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Limiting factors of durian rind composting by natural technology during the wet period

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ABSTRACT

This study aims to examine the composting of durian rinds by using natural technology through the aerobic degradation of normal flora bacteria from the rinds by the utilization of paddy soil containing iron (Fe) compound used as an energy source during Thailand's wet period. The sample collection process was obtained once a week for 12 weeks as this is to analyze the physical, chemical and microbiological characteristics of the rinds. The results showed that within the first 4 weeks, the temperature of the compost has decreased while the moisture content has increased. More so at 5 weeks it was shown that the nitrogen content decreases significantly as there was no degradation activity although there is still a large amount of Iron (Fe) compound left enough to be used as an energy source in the aerobic degradation process. Where this can be explained by the process of cell multiplication and bacterial decomposition that requires nitrogen, therefor the result in the decreased temperature caused by the high levels of moisture as well as the total nitrogen and C: N ratio does not meet the standard of organic fertilizer as this can be concluded that nitrogen is a limiting factor in the process of decomposing oxygenated durian rinds of bacteria during the rainy season.

***Key words**: Organic Waste, Composting, Aerobic degradation, Waste utilization, Durian*

Introduction

Located in the tropical climate zone, Thailand has abundant amount of soil and water resources which accordingly, yield exceptional agricultureal yields. This is specifically true in the sense in the amount of fruits and vegetables products. One type of product that is grown natively in Thailand, is the Durian fruit; a popular fruit both domestically and internationally as it has been regarded as the king of fruits. In 2018, the country had transported approximately 32,471.2 tons of durians, worth about 5,918.3 million baht. One of the essential origination of durian cultivation in Thailand is from Chanthaburi Province as its geographical and meteorological conditions are very suitable for its cultivation. In 2019, Chanthaburi province has produced approximately 339,292 tons of durian products (Office of Agricultural Economics, 2019). However, it was that only the edible parts that were sold as this is accounted for only 15-30 percent of its total weight, while the remaining 70-85 percent being its rind. (Masrol *et al.*, 2015)

The chemical composition of the durian rind consisted of cellulose, hemicellulose and lignin at a percentage about 57-67, 30.7 and 13.6% (Patpen *et al*., 2014; Shaiful *et al*., 2015), this composition is a starting point at which it is probable that large amounts of durian rinds can be utilized in the making of the organic compost through the biodegradation process of aerobic bacteria in nature (Isha *et al*., 2017; Bilyana, 2019; Mansi, *et al*., 2020; Phadpin *et al*., 2020). Since Chanthaburi province has a sufficient amount of rainfall covering nearly 6 months; this also correlates to the duration of harvesting season. However, it is the moisture content that plays a crucial part in the mechanism of bacterial degradation. Under the conditions of a moisture deficit, aerobic degradation is promoted in the presence of free oxygen (O_2) or on the contrary, over moistening may lead to the development of anaerobic processes by decreasing the oxidation-reduction potential (Lyngkilde and Christensen, 1992). However, in the continuous promotion of aerobic digestion, the use of paddy soil in the concrete box is selected. Paddy soil has been considered as an electron acceptor, a critical source of energy for aerobic bacteria in its utilization process of aerobic degradation. In providing that the oxygen in the compost pile is low, these iron (Fe) compounds in paddy soil are provided by the various forms including ferric oxide and ferric hydroxide (Alexander, 1961; Evgenya *et al.*, 2004; Wei, 2014). As iron (Fe) compounds are comparatively higher than other electron acceptors, they can use this energy to decompose of organic waste. As a result, it is made it more applicable for large number of organic waste can be used as an electron acceptors by aerobic bacteria as a mechanism of decomposing the organic waste. In addition, they can prevent the formation of anaerobic degradation in which the production of methane gas by methanogenesis process based on the concentration of electron donors that falls to a too low level for methanogenic bacteria. (Pimpan *et al.*, 1994; Bond and Lovley, 2002; Musfique and Lin, 2017)

Therefore, from the knowledge, it is suggested that in the compost management of the durian rinds should be degraded into making compost, as by considering the environmental factors as the paddy soil having an abundance of electron acceptor where naturally found aerobic bacteria are able to use as an energy source for its aerobic degradation during the wet period.

