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Anaerobic Co Digestion of Kitchen Waste With Cattle Dung and Poultry Manure A Means to Overcome The Problems of Anaerobic Mono Digestion and Improve The Production of Biogas

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Abstract

Anaerobic mono digestion usually suffers from several problems at high rates of organic load, which leads to a negative effect on the activity of methane producing bacteria, which leads to a decrease in biogas production. Therefore, it is important to find scientific alternatives to overcome these problems. In this study, the low efficiency of anaerobic mono digestion of kitchen waste was efficiently overcome by anaerobic co digestion of kitchen waste with cattle dung and poultry manure. The results indicated that anaerobic co digestion for kitchen waste with cattle dung (T4) has significantly increased the production of biogas more than anaerobic mono digestion for kitchen waste (T3). The obtained results showed that the produced biogas ranged from 17.68 to 30.95 L, and the highest production was observed from T1 (cattle manure and starter), followed by T4 (kitchen waste, cattle dung and starter) and the lowest production resulting from T2 (poultry manure and starter). The results also indicated that methane production ranged from 10.08 to 19.87 liters, and that T1 (cattle manure and starter) was more productive than T4 (kitchen waste, cattle dung and starter), and T4 outperformed other treatments in methane production. Biogas and methane production rates were based on either total solid or volatile solid where, ranged between 136.53- 189.96 L/Kg consumed biogas and 77.84- 121.95 L/Kg consumed methane. Volatile fatty acids concentration was decreased after anaerobic fermentation process. Also, the pH values increased at the end of anaerobic digestion the values ranged between 7.65- 8.02. After anaerobic digestion, the total and faecal coliform count as well as *Salmonella & Shigella* were not discovered. The numbers of total bacterial count, aerobic cellulose decomposers and acid producers (aerobic and anaerobic) were decreased after anaerobic digestion. In contrast, the numbers of anaerobic cellulose decomposers were increased after anaerobic digestion.

Keywords: Anaerobic digestion, Kitchen waste, Cattle dung, Poultry manure and Biogas.

