.0 t of pineapple residues, including stems and leaves, were collected at Tan Phuoc before being transferred to the composting site. Pineapple residues were shredded into pieces of 2–3 cm length using a cutter machine and air-dried for 2–3 d. Food waste was collected from the Tan Phuoc market and then classified to obtain the organic waste before composting. The seeding microorganisms including Bacillus sp., Aspergillus sp. and Tricoderma sp. were cultured a nutrient medium primarily containing molasses with the addition of yeast extract and K_2HPO_4 salt.

2.2 Composting operation

The composting was operated from February to April 2020. The pineapple residues and organic food waste were mixed at a 10:1 ratio on a weight basis (Hoang et al., 2019). The seeding microorganism solution was added at 0.1 % v/w. The composting materials were spread in layers and sprayed with the useful microorganisms. As a result, the pile was pyramid shaped with a bottom diameter of approximately 5 m and a height of about 1.5 m (Figure 1). The total weight of the pile was roughly 5.5 t.

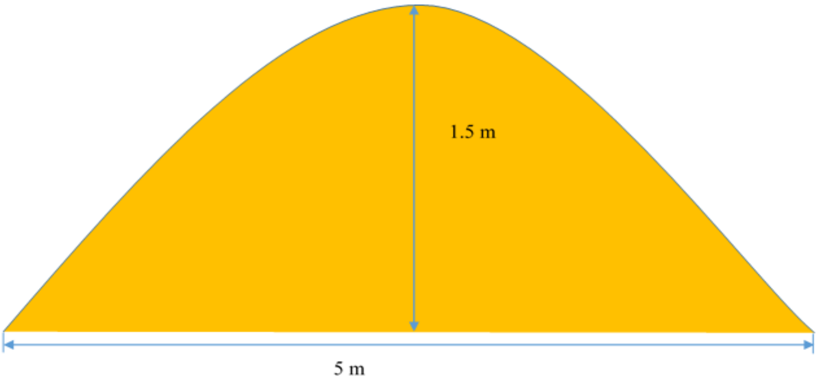

Figure 1: The composting pile model.

2.3 Chemical, physical and bacterial density analysis

The ambient, outermost and central temperatures of the pile were checked daily at 9 A.M using a digital thermometer (REOTEMP Backyard Compost Thermometer). The composting mixture was turned, and the pile was reconstituted every 3 d. Composting was complete when the pile's central temperature was nearly equal to the ambient temperature. Then, the compost sample was used to analyse the pH, moisture content and microbial density of thermophilic and mesophilic microorganisms following the previously described method (Nakasaki et al., 2013). The compost sample was also sent to the Quality Assurance and Testing Center 3 (QUATEST 3), Vietnam to examine the total organic content, useful microorganisms, pathogenic bacteria (*E.*

coli and *Salmonella* spp.) and heavy metal contents (Cd, As, Pb and Hg). The Vietnam standard for compost management No. 01-189:2019/BNNPTNT was used to evaluate the compost quality.

2.4 Phytotoxycity test

A phytotoxicity test based on a germination bioassay was carried out using the method described by Zucconi et al. (1981). Ten g of compost sample was diluted in sterile distilled water at a ratio of 1:10 and shaken for 1 h. The solution was centrifuged for 10 min at 13,000 rpm and then filtered through Whatman No. 2 filter paper (Merck KGaA, Darmstadt, Germany). 9 mL of the extract was injected into a 9 cm-diameter plastic container with sterile filter paper containing 10 mung bean seeds. Aseptic distilled water was used to replace the extract in the control treatment. Boxes were wrapped with parafilm to prevent moisture loss and stored in the dark at room temperature (approximately 30 °C). All experiments were performed in triplicate. After 4 d, germination rate, root length, shoot length, number of roots and shoot diameter were assessed. The germination index (GI) was calculated as in Eq(1):

$$GI = \frac{seed\ germination\ of\ treatment}{seed\ germination\ of\ control} \times \frac{mean\ root\ length\ of\ treatment}{mean\ root\ length\ of\ control} \times 100 \quad (1)$$

2.5 Data analysis

Data for stem length, root length, number of roots and stem diameter were analysed with a t-test ($P \leq 0.05$) using R software version 4.0.0 (Knezevic et al., 2007).

