MAKERERE UNIVERSITY

COLLEGE OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES

SCHOOL OF FOOD TECHNOLOGY NUTRITION AND BIO-ENGINEERING

DEPARTMENT OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING

ANAEROBIC CO-DIGESTION OF FAECAL SLUDGE AND BANANA PEELS

NAKIKOOLA BERNA

1900704385

19/U/4385/PS

A RESEARCH REPORT SUBMITTED IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN AGRICULTURAL ENGINEERING AT MAKERERE UNIVERSITY

2023

Declaration

This research report is my original work and has not been presented for a degree in any other university.

Signature: .... Date: 20-07-2023 ....

Name: Nakikoola Berna 19/U/4385/PS

Approval

This report has been submitted for examination with our approval as university supervisors

1. Signature .... Date ....

   Name: Dr. Kizito Simon Savio

   Department of forestry, Environmental and Geographical sciences

   Makerere University

2. Signature .... Date 11-07-2023 ....

   Name: Dr. Peter Tumutegyereize

   Department of Agricultural and Biosystems Engineering

   Makerere University

DEDICATION

I dedicate this research project report to all those who have supported and inspired me throughout this challenging yet rewarding journey. To my family, thank you for your unwavering love, encouragement, and belief in my abilities. Your constant support has been my pillar of strength, and I am grateful for the sacrifices you have made to help me pursue my academic aspirations.

To my supervisors Dr.Kizito Simon Savio and Dr.Tumutegyereize Peter, I am deeply grateful for your guidance, expertise, and invaluable insights. Your dedication to expanding knowledge, your constructive critism and unwavering commitment to excellence have shaped the trajectory of this research. I am privileged to have had the opportunity to learn from you and be guided by your expertise.

ACKNOWLEDGEMENT

I would like to extend my sincere gratitude and appreciation to all those who have contributed to the completion of this research project report.

First and foremost, I extend my deepest thanks to my supervisors Dr. Kizito Simon Savio and Dr.Tumutegyeireize Peter whose guidance, expertise, and unwavering support have been instrumental in shaping the direction and quality of this research. Their valuable insights, constructive feedback, and constant encouragement have been invaluable throughout this journey. I am grateful for their mentorship and the opportunity to learn from their vast knowledge and experience.

I am indebted to Nabbagala Martha , Nagenda John and Tumwesigye Kabateraine my research teammates , whose collaboration ,dedication and shared passion for the subject matter have greatly enriched this study. Their diverse perspectives and contributions have fostered a stimulating environment for intellectual exchange and have undoubtedly influenced the outcome of this research.

I would also like to thank my father Mr. Ssenabulya Julius and my mother Ms. Babirye Josephine for their unwavering support, understanding, and encouragement throughout this research project.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

WWTP -Waste Water Treatment Plant

TS - Total Solids

TVS - Total Volatile Solids

AD - Anaerobic Digestion

BSF -Black Soldier Fly

NH3 - Ammonia

$CO (NH_2)_2$ -Urea

WSPs - Waste Stabilization Ponds

WW -Waste Water

FS -Faecal Sludge

TSS -Total Suspended Solids

BOD -Biochemical Oxygen Demand

CO_2 -Carbon dioxide

H2 -Hydrogen gas

H_2S - Hydrogen Sulphide

VFA - Volatile Fatty Acids

pH -Potential of Hydrogen

C/N -Carbon to Nitrogen ratio

AcoD -Anaerobic co-digestion

MUARIK -Makerere University Agricultural Reaseach Institute Kabanyolo

CoVAB - College of Veterinary Medicine, Animal Resources And BioSecurity

Labs -laboratories

MC - Moisture Content

VS - Volatile Solids

Abstract

The abundance of agricultural wastes produced from banana peels and human waste from households has resulted in the difficulties of disposing of large amounts of waste. Anaerobic digestion is a way to reduce waste and generate renewable energy sources including biogas. In this study, banana peels were co-digested with faecal sludge in batch experiments under ambient temperature at 25±5°C at a working volume of 18 liters in 20 liters reactors. The effects of different substrate mix ratios on methane yields were investigated. The batch study was conducted at 8% VS at three different substrate ratio faecal sludge to banana peels (FS: BP) (1:1, 1:2 and 1:3) and a control (1:0). Overall biogas collection at 1:3 ratio of FS:BP resulted into the highest biogas production of 26 liters, followed by 1:3 ratio (C2) with 930 ml biogas yield. The highest methane yield was achieved with reactor C2 of 1:3 ratio (15.21 CH_4/g VS). In conclusion, the production of methane from pineapple wastes co-digested with cow dung was proven to be a good strategy to minimize solid wastes mainly pineapple waste.

CHAPTER 1: INTRODUCTION

1.1 Background

Generally, each individual creates 0.50 liters of sludge every day (Afifah & Priadi, 2017). Implying that a family of six people produces 3liters of faecal sludge in a day. Worldwide over 2.7 billion people rely on onsite sanitation technologies for example pit latrines, septic tanks and pour-flash latrines for their sanitation needs (Semiyaga et al., 2015). The volume of faecal sludge produced yearly is increasing due to population growth and urbanization. In several urban centers of low-and middle-income countries, less than 50% of the daily produced faecal sludge is collected. The collected faecal sludge is either transported to centralized treatment facilities or disposed off in the surrounding environment (Semiyaga et al., 2015). This presents a major sanitation problem for developing countries due to inadequate and inappropriate faecal sludge treatment (Nsiah-Gyambibi et al., 2021)

Reusing faecal sludge in agriculture as a fertilizer and as a soil amendment is advantageous since it contains high levels of organic carbon and nutrients (Singh et al., 2017). Agriculture is a key component of food production since it helps feed people as the world's population and need for food both expand. Excreta is a readily available, inexpensive fertilizer that contains all the nutrients needed for a crop to grow (Femi, 2013). However, it is an environmental and health threat because it has harmful microbe levels that are 10–100 times greater than those in wastewater (Singh et al., 2017). If excreta is distributed uncontrollably, the number of nutrients and the presence of pathogenic microorganisms may contaminate the soil, plants, surface water, and groundwater. Eutrophication can result from nutrient enrichment in aquatic environments that accelerate the growth of plants and algae, endangering the aquatic ecosystems naturally (Vinnerås & Jönsson, 2002). Humans can contract pathogens through their skin, by drinking water, or by eating contaminated food that has come into contact with feces. Upon introduction to humans, the viruses may transmit deadly illnesses such as diarrhea and cholera (Singh et al., 2017).