Materials and Method

Composting

In gathering the require materials, the durian rinds

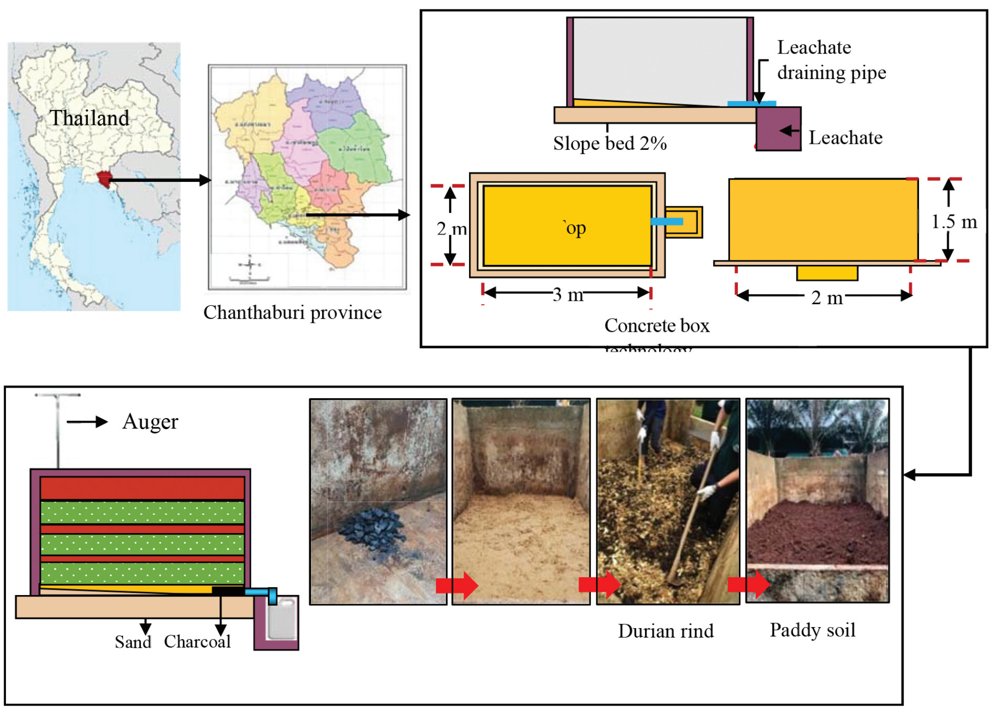

Fig. 1. Location of the project site at Chanthaburi Province and the concrete box technology

were accumulated from the fruit market in Chanthaburi Province, where they were cut into 5-10 cm pieces in size, while 1,000 kg of paddy dry soil were prepared. When ready, the chopped rinds are then placed into a concrete box of a 2 by 3 m with the height of 1.50 m. where at the base of the box there are leachate drainage holes that is covered with charcoal and coarse sand with the thickness of 20 cm. In placing the durian rind into the box, the rinds are placed in a downward manner with the alternation with the paddy soil making 3 layers in total. From this it was that 670 kg of durian rind are utilized with 210 kg of paddy soil. While the top most layer was covered with 630 kg of paddy soil as the entire waste compost was watered 60 liters per week (Chunkao, 2018). However, in a presence of rain, no surplus water is necessitated. (Fig. 1)

Sampling

The air temperature and temperature of the compost pile was monitored every day at 07.00 am. with a thermometer while the rainfall measurements were also conducted with a rain gauge every day in case of rain. In the composition of the leachate, the Oxidation- Reduction Potential (ORP) was monitor with a ORP meter. In sampling of the compost, the sample was asscessed once a week for 3 months with the use of the hand soil auger. Prior to the sampling processes, the quartering method was applied with the sample being splited into 2 parts. The first part is dried in hot air oven at 70 °C until dry and arid then a sieve, diameter of 0.5 mm to determine both the physical and chemical parameters. For the second part, the sample is preserved in plastic bags by the aseptic technique as they are stored at 4°C for further studied of its microbiological composition. (Fig. 1)

Sample Analysis

In the analysis of the organic compost includes parameters of moisture, total nitrogen (TN) through the Kjeldahl Method, organic carbon with the Walkley-Black method, the carbon-nitrogen ratio (C:N ratio) and total iron utilized with the Atomic Absorption Spectrophotometer (AAS) Method following the Official Method of Analysis of AOAC International (AOAC, 2012). The Total Bacteria was also assessed by the Serial Dilution Technique; as well as using the Plate Count Agar (PCA; Himedia) that adds the fungi inhibitor of 0.025% Sodium Propionate (Merck) through the spread the Plate Technique as they are stored with the temperature equivalent with the incubated compost pile for 24-48 hours. Where prior to the storing process, the number of bacteria were counted as CFU g^{-1} compost. (Beishier, 1991; Department of microbiology, 2011).

Statistical analysis

The Analysis of Variance (ANOVA) had contrasted the variances by Duncan's Multiple Range test (DMRT) at a 95% confidence level ($P \leq 0.05$). The relationship between parameters was determined by Pearson correlation analysis.

