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Role of Additives in the Composting of Human Feces

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Abstract

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This research present the effect of additives on human feces with different ratios to improve the composting conditions of small-scale on-site feces treatment for urine dividing dry toilet (UDDT). Additives play as an important role for pathogen removal efficiency, reducing nitrogen loss and decomposition of organic matter. Depending on the characteristics of the additives and using amount, the effects are different. For those purposes, two additives; ash and rice straw were selected which are readily available in the local areas, especially in rural and agricultural sites. All the experiments were performed in laboratory scales.

Feces and ash were mixed into three ratios (1:1, 1:3, 1:5) to estimate the optimal amount to have better effects on composting process and end-products. pH, organic matter content or total organic carbon content and mainly, Escherichia coli (E.coli) concentration changes were measured during the process. Highest pH 11.28 was obtain from (1:3) ratio while it had very lower reduction rate of organic matter .1:1 (v/v) achieved pH 10.8 and it maintained pH >10, a sanitization level, even after the experiment period. The E.coli concentration level to meet the guideline of WHO (2006) while maintaining the highest decomposition rate. Thus 1:1 presented the most effective for overall feces treatment with ash.

For stabilization the organic matter, different ratios with feces and rice straw (1:0.5, 1:1, 1:2) were also investigate Among three ratio Feces and rice straw, ratio 1:2 (v/v) reduced the TOC content from 51% to 22%. Which shown the better results for decomposition of organic matter. It also had high recovering soluble TN and reducing E.coli content. It achieve the mature compost after 70 days. However, it took 84 days to reach the safety level of pathogens concentration. Thus, 1:2 presented the most effective for overall feces treatment with rice straw.

To obtain pathogen free mature compost during a short time, 2 additives were mixed together with feces by following the optimal ratios F:Ash:RS (1:1:2). Combine mixing of rice straw and ash showed the better results compare to one additive. That was due to organic matter stabilization by rice straw and pathogen reduction by the present of ash happened at the same time. Thus, 1:1: 2 ratio of Feces, ash, rice straw is a good portion for composting of human feces in dry toilet to achieve pathogen free mature compost.

Keywords: Composting toilet; ash; rice straw; E.coli reduction; pH; organic matter decomposition; nitrogen loss; treatment time.

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Chapter 1: Introduction

1.1 Background

1.1.1 Current global sanitation

The rapid growth of world population affect the environment in many aspects. The demand of basic requirements of daily life such as foods, houses and sanitation facilities become high all over the world, especially in low-income countries and sanitation plays as the most important aspect of community well-being since it protects human health. Sanitation related to the provision of facilities and services for the safe management of human excreta from the toilet to containment and storage and treatment onsite or conveyance, treatment and eventual safe end use or disposal (WHO 2020). Sanitation facilities such as toilets, latrines, mechanized wastewater treatment, are currently set up as a way to treat human excreta and grey water to protect human health and the environment including water bodies, which are sources for drinking water (Naughton, C. et al., 2017) and there are many places where even basic sanitation services are not available. Globally, 4.5 billion people do not have toilets at home that safely manage excreta. Among them, 600 million share a toilet or latrine with other households, 2.4 billion do not have basic sanitation services, 892million defecate in open area (WHO 2017). Since 1990 the number of people without access has remained almost constant: in 1990 this figure was 2.49 billion, and in 2015 it has reduced to 2.39 billion (figure 1.1). However, figure (1.2) shows the number of people without access to improved sanitation facilities; which ensure hygienic separation of human excreta from human contact, including flush/pour flush (to piped sewer system, septic tank, pit latrine), ventilated improved pit (VIP) latrine, pit latrine with slab, and composting toilet , by region. Over 90% of those without access in 2015 resided in Asia, the Pacific or Sub-Saharan Africa. The largest region share was from South Asia, accounting for 40% – nearly one billion did not have access. This was followed by Sub-Saharan Africa with nearly 30% (706 million), and East Asia & Pacific with around 22% (520 million) (Hannah Ritchie (2019)).

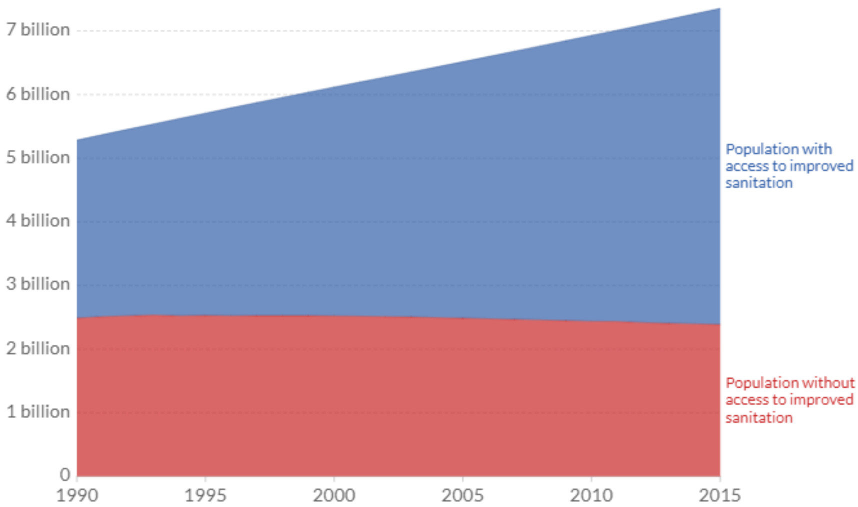

Figure 1. 1Number of people with and without access to improved sanitation

facilities, World, 1990 to 2015

(Source: World Bank, World Development Indicators)

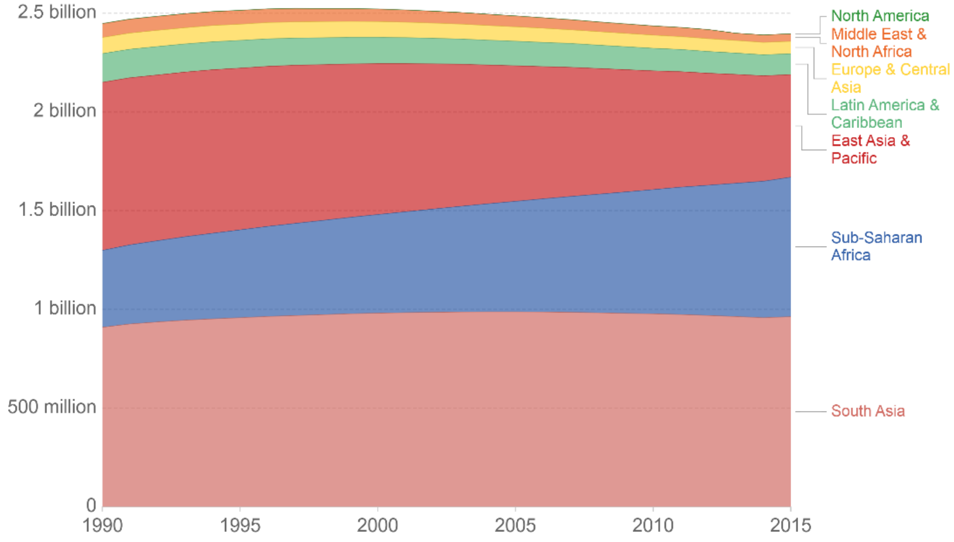

Figure 1. 2 Number of people without access to improved sanitation facilities, 1990 to 2015 (Source: World Bank, World Development Indicators)

Open defecation has historically been most widespread among the poorest residents whether in urban or rural area. In India, the number of people practicing open defecation decreased by 55% from 767 million to 344 million between 2000 and 2017, but India still had the largest number of people practicing open defecation in 2017, followed by Nigeria and Indonesia (Figure 1.3). This leads regularly exposed feces, which presented daily in the environment, to people through direct contact. The risk of spreading diarrheal and waterborne diseases is due to the lack of regular handwashing and microbial contamination of water in homes and communities. Poor sanitation can also have butterfly effect in delaying national development because people are suffering from illnesses and living shorter lives, in that way producing and earning less, and incapable to pay for education and stable futures.