In Uganda this becomes a concern when wastewater, whether it has been treated, used for irrigation of crops and sludge for fertilizing or not (Singh et al., 2017). Proper excreta disposal, good cleanliness, public health protection and treatment of faecal sludge to remove possibly hazardous components before reuse is necessary. Studies have demonstrated that during storage of faecal sludge, the detected amount of E. coli, bacteriophages, and Ascaris eggs is decreased by the lime and urea treatment at Lubigi sewage treatment plant. Even the reference drying bed used as a control demonstrated a decrease in pathogens, however not as effectively as when pesticides are used. The treatment process is accelerated by the chemical addition. The findings demonstrate that the length of pre-treatment in the drying beds affects the initial levels of pathogens before chemical addition; the longer the pre-treatment, the lower the level of pathogens discovered.

Faecal sludge can be used as a substrate for biogas production, however in comparison to other substrates, the potential for biogas from faecal sludge is very small ranging from 0.009 to 0.028 m3/kg VS. It may be due to the sludge's low C/N ratio of 7.9, which necessitates the use of other substrates to raise it to the ideal level of 20–30 by using the co-digestion process. Treatment of anaerobic co-digestion can boost stable biogas generation, decrease inhibitor of the primary substrate, improve nutritional balance, and stabilize digestion process. Sludge can be co-digested anaerobically by adding a substrate with a greater C/N ratio, such as banana peels with C/N ratio of 35 (Afifah & Priadi, 2017). Anaerobic codigestion is the process of feeding two or more kinds of organic substrates during anaerobic digestion (Hagos et al., 2017).

The huge banana wastes generated and currently underutilized are rich in organic matter with high moisture content and thus a good substrate for biogas production through anaerobic digestion (Gumisiriza et al., 2019). Based on this context, the study's objectives are to identify the anaerobic co-digestion process that occurs in faecal sludge with banana peels, the variation in sludge concentration that has the greatest potential for biogas production, and a comparison of this process to anaerobic digestion of faecal sludge alone.

1.2 Problem statement

Faecal sludge management is an issue in developing countries where affordable sanitation facilities are not accessible (Singh et al., 2017). However, developing countries have carried out faecal sludge treatment using settling/thickening tanks, unplanted/planted drying beds, co-composting, deep row entrenchment, anaerobic digestion, vermicomposting among others (Pradeep, 2015). In Uganda, the National Water and Sewage Corporation (NWSC) treatment plant in Bugolobi and Lubigi (the major faecal sludge treatment plant in Uganda) co-treats the liquid effluent from the faecal sludge with wastewater in the sedimentation tanks. The liquid effluent is directed from the thickening chamber to the anaerobic pond and the faecal sludge solid directed to the drying beds (Nuwagira, 2021). Farmers typically collect the faecal sludge cake from the Lubigi sewage treatment facility to utilize it as fertilizer because of the declining soil fertility issue in Uganda (Nuwagira, 2021). However, the pathogens, heavy metals, and organic pollutants contained in this faecal sludge cake could harm their farming operations.

It is worth mentioning that more than three million tonnes of banana waste are thought to be produced annually in Uganda as a result of banana industrialization (Tumutegyereize et al., 2011). Unfortunately, the incorrect management of this banana waste results in uncontrolled dumping, composting, and to a lesser extent, animal feeding. Studies show that these practices may have an impact on the spread of the banana bacterial wilt disease (Gumisiriza et al., 2019) . Faecal sludge cake is good for anaerobic digestion because it has a pH that is practically neutral (pH 7.6), according to the data (Agani et al., 2016). .However, despite the fact that anaerobic digestion is often used to stabilize and convert organic wastes into methane and biological fertilizer, when applied to faecal sludge cake, it doesn’t yield good methane due to its high content of nitrogen (Agani et al., 2016). This suggests the need to explore the anaerobic co-digestion process of Faecal Sludge cake with banana peels as well as investigate the suitability of bio-slurry as a crop fertilizer.

1.3 Objectives

1.3.1 Main objective

The main objective of the study was to explore the Anaerobic Co-digestion process of Faecal Sludge with banana peels as well as investigate the suitability of bio-slurry as a crop fertilizer.

1.3.2 Specific objectives

1. To determine physico-chemical characteristics of faecal sludge and banana peels
2. To determine the effect of different co digestion ratios of faecal Sludge cake and banana peels on biogas production
3. To assess the suitability of the digestate in relation to bio fertilization.

1.4 Justification

This study is aimed at optimizing the anaerobic co digestion process of faecal sludge cake with banana peels as well as investigate the suitability of bio-slurry as a crop fertilizer. The results from this study will aid in determining the proper mix ratios for optimal methane gas output and also will aid in assessing the nutrient levels in the faecal sludge cake and banana peels and their suitability for crop growth. This will help farmers by solving the problem of declining soil fertility there by boosting crop productivity. On the other hand it will also help in the proper management of faecal sludge as it will be converted into biogas which is a form of energy for cooking, lighting am

1.5 Hypothesis

- ✓ Co digestion of faecal sludge with banana peels improves methane yield
- ✓ Co digesting faecal sludge and banana peels improves bio fertilizers quality compared to faecal sludge alone.

CHAPTER 2: LITERATURE REVIEW

2.1 Faecal Sludge

Faecal sludge is partly digested excreta that comes from on-site sanitation systems, e.g. pit latrines, septic tanks and dry toilets (Lindberg & Rost, 2018). Faecal Sludge differs in their concentration, consistency and quantity (Strauss, 2002). Based on the stabilization of the biodegradable organic matter faecal sludge is like slurry or semisolid. The characteristics of excreta vary from place to place depending on the dietary habits of people. In order to select the suitable treatment and management based on socio-economic levels, it is important to estimate the quantity and quality of faecal sludge (Pradeep, 2015).

2.1.1 Characteristics of faecal sludge

Faecal Sludge mainly contains very high moisture, pathogens, organic matter, and nutrients. There are also traces of heavy metals contained in faecal sludge. Depending on its source of collection as well as type of toilets used, filling rate of FS, storage duration, frequency of collection, method of collection, inflow and infiltration of leachate and climatic conditions faecal sludge can be characterized. Furthermore, mixing of domestic wastewater especially from kitchen waste seriously hinders the microbial activity due to scum (fat, oil and grease). This microbial activity improves the degradation of organic matter biologically. Faecal sludge characteristics are extrermely varied from unstabilized to stabilized state therefore it is essential to manage its stability.