Results and Discussion

Characteristics of soil and durian rinds before composting

The moisture of the soil and the durian rinds before composting demonstrated a very high level of moisture content at 81.7%. As a consequence, this could have impacted the oxygen exchanges within the compost pile causing a condition in which the oxygen supply was inhibited; (Lyngkilde and Christensen, 1992; Sharma *et al.*, 1997; Sanchez *et al.*, 2017). In general, the recommended levels of moisture for the aerobic bacteria degradation mechanism should be between 50-60% (Robert, 2001; Gajalakshmi and Abbasi, 2008). Nevertheless, the paddy soil that is utilized with the durian rinds from the assessment comprised of 910.0 mg/kg of iron as this was significant enough for bacteria to decompose the durian rind (Ponnamperuma, 1981). The Durian rinds likewise consisted of sufficient quantities of organic carbon and C:N ratios; which were very much applicable for aerobic bacterial degradation and soil where it was determined that the amount of bacteria was 1.82×10^8 and 9.7×10^4

Table 1. The aspects of durian rinds and paddy soil before composting.

Parameters	Unit	Capacity: Paddy soil	Capacity: Durian rinds
Moisture	%	22.0	81.7
Total nitrogen	%	0.1	0.8
Organic carbon	%	0.7	46.4
C: N ratios	-	6.6:1	55.2:1
Total Fe	mg kg^{-1}	910.0	533.0
Total bacteria	CFU g^{-1}	9.7×10^4	1.82×10^8

CFU g^{-1}, respectively. Where this is a very suitable quantity for the degradation process of the durian rinds in Table 1. (Tortora *et al.,* 2001; Bernal *et al.,* 2009; Madar *et al.,* 2013).

The physical, chemical and biological parameters of the organic compost

Prior to the degradation period of 12 weeks, the measured moisture of the compost was 54.5%, with the total nitrogen capacity at 0.05%, while the C:N ratio was 159.01:1, with the total iron composition being 1,783.0 mg kg^{-1} and the total bacteria was at 2.94×10^6 CFU g^{-1}. In the comparison made with the compost guidelines of the Department of Agriculture (2008), moisture and C:N ratios were higher than that of the guideline (C:N ratio must not exceed 20:1 and dampness composition should not be over 35%). Furthermore, the nitrogen content was 1% lower than the guidelines as shown in Table 2.

Temperature and moisture

The relationship between the temperature and moisture of the compost were significantly different ($p \leq 0.05$) as this explanation would be because of the volume of rain that fell throughout the degradation period that have gradually increase from 0.7 to 33.7 mm. Together with the Durian rind being made up of organic materials. It would possess an excellent water holding capabilities (Jan *et al*., 2010) (Fig. 2A). As a result of too much water within the composting unit increasing the moisture that effected the moisture factor causing the fluctuation between 45.9 to 67.01%. This could have impacted the oxygen exchanges within the compost pile causing a condition in which the oxygen supply to be inhibited (Lyngkilde and Christensen, 1992; Sharma *et al.,* 1997; Sanchez *et al.,* 2017), the anaerobic condition is then promoted, as shown in Fig. 2B. Where this is because the properties of water would displace the air within the micropores trapping oxygen (Das and Keener, 1997; Sanchez *et al.,* 2017). In addition to the explanation on the anaerobic condition, it is recognized from the negative ORP values throughout the first 4 weeks ranging from -50 to -250 mV, causing a loss in the nitrogen and sulfur content from the compost that would have led to denitrification and sulfide formation respectively.

For the temperature in the compost, there is a decreasing trends found in the range of 35.0-35 °C as lastly, this factor has resulted from rainwater that influence the temperature fluctuations within the compost (Bernal *et al*., 2009) (Fig. 2C).

Total nitrogen, Organic carbon and the C:N ratio

There was a statistically significant difference

Table 2. The physical, chemical and biological parameters **of** the compost.