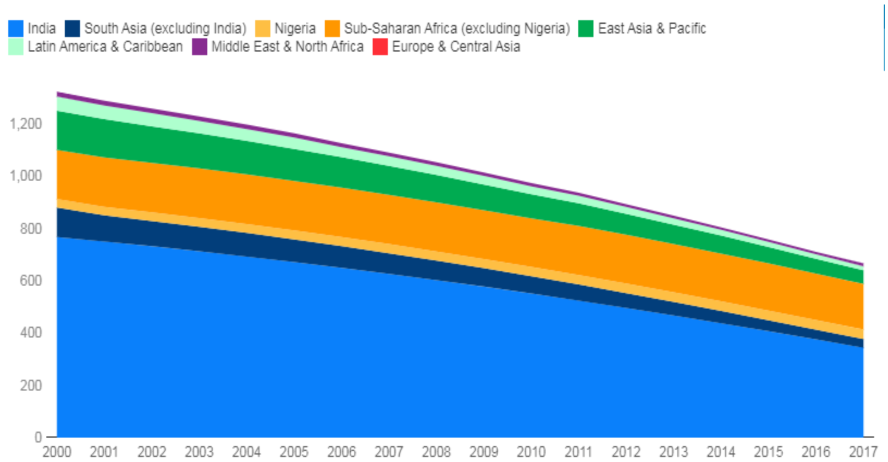

Figure 1. 3 People practicing open defecation

(Source: WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene; WDI (SH.STA.ODFC.ZS))

Therefore, 2015 United Nation's (UN) Sustainable Development Goal (SDG) 6 for 2030 aims to achieve equitable access to safely managed water and adequate sanitation for all and end open defecation. In order to achieve the SDG 6 goal in 2030, several countries build millions of toilets all around the world, (e.g. India) and many of them faced with some failures and difficulties. Developing and building sanitation facilities are not always easy normally, since it involves two part: before sanitation (water) and after sanitation (sewage treatment) (figure 1.4). Normal flush toilet needs to use water and has higher cost to build and energy to connect with the wastewater treatment plant. It also has concerned about transporting or leakage into soil, which can rise the environmental pollution in residential area as well in recipient surface waters and ground water that can lead to transmissions of diseases. Since 2000, the Joint Monitoring Program (WHO/UNICEF) of the Millennium Development Goals (MDG) has consistently reported that the share of the population in low-and middle-income countries that use pit latrines, septic tanks, and systems termed as 'unimproved' sanitation facilities is growing (Doulaye Kone, 2014).

Decentralized systems or treatment at source are the only ways ahead, considering the population load and the never-ending demand for scaling up centralized sewage systems. This might happen in the distant future, as acceptance would take time.

Figure 1. 4 General Sanitation Service Chain

1.1.2 Urine-diverting dry toilet (UDDT)

WHO (2006) suggested lower cost options such as On-site Sanitation Systems including Ventilated-Improved Pit (VIP), septic systems, dry toilets and composting toilets which require little or no use of water for conveyance of wastes and less mechanically intensive sanitation technologies systems since they are disconnect from water supply system and wastewater infrastructure. These decentralized systems are a lower cost option and offer greater opportunity for localized resource recovery of energy, water, and nutrients (WWDR, 2017) than the traditional and large centralized systems,. Generally, there are two types of dry or composting toilets system: source separating/urine-diverting dry toilet (UDDT) and mixed latrine microbial composting toilet (Figure 1.5). The separate collection of feces and urine in UDDT has many advantages, such as odor-free set-up, pathogen reduction and sustainable utilizing nutrients by composting, no artificial chemical addition, no or limited residue. It also provides social benefits since composted feces and urine collected from UDDTs can be used in farming as a soil amendment and nutrient-rich fertilizer. Therefore, UDDT is an example of a technology to achieve a sustainable sanitation system, which is an alternative to pit latrines and flush toilets, especially where water is scarce, a connection to a sewer system and centralized wastewater treatment plant is not feasible or desired.

Cover material or additive such as soil, lime, sawdust, etc., is needed to spread on the feces after each defecation or collecting phase in order to keep flies away, reduce the odor and effect conditions of moisture, pH, temperature, nutrients and others which impact on the rate of inactivation of pathogens in feces (Esrey et al., 1998, Niwagaba et.al., 2009). Controlling the pathogen risk is an important issue to deliberate in UDDT. The use of UDDT and safety guidelines have been publish and the use of end-products should be free of pathogens (WHO, 2006, 2018). Thus, cover materials or additives are the essential for the dry toilet not only to cover the feces but also to inoculate them with beneficial soil microbes.

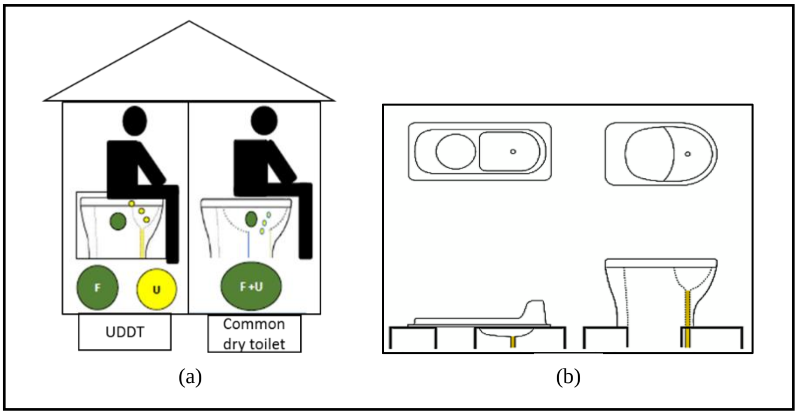

Figure 1. 5 Diagram of dry toilet

(a) Difference between UDDT and common dry toilet, (b) Schematic of the Urine Diverting Dry Toilet (UDDT) "Source: Tilley et al. (2014)"

1.1.3 Human feces

Despite the fact that human feces is natural soil conditioner because of its components (nitrogen and phosphorus) (Table 1.1), treatment needs to be done before the end use of the final products and for safety aspects of both human and environment since it contains pathogens as well. The main intentions of feces treatment are reduction of pathogen content, stabilization of organic matter and nutrients recovery. Before discharging treated back to the environment or used in the agricultural field, it is important to make sure that the pathogens content needs to be below the allowance limit of the National/International standard (WHO, 2006).

Table 1. 1 Characteristics of human feces (Source: Funamizu, 2019)

Parameter	Average Content	Production per capital per day
Moisture	81.8%	106 g
TS	18.2%	24 g
VS	84.4%	20 g
pH	7.5	-
NH_3-N	3.4 mg/g	82 mg
TN	60.1 mg/g	1.44g
NO_3-N	0.03 mg/g	0.7 mg
PO_4-P	4.5 mg/g	108 mg
COD	1.45mgO2/mg	35g O_2

1.1.4 Role of additives in composting human feces

Composting is a bio-oxidative process that lead to organic matter mineralization and transformation (Zucconi and de Bertoldi 1987). Microorganisms oxidize organic compounds under aerobic conditions by producing carbon dioxide, ammonia, volatile compounds and heat. Composting is used to treat manures, green wastes and municipal solid wastes (Goyal et al. 2005).

Environment conditions such as water content, temperature, carbon and nitrogen content, pH, particle sizes, etc., have effects on the composting process. Those factors depend on the formulation of the compost mix (Bernal 2009).

Thus, other external materials are necessary to enhance the composting process. Materials such as soil, ash, leaves, rice husk, etc. have been used to sprinkle on the human manure to keep away flies also to reduce the odors after defecation since ancient time. Afterward, it found out that the additives help to get the better environmental conditions, which have impact on the rate of inactivation of pathogens in human manure (Austin 2008). Therefore, additives are the important material to operate and manage the composting process.

Controlling compost parameter and influencing them with additives have major impacts to compost qualities and environmental impacts of composting, such as reduction pathogen rate, producing of greenhouse gases and other volatile compounds: NH3, Sulphur-containing compounds and volatile organic compounds.(Maulini D. et al., 2014). Normally, several additives such as rice husk, rice straw, sawdust, wood ash, etc., are used depending on the availably materials in the neighborhoods.

There are various amounts of studies focused on examination the effect of different additives in composting processes of animals manures, food wastes and sludge while less researches on the composting of human feces with natural base additives for the source-separated toilets have been showed (Barthod et al., 2018). Thus, this thesis investigates the effects of ash and rice straw additives during composing process of human feces with different ratios.

1.2 Objectives

This study focus on the effect of the local additives on the composting process by mixing with human manure. Thus, the objectives of the research are to:

1. To investigate the effect of ash on composting for human feces with different mixing ratios.
    - Reduce E.coli content in a short time
2. To investigate the effect of rice straw on composting for human feces with different mixing ratios.
    - Stabilize the organic matter
3. Combine mixing of rice straw and ash to reduce the treatment time

    -the addition of

    - Rice straw for organic matter stabilization
    - Ash for pathogen reduction at the same time.