Table 2- 1 : Characteristics of Faecal Sludge from Different Facilities

Parameter	FS source Public toilet	FS source Septage	WWTP Sludge

pH	1.5 -12.6	-	-
	6.55-9.34	-	-
TS (mg/L)	52,500	12,000	-
	30,000	35,000	-
		22,000	-
		34,106	-
TVS (%TS)	≥ 3.5%	3%	
	68	50-73	
	65	45	
TN (mg/L)	-	190 – 300	-
	-	-	32-250
$NH_{4-}N$	3,300	150 – 1,200	-
(mg/L)	2,000	400	2-168
	2,000 -5, 000	1.000	30-70
TP (mgP/L)	450	150	09 -063

(Charles et al., 2014)

2.2 Faecal sludge Pretreatment

2.2.1 Screening and grit removal

Faecal sludge for example wastewater goes through separate screening and grit removal units. Bar screens are placed where the influent comes in from (Strande & Brdjanovic, 2014) The bar screens at the influent remove municipal solid waste and large solids from both the faecal sludge and wastewater that helps in prevention of clogging and pump failures. In order to make a physical barrier that retains the coarse solids and let the liquid go through, bar screens are either placed vertically or inclined against the incoming flow. After going through both the coarse and fine screens, then they go through the grit chamber that helps in the removal of grit. According to (Tayler, 2018), faecal sludge contains a high concentration of grit. This high content in grit content increases the rate at which sludge accumulates in the ponds and may also damage the mechanical equipment.

2.2.2 Settling-thickening Tank

To separate the solids from the liquid flow faecal sludge is then forwarded into the sedimentation tank. Scraper mechanism is used to push sludge that settles along the length of the tank back to the sump to ensure proper flow in the sedimentation tanks (Tayler, 2018). Solidified faecal sludge is sent to thickening chamber and then to the drying beds at the Lubigi sewage treatment plant. The liquid effluent is then connected to the influent wastewater into the anaerobic pond. The efficiency of settling-thickening tanks with respect to removal of total suspended solids (TSS) can reach up to 80% where the tanks have been adequately designed and operated (Strande & Brdjanovic, 2014).

2.3 Wastewater and faecal sludge parameters

2.3.1 Solids

The solids in the mixture of wastewater effluent and liquid effluent can be either organic (volatile) or inorganic (fixed) and can be either suspended (those that are not able to pass through a filter) or dissolved (those that pass through the filter). The suspended solids include floating material, settleable material and colloidal material while the dissolved solids are in solution (Lindberg & Rost, 2018).The size of the solid particles depends on the source of the sludge and the prior treatment. Solids content of the wastewater effluent and liquid effluent will vary, depending on local conditions such as ambient temperatures that are favorable for the bacteria (Doulaye et al., 2004). Treatment mechanisms involve the removal of suspended solids by the sedimentation process. The suspended solids from facultative ponds are approximately 60−90 per cent algae. The algal content that is present in the ponds contributes to relatively high BOD and TSS levels in the effluent compared with other treatment processes. Facultative ponds treating wastewater have reported TSS removal efficiencies of 70–80% (Doulaye et al., 2004).

2.3.3 Nutrients

Mostly nitrogen and phosphorus are the nutrients found in the household faecal and wastewater sludge. The faecal and waste water sludge contain up to 0.7% nitrogen a percentage of wet weight which is about 5 to 11 g per day. Incase these nutrients are released to the environment in an uncontrolled manner, they will cause eutrophication and contamination of the environment (Lindberg & Rost, 2018). To a variety of fish ammonia can be toxic in relatively low concentration. The concentration of nitrogen leaving the preliminary treatment is an important factor in determining the size and the cost of the entire system (Sherwood, 1984). Nitrogen exists in wastewater in different forms which include primarily organic nitrogen, ammonia and nitrate. Nitrogen concentration in typical municipal wastewater ranges from 15 to greater than 50 mg/l. Under favorable conditions, WSPs can achieve up to 80% removal of nitrogen (Sherwood, 1984). Organic nitrogen is hydrolyzed to ammonia in anaerobic ponds after which the ammonia is incorporated into algal biomass in facultative and maturation ponds (Kayombo et al., 2005).

Typical influent wastewater contains a total phosphorous concentration of 5-9 mg/l. Phosphorus exists in various types in wastewater such as orthophosphate, polyphosphate and organically bound phosphates. Total Phosphorus includes soluble and particulate phosphorus. Phosphorous is removed through uptake by algal biomass, precipitation and sedimentation. Increasing the number of maturation ponds is the best way to remove much of the phosphorus (Kayombo et al., 2005). This implies that for efficient removal of phosphorous, more land area is required.

2.3.4 Pathogenic microorganisms

Both untreated and partially treated wastewater as well as liquid faecal sludge discharge always contain pathogens. If some of the produced effluent is recycled, the release of untreated or only partially treated WW into the environment has detrimental impacts. The harmful microorganisms found in feces include bacteria, viruses, protozoa, and helminths (Strande & Brdjanovic, 2014). The concentration of helminth eggs in the biosolids is largely dependent on the prevalence and intensity of infection in the population from which FS or wastewater is collected (Koné et al., 2007). Raw faeces, final effluent, and aquatic habitats are where the pathogens are found (Dias et al., 2018). These pathogenic organisms can make people sick when they come into contact with things like contaminated water or food, which is a worry for everyone throughout the world. Humans may have diarrhea, hepatitis, and fever, among other side effects (Strande & Brdjanovic, 2014).

When wastewater is used for irrigation, these waterborne diseases become an issue because this wastewater can cause the spread of pathogenic microorganisms. Pit latrines that store faeces for several years experience a drop in pathogen volume and concentration over this time. A distinction is often made between high-strength faecal sludge and lower strength septage, with the strength defined in terms of oxygen demand and suspended solids concentration. This distinction is qualitative, rather than quantitative, and should not obscure the fact that both faecal sludge and septage exert a high oxygen demand, have high solids content, and contain large numbers of pathogens (Tayler, 2018).

2.4 Sludge treatment methods

2.4.1 Physical sludge treatment

Dewatering is an important physical treatment mechanism where liquid and solid phases are separated when treating faecal sludge. The mass of the sludge is reduced by watering faecal sludge which is beneficial prior to transport and further treatment, such as composting for resource recovery. Furthermore, since microorganisms need water for survival the reduced water content of the faecal sludge reduces the active pathogens,(Strande & Brdjanovic, 2014).Therefore, dewatering treatment mechanisms reduce the level of active pathogens. Faecal sludge has a high content of water, which can be either free or bound to particles. Free water takes the biggest percentage and can be easily removed by techniques such as settling and infiltration. More advanced techniques like centrifugation or evaporation can be used to remove the physically bound water (Strande & Brdjanovic, 2014). Centrifugation separates liquids and solids by compression and concentration of solids along the walls of a centrifuge while it rotates at a high speed.