Compost Age (Weeks)	Temperature (°C)	Moisture (%)	OC (%)	Total N(%)	C: N ratio (-)	Total Fe (mg kg^{-1})	Total Bacteria (CFU g^{-1})
Standard 1/	-	≤35	-	≥ 1	≤ 20	-	-
0	nd	62.84^{ab}	19.93^{a}	0.63^{a}	31.70^{e}	1,725.87^{cd}	1.38×10^{7} ^{a}
1	35.0^{a}	53.99^{abc}	3.30^{g}	0.07^{cd}	49.94^{e}	1,742.54^{bcd}	2.25×10^{6} ^{cde}
2	33.5^{b}	50.34^{bc}	8.93^{bc}	0.28^{b}	31.91^{e}	1,732.75^{cd}	1.58×10^{6} ^{de}
3	33.8^{b}	45.92^{c}	3.87^{fg}	0.04^{fg}	83.02^{d}	1,750.76^{abcd}	1.11×10^{7} ^{b}
4	33.0^{b}	54.89^{abc}	4.50^{f}	0.03^{g}	157.04^{bc}	1,729.18^{cd}	2.25×10^{6} ^{cde}
5	30.7^{cd}	62.87^{ab}	20.53^{a}	0.09^{c}	225.72^{a}	1,715.37^{d}	2.33×10^{6} ^{cde}
6	31.3^{c}	63.26^{ab}	8.33^{cd}	0.06^{ed}	142.33^{bc}	1,728.32^{cd}	2.16×10^{6} ^{cde}
7	29.7^{d}	67.01^{a}	9.80^{b}	0.06^{ed}	163.00^{b}	1,770.7^{0ab}	2.50×10^{6} ^{cde}
8	29.7^{d}	59.12^{ab}	7.80^{d}	0.05^{ef}	150.20^{bc}	1,772.36^{ab}	2.83×10^{6} ^{cd}
9	31.1^{c}	62.87^{ab}	5.77^{e}	0.04^{gf}	154.06^{bc}	1,783.33^{a}	1.25×10^{6} ^{e}
10	30.3^{cd}	60.42^{abc}	9.23^{bc}	0.07^{de}	138.27^{c}	1,777.18^{ab}	2.37×10^{6} ^{cde}
11	30.1^{cd}	55.80^{abc}	6.03^{e}	0.04^{gf}	163.79^{b}	1,761.19^{abc}	1.80×10^{6} ^{cde}
12	29.5^{d}	54.53^{abc}	7.93^{d}	0.05^{ef}	159.01^{bc}	1,783.00^{a}	2.94×10^{6} ^{c}
F-test	ns	ns	*	*	*	*	*

Remarks: ns = No statistical differences at 95% confidence level
* = Statistical variances at a level of 95% confidence
nd = Non Detect
^{1}/ = Standard from Department of agriculture (2008)

($p \leq 0.05$) between the total nitrogen to the organic carbon and the C:N ratio of compost (Table 2). Where the concentration of nitrogen rapidly decreases as a result of moisture in relation to the ORP value (Fig. 2B) creating an anaerobic condition that resulted in the denitrification and ferric ammonium oxidation that lead the production of organic nitrogen developing into nitrogen gas (N_2). (Sommer, 2001; Clement *et al.*, 2005; Sawayama, 2006; Xuezhi *et al.*, 2018). This reaction resulted in a rapid loss of nitrogen in the compost from 0.63% down to 0.03%, while also produces sulfides resulting in hydrogen sulfide gas that leads to unpleasant odor. Furthermore, the hydrogen sulfide gas will also react to the iron (Fe) compounds in the reduction form resulting in iron sulfide (FeS) which leads to the color of the leachate being black within the first 4 weeks (Yongzhen *et al.*, 2017).

However, it also shown that within the first 4 weeks, there was the process of bacterial degradation base on the exciting nitrogen compounds found in the compost that is able to play an important role in formation of bacteria cells. Therefore, these bacteria will be able to use the nitrogen in the degradation of organic carbon that leads to the significant decrease in organic carbon and the C:N ratio. When the compost has reached the 5th weeks, it was determined that organic carbon had increased from 4.5% to 20.53%. This was because the Durian rind presented a synthetic composition of cellulose that