Introduction

Unchecked population growth and industrial development are the causes of the rise in energy demand and greenhouse gas emissions **(Shirzad *et al.*, 2019)**. Recent changes in solid waste management are a result of worries about climate change and the depletion of natural resources **(Paritosh *et al.*, 2021)**. It can be difficult to identify the most environmentally friendly technology for generating bioenergy from agro-industrial waste products that avoid or reduce pollution and greenhouse gas emissions **(Solís *et al.,* 2022)**. In recent years, renewable energy has drawn a lot of attention as a way to address the world's energy needs. Amidst the growth in worries about energy security, it also offers significant environmental advantages against the various environmental issues linked to fossil fuels. Biogas from anaerobic digestion (AD) provides renewable and sustainable energy as an alternative to fossil fuels. Additionally, biogas technology, particularly in rural parts of developing nations, is a sustainable method of handling organic waste with huge energy and health benefits **(Yang *et al.,* 2023)**. According to **Awe *et al.* (2017),** biogas is an optional energy source that can be created from biodegradable natural materials. It generally comprises of the gases methane (CH_4), carbon dioxide (CO_2), hydrogen sulfide (H_2S), a little measure of dampness, and siloxanes. Different organization of biofuel is furthermore point by point depending on the wellspring of creation. Combination of biogas with level of each and every constituent gas is 45-70% of methane (CH_4), 30-40% of carbon dioxide gas (CO_2) and 1-1.5% of hydrogen sulfide (H_2S) gas as significant parts and it is vary in organizations subject to wellspring of biogas creation (sewage digester, natural buildups digester and landfill sources). Consuming or oxidization of methane, hydrogen or carbon monoxide (CO) with oxygen is imparted to deliver adequate proportion of energy with its utilization for cooking or warming purposes. Underway of synthetic substances or biochemical, hydrogen and combination gas, biogas is used as starting material or fuel sources. By using it as a source of renewable energy, anaerobic digestion can cut down on greenhouse gas emissions. Digesters use the anaerobic process to turn waste's organic material into methane (CH_4), carbon dioxide (CO_2), NH3, and H_2S. When compared to the treatment of conventional manure, the capture and combustion of CH_4 in digesters can lower greenhouse gas emissions **(Flesch *et al.,* 2011)**. Anaerobic digestion (AD), a low-cost procedure, is used to break down complex organic matter in an interdependent manner by three functional microbial groups, including the fermentative, acidogenic, and methanogenic bacteria. The following types of microorganisms carry out the four steps in the conversion of complex organics into biogas: The steps of hydrolysis come first, followed by those of acidogenesis, acetogenesis, and finally, those of methanogenesis **(Jia, 2020)**. The anaerobic mono-digestion process still faces numerous challenges, including inadequate biodegradation and biogas generation, imbalanced nutrient levels, and a lack of anaerobic bacteria in the AD system **(Hagos *et al.,* 2017)**. Due to these reasons, some studies have found that employing co-digestion to hasten the biological conversion rate of organic materials in the AD system has improved AD performance **(Abbas *et al.,* 2023)**. Anaerobic digestion (AD), a continuous biochemical procedure used to detoxify organic wastes, also generates biogas in anoxic environments **(Ali *et al.,* 2019)**. In the absence of external electron acceptors, complex microbial consortia composed of many types of bacteria and archaea drive the AD process by degrading complex organic polymers into energy-rich methane **(Ali *et al.,* 2020)**. Hydrolysis, acidogenesis, acetogenesis, and methanogenesis are the four sequential and distinctive processes that turn organic molecules into biogas **(Deena *et al.,* 2022)**. While methanogenic bacteria produce CH4 through the methanogenesis stage via acetoclastic, hydrogenotrophic, and methylotrophic pathways, the fermentative bacterial community converts complex high molecular weight organic compounds to low molecular weight compounds such as alcohols, organic acids, hydrogen, and carbon dioxide **(Berghuis *et al.,* 2019)**. Methanogens, or bacteria that produce CH_4, are among the microbes in the biogas-producing microbiota that are most susceptible to environmental factors that can hinder the process. In order to optimise and enhance the AD process, a full understanding of the microbial consortia involved in the biomethanation process is necessary **(Ali *et al.,* 2021)**. In addition, a number of additional variables, including volatile fatty acids (VFAs), pH, and C/N ratio, might influence the digester's performance. From a biological perspective, all bacteria require N and C to create cell structures and proteins. Unsuitable C/N ratios can cause a buildup of high VFAs in the digester, which can lead to high total nitrogen (TN) and a fall in pH. Both TN and VFAs are crucial components of the AD process. Low pH and high VFA and TN concentrations in the digester would likely hinder the AD process by reducing CH4-producing bacterial activity **(Ali *et al.,* 2022)**. Anaerobic digestion typically has pH control issues at high rates of organic load, which has a negative impact on methanogenic activity **(Amodeo *et al.,* 2021)**, So it's important to identify workable alternatives. Anaerobic co-digestion, which entails a combination of several substrates creating a nutritional balance, figuring out the proper amount of each substrate when performing anaerobic digestion, and improving the process' effectiveness, is recommended as a way to get over these restrictions. By generating harmony and advantageous synergy in the digestible substrate, this method has many advantages. These advantages include improved biodigester performance, a good C/N ratio that lowers nitrogen concentration and increases methane yields, as well as increased biodegradability and balance in metabolic activity. In order to achieve all the mentioned benefits, it was decided that the combination of suitable wastes was appropriate **(Sillero *et al.,* 2023)**. Whether they are plant or animal waste, Egypt produces an estimated 116.5 million tonnes of agricultural waste annually. Egypt produces 39.5 million tonnes of plant wastes annually, divided into three seasons, from 15.7 million feddans of field crops. About 22 million tonnes of waste are generated annually during the summer season from an area of 8 million feddans, 1.5 million tonnes are generated annually during the nile season from an area of 0.7 million feddans, and about 16 million tonnes are generated annually during the winter season from an area of 7 million feddans. The yearly waste from 20 million heads of animals amounts to around 77 million tonnes **(ADP, 2016)**. Animal manure was once used as fertilizer. Because animal manure has a plethora of nutrients, crop fields have traditionally favoured using it. Animal manure contains significant amounts of nitrogen, phosphorous, and potassium for plants, along with other essential micronutrients. In addition to improving the soil's nutrient supply, animal dung also increases the amount of organic matter, water and nutrient retention, fertility, and tilth **(Sendaaza, 2018)**. However, the effects of storing manure and using it as a soil amendment. Some of the problems mentioned include surface water contamination, ammonia emissions in the air, and nutrient leaching in the groundwater. Due to the high moisture content of fresh animal manure, applying it as fertiliser carries a significant environmental risk. However, AD of animal manure has proven to be a successful, economical, and environmentally friendly risk reduction strategy. The poultry industry is growing swiftly, producing a sizable volume of animal excrement that needs to be treated in addition to being consumed by humans. Improper manure management can have a number of negative effects, such as odour problems, rodent, insect, and other pest attraction, the release of animal diseases, groundwater contamination, surface water runoff, deterioration of the biological structure of the soil, etc. NH_3, the greenhouse gases CH_4 and CO_2, and emissions from waste storage facilities all contribute to air pollution issues **(Böjti *et al.,* 2017)**. As a result, a PM treatment strategy is needed. Due to PM's high biological degradability, anaerobic digestion is viewed as a promising solution for reducing these types of wastes and recovering bioenergy. However, anaerobic digestion is prevented by the production of ammonia, particularly when digestion is taking place in a thermophilic environment, due to a high organic nitrogen content, a low C/N ratio, undigested protein, and uric acid. A common method to prevent ammonia inhibition is to dilute the substrate, usually with fresh water. Before being supplied to a digester, fresh PM must be diluted so that the concentration of total solids (TS), which can range from 20% to 62.4%, is between 0.5 and 3%. This will stop ammonia from accumulating. This increases water consumption and the cost of processing manure outflow on the one hand, while decreasing the quantity of biogas produced per unit of digester volume on the other **(Carlini *et al.,* 2015)**. Vegetables, fruits, leftovers, fruit shells, eggshells, and other items produced in daily living, the food manufacturing industry, and the food service sector are the main components of kitchen waste (KW) **(Chhandama *et al.,* 2022)**. Over 1.3 billion tonnes of KW are produced worldwide each year, according to the Food and Agriculture Organisation of the United Nations **(Su *et al.,* 2022)**. Therefore, the question of how to use KW safely and creatively has drawn more and more public attention. Given that KW has a high amount of organic materials and moisture, inappropriate handling of it could have a variety of detrimental effects, such as the spread of viruses, pollution of the water supply, the emission of polluting gases, etc. **(Li and Jin, 2015)**. Landfilling, anaerobic fermentation, composting, and bio-drying are some of the current popular treatment methods for KW, however each of these methods has a number of disadvantages. Following the landfilling process, KW produces landfill gas and leachate., which contaminate the soil, groundwater, and air in the area. **(Huang and Fooladi, 2021)**. KW can use anaerobic digestion to efficiently use energy. Anaerobic digestion will be used most frequently in the new waste treatment technique in pilot communities **(Yu *et al.,* 2021)**. However, the system is vulnerable to acidity during anaerobic digestion, which can cause treatment to fail. Additionally, it is challenging to regulate complicated factors, and the technical apparatus is not yet flawless **(Ajay *et al.,* 2021)**. In this study, we aim to improve and increase biogas production from kitchen waste by anaerobic co-digestion with cattle dung and poultry manure.