Evaporation happens when water changes phase from liquid to vapour due to solar energy and is released into the air (Strande & Brdjanovic, 2014). Storage is a sludge treatment method, which enables pathogen die-off as the sludge dries. One year of storage is suggested in warmer areas, while 18 months is recommended in colder areas. These recommendations should be applied when storage is used as a treatment method to prevent re-growth of pathogens (Femi, 2013).

2.4.2 Biological sludge treatment

Biological treatment of faecal sludge utilizes the metabolism of microorganisms naturally occurring in the faecal matter. The microorganisms can provide the desired outcomes such as degradation of organic matter and reduction of odour and pathogens under controlled conditions (Strande & Brdjanovic, 2014). The temperature of the sludge, as well as the level of nutrients and oxygen in the sludge are the important factors that affect the activity of the microorganisms. World wide

Black Soldier flies (BSF) can be found in temperate climates. The BSF has been investigated for the degradation of faecal sludge as the fly larvae feed on decaying organic material (Lalander et al., 2013). There is a low risk of being a vector for disease transmission since the BSF feed only during the larval stage. The BSF larvae can reduce organic waste of up to 75% its volume and the larvae growth stage varies from 2 weeks to 4 months (Strande & Brdjanovic, 2014). The BSF larval activity sanitizes the sludge as inactivation of bacteria such as *Salmonella* spp. and *E. coli* has been discovered. However, the impact of BSF on other bacteria, viruses and parasitic organisms in faecal sludge have not been thoroughly studied (Lalander et al., 2013).

Vermicomposting is a method using earthworms to reduce the volume of organic wastes. Studies have shown that the worms can reduce coliforms and Helminth eggs in faecal sludge (Strande & Brdjanovic, 2014). Although, the vermicomposting process cannot be carried out at thermophilic temperatures which is the reason why adequate pathogen removal is not ensured. This necessitates additional treatment since the technology is not fully developed (Strande & Brdjanovic, 2014).

2.4.3 Chemical sludge treatment

Alkaline stabilization of faecal sludge can be carried out either pre- or post-dewatering. However, if performed prior to dewatering, the required amount of alkaline material increases. The microbial activity is affected by adding an alkaline material e.g. lime to raise the pH to greater 12 (Strande & Brdjanovic, 2014). This in turn reduces the odour and level of pathogen in the sludge. Excess dose of lime is required to prevent the pH from being decreased again which enable regrowth of pathogens. To stabilize alkaline level of faecal sludge, ash is a readily available and cost efficient material (Graesser et al., 2015). According to studies coal fly ash can prevent regrowth of faecal coliforms if added to faecal sludge(Alkan et al., 2007) . The method of using fly ash might require a combination of treatments to inactivate pathogens more effectively.

When it comes to in activation of microorganisms, ammonia treatment of faecal sludge is effective although the exact mechanisms are not completely understood (Strande & Brdjanovic, 2014). The ammonia can, for instance, be in the form of aqueous ammonia, NH3 (aq), or urea, CO (NH2)2, which rapidly transforms to ammonia. Disinfection by aqueous ammonia or urea has been proved to be effective in urine, sewage sludge and compost treatment, but is still in research

when it comes to faecal sludge. The pH must be above 8.5 for the disinfection to be efficient

and regrowth of pathogens will not occur as long as the pH is stable (Strande & Brdjanovic, 2014).

2.4.4 Anaerobic digestion

Anaerobic digester (AD) has been adopted to stabilize the sludge from activated sludge plant. The high concentration of organic matter in the sludge undergoes into different biochemical reactions and produces mixture of gases (Park et al., 2005). It principally works into 4 digestion process: hydrolysis, acidogenesis, acetogenesis and methanogenesis.

Hydrolysis

Hydrolysis is the first stage of the AD process where complex molecular compounds such as carbohydrates, proteins, and fatty acids are transformed into simpler and soluble molecular compounds such as sugars, amino acids and fatty acids(Mir et al., 2016) . Equation (1) represents the overall reaction in this stage.

$(C_6H_{12}O_6)_x + (H_2O) \longrightarrow X\ (C_6H_{12}O_6)$ (1)

Extracellular enzymes are released by microorganisms that are responsible for hydrolysis, and this causes the transformation to happen (Mishra et al., 2018). The rate-limiting stage in the AD process is the hydrolysis of complex organic molecules like lignocellulose materials, which is extremely sluggish (Liew et al., 2011). So one way to enhance the AD process is to look into ways to make the hydrolysis stage better (Richard et al., 2019).

Acidogenesis and acetogenesis

A wide number of facultative and obligate anaerobic bacteria transform the byproducts of hydrolysis into new forms to be utilized in following stages during the second stage of the AD process, known as acidogenesis. For instance, organic acids, volatile fatty acids (VFAs), alcohols, and some inorganic chemicals like CO2, H2, H2S, and NH3 are produced from sugars, amino acids, and fatty acids (Zhou et al., 2018).

$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2$ (2)

$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O$ (3)

$C_6H_{12}O_6 \rightarrow 3CH_3COOH$ (4)

The third step of anaerobic metabolism is called acetogenesis, and during this phase, acetogenic bacteria transform the byproducts of acidogenesis into acetate, hydrogen, and carbon dioxide (Mishra et al., 2018). This stage's overall responses are represented in the equations below.

$CH_3CH_2COOH + 2H_2O \rightarrow CH_3COOH + CO_2 + 3H_2$ (5)

$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2H_2O$ (6)

$CH_3COO^- + 4H_2O \rightarrow 2HCO_3^- + H^+ + 4H_2$ (7)

Methanogenesis

The final metabolic stage of the AD process is meth anogenesis, where acetotrophic methanogens and hydrogen trophic methanogens primarily function to break down organic molecules and produce biogas. Since hydrogen is typically scarce in AD systems, the majority of methane roughly 70% comes from acetate and less than 30% from hydrogenotrophic methanogens (Mir et al., 2016).

Hydrogenotrophic methanogens employ carbon dioxide and hydrogen to make methane, as opposed to acetotrophic methanogens, which break down acetate to produce methane and carbon dioxide Eqs. (8) and (9). Additionally, ethanol can be converted to methane through substrate oxidation (Eq.10)

$CH_3CHOOH \longrightarrow CH_4 + CO2$ (8)

$CO_2 + 4H_2 \longleftrightarrow CH_4 + 2H_2O$ (9)

$2CH_3CH_2OH + CO_2 \longrightarrow CH_4 + 2CH_3COOH$ (10)

Operating parameters in anaerobic digestion.