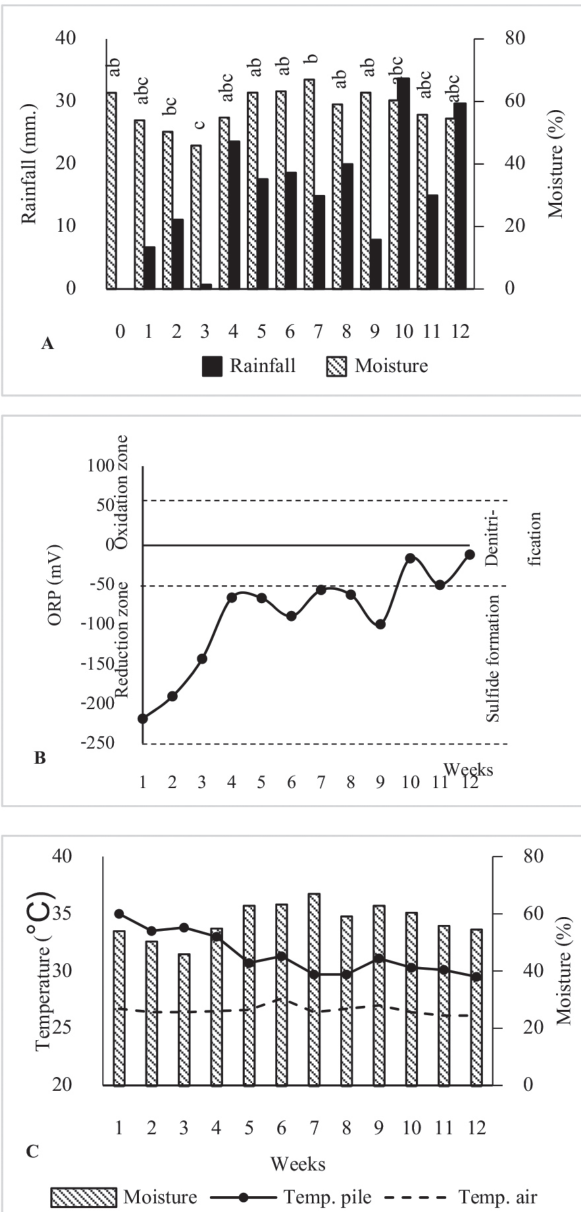

Fig. 2. Substantial development of the compost heap (A) Rain and dampness complement (B) Oxidation-Potential Reduction (ORP) and (C) Moisture and Temperature

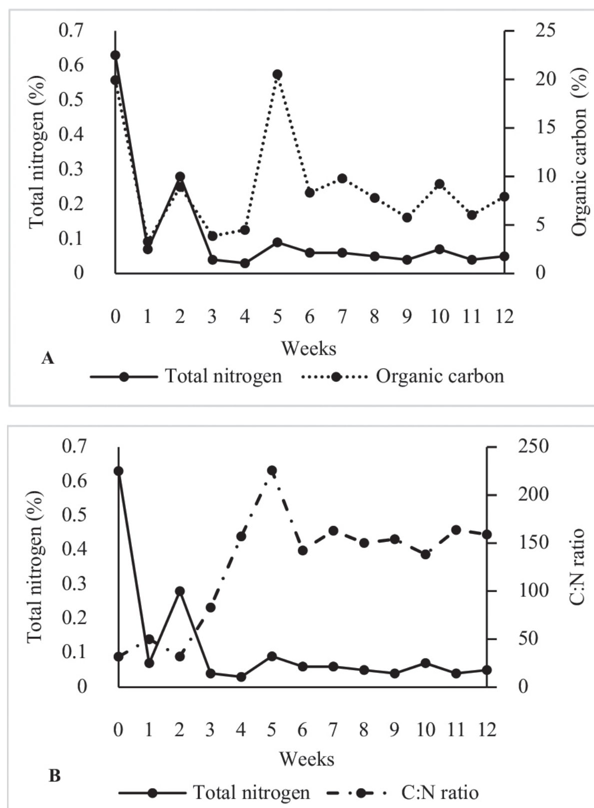

Fig. 3. Synthetic fluctuations in compost heaps (A) nitrogen comprisement per organic carbon and (B) the aggregate of nitrogen per C:N ratio

bound with hemicellulose, where the primary integral of xylose and had lignin as the outer system, with this the result of the degradation process would produce a variety of organic carbon that is released into the compost; of which includes sugar, alcohol, and abounding types of organic acids (Jaiboon *et al.*, 2016; Tulaphitak *et al.*, 2018). This production would have increased the organic carbon while at this point, the remaining amount of nitrogen in the box is not efficient for the cells generation of bacteria (Magasanik, 1993) summarizing that after 5 weeks, the amount of bacteria in the box have remained constant and will no longer degrade as the C:N ratio constantly increase as shown in Fig. 3B.

Total iron content and total bacteria

The total iron and bacteria content were significantly different ($p \leq 0.05$) as shown in Table 2. The amount of iron that have decreased significantly during the first 4 weeks. Where within the first 4 weeks the loss of iron (Fig. 4) were from the sulfide formation process (Fig. 2B) resulting in hydrogen sulfide that can react with iron in the paddy soil forming iron sulfide (FeS) that would then be dissolve with the leachate (Ponnamperuma, 1981; Yongzhen *et al.*, 2017).

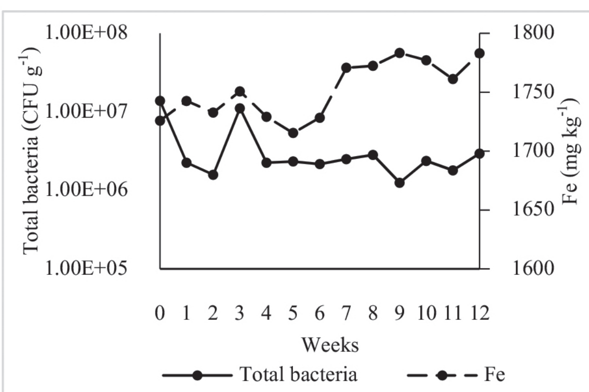

Fig. 4. The number of bacteria and iron in the composition

Also, it is the FeS that has an impact on slow down the biochemical process in the bacteria cells forming a Lag phase leading to a decrease in the degradation rate (Ivan *et al.*, 2019). Besides, the FeS will also inhabit the growth of bacteria, causing it to decrease (Kushkevych *et al.*, 2019). While within the first 4 weeks period it was found that the total nitrogen can still be detected in the compost concluding that the bacteria using nitrogen in the process of cell manipulation allowing for further degradation in the 4th week. The organic carbon and that C:N ratio, on the other hand it was found to have decreased during the first 4 weeks as it was in the 5th week to the 12th week, that the total bacteria and iron content in the compost did not change as this is in consistent with the stable organic carbon and C:N ratio that does not differ significantly shows that there is no degradation activity.