3. Results and discussion

3.1 Composting temperature profile

Central and boundary temperatures of the composting pile and the ambient temperature throughout the composting period are shown in Figure 2. The ambient temperature fluctuated from 32 °C to 36 °C during the composting period. The central temperature sharply increased in the first stage, reaching a peak of 72 °C on day 7. The temperature increased during the initial composting stage, indicating that the mesophiles were inhibited, and the thermophiles had been necessarily established (Nakasaki et al., 2013). The temperature was maintained above 65 °C for the next 12 d. A slight decrease in temperature appeared from days 19 to 34 but remained higher than 60 °C during this period. From day 35, the composting temperature sharply decreased to nearly ambient temperature on day 45.
The turning process brought the composting materials from the outermost zone to the central zone and led to rapid degradation of the organic matter (Kuok et al., 2012). The temperature at the outermost pile region was 1–14 °C higher than the ambient temperature (Figure 2).

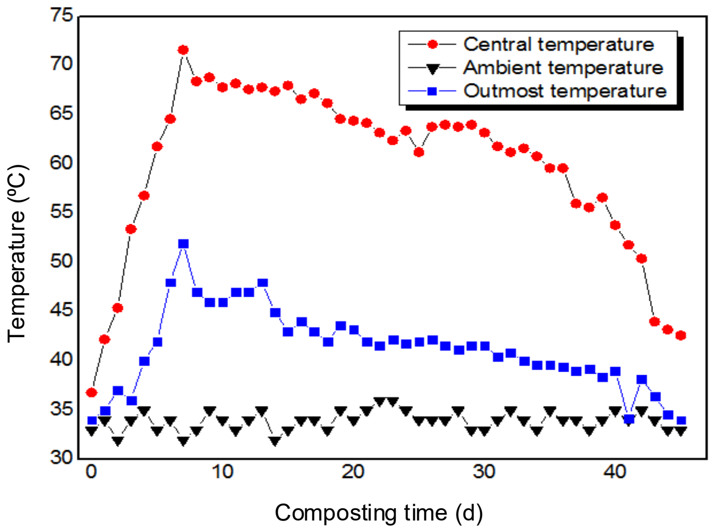

Figure 2: Composting and ambient temperature reading by date.

The composting pile temperature-time course was a convenient parameter for determining the composting process stages (Tang et al., 2011). The addition of food waste and beneficial microorganisms increased the organic matter decomposition rate and resulted in higher composting pile temperatures (Horvath, 1972).

During the initial composting process stage, mesophilic bacteria used available and digestible substances (sugars and proteins), resulting in the accumulation of heat from metabolism, which caused the temperature to rise rapidly to the thermophilic stage (Day and Shaw, 2000).
During this thermophilic phase, thermophilic microorganisms degraded other proteins and carbohydrates, including relatively stable compounds such as lignin, cellulose and hemicellulose (Upadhyay et al., 2013). At day 45, the composting process was completed when the pile temperature was equivalent to ambient temperature. The mature compost was dark brown and soft compared to the green of raw pineapple residues (Figure 3).

(a) (b)

Figure 3: Color of (a)raw pineapple residues and (b)mature compost

3.2 Compost properties analysis

The mature compost was analysed at the QUATEST 3. The compost quality was evaluated according to the Vietnam standard for compost management (QCVN 01-189:2019/BNNPTNT). The results are provided in Table 1. The final compost contained 32.3 % organic matter, compared to a minimum value of 15 % for the standard. Organic substances were accumulated during bacterial and fungal decomposition (Francou et al., 2005). Useful microorganisms, such as nitrogen-fixing and cellulose-solubilising ones, were approximately 9.7 x 107 CFU/g, and 6.1 x 107 CFU/g. Heavy metals such as Hg, Cd, As and Hg were lower than the thresholds outlined in the standard. Besides, the high temperature of the thermophilic phase and the mixing of materials significantly destroyed pathogenic microorganisms during composting (Kuok et al., 2012). Harmful microorganisms, such as Salmonella spp./25g and E. coli were negative and 9.3 x 102 MPN/g. All values satisfied the requirements in the standard.

Table 1: Physicochemical and microbial cell density of the final compost

Property	Test result	Vietnam standard
Total organic matter (%)	32.3	≥ 15
Pb (mg/kg)	1.6	≤ 200
Cd (mg/kg)	< 0.077*	≤ 5
As (mg/kg)	undetected	≤ 10
Hg (mg/kg)	undetected	≤ 2
*E. coli (*MPN/g)	9.3×10^2	≤ 1.1×10^3
Samonella ssp./25g	undetected	undetected
Nitrogen – fixing microorganisms (CFU/g)	9.7×10^7	1×10^6
Cellulose – solubilizing microorganisms (CFU/g)	6.1×10^7	1×10^6
Thermophilic microorganisms (CFU/g)	3.8×10^7	
Mesophilic microorganisms (CFU/g)	2.0×10^8	
Moisture (%)	56	
pH	7.3	

* Quantitative limit of the method

Many other parameters, such as thermophilic and mesophilic bacterial counts, pH and compost moisture content were also examined. Mesophilic and thermophilic bacterial cell densities were 3.8 x 107 CFU/g and 2.0 x 108 CFU/g (Figure 4), and the final compost's moisture reached 56 %, consistent with previous studies (Ch'ng et al., 2013). The high temperature of the thermophilic stage caused water loss, resulting in decreased moisture content during the composting process. The compost pH reached 7.3, which is highly suitable for plant physiological processes. From all of the above results, the compost analysed in this study was found to be suitable and safe for plant cultivation.