Volatile Fatty Acids.

If there is an accumulation of VFA, this can be explained by either an overloading of organic matter or by the suppression of methanogenic microbial populations as a result of other influences. When VFA accumulation occurs, the pH value decreases, and action must be done to prevent reactor failure. The activities of the methanogenic bacteria, which also produce alkalinity in the form of carbon dioxide, ammonia, and bicarbonate, could often offset this pH fall.

PH value

The solubilization of organic materials is affected by the pH concentration, which has a significant impact on the AD system (Feng et al., 2015). The pH level serves as a gauge for the volume of VFAs produced during AD. Because methanogenic bacteria are highly sensitive to pH, a high concentration of VFAs will cause pH to drop to levels where the methanogenic bacteria are severely inhibited. The pH range of 6.5 to 7.2 that a digester typically operates in is ideal for methanogenic bacteria.

Carbon to Nitrogen Ratio

The carbon to nitrogen (C/N) ratio of organic materials affects the entire AcoD process (Reilly et al., 2016). Substrates with an optimal C/N ratio provide sufficient nutrients for microorganisms to maximize biogas production. Lower C/N values leads to higher concentrations of ammonia and impede microbial growth. When the C/N ratio is greater than the optimal value in the fermentation process, large amounts of VFAs are produced. Thus, maintaining an appropriate C/N ratio is important in the AcoD technique of biogas generation. Thus, for optimum functioning microbes usually need 25-30:1 ratio of C to N (Chen et al., 2008).

Inoculum to Substrate ratio

The inoculum to substrate (I:S) ratio is a crucial operating parameter during the start-up period of anaerobic digestion (AD) processes and this ratio shows high differentiation with respect to substrate composition (Akyol,2014a). According to literature, the maximum volume of inoculum should not exceed 30% of the total volume of the substrate.

2.4.5 Current treatment at Lubigi sewage treatment plant

Lubigi sewage treatment plant in Kampala, Uganda, treats domestic wastewater and faecal sludge from pit latrines and septic tanks with a capacity of 5,400 m3/day and a current flow of 3,000 m3/day. The treatment plant has 19 drying beds for the faecal sludge treatment. Each bed is 7x34 meters and treats approximately 71,000 litres of sludge at a time. The wastewater and the faecal sludge are treated separately in the treatment plant, therefore the drying beds contain pure faecal sludge. The sludge that enters the treatment plant originates mainly from pit latrines and septic tanks in homes and other premises and is transported to the treatment plant via trucks. Figure illustrates the different treatment steps of the sludge arriving at Lubigi. Note that the domestic wastewater is treated separately and is not presented in Figure 2.

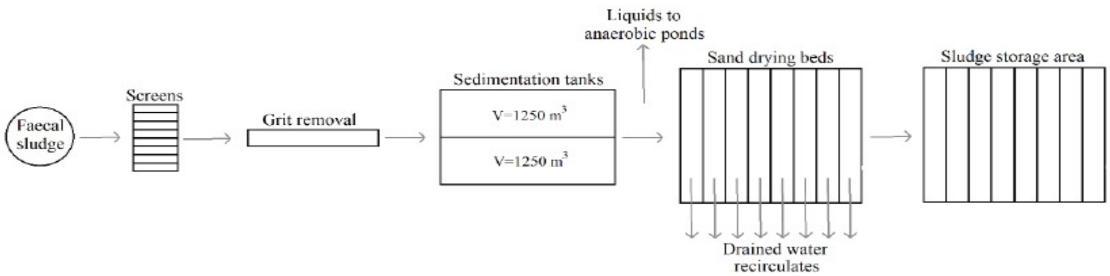


Figure 2- 1 Different sludge treatment steps

During primary treatment solid waste is removed as the faecal sludge is transported through screens and a channel for settling of sand and grit. A sedimentation tank is used in secondary treatment to enable further settling of solids and the faecal sludge stored in the sedimentation tank for a maximum of three months. The tank is filled with faecal sludge in the first month. It is then continuously pumped to the drying beds for further treatment. New incoming sludge is filled in the tank at the same time. The sedimentation tank is left to settle the sludge in the last month.

Before being transferred to anaerobic ponds where it is co-treated together with wastewater, the liquid part of the faecal sludge has a retention time of three days. The settled sludge is then transferred to the drying beds by pumping. The waste water treatment line the receives drained water from the drying beds filled with faecal sludge for co-treatment. The sludge takes 4-8 weeks to dry in the beds, although the length of time depends on the quantity of precipitation that has fallen as well as the state of the roofs that cover the beds, since they are leaking. The sludge is kept in storage for an additional six months after drying (Lindberg & Rost, 2018). The sludge cake is then sold to farmers to be used as a fertilizer after a total treatment of approximately 11 months.

CHAPTER 3: METHODOLOGY

In this research project, the evaluation of biogas production potential from co-digestion of cow dung and dried pineapple peels was conducted using lab scale batch reactors. The methodology was conducted in five stages that include; research design, sampling strategy, data collection methods and tools, data management and data analysis and statistical analysis method.

Research design

Experimental design and setup

The experiment was conducted according to (Song et al., 2012) by using anaerobic digesters of capacity 20liters as shown in the Figure A-3-2 in the appendices. Batch reactors were used to determine the co digestions of faecal sludge and banana peels. The working volume of each digester was 18 liters and headspace of 2 liters, including inoculum and an appropriate amount of substrate (faecal sludge and banana peels) which was calculated using (x/1800)= 8%, x/Vs to get the appropriate amount of substrates to put in each digestor. The inoculum was obtained from a field scale working digester at MUARIK, and to eliminate oxygen traces and assure anaerobic conditions, pure nitrogen gas was flushed into the digestors for 2 minutes as shown Figure A-3-1 in the appendices, and the digestors were tightly closed with silicon to avoid any leakages. Water was added to fill the liquid volumes up to effective volumes of 18liters to maintain a volatile solids (VS) content of 8% (Song et al., 2012). All reactors were gently mixed manually for approximately 2minutes. To obtain the best mixing ratio of the co-digestion of faecal sludge supplemented with banana peels, different mixing mass ratios at 1:1, 1:2 and 1:3 were tested under ambient conditions (25±5°C) in an enclosed room in MUARIK for 35 days. Faecal sludge (1:0) was anaerobically digested as control. Each treatment was performed once with a control to investigate the effect of different mixed ratios on biogas production. The treatments were labelled 1:0, 1:1, 1:2 and 1:3. Where 1 represents faecal sludge and 1,2,3 represent banana peels. The biogas produced was measured using car tyre tubes abd gas bags as shown in Figure 3-5.