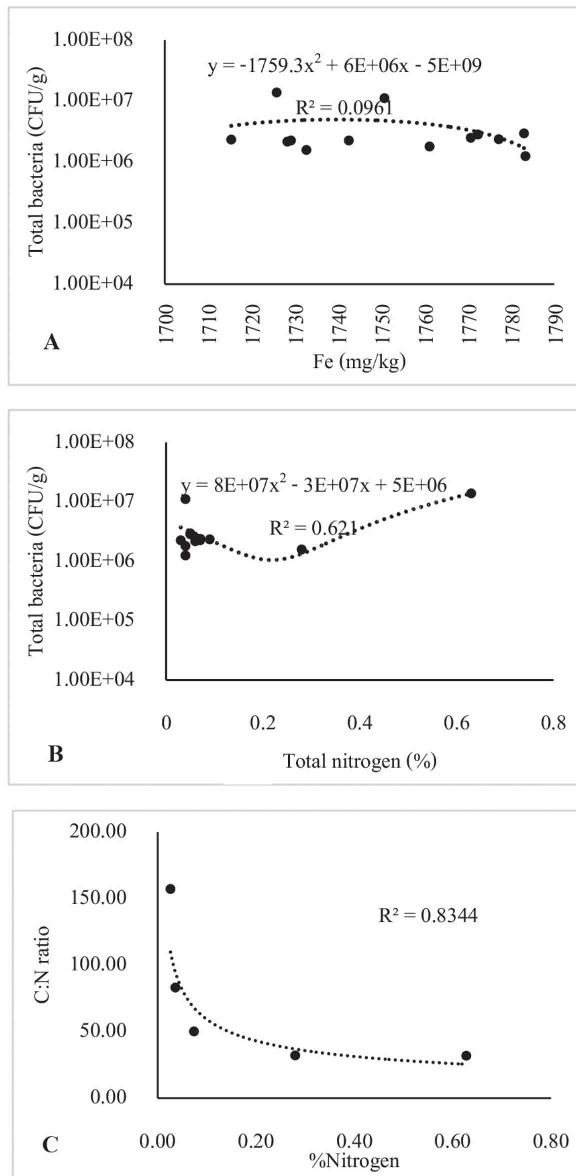

Fig. 5. The correlation coefficient between (A) total bacteria and total Fe, (B) total bacteria, total nitrogen, (C) C: N ratio and total nitrogen

Factors affecting the degradation of durian rind in the rainy season

From the analysis of the compost in Table 2, it was demonstrated that the compost from durian rind was not in conformity with the National organic fertilizer guidelines, Thailand. Moreover, it was recognized that from the increased the C:N ratio and the total nitrogen value that are lowered than the guidelines.

This indicates that there no bacteriological degradation activity despite the compost. Comprising of iron (total Fe) that can function as an energy for the bacteria to be utilized as an electron acceptor in the degradation mechanism. Nonetheless, it was found in this research that the bacteria did not utilize the iron (Fig. 5A), which could be ascertained from the correlation coefficient of the total bacterial volume and the low iron content ($r^2 = 0.0961$) as aerobic bacterial degradation requires the utilization of nitrogen (Magasanik, 1993; Sanchez *et al.,* 2017). To explain the correlation of the total bacteria and nitrogen. Fig 5B indicates a r^2 values of 0.621 as this roughly indicates that bacteria increased and decrease in accordance with the levels of nitrogen. In the same manner with the nitrogen, the generation of the bacteria also correspond to the C:N ratio, where higher ratio would means that the is imbalance in the composition of carbon and nitrogen that could be used in the bacterial degradation process. This was seen with the r^2 values of 0.8344 between the ratio and the nitrogen percentage summarizing that nitrogen is a limiting factor in the process of aerobic degradation of durian rind during the wet period.

Conclusion

The degradation of durian rinds for the production of compost by means of natural technology using iron compounds in paddy soil as an energy source for bacteria in the aerobic digestion process during the rainy season of Thailand found that the high levels of moisture would cause the compost to lose nitrogen through the denitrification process. Whilst there is still an abundant amount of iron oxide that can be used as an electron acceptor within the technology but was not used as instead it was used in the sulfide formation process. From these processes, the result is clear that it has negatively affect the bacteria within the technology in terms of the multiplication and degradation activities resulting in a higher ratio of nitrogen to carbon. Thus, it is the nitrogen that have been the limiting factor in the process decomposing organic durian rind in the rainy season. Where it is recommended that adding nitrogen source into the durian rinds compost during the wet period would promote the degradation progress of aerobic bacteria within the compost.