Materials and methods

Materials

Kitchen waste was collected from the restaurant of Faculty of Agriculture, Cairo University. It was used within 1-2 days, as fresh as possible. Poultry manure was collected from the farm of Faculty of Agriculture, Cairo University. Within one to two days, it was consumed as quickly as possible. Fresh cattle dung was collected from the farms of Faculty of Agriculture, Cairo University. It was used within 1-2 days, as fresh as possible. Starter was taken from an old working biogas digester at Training Center for Recycling of Agricultural Residues (TCRAR), Agric, Res. Center at Moshtohor, Kalubia Governorate. Sigma-Aldrich Company generously provided all of the chemicals and salts.

Experimental procedure

This experiment was carried out at Soils, Water and Environments Research Institute (SWERI), Agriculture Research Center (ARC), Egypt to evaluate the biogas resulting from anaerobic mono-digestion process and anaerobic co-digestion proposed of some treatments which consist of kitchen waste, poultry manure and cattle dung. Calcium carbonate ($CaCO_3$) was added by rate 2.5% from initial total solids to adjust pH. The blending were loaded in 3.5 liter laboratory digesters and kept for 50 days under condition of anaerobic digestion in incubator at 35°C and each treatment carried out in three digesters. Seven biogas mixtures were prepared as follows:

T1: 1687.5 g cattle dung + 750 milli liter starter + 562.5 milli liter water.