1.3 Dissertation structure

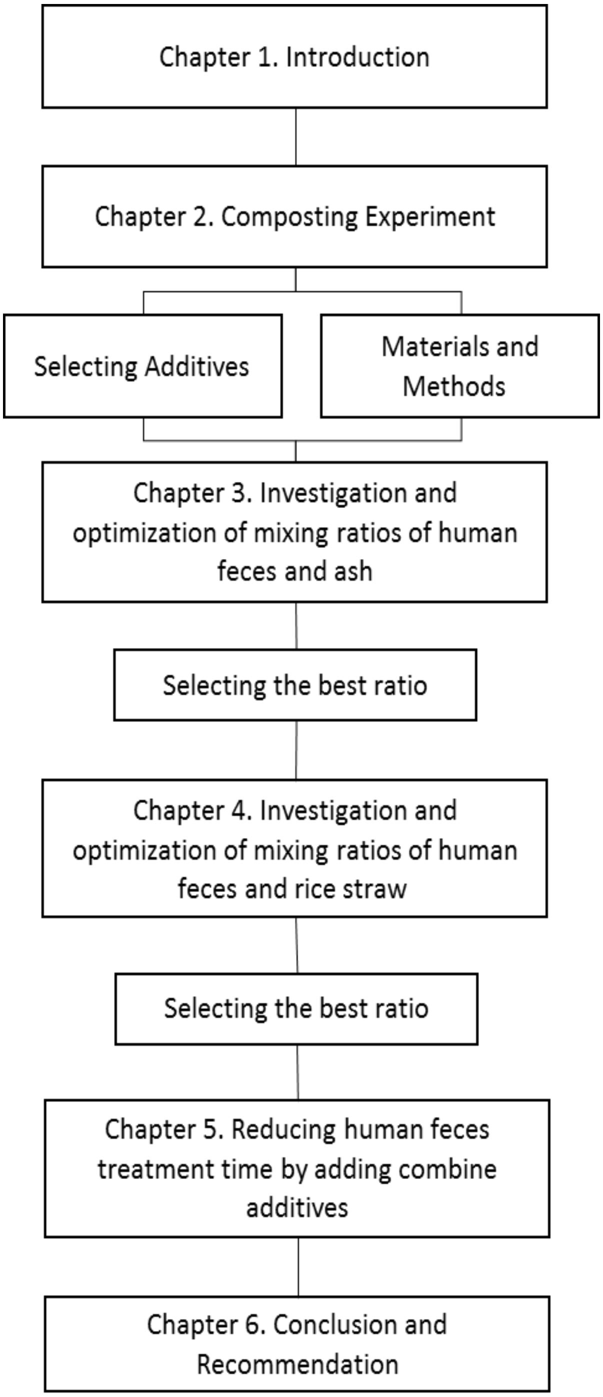

Figure 1. 6 Dissertation Structure

Chapter 1 contains general information about current global sanitation urine-diverting dry toilet (UDDT), role of additives in composting human feces, objectives and structure of dissertation. Chapter 2 is about the selection of additives, materials and methods of all the experiments, which were conducted. Chapter 3 indicates the experiment results of optimization of mixing ratios of human feces and ash, which conducted to have best optimum amount of ash need to add in order to reduce the pathogen content. Chapter 4 investigate the optimization of mixing ratios of human feces and rice straw to have better effect on stabilization of the organic matter . In chapeter 5, the best optimum ratios of ash and rice straw, got from the previous two experiments, were mixed together with human feces to reduce the treatment time. Final chapter 6 is the conclusion of this study and recommendation for future study.

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Chapter 2: Choosing Additives and Composting Experiment

2.1 Choosing additives

Depending on the materials that are use, some of them may only act on the physical structure of the compost, aeration, but most of the time, they have effects on other composting parameters by reducing leaching, gas emissions, improving organic matter degradation, nutrient content and availability in the final products (Barthod J., et al., 2018). Various substrates might be added to waste during the composting process which can be organic, mineral, biological or a mixture of substrates.

Mineral additives: lime, clay, wood ash, fly ash, are said to be effectives in activation of pathogens in human feces due to their alkaline nature. The alkaline materials increase the pH 10, a sanitizing level, where pathogen destroyed (Laboy-Nieves, E.N., et al. 2009). Other advantages of alkaline materials are their high availability and their low cost as industrial wastes or cooking wastes. Wood ash has been testified in research studies in China, Vietnam, South Africa and other countries to be effective in raising the pH of feces to sanitizing levels for pathogen die off. However, all the studies were lacked to perform on human raw feces for on-site sanitation treatment purposed. Information on the optimum amount of ash required to add in order to increase pH of feces and pathogen die off rate need to be performed (Isaac M., 2016). Thus, in this study, ash was chosen as a one of the additives.

Organic additives, such as residual straw, grass clippings, crushed hardwood materials, sawdust, cornstalk, rice straw and rice husk, can get easily in the rural area and agriculture fields since they have many several products. On the other hand, the lack of cost-effective technologies and inappropriate disposal (burning larger amount of rice straw, corn stalk and other agricultural wastes) caused the environmental pollution (Li Xiujin, et al., 2008). Many developing countries depends on the agricultural industry and using organic additives in the composing process can be one of the effective ways to decrease the environmental pollution and the end-products can be reuse as soil conditioner. Organic additives mostly help to ensure organic matter degradation and prevent N leaching during composting (Doublet et al.2011). Regrading to those reasons, rice straw was used as another additives in this study.

2.2 Materials and Methods

2.2.1 Materials preparation

Fresh samples of source separated human manure were collected from the feces tank of ROS system in Building 35, Seoul National University, Republic of Korea. Ash, obtained after burning woods, was received from "Supsok Hanbang Land" (75-5, Bonwonsa-gil, Sodaemun-gu, Seoul) and cool down at the room temperature. Rice straw was provided by an urban farming center which located in Nowon district, Seoul (37 38'47"N 127 5'8"E). It was sieved to 2mm after drying at the room temperature. The samples for experiments were prepared by mixing human feces with two additives according to chosen v/v ratios.

2.2.1 Composting experiment design

Three different experiments: Feces and Ash, Feces and Rice Straw, Feces and combine mixing additives, were done. Composting process of feces and ash was monitored for 1 month with 3 different v/v feces and ash ratios (1:1, 1:3 and 1:5) and raw manure. Feces and rice straw ratios (1:0.5, 1:1, 1:2) were selected for second experiment. The mixtures were put into 7.5L composting plastic buckets separately.To maintain the aeration condition during composting process several 2mm holes made around the container. Three samples of (feces-ash), three samples of feces: rice straw, one sample of Feces: RS: Ash and raw samples were labeled as A1, A2, A 3, S1, S2, S3, F+RS+A and Raw respectively (figure 2.1,2.2 and 2.3). New raw samples of feces were made alongside with other samples. Experiment for feces and ash ratios were performed first, followed by feces and rice straw ratios. After getting the best composting ratios from two pervious experiments, the last part, feces with combine mixing additives and feces was implemented. Composting piles of first experiment were turned over once a week and samples for analysis were took from the middle the piles to analyze weekly (Table 2.1). For the second experiment, piles were turned over once per two week and samples for analysis were took from the middle the piles to analyze once a week for first 1 month and later, it changed to one time per 2 weeks (Table 2.2). Third experiment was conducted by using same methods with the second experiment but there was no turning during third experiment.