3.1 Determination of the physico-chemical characteristics of faecal sludge and banana peels.

The physical and chemical composition of the feedstock was evaluated before digestion using standard procedures (Federation & Association, 2005). Parameters analyzed were pH , moisture content, total solids, ash content and volatile solids.

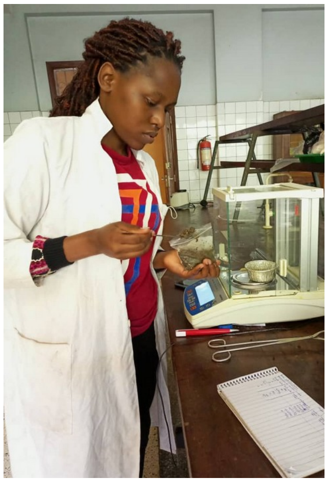


Figure 3- 1 measurement of substrates using a weighing scale before putting them in the oven for moisture content

Figure 3- 2 Removal of samples from the oven

Figure 3- 3 Putting sample in the furnace to test for ash content and volatile solids

The pH of the different treatments was measured every after 2 days using a pH meter For the moisture content, the samples were dried in moisture dish in an oven at 105ºC until constant weights were obtained. Pre-dried samples obtained from moisture content analysis were ashed in furnace at 550ºC overnight to determine the ash content of the samples. The convection oven method was used to determine the total solids in 4 grams of the slurry sample.

3.2 Determination of the effect of different co digestion ratios of faecal Sludge and banana peels on biogas quantity and quality.

Mixing ratios of FS to banana peels had four levels, namely 1:0 (control), 1:3,1:2, 1:1 where1:faecal sludge and 1,2 and 3 banana peels. The temperature was ambient (25◦C-30◦C). Laboratory batch reactors (1) with a total volume of 20 liters were used. The reactors were made of stainless steel. The effective (working) volume of each reactor was maintained at 18 liters.

The reactor was provided with suitable arrangements for feeding, gas collection, and draining of residues (digestate).The reactors were stirred manually using a stirrer once a day to ensure homogenous conditions in them.

The experiment was arranged as shown in the Figure 6 and 7 below

Figure 3- 4 Arrangement of the reactors

Figure 3- 5 How reactors were labelled

Biogas yield was measured weekly by emptying the gas in the car tyre tubes into urine bags.

A biogas sample was taken weekly from the gas holder and analyzed for methane, carbon dioxide and oxygen content using a GA2000 portable infrared gas analyzer (Geotechnical instruments, Leamington Spa, UK). Figure 8 ,9 and 4 show how gas was collected and taken for analysis using a gas analyzer at CAES labs.

Figure 3- 6 Gas collectected in urine bags to be taken for analysis

Figure 3- 7 Collecting gas from car tyre tibe into the urine bag

3.3 **Determination of digestate characteristics in relation to bio fertilization.**

Digestate was tested for the content of nutrients such as nitrogen, phosphorus and potassium and the nutrients from the COVAB labs.

3.4 Data Analysis

The data obtained was input into Excel 2016. The univariate procedure of R-version 4.13 was used to check for the normality of the data before analysis.

CHAPTER 4: RESULTS AND DISCUSSIONS

The substrates were characterized based on their TS, VS, MC, Ash content and pH, and the results are summarized in Table 2 and table 3 as shown. It can be seen from the characterization results, the TS, VS ,ash content were within range according to (Deressa et al., 2015).

4.1 Characterization of banana peels and faecal sludge

Table 4- 1: Characterization of banana peels and faecal sludge

Treatment	Moisture content	Total solids	Ash content	Volatile solids
1:0	63.29±1.71	36.71±1.71	38.74±6.73	61.37±6.73
1:1	73.80± 0.49	26.2±0.49	30.83±6.02	69.17±6.02
1:2	74.40±1.45	25.22±1.45	23.73±3.81	76.27±3.81
1:3	75.31±0.26	24.69±0.26	27.2±13.68	72.8±13.68

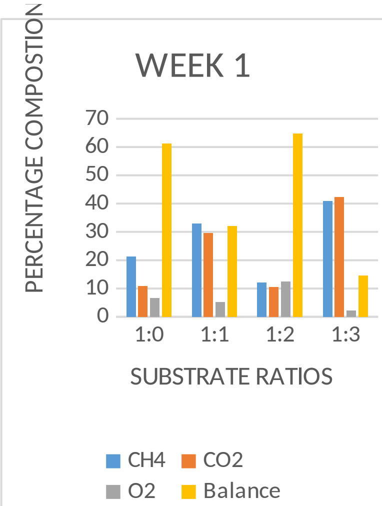
Table 4- 2: pH Values for the different treatments over

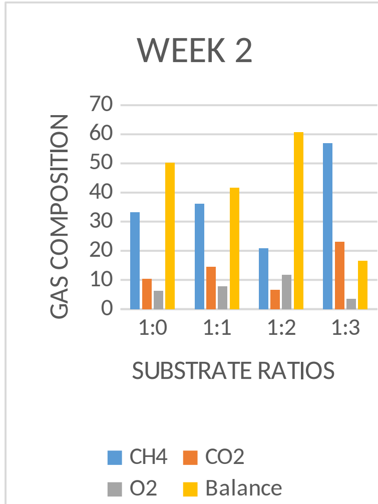
Treatment ratio	1:0	1:1	1:2	1:3	Time (days)
pH	6.83	7.04	7.27	7.31	0
	7.27	7.38	7.43	7.47	7
	7.33	7.35	7.33	7.41	9
	7.24	7.36	7.26	7.31	11
	7.24	7.44	7.44	7.39	14
	7.2	7.67	7.46	7.38	16
	7.41	7.45	7.66	7.41	18
	7.30	7.44	7.50	7.4	21
	7.26	7.43	7.68	7.79	23
	7.26	7.66	7.75	7.47	25
	7.27	7.43	7.68	7.79	28
	7.31	7.44	7.51	7.62	30
	7.25	7.32	7.43	7.55	33
	7.19	7.20	7.35	7.40	36

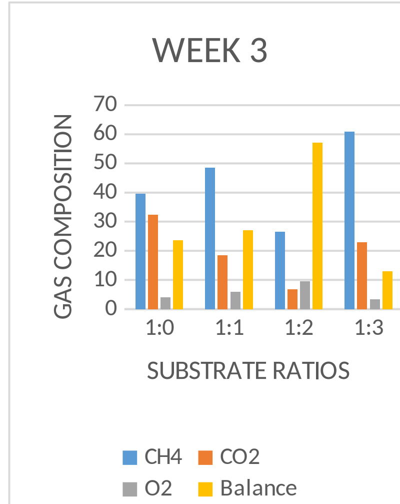
Results from the table show that throughout the experiment the pH values kept within range as compared to (JI & Agbo, 2010)