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Conflict of Interest: The authors declare that they have no conflict of interest.

References

Alexander, M. 1961. *Introduction to Soil Microbiology.* John Wiley & Sons, Inc., New York.

AOAC. 2012. *Official Method of Analysis of AOAC International. 19thed*, AOAC International Inc., Gaithersberg, MD.

Beishier, L. 1991. *Microbiology in Practice. 5thed*. Harper Collins Publisher, Inc. New York, pp 514

Bernal, M.P., Alburquerque, J.A. and Moral, R. 2009. Composting of Animal Manures and Chemical Criteria for Compost Maturity Assessment: A Review. *Bioresource Technology*. 100: 544-5453.

Bilyana, G. P. 2019. Dynamics of Microflora in the Process of Composting Organic Waste and Bioplastics. *EC Microbiology.* 15 (10): 986-993.

Chunkao, K., Pattamapitoon, T., Chanthasoon, C., Bualert, S., Taychikunanon, A., Vongsawan, N. and Mokatip, S. 2018. King Bhumibol's Royally Initiative Nature-by-Nature Process for Activating Digestion Period in Municipal Garbage Composting. In: *The 33th International Conference on Solid Waste Technology and Management 11-14 March 2018*, Annapolis, USA.

Clement, J.C., Shrestha, J., Ehrenfeld, J.G. and Jaffe, P.R. 2005. Ammonium Oxidation Coupled to Dissimilatory Reduction of Iron Under Anaerobic Conditions in Wetland Soils. *Soil Biology and Biochemistry*. 37 : 2323-2328.

Bond, D.R and Lovley, D.R. 2002. Reduction of Fe (III) oxide by methanogens in the presence and absence of extracellular quinones. *Environmental Microbiology*. 4 (2) : 115-24.

Das, K. and Keener, H.M. 1997. Moisture effect on compaction and permeability in compost. *Journal of Environmental Engineering*. 123: 275-281. https://doi.org/ 10.1061/ (ASCE) 0733-9372(1997)123: 3(275)

Department of agriculture. 2008. *A guide book for organic fertilizer analysis*. Department of agriculture, Bangkok, Thailand.

Department of microbiology. 2011. *Microbiology Laboratory. 6th ed*. Chaopraya printing system Co., Ltd., Bangkok, Thailand.

Anderson, R.T., Vodyanitskii, Y.N., Sivtsov, A.V. and Yuretich, R. 2004. Importance of Clay Size Minerals for Fe (III) Respiration in a Petrolium-Contamiated Aquifer. *Geobiology*. 2 : 67-76.

Gajalakshmi, S. and Abbasi, S.A. 2008. Solid Waste Management By Composting: State of The Art. *Critical Reviews in Environmental Science and Technology*. 38: 311-400.

Isha, V., Sivaprakasam, S. and Kalamdhad, A. 2017. Isolation and Identification of Bacteria from Rotary Drum Compost of Water Hyacinth. *International Journal of Recycling of Organic Waste in Agriculture*. 6 : 245-253.

Ivan, K., Dordevic, D. and Vitezova, M. 2019. Toxicity of hydrogen sulfide toward sulfatereducing bacteria *Desulfovibrio piger* Vib-7. *Archives of Microbiology*. 201: 389-397.

Jaiboon, K., Lertwattanasakul, N., Limtong, P. and Limtong, S. 2016. Yeasts from peat in a tropical peat swamp forest in Thailand and their ability to produce ethanol, indole-3-acetic acid and extracellular enzymes. *Mycol Progress*. 15 : 755–770.

Jan, M. L., Traore, S., Wang, Y. M. and Kan, C.E. 2010. The effect of organic matter amendment on soil water holding capacity change for irrigation water saving: Case study in Sahelian environment of Africa. *Scientific Research and Essays*. 5 (23) : 3564-3571.

Lyngkilde, J. and Christensen, T. H. 1992. Fate of organic contaminants in the redox zones of a landfill leachate pollution plume (Vejen, Denmark). *Journal of Contaminant Hydrology*. 10 (4) : 291-307.

Kushkevych, I., Dordevic, D. and Vitezova, M. 2019. Toxicity of hydrogen sulfide toward sulfate-reducing bacteria *Desulfovibrio piger* Vib-7. *Archives of Microbiology*. 201:389-397.