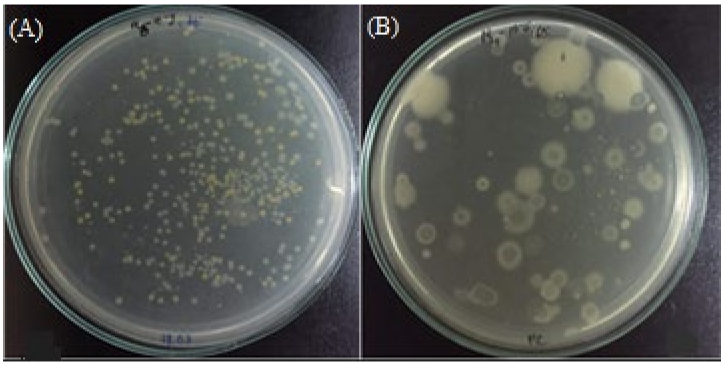

Figure 4: Bacterial colonies on Lubria-Bertani medium of (a) Mesophilic bacterial plate and (b) thermophilic bacterial plate.

3.3 Phytotoxicity test

The germination index is a sensitive parameter for assessing compost toxicity to plants. This index is determined via two indicators of germination rate—root length of the sample and control (Tiquia and Tam, 1998). The mung bean germination index in this test was 141.56 % higher than the minimum value of 80 % for the germination test, showing that the compost was nontoxic and mature (Ch'ng et al., 2013). The addition of food waste and useful microorganisms helped to decay macromolecules such as cellulose, lignin and hemicellulose compared to using only pineapple residues (Ayed et al., 2007).
For the germination index analysis, mung bean growth parameters were also determined. The results of the analysis of root length, stem length, stem diameter and number of roots are shown in Table 2. The stem length and diameter derived from the compost treatment were 135.7 mm and 15.1 mm, compared to 118.1 mm and 15.5 mm, for the control treatment. A significant difference between control and treatment ($p < 0.05$) was not found. The compost did not affect the length and diameter of the mung bean stem during the 4-day observation period. The root length and number of roots increased by 372.8 % and 22.6 %, after compost treatment. Both indicators significantly increased compared to the control treatment ($p < 0.05$); in particular, root length increased by many folds compared to the control. The compost in this study effectively enhanced the growth of mung bean roots during the 4-day observation period, which was a prerequisite for efficient plant growth in the later stages. The compost in this study increased the root length to 372.8 %, substantially higher than the 53.9 % reported in Liu and colleagues' (2013) study, where composting of pineapple residues and microorganisms, without food waste, was used. In contrast to Liu and co-workers' (2013) research, there was no similarity in the development of stem and root length in the current study. The roots were more sensitive to the environment than the stem because they were in direct contact with the compost extract (Akhter et al., 2015). These data again demonstrated that the addition of food waste substantially improved compost quality.

Table 2: Effect of the final compost on mung bean growth properties.

	Mean of root – length (mm)	Mean of stem – length (mm)	Mean number of roots	Mean of stem diameter (mm)
Compost	151.3*	135.7	24.4*	15.1
Control	32.0	118.1	10.4	15.5

Values with * within in a column are significant different by the t-test (P≤0.05)

4. Conclusions

With the increasing amount of pineapple residues and food waste in Vietnam, an efficient and environmentally friendly treatment of these wastes on a large scale is essential. This study succeeded in composting two wastes at a pilot scale. The composting process was completed after 45 d, with the highest compost pile temperature reaching 72 °C on day 7. Total organic matter, beneficial microorganisms, pathogenic microorganisms, heavy metals, pH, moisture content and phytotoxicity results demonstrated that the compost satisfied Vietnamese compost management standards. The compost analysed in this study was of good quality and might be effective for plants. With the published studies, this is the first study on composting of pineapple residues and food waste at a pilot scale. This research is expected to contribute to reducing environmental pollution and enhancing sustainable pineapple farming in the Mekong Delta, Vietnam. In the future, the composting procedure will be guided to farmers to treat the wastes in the region.

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