T2: 1080 g poultry manure + 750 milli liter starter + 1170 milli liter water.

T3: 675 g kitchen waste + 750 milli liter starter + 1575 milli liter water.

T4: 843.75 g cattle dung + 337.5 g kitchen waste + 750 milli liter starter + 1068.75 milli liter water.

T5: 562.5 g cattle dung + 225 g kitchen waste + 360 g poultry manure + 750 milli liter starter + 11.2.5 milli liter water.

T6: 540 g poultry manure+ 337.5 g kitchen waste + 750 milli liter starter + 1372.5 milli liter water.

T7: 540 g poultry manure+ 843.75 g cattle dung + 750 milli liter starter + 866.25 milli liter water.

The biogas developed was measured for two days, while its CH_4 and CO_2 contents were measured throughout the experimental periods every two days. The physical and chemical characteristics of kitchen waste, poultry manure, cattle dung and starter were assessed. Microbiological determinations like as total count bacteria, total coliform group as an indicator of pathogenic bacteria, faecal coliform as well as *Salmonella* and *Shigella*, cellulose decomposers (aerobic and anaerobic) and acid producing bacteria (aerobic and anaerobic) were determined at the start and the completion of the anaerobic digestion. Additionally, the experiment's initial and final determinations of the physical and chemical properties, this included: total volatile fatty acids (VFAs) as acetic acid, pH, ammoniacal nitrogen (NH_4-N), total nitrogen (TN), total phosphorus (P), total potassium (K), total solids (TS), volatile solids (VS) and ash.

Analytical methods

Daily biogas production was calculated based on **(Maramba *et al.,* 1978).** Gas-liquid chromatography was used to determine the methane content in accordance with **Wujick and Jewell (1980)**. Carbon dioxide was evaluated by method for Orsats apparatus, utilizing 33% potassium hydroxide solution for CO_2 absorption as depicted by **Hamilton and Stephen (1964)**. The standard method suggested by **APHA (1992)** was used to determine total solids (TS), volatile solids (VS), organic carbon (OC), total phosphorus (TP), total potassium (TK), and total volatile fatty acids (VFAs). The usual procedure suggested by **Page *et al.* (1982)** was used to measure moisture content (M.C), organic matter (O.M), ammoniacal nitrogen (NH_4-N), and nitrate nitrogen (NO_3-N). The pH readings were calculated based on **Jodice *et al.* (1982)**. According to **Richards (1954)**, electrical conductivity (EC) was estimated. Total, fecal coliform bacteria, *Salmonellae* and *Shigella* were determined according to **(Difico, 1985)**. Total bacteria count was determined according to **(Allen, 1959)**. According to **Cunningham (1954)**, the Most Probable Number (MPN) technique was used to count the bacteria that produce aerobic and anaerobic acids on nutrient broth medium. According to **Cochran (1950)**, the most probable number technique (MPN) was used to identify both aerobic and anaerobic cellulose-decomposing bacteria.

Statistical analysis

Utilising the analytical programme COSTAT, analysis of variance was performed on all collected data to determine the significance of treatment effects. According to **Snedecor and Cochran (1991)**, multiple range tests and the LSD at 0.05 threshold of significance approach were used to compare the means. The model used for statistical analyses was as organized in Randomized Complete Block Design in three replications.

Results and Discussion

physical and chemical properties of kitchen waste, poultry manure, cattle dung and starter

The physical and chemical evaluation of the used kitchen waste, poultry manure, cattle dung and starter for biogas production were shown in Table 1. The obtained outcomes revealed

Table 1. Physical and chemical properties of kitchen waste, poultry manure, cattle dung and starter.