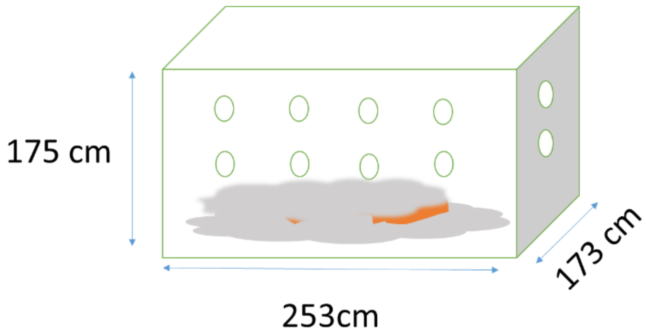

Figure 2. 1 Composting reactor used in this study

Figure 2. 2 Optimizing the addition of ash (feces :ash) (v/v)

Figure 2. 3 Optimizing the addition of ash (feces : rice straw) (v/v)

Table 2. 1 Summary of composting condition for optimizing ash ratios

Items	Value
Additives	Ash
Buckets volume	7.5 L
Mixing ratio (Feces : Ash) (v/v)	1:1, 1:3, 1:5
Monitoring period	2 months
Taking samples	Weekly
Temperature	~25℃

Table 2. 2 Summary of composting condition for optimizing rice straw ratio

Items	Value
Additives	Rice Straw
Buckets volume	7.5 L
Mixing ratio (Feces : Ash) (v/v)	1:0.5, 1:1, 1:2
Monitoring period	3 months
Taking samples	Weekly first one month. Later, one time per 2 weeks.
Temperature	~25℃

2.2.2 Measurement of physio-chemical properties

Physical and chemical properties (i.e temperature, moisture content, total organic carbon (TOC), pH, total dissolved nitrogen, total phosphorus) of raw sample and mixture piles were analyzed weekly. pH of the samples were measure with pH meter (DKK-TOA Portable pH Meter HM-31P) after extracting from 1:10 (w/v) feces soil : distilled water mix (Yadav & Garg, 2009).

Collected samples were air-dried and made them into small powder by using mortar and pestle. Prepared samples were passed through 0.25-mm sieve to measure TOC. TOC was determined by using dry oxidative combustion method, a Shimadzu TOC analyzer with a solid sample module (SSM-5000A; Shimadzu Corp., Kyoto, Japan) was used (Nelson and Somners 1996). Table 3.2 mentioned the summary physicochemical and biological properties of raw materials.

Ammonium-nitrogen (NH_4^+ -N), nitrate-nitrogen (NO_3^- -N) and total soluble nitrogen were measured by the extraction. Sample and distilled water (1:10) (w/v) ratio was mixed by using magnetic stirrer for 2.5 h at 255 rpm. After that, centrifugal separator was used to separate the solid and liquid part of the solution at 14000 rpm for 15 minutes. The liquid part was used for the analysis after filtering through a 45µm membrane. The analysis were determined by using the HUMAS UV/Visible spectrometer, Model HS-3300 (HUMAS, Korea). The concentration of total soluble nitrogen was calculated by following the measured value of dry weight through TS.

Table 2. 3 Physicochemical and biological properties of raw materials

Sample	Organic matter content (%)	Total soluble nitrogen (%)	pH	E.coli
Feces	96 ± 2	2.89 ± 2	8.8	8.5-9
Ash	40.2 ± 2	0.89 ± 2	6.2	nd
Rice Straw	40.2 ± 2	0.89 ± 2	6.2	nd

2.2.3 E.coli analysis

The collected samples were also analyzed for E.coli, an important indicator to evaluate microbial risk (Feachem et al., 1983). Samples from each reactor were weighed 1 g and mixed with 10 ml of distilled water by using magnetic stirrer for 15 minutes at 250 rpm. All the equipment that would be using for this analysis, including distilled water, were autoclaved at 121^{o}C for 15 minutes. A ten-fold dilution series of faeces: distilled water were prepared and from which 0.1 ml aliquot was spread onto the M-TEC ChromoSelect Agar (Sigma-Aldrich) surface. After that, all the plates were incubated for 2 h at 37^{o}C, before moving them to another incubator with the temperature of 46^{o}C for 22 ± 2 h. The numbers of E.coli were showed as log10 colony forming unit per g of dry weight sample (log 10 cfu/ g dry weight).

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Chapter 3: Investigation and optimization of mixing ratios of human feces and ash

3.1 Results and discussion

3.1.1 pH

Compost quality was determined by its physical, chemical and biological characteristics. Since some of these characteristics are somewhat subjective, there is no set method of determining compost quality. The degree of the compost quality depend on the use of the end use and sensitivity of that end use. Physical characteristics used to determine compost quality are particle size, texture, appearance and absence of non-compostable debris.

The results in Fig (2.2) indicate the alterations of pH in different ratios of feces and ash. The pattern of pH variation was different in the raw which had no ash add to the feces and it had least increments in pH and highest pH reduction compare to three other experiments. The initial pH of the raw sample was 8.8 and later declined to 7.9 at the end of the period. Meanwhile, the changes in pH of three ratios were virtually similar which constantly increased during the composting period. The values of pH from A1, A2 and A3 steadily increased from 9.56 to 10.8, from 9.9 to 10.9 and from 10.5 to 11.28 respectively. The highest pH value 11.28 was achieved from A3 (F:A=1:5) after 56 days. This was due to the alkaline nature of ash that implied to get a higher pH during a short time compare to other additives (Schonning C. et al., 2004) This showed that a higher ash dosage resulted in a higher pH (Pescon et al., 2007) although differences of final pH among three reactors were not very high. The slow increase in pH, regardless of high ash dosage, was may be due to the acid formation phase of the composting process, which also counteracted at the high pH (Mohee R. et al., 2015). Nonetheless, the pH values from A1, A2 and A3 reached the pH requirement for pathogen destruction (pH >10) (WHO 2006).

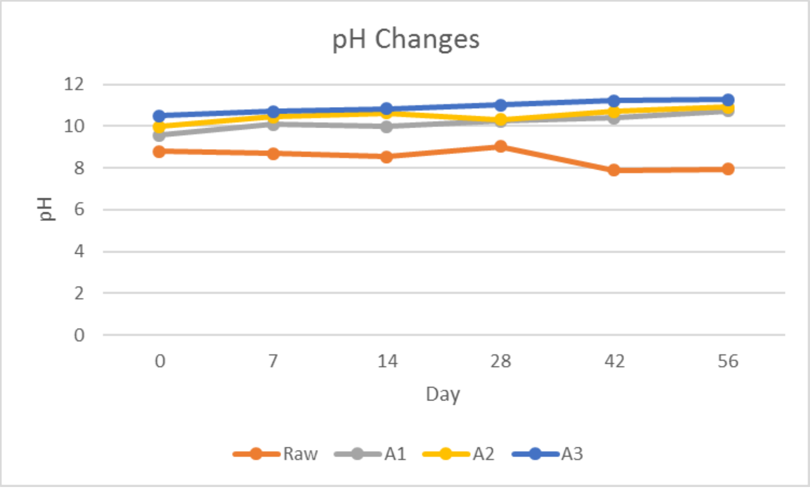

Figure 3. 1 Changing of pH during composting period with different ratios of feces and ash

3.1.2 E.coli die off

The changes of E.coli during composting process from three different ratios were showed in Figure 3.2. Compare to the raw sample, the concentration of E.coli from the matrixes decrease significantly since first week of the experiment period. This showed that using ash as an additive can improve the E.coli die off significantly. Even after 14 days, E.coli continuously decreased in all experiment. Despite the different amounts that added in the feces, the reduction rate of the E.coli in were almost similar. A3 achieved the target E.coli concentration after 14 days, followed by A3 and A2 after 20 and 28 days respectively. E.coli in A3 and A1 decreased by 3.5 log10 cfu/g while A2 decreased by 4 log10 cfu/g. After 28 days, the concentration of E.coli in all samples met the guideline of WHO (2006). E.coli was not detected in 3 buckets after 2 months. The rapid reduced of E.coli content is due to high pH of ash, low moisture content and also probably rapid die-off while microorganisms still adapt and thus more of the organisms come into contact with ash (Niwagaba et al., 2009). At the end of experimental period, A1 and A3 had same higher E.coli reduction rate than A2. Therefore, A1 (1:1) ratio is assume as an optimum amount of ash for E.coli die off.