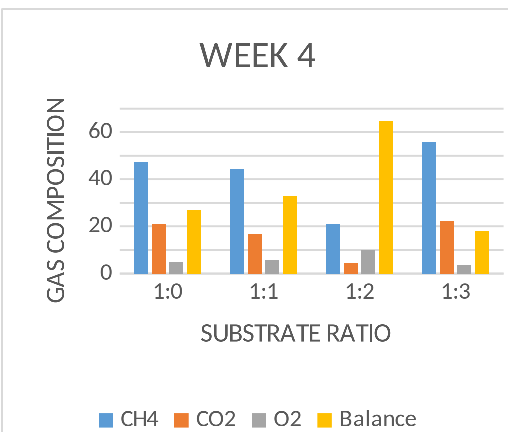
4.2 Effect of the different co-digestion ratios on gas quality and quantity

Graphs showing the methane content for the different weeks.









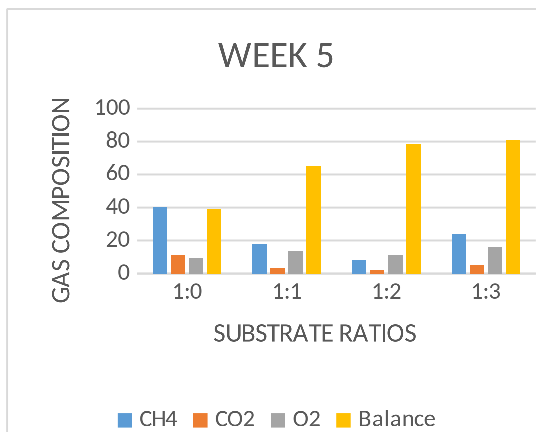


Table 1 the gas volume obtained from the different treatments

Treatment ratio	Gas volume (ltrs)
1:0	19
1:1	16
1:2	10
1:3	26

According to the graphs and table 5 shown in appendix 5 the gas quality kept on improving weekly up week 4 with the treatment that has ratio 1:3 (faecal sludge : banana peels) having the highest overall gas volume and quality. In week 5 the gas quality dropped this is an exceptional case as compared to the different literature which calls for in-depth analysis and further experimentation to validate these results and gain a comprehensive understanding of the specific factors influencing gas quality in this particular anaerobic co-digestion system

4.3 Digestate Characterization

Table 4- 3: Digestate Characterization

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)
1:0	$3.7^{a} \pm 0.3$	$3.4^{a} \pm 0.4$	$4.0^{a}\pm0.02$
1:1	$2.1^{a}\pm0.2$	$2.5^{b}\pm0.2$	$6.2^{a}\pm0.4$
1:2	$3.3^{a}\pm1.3$	$2.6^{b}\pm0.3$	$4.8^{a}\pm0.3$
1:3	$2.2^{a}\pm0.3$	$3.0^{ab}\pm0.1$	$4.5^{a}\pm0.5$

Data is represented as means ± standard deviation values for the different treatments. ab are superscripts where by the same superscript with in the column means treatments do not differ significantly ($p \geq 0.05$).

According the results in the table above the nitrogen phosphorus and potassium contents were with in range for the four different treatments as compared to (Barampouti et al., 2020)

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

It can be concluded that the co-digestion of faecal sludge and banana peels has proved that the addition of banana peels has the potential of increasing biogas volume and quality.

The pH, moisture content, total solids, volatile solids and ash content results were within the range for anaerobic digestion.

The most effective composition for producing biogas was the ratio 1:3, which composed of 1 part of faecal sludge and 3 parts of banana peels. This produced an overall biogas volume of 26litres.

The nutrient content in the digestate was within the range for phosphorus, nitrogen and potassium

Thus, it was seen that successful implementation of the anaerobic co-digestion as a method of waste treatment has the potential to change the concept of waste into energy which will lead to total utilization of renewable energy resources in reducing energy requirement, making it readily available and minimizing environmental pollution.

5.2 Recommendations

In-depth analysis and further experimentation would be required to validate these results and gain a comprehensive understanding of the specific factors influencing gas production and the gas quality in this particular anaerobic co-digestion system.

REFERENCES

Afifah, U., & Priadi, C. R. (2017). Biogas potential from anaerobic co-digestion of faecal sludge with food waste and garden waste. AIP Conference Proceedings,

Agani, I. C., Suanon, F., Dimon, B., Ifon, E. B., Yovo, F., Wotto, V. D., Abass, O. K., & Kumwimba, M. N. (2016). Enhancement of faecal sludge conversion into biogas using iron powder during anaerobic digestion process. *American Journal of Environmental Protection*, *5*(6), 179-186.

Alkan, U., Topac, F., Birden, B., & Baskaya, H. (2007). Bacterial regrowth potential in alkaline sludges from open-sun and covered sludge drying beds. *Environmental technology*, *28*(10), 1111-1118.

Barampouti, E., Mai, S., Malamis, D., Moustakas, K., & Loizidou, M. (2020). Exploring technological alternatives of nutrient recovery from digestate as a secondary resource. *Renewable and sustainable energy reviews*, *134*, 110379.

Chen, Y., Cheng, J. J., & Creamer, K. S. (2008). Inhibition of anaerobic digestion process: a review. *Bioresource technology*, *99*(10), 4044-4064.

Deressa, L., Libsu, S., Chavan, R., Manaye, D., & Dabassa, A. (2015). Production of biogas from fruit and vegetable wastes mixed with different wastes. *Environment and Ecology Research*, *3*(3), 65-71.

Federation, W. E., & Association, A. (2005). Standard methods for the examination of water and wastewater. *American Public Health Association (APHA): Washington, DC, USA*, *21*.

Femi, A. (2013). Perception of performance appraisal and workers' performance in Wema Bank Headquarters, Lagos. *Global Journal of Arts, Humanities and Social Sciences*, *1*(4), 89-101.

Graesser, A. C., Li, H., & Feng, S. (2015). 13 Constructing inferences in naturalistic reading contexts. *Inferences during reading*, 290.

Gumisiriza, R., Hawumba, J., Simon, A., Balyeidhusa, P., Okure, M., & Hensel, O. (2019). Processing of East African highland green bananas: waste generation and characterization as a potential feedstock for biogas production in Uganda. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*, *53*(1), 215-236.