Madar, D., Dekel, E., Bren, A., Zimmer, A., Porat, Z. and Alon, U. 2013. Promoter activity dynamics in the lag phase of *Escherichia coli*. *BMC System Biology*. 7 : 136-14.

Magasanik, B. 1993. The regulation of nitrogen utilization in enteric bacteria. *Journal of Cellular Biochemistry*. 51: 34-40.

Mansi R., Nandal, M. and Khosla, B. 2020. Microbes as vital additives for solid waste composting. *Heliyon*. 6 (2): 1-11.

Masrol, S.R., Ibrahim, M.H.I. and Adnan, S. 2015. Chemical-Mechanical Pulping of Durian Rinds. In: *2nd International Materials, Industrial, and Manufacturing Engineering Conference (MIMEC2015)*. 4-6 February 2015, Bali Indonesia, pp. 171-180.

Musfique, A. and Lin, L.S. 2017. Ferric Reduction in Organic Matter Oxidation and Its Applicability for Anaerobic Wastewater Treatment: A Review and Future Aspects. *Reviews in Environmental Science and Bio/Technology.* 16 : 273-287.

Office of Agricultural Economics. 2019. *Thailand Foreign Agricultural Trade*, Bangkok, Thailand.

Patpen, P., Abdul Rahman, R., Talib, R. A. and Abdan, K. 2014. Extraction and Characterization of Cellulose from Durian Rind. *Agriculture and Agricultural Science Procedia*. 2 : 237-243.

Pimpan, J., Murase, J., Prabuddham, P., Hasathon, Y., Khomthong, N., Naklang, K., Watanabe, A., Haraguchi, H. and Kimura, M. 1994. Methane Emission from Plots with Differences in Fertilizer Application in Thai Paddy Fields. *Soil Science and Plant Nutrition*. 40 (1) : 63-71.

Phadpin, A, Chunkao, K. and Pattamapitoon, T. 2020. Bacterial Communities as Induced by Volatile Gases Releasing From Organic Compounds In Food Wastes And Bio-Wastes In Bangkok, Thailand. *Ecology, Environment and Conservation*. 26 Suppl.: 46-55.

Ponnamperuma, F.N. 1981. *Some Aspects of The Physical, Chemical, Chemistry of Paddy Soils. In: Proc. Symp*. On Paddy Soil. Inst. Soil Sci. Academia Sinaca, Science Press, New York.

Robert, R. 2001. Getting Moisture into the Compost Pile-A Survey of Operators in Various Regions of the U.S. Provides Insights into Keeping the Composting Process Wet Enough. *J. Bio Cycle.* 42 : 51-56.

Sanchez, O.J., Ospina, D.A. and Montoya, S. 2017. Compost Supplementation with Nutrients and Microorganisms in Composting Process. *Waste Management*. 69 : 136-153.

Sawayama, S. 2006. Possibility of Anoxic Ferric Ammonium Oxidation. *Journal of Bioscience and Bioengineering.* 101 : 70-72.

Shaiful R. M., Ibrahimb, M. H. I. and Adnand, S. 2015. Chemi-mechanical Pulping of Durian Rinds. *Procedia Manufacturing.* 2 : 171-180.

Sharma, V.K., Canditelli, M., Fortuna, F. and Cornacchia, G. 1997. Processing of Urban and Agro-Industrial Residues by Aerobic Composting: Review. *Energy Conversion and Management*. 38 (5) : 453-478.

Sommer, S.G. 2001. Effect of Composting on Nutrient Loss and Nitrogen Availability of Cattle Deep Litter. *European Journal of Agronomy*. 14: 123-133.

Tortora, G.J., Funke, B.R. and Case, C.L. 2001. *Microbiology: An Introduction. 7th ed*. Benjamin-Cummings Publishing, Inc. Wesley Longman, Inc. California.

Tulaphitak, D., Saenjan, P., Dejbhimon, K. and Torpol, P. 2018. Characterization of organic carbon and carbon sequestration in a sandy paddy soil amended with organic residues. *Khon Kaen Agr. J*. 46 Suppl. (1): 1169-1174.

Wei, L., Ai, Z., Cao, M. and Zhang, L. 2014. Ferrous ions promoted aerobic simazine degradation with Fe@Fe_2O_3 core–shell nanowires. *Applied Catalysis B: Environmental*. 150-151 : 1-11.

Xuezhi, T., Shao, D. and Gu, W. 2018. Effects of temperature and soil moisture on gross nitrification and denitrification rates of a Chinese lowland paddy field soil. *Paddy and Water Environment*. 16 : 687-698.

Yongzhen, X., Lu, C., Hou, N., Xin, Y., Liu, J., Liu, H. and Xun, L. 2017. Sulfide production and oxidation by heterotrophic bacteria under aerobic conditions. *The ISME Journal*. 11 : 2754-2766..