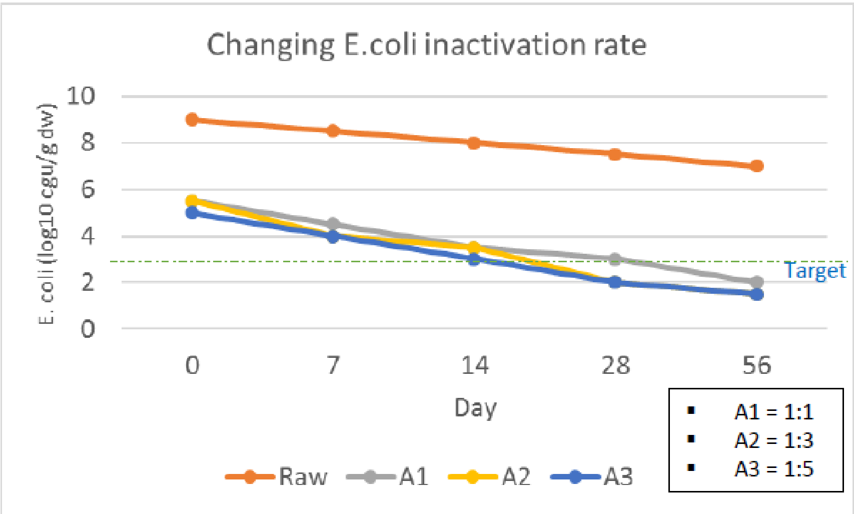

Figure 3. 2 Changing E.coli inactivation rate during decomposition

3.1.3 Total organic matter reduction

TOC reduction or mass balance and carbon dioxide emission can be use as indicator of the estimation of organic matter decomposition during composting. In this study, the decomposition of organic matter was described with TOC reduction content. TOC content in all samples decrease very slowly.

Ash has high moisture absorption that cause to decrease in moisture content which has effect on decomposing rate. High pH also slower the microbial activity to break down the organic matter. Among all the sample, A3 has lowest TOC content (22% dw) which was slowly decrease from (26% dw) and A2 decreased from (27% dw) to (22% dw) after 56 days. Highest TOC reduction was occurred from A1 TOC, it decreased from (36% dw) to (27 % dw) at the end of the experiment. Therefore, A1 (1:1) ratio is assume as best amount to add to get higher decomposition rate of organic matter.

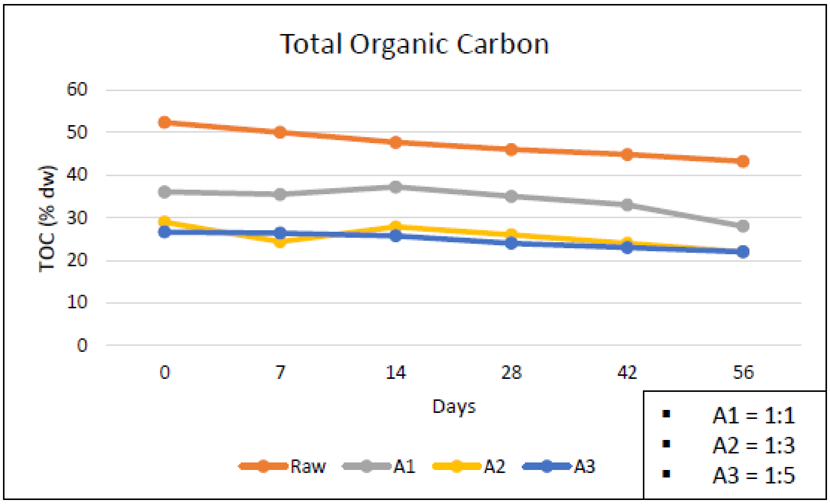

Figure 3. 3 Changing TOC content during composition

3.2 Summary

The results from this chapter showed the optimization mixing ratios of human feces and ash effect on pH, E.coli. die off and TOC content. Feces and ash ratio 1:1 (v/v) had the better results compare to other two ratios. It reached pH >10 for sanitization level even after the experiment period and reduced the E.coli concentration level to meet the guideline of WHO (2006) while maintaining the highest decomposition rate. Thus 1:1 presented the most effective for overall feces treatment with ash.

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Chapter 4: Investigation and optimization of mixing ratios of human feces and rice straw

4.1Results and discussion

4.1.1 pH

Figure 3.1 showed the variation of pH which occurred during compositing of three different ratios (F:RS) and raw feces. The pH of the compost piles showed a gradual change from neutral to alkaline conditions at the beginning of the composting period which later decrease during degradation process. Although the different ratios of feces and rice straw, overall pH changes from S1, S2 and S3 were not very high. The initial values of Raw, S1, S2 and S3 were 8.83, 8.56, 8.61 and 8.71 respectively. The maximum pH 9.03 was obtained from S2 on the 14^{th} day followed by 9.01 from S1 on the 42^{nd} day. Increasing in pH was the result from the degradation of acids along with organic matter through enhanced biological activity. After one month, pH from Raw, S1, S2 and S3 were decreased to 7.73, 7.83, 7.71 and 7.65 respectively. This decrease result was from the formation of organic acids and volatilization of ammonia (Chen and Inbar, 1993). As composting proceeds, the organic acids became neutralize and mature animal composts tend towards a neutral pH 7. Thus, S3 (1:2) showed the good result in changing pH compared to other two ratios.

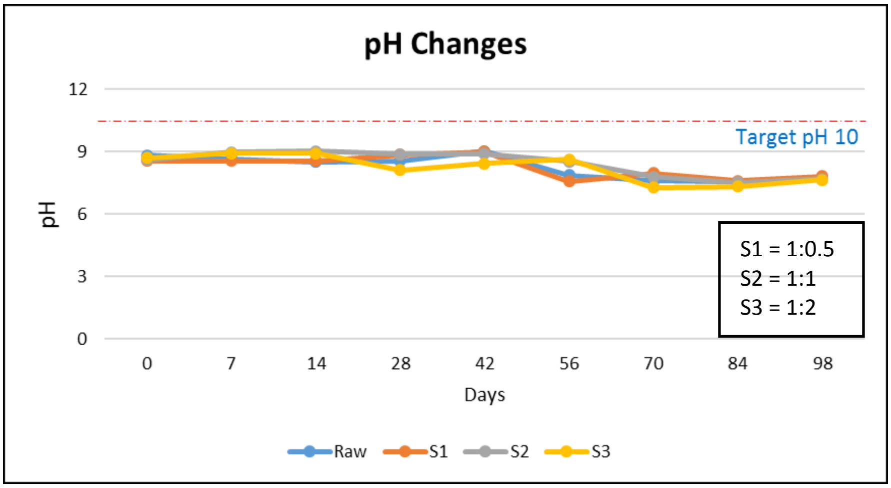

Figure 4. 1 Changing of pH during composting period with different ratios of feces and rice straw

4.1.2 Changes in NH4+/NO3-

Changes in NH4+/NO3- of matrixes where showed in figure 4.2. As displayed in results, raw sample had higher NH4+/NO3- ratio than other three experiments. The initial concentration of NH4+ was higher than NO3-. NH4+/NO3- decreased significantly throughout the composting process in all mixtures. This was due to the NH4+ content combined with high pH during experiment period that caused the loss of NH4+ through NH3 gas. Formation of NO3- through nitrification may also effect the reducing the ratio. NH4+/NO3- ratio decreased rapidly during 28 days in S3 and reach the ratio 1 in 70 days compare to S1 and S3. It can be assumed that more amount of rice straw help to increase the reduction rate of NH4+/NO3- ratio. Nitrification mainly occurred during the stable stage of the compost (Bernal et al., 1998). Generally the ratios of less than or equal 1 were considered indicative of mature compost (Pare et al., 1998 : Ko H.J et al, 2008).

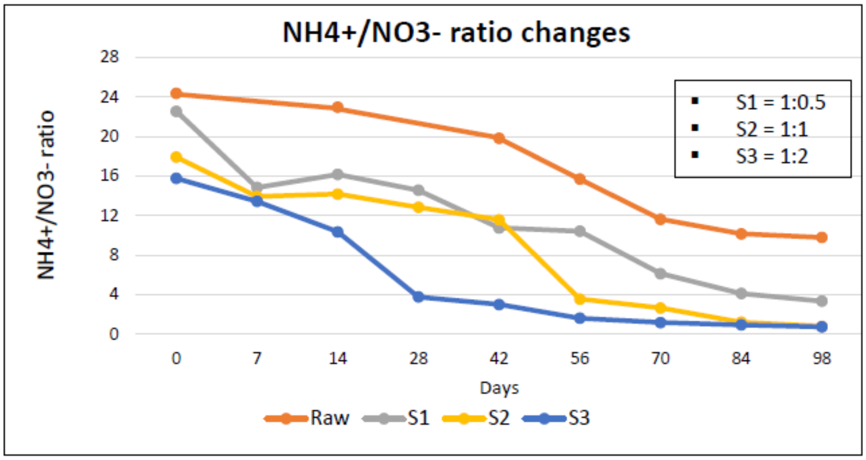

Figure 4. 2 Changing of NH4+/NO3-ratio during composting time

4.1.3 Changes in Soluble TN

Changes in soluble TN of matrixes where showed in figure 4.3. As displayed in results, Compare to initial states, the decrease of soluble TN in all samples were highly significant. Loss of nitrogen during composting process is a natural process which caused by decomposition and transformation of nitrogen to loss through ammonium evaporation or denitrification process. The highest amount of soluble TN was occoured in S3 at the end of the composting period compare to S1 and S3. Thus, it showed the 1:2 ratio of rice straw could reduce the loss of nitrogen during composting process and limiting N losses by volatilization (Doublet et al., 2011).