Hagos, K., Zong, J., Li, D., Liu, C., & Lu, X. (2017). Anaerobic co-digestion process for biogas production: Progress, challenges and perspectives. *Renewable and sustainable energy reviews*, *76*, 1485-1496.

JI, E., & Agbo, K. (2010). Studies on the microbial spectrum in anaerobic biomethannization of cow dung in 10 m 3 fixed dome biogas digester.

Kayombo, S., Mbwette, T., Katima, J., Ladegaard, N., & Jørgensen, S. (2005). Waste stabilization ponds and constructed wetlands design manual. *UNEP-IETC with the Danish International Development Agency (Danida)*, 1-59.

Koné, D., Cofie, O., Zurbrügg, C., Gallizzi, K., Moser, D., Drescher, S., & Strauss, M. (2007). Helminth eggs inactivation efficiency by faecal sludge dewatering and co-composting in tropical climates. *Water research*, *41*(19), 4397-4402.

Lalander, C., Diener, S., Magri, M. E., Zurbrügg, C., Lindström, A., & Vinnerås, B. (2013). Faecal sludge management with the larvae of the black soldier fly (Hermetia illucens)—From a hygiene aspect. *Science of the Total Environment*, *458*, 312-318.

Liew, L. N., Shi, J., & Li, Y. (2011). Enhancing the solid-state anaerobic digestion of fallen leaves through simultaneous alkaline treatment. *Bioresource technology*, *102*(19), 8828-8834.

Lindberg, E., & Rost, A. (2018). Treatment of faecal sludge from pit latrines and septic tanks using lime and urea: Pathogen die-off with respect to time of storage. In.

Mir, M. A., Hussain, A., & Verma, C. (2016). Design considerations and operational performance of anaerobic digester: A review. *Cogent Engineering*, *3*(1), 1181696.

Mishra, S., Singh, P. K., Dash, S., & Pattnaik, R. (2018). Microbial pretreatment of lignocellulosic biomass for enhanced biomethanation and waste management. *3 Biotech*, *8*(11), 1-12.

Nsiah-Gyambibi, R., Essandoh, H. M. K., Asiedu, N. Y., & Fei-Baffoe, B. (2021). Valorization of faecal sludge stabilization via vermicomposting in microcosm enriched substrates using organic soils for vermicompost production. *Heliyon*, *7*(3), e06422.
Nuwagira, N. (2021). *Assessment of the performance of Lubigi sewage and faecal sludge treatment plant*.
Park, C., Lee, C., Kim, S., Chen, Y., & Chase, H. A. (2005). Upgrading of anaerobic digestion by incorporating two different hydrolysis processes. *Journal of bioscience and bioengineering*, *100*(2), 164-167.
Pradeep, S. V. (2015). *Effects of biomass addition and fermentation on the energy content of hydrochar produced by hydrothermal carbonization (HTC) with faecal sludge* UNESCO-IHE].
Richard, E. N., Hilonga, A., Machunda, R. L., & Njau, K. N. (2019). A review on strategies to optimize metabolic stages of anaerobic digestion of municipal solid wastes towards enhanced resources recovery. *Sustainable Environment Research*, *29*(1), 1-13.
Semiyaga, S., Okure, M. A., Niwagaba, C. B., Katukiza, A. Y., & Kansiime, F. (2015). Decentralized options for faecal sludge management in urban slum areas of Sub-Saharan Africa: A review of technologies, practices and end-uses. *Resources, Conservation and Recycling*, *104*, 109-119.
Singh, S., Mohan, R. R., Rathi, S., & Raju, N. J. (2017). Technology options for faecal sludge management in developing countries: Benefits and revenue from reuse. *Environmental Technology & Innovation*, *7*, 203-218.
Song, Z., Yang, G., Guo, Y., & Zhang, T. (2012). Comparison of two chemical pretreatments of rice straw for biogas production by anaerobic digestion. *BioResources*, *7*(3), 3223-3236.
Strande, L., & Brdjanovic, D. (2014). *Faecal sludge management: Systems approach for implementation and operation*. IWA publishing.
Tayler, K. (2018). Faecal Sludge and Septage Treatment: A guide for low-and middle-income countries.
Tumutegyereize, P., Muranga, F., Kawongolo, J., & Nabugoomu, F. (2011). Optimization of biogas production from banana peels: effect of particle size on methane yield. *African Journal of Biotechnology*, *10*(79), 18243-18251.
Vinnerås, B., & Jönsson, H. (2002). The performance and potential of faecal separation and urine diversion to recycle plant nutrients in household wastewater. *Bioresource technology*, *84*(3), 275-282.
Zhou, M., Yan, B., Wong, J. W., & Zhang, Y. (2018). Enhanced volatile fatty acids production from anaerobic fermentation of food waste: A mini-review focusing on acidogenic metabolic pathways. *Bioresource technology*, *248*, 68-78.

APPENDIX

Appendice 1: substrate preparation

Figure A-1- 1 : weighing the substrates to be put in each treatment

Figure A-1- 2: collecting innoculum

Figure A-1- 3 : Feeding reactors

Appendice 2: Substrate characterization

Figure A-2- 1: Measuring substrates for moisture content ,total solids and volatile solids characterization

Figure A-2- 2: 0.5 measuring pH

Appendice 3: Experimental set up

Figure A-3- 1: Purging using nitrogen 1

Figure A-3- 2 Experimental set up

Appendice 4 : Gas analysis

Figure A-4- 1: 0.8Passing gas over the gas analyzer

Figure A-4- 2 : 0.1 Gas analyzer

Appendice 5:

Table A -1: Gas composition for 5 weeks

Substrate ratio	Time (weeks)	Methane %	CO2 %	O2%	Balance
1:0	1	21.3	10.9	6.6	61.2
1:1		33	29.7	5.2	32.1
1:2		12.1	10.6	12.5	64.8
1:3		40.9	42.3	2.2	14.6
1:0	2	33.3	10.3	6.2	50.3
1:1		36.2	14.5	7.7	41.7
1:2		20.9	6.6	11.8	60.7
1:3		56.9	23.1	3.5	16.5
1:0	3	39.5	32.3	4.1	23.6
1:1		48.5	18.5	5.8	22.8
1:2		26.6	6.8	9.5	3.4
1:3		60.8	22.8	3.4	13
1:0	4	47.4	20.9	4.7	27
1:1		44.4	16.9	5.9	32.8
1:2		21	4.3	9.8	64.9
1:3		55.7	22.3	3.8	18.1
1:0	5	40.4	11.1	9.5	39
1:1		17.7	3.5	13.6	65.3
1:2		8.3	2.4	11.1	78.2
1:3		24	4.9	15.8	80.7