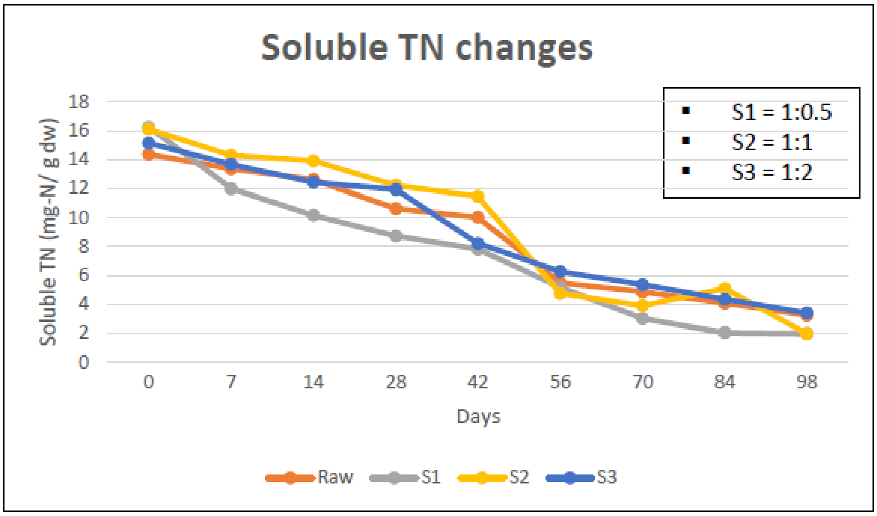

Figure 4. 3 Changing of Soluble TN during composting time

4.1.4 E.coli die off

The changes of E.coli during composting process from three different ratios were showed in Figure 4.4. Compare to the raw sample, the concentration of E.coli from the matrixes decrease since first week of the experiment period. This showed that using rice straw as an additive can improve the E.coli die off. After 56 days, E.coli continuously decreased significantly in all experiment. Despite the different amounts of rice straw that added in the feces, the reduction rate of the E.coli in were almost similar in S2 and S3, reduced by 4 log10 cfu/g. They achieved the target E.coli concentration after 84 days, while S1 did not reach the target rate the concentration of E.coli in all samples met the guideline of WHO (2006). E.coli was not detected in S2 and S3 after 3 months. The slow reduced of E.coli content is due to the lack of high pH and temperature. Therefore, S3 (1:2) ratio is assume as an optimum amount of rice straw for E.coli die off.

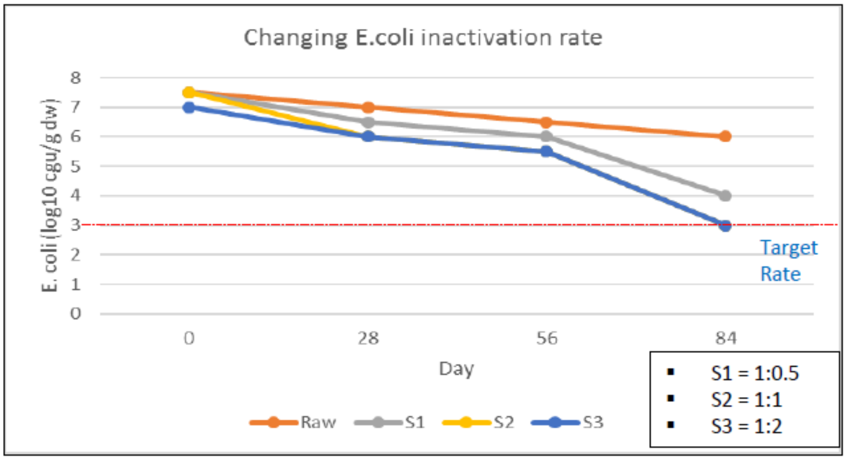

Figure 4. 4 Changing E.coli inactivation rate during decomposition

4.1.5 Total organic matter reduction

Figure 4.4 showed the organic matter changing during decomposition. TOC decrease in all sample steadily throughout the composting process. Highest reduction of TOC content was occurred in S3 that reduced from 51% to 22%. Meanwhile,S1 and S2 reduced 22% and 25% respectively. The decrease in TOC is related to microbial respiration and amount of carbon dioxide released which depends on the rate of mineralization through microbial activities and thus, large amount of TOC decreasing is corresponding with the higher rate of decomposition by microbial activities. The carbon available in rice straw helps and air void help the microorganism to increase.

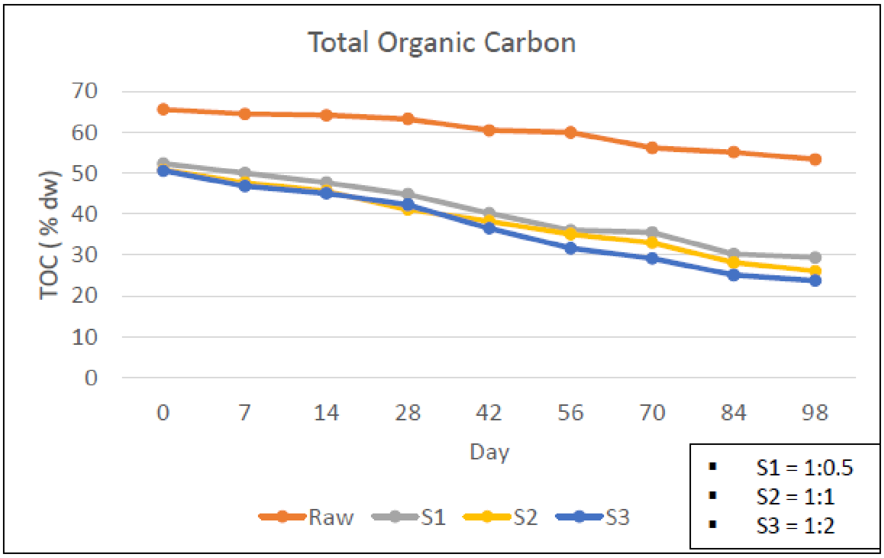

Figure 4. 5 Changing TOC content during composition

4.2 Summary

The results from this chapter showed the optimization mixing ratios of human feces and rice straw effect on, physicochemical changes and E.coli. die off. Among three ratio Feces and rice straw, ratio 1:2 (v/v) had the better results for decomposition of organic matter, recovering soluble TN and reducing E.coli content. Thus 1:2 presented the most effective for overall feces treatment with rice straw.

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Chapter 5: Reducing human feces treatment time by adding combine additives

5.1 Introduction

After conducting the experiments to get the optimum amount of additives: ash and rice straw, that need to be added in the composting process of human feces, the experiment of adding combine additives was performed. Table 5.1 showed the summary of composting condition with combine additives. Compost ration of Feces: Ash : Rice Straw (1:1:2) was made to have better physicochemical properties and pathogen reduction rate compare to previous results since adding one only additive is cannot be effective for overall process.

Table 5. 1 Summary of composting condition with combine additives

Items	Value
Additives	Ash and Rice Straw
Buckets volume	7.5 L
Mixing ratio (Feces : Ash: RS) (v/v)	1:1:2
Monitoring period	2 months
Taking samples	Weekly first one month. Later, one time per 2 weeks.
Temperature	~25℃

5.2. Composting experiment design and Physio-chemical analysis.

The composting design and physicochemical parameters were made and analyzed as described in chapter 2.

5.3 Result and discussion

5.3.1 pH

Figure 5.1 showed the variation of pH which occurred during compositing of matrix and raw feces. According to the results, pH of mixture is moderately increased during first week which reach to the sanitization pH level 10. Decreasing after two weeks was due to volatile organic acids breakdown by microorganisms under aerobic conditions and the volatilization of ammonia (Chen and Inbar, 1993). As composting proceeds, the organic acids became neutralize and compost pile tend towards pH 8. Parallel to the final pH results from F:A (1:1) 10.8 and F:RS (1:2) 7.65, the result of the final pH for combine additives is at moderate 8, which also reached the sanitization pH level during the composting period. Thus, the end product of the compost did not have high alkalinity compare with the pH from the experiment with ash alone

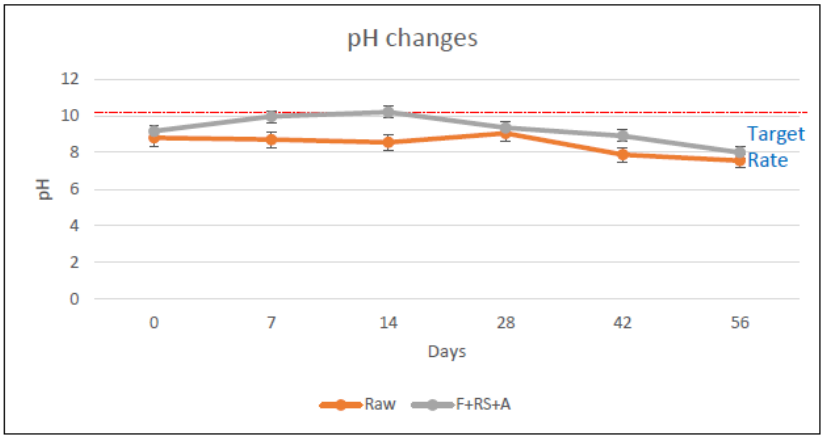

Figure 5. 1 Changing of pH during composting period

5.3.2 Changes in NH4+/NO3-

Changes in NH4+/NO3- of matrixes where showed in figure 5.2. As displayed in results, raw sample had higher NH4+/NO3- ratio than the sample. The initial concentration of NH4+ was higher than NO3-. NH4+/NO3- decreased significantly throughout the composting process in all mixtures. This was due to the NH4+ content combined with high pH during experiment period that caused the loss of NH4+ through NH3 gas. Formation of NO3- through nitrification may also effect the reducing the ratio (Yang et al., 2020). NH4+/NO3- ratio decreased rapidly during 14 days in the sample and reach the ratio 1 in after 2 months. It can be assumed that the additivies help to increase the reduction rate of NH4+/NO3- ratio. Nitrification mainly occurred during the stable stage of the compost (Bernal et al., 1998). Generally the ratios of less than or equal 1 were considered indicative of mature compost (Pare et al., 1998 : Ko H.J et al, 2008). Comparing with the NH4+/NO3- ratio from F:RS (1:2) that achieved 1in the 28 days, the result from this experiment took longer time. This is due to present of ash which inhibited the microbial activity.

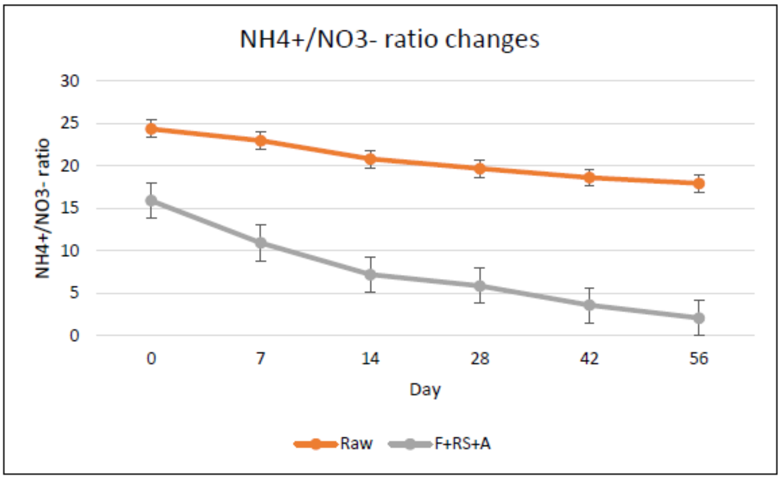

Figure 5. 2 Changing of NH4+/NO3-ratio during composting time

5.3.3 Changes in Soluble TN

Changes in soluble TN of during composting time was showed in figure 5.3. As displayed in results, Compare to initial states, the decrease of soluble TN in all samples were highly significant. Loss of nitrogen during composting process is a natural process which caused associated with ammonia volatilization (Morisaki et al., 1989). Thus, it showed the 1:2 ratio of rice straw could reduce the loss of nitrogen during composting process and limiting N losses by volatilization (Doublet et al., 2011). Comparing with the soluble TN from F:RS (1:2) 3.4 (mg-N/ g dw) , the result from this experiment has higher soluble TN (5.1 mg-N/ g dw). Therefore, it showed that adding combine additives to composting pile was better for soluble TN recovery process.

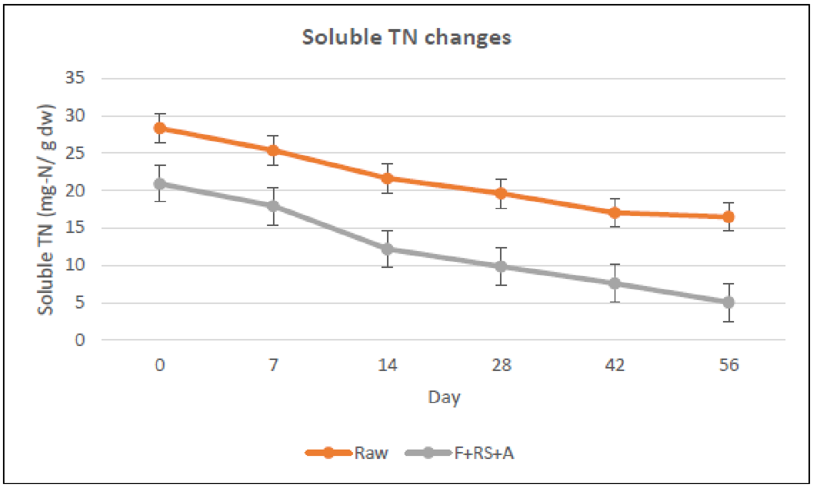

Figure 5. 3 Changing of Soluble TN during composting time

5.3.4 E.coli die off

The E.coli inactivation rate changes during decomposition process was showed at Figure 4. The E.coli content from the mixture of feces and additives significantly decreased since first week of the experiment period compare to the raw sample. This showed that using combine additive can improve the E.coli die off alongside with ash experiment. After 28 days, the E.coli concentration reduced from 7 log10 cfu/g to 3 log10 cfu/g; the target rate of the concentration of E.coli from the guideline of WHO (2006). Therefore, E.coli detection rate was achieved towards the reduction at the end of experimental period. There was no detection of E.coli after 56 days. This result was same with the results from feces and ash ratio which achieved the target rate of the E.coli content after 28 days and faster than the results from feces and rice straw ratio. Therefore, it can be said that mixture of feces and additives had same effect on pathogen reduction with feces and ash ratios.

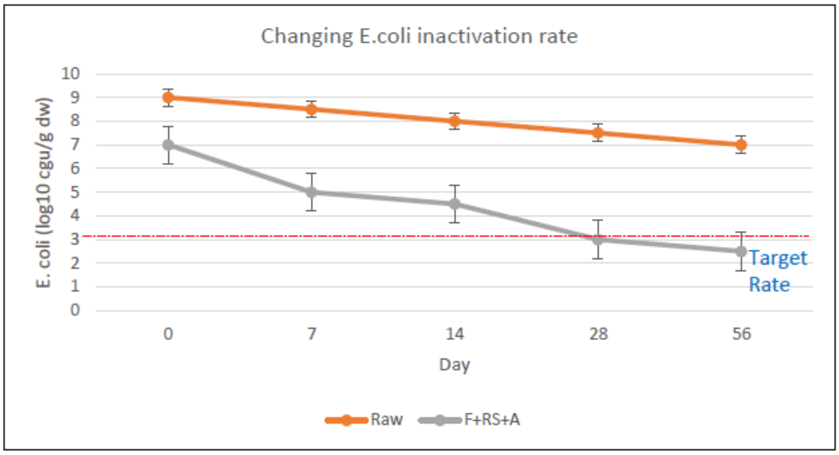

Figure 5. 4 Changing E.coli inactivation rate during decomposition

5.3.5 Total organic matter reduction

The variation organic matter during decomposition shows in figure 5.4 compared with the raw sample. The trend of organic matter from the mixture of feces:RS:A (1:2:1) shows continuously reduced after one week compared with the raw sample. OM the mixture reduced from 71% to 27% at the end of the composting period. The decomposition of organic matter occur under the operation of microorganism bacteria. The result of combine mixing additives and feces points out that the environment factors such as moisture content, particle size, aerobic condition and pH also effect the decomposition of organic matter. Moreover, the degradation rate of the OM decreased gradually as composting progresses because of the reduction in available carbon sources, and synthesis reactions of new complex and polymerized organic compounds overcome the mineralization during mature phase (Bernal et al., 2009).

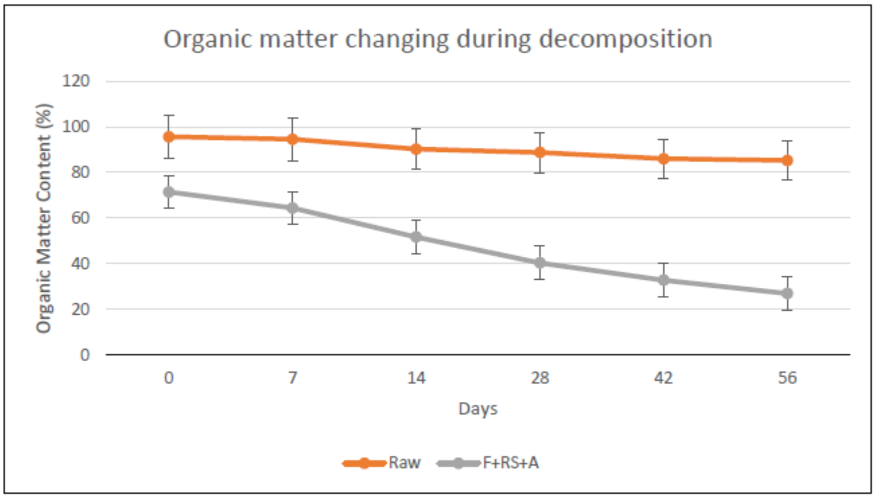

Figure 5. 5 Changing TOC content during composition

5.4 Summary

The results from this chapter showed combine additives effect on, physicochemical changes and E.coli. die off. Mixing the right ratio of feces, rice straw and ash accomplished the improvement in physicochemical parameters, which could not had if only ash or rice straw was used. Despite having rice straw, the reduction amount of E.coli concentration was shorten and same with the time when ash was used (2 months). Therefore human feces treatment time for composting method can be reduce by adding ratio feces: Ash : Rice Straw (1:1:2).

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Chapter 6: Conclusion and Recommendation

6.1 Summary

The composting is a biological process that involves the aerobic decomposition of organic matter to produce a humus-like product called compost. This study is based on the experiment results to make the criteria for good composting to estimate the strength of different additives application for composting toilet. The simulation of composting process was taking place in laboratory with 7.5 L composting bucket with different ratios of feces with ash and rice straw.

Experiments from three different ratios of feces:ash (1:1, 1:3, 1:5), showed that ash is high effect on the reducing of pathogen during short time due to the alkaline nature. The final pH of 3 ratios were 10.8, 10.9 and 11.28. All the samples reached pH >10 for sanitization level even after the experiment period and reduced the E.coli concentration level to meet the guideline of WHO (2006). The highest rate of the decomposition of organic matter was gained from (1:1) ratio. Thus, feces and ash ratio 1:1 (v/v) had the better results compare to other two ratios for overall performance. Using ash as an additive is mainly effective for Pathogen die off.

The results of different ratios with feces and rice straw (1:0.5, 1:1, 1:2) showed that it could enhance the decomposition of organic matter, reduction of nitrogen loss from feces, Among three ratio Feces and rice straw, ratio 1:2 (v/v) had the better results for decomposition of organic matter, recovering soluble TN and reducing E.coli content. It achieve the mature compost after 70 days.

However, it took 84 days to reach the safety level of pathogens concentration. Thus, 1:2 presented the most effective for overall feces treatment with rice straw. It demonstrating that rice straw can be the suitability additive for the operation of composting toilet especially to achieve mature compost.

After getting optimal amount of additives, compost ration of Feces: Ash: Rice Straw (1:1:2) was conducted. The reduction amount of E.coli concentration was shorten and same with the time when ash was used (2 months) as well as mature compost was obtained. Recovery soluble TN was higher than previous experiment. Therefore, the ratio feces: Ash : Rice Straw (1:1:2) can help to obtain pathogen free mature compost from household UDDT in a short time where cannot achieve high temperature.

6.2 Recommendation

All the experiments were performed with lab scales in non-artificial environment during cold seasons. The temperature of the samples were not higher 45C, even after rice straw was added. Environment conditions also affected the results of the experiment such as temperature and moisture. Many researches shown that microbial activities are better at when the temperature is over 60C. Thus, more study about reactor designs to raise the temperature of the compost bin for small-scale compost are needed. It would be better if large scale is performed with the optimum ratios of feces, ash and rice straw that got from this research. The stability and maturity of the compost cannot be established by a single parameter. Carbon and nitrogen is known as the one of the factors in composting which should be around 20:1. However, it was not investigated in this research Several indices based on chemical and stability parameters need to be compared for further use of end products from human excrete composting. For the future studies, testing Nonetheless, it is necessary to meet the official standard criteria from different countries.

국문초록

인분 퇴비화에 대한 첨가제의 역할

이 연구는 인분에 있어 분변 분리형 건식 화장실(UDDT)로부터의 소규모 현지 인분 처리를 위한 퇴비화 조건 향상에 대한 첨가제의 역할을 보여준다. 첨가제는 질소 손실을 줄이고 유기물질의 분해를 줄이면서, 병원균 제거 효율에 있어 중요한 역할을 한다. 첨가제의 성분과 사용하는 양에 따라 효과는 다르다. 그러한 목적으로 재와 볏짚의 2가지 첨가제가 선정이 되었고, 이들은 현지 지역, 특히 시골 및 농경지에서 쉽게 구할 수 있다. 모든 실험은 실험실 규모로 진행이 되었다.

변과 재는 퇴비화 과정 및 생성물에 보다 나은 효과를 줄 수 있는 최적의 양을 선정하기 위하여 3가지 비율(1:1, 1:3, 1:5)로 혼합이 되었다. pH, 유기물질 함량 또는 총 유기탄소 함량이 주로 측정이 되었으며, E.Coli 농도 변화가 실험 과정에서 측정이 되었다. 최대 pH 11.28이 1:3 비율 조건에서 얻어졌으며, 이 조건에서 유기물질의 감소율은 매우 낮았다. 1:1(v/v) 조건은 pH 10.8의 결과값을 보였으며, pH>10을 멸균 조건에서 실험 기간 이후에도 계속적으로 유지하였다. E.Coli 농도는 WHO기준(2006)을 만족하며 가장 높은 분해율을 보였다. 그래서 1:1 비율이 재를 이용한 전체 변 처리에서 가장 효과적인 것으로 보인다.

유기물질의 안정화를 위하여, 각각 다른 비율(1:0.5, 1:1, 1:2)의 변과 볏짚 혼합물이 조사되었다. 3가지 비율의 변과 볏짚 중, 1:2(v/v) 비율에서 총유기탄소 비율을 51%에서 22%으로 줄였으며, 유기물질 분해에 더 나은 결과를 보였다. 이 조건은 또한 용해성 총 질소의

회수율이 가장 높았으며 E.Coli 제거율이 가장 높았다. 이 조건은 70일 이후에 숙성된 퇴비화 작업이 마쳐졌다. 하지만, 병원균 농도를 안정적으로 맞추는데 있어서는 84일이 소요되었다. 그럼에도 불구하고, 1:2 비율이 볏짚을 이용한 변의 전반적인 처리에 가장 효과적인 것을 확인하였다.

짧은 시간 내에 병원균이 없는 숙성된 퇴비를 얻기 위해서, 2개의 첨가제가 다음의 최적 비율로 변과 혼합이 되었다: F:Ash:RS (1:1:2). 볏짚과 재를 섞은 결과는 하나의 첨가제만을 사용한 것과 비교하였을 때 더 나은 결과를 보였다. 이것은 볏짚을 이용한 유기물질의 안정화와 재를 이용한 병원균 저감이 동시에 일어났기 때문으로 사료된다. 그러므로 건식 화장실에 있어서 1:1:2 비율의 변, 재, 볏짚의 비율이 병원균이 없는 숙성된 퇴비를 만드는데 가장 최적이다.

키워드: 퇴비화; 재; 볏짚; 대장균 저감; pH; 유기물질 분해; 질소 저감; 처리시간

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