Character	**Kitchen waste**	**Poultry manure**	**Cattle dung**	**Starter**
Moisture content %	70.00	75.00	81.00	90.00
Total solids %	30.00	25.00	19.00	10.00
pH (1:10)	6.50	7.51	7.32	7.22
EC (1:10) dS/m	9.00	19.00	4.18	4.03
Ammoniacal –N (ppm)	575.00	2918.00	445.00	521.00
Nitrate –N (ppm)	35.00	71.00	25.00	5.00
Organic matter (O.M) %	94.72	82.48	58.41	50.87
Ash %	5.28	17.52	41.59	49.13
Organic carbon %	54.94	47.84	33.88	29.50
Total nitrogen %	1.67	2.99	1.13	1.64
C/N ratio	32.90: 1	16.33: 1	29.98: 1	17.99: 1
Total phosphorus (%P)	0.36	2.70	0.60	0.52
Total potassium (%K)	0.88	1.40	0.46	0.73
Volatile fatty acid (meq/kg)	8.00	6.00	11.36	5.00

that the percentages of moisture content, total solids, organic matter, organic carbon, total nitrogen, total phosphorus, and total potassium, respectively, for kitchen waste, poultry manure, cattle dung and starter were (59.79, 70.00, 75.00, 81.00, 90.00%), (30.00, 25.00, 19.00, 10.00%), (94.72, 82.48, 58.41, 50.87%), (54.94, 47.84, 33.88, 29.50%), (1.67, 2.99, 1.13, 1.64%), (0.36, 2.70, 0.60, 0.52%) and (0.88, 1.40, 0.46, 0.73%). But, the ash contents for kitchen waste, poultry manure, cattle dung and starter were determined to be 5.28, 17.52, 41.59 and 49.13%, respectively. Additionally, these results demonstrated that poultry manure ammoniacal nitrogen content (2918 ppm) was higher than kitchen waste (575 ppm) and also higher than starter and cattle dung (521 and 445 ppm, respectively). The amounts of volatile fatty acids in kitchen waste, poultry manure, cattle dung and starter, however, were 8.00, 6.00, 11.36, and 5.00 meq/Kg, respectively. The obtained outcomes concur with those that were reported by **Estefanous *et al.* (2010), Afifi *et al.* (2020) and El-Khayat *et al.* (2021).** They discovered similar results.

Changes of total bacterial count during of different mixtures of wastes at initial and after anaerobic digestion

Changes of total bacterial count during of different mixtures of wastes throughout the anaerobic digestion are shown in Table 2. The numbers of total bacterial count at initial of anaerobic digestion for all fermenters were between 1.65 × 10^6 and 9.71 × 10^6 cfu/mL. These numbers decreased during after anaerobic digestion to be between 0.76 × 10^6 and 3.24 × 10^6 cfu/mL. This might be because of one or more of these factors: rivalry, hostility and anaerobic circumstances. The acquired results are similar to those attained by **Afifi *et al.* (2020)** found that all biogas slurry produced from poultry manure by anaerobic co-digestion with kitchen wastes contains a respectable quantity of total count bacterial, fungi, and actinomycetes.

Table 2. Changes of total bacterial count and pathogenic bacteria (cfu/mL) during of different mixtures of wastes at initial and after anaerobic digestion.

Treatments	**Total bacterial count × 10^6**		**Total coliform×10^5**		**Faecal Coliform × 10^4**		***Salmonella* and *Shigella* × 10^4**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
T1	9.71	3.24	56.62	nd	25.09	nd	4.25	nd
T2	3.08	0.76	60.65	nd	32.52	nd	6.41	nd
T3	7.15	2.09	55.18	nd	29.14	nd	3.79	nd
T4	8.23	2.95	52.14	nd	21.13	nd	2.51	nd
T5	5.87	1.85	43.96	nd	17.65	nd	2.03	nd
T6	4.56	1.14	35.41	nd	12.14	nd	1.35	nd
T7	1.65	0.92	49.24	nd	30.08	nd	4.21	nd

T1: cattle dung + starter + water, T2: poultry manure + starter + water, T3: kitchen waste + starter + water, T4: cattle dung + kitchen waste + starter + water, T5: cattle dung + kitchen waste + poultry manure + starter + water, T6: poultry manure+ kitchen waste + starter + water, T7: poultry manure+ cattle dung + starter + water.

Changes of pathogenic bacteria during of different mixtures of wastes at initial and after anaerobic digestion:

Total and fecal coliform bacteria and *Salmonella & Shigella* were observed during the anaerobic digestion in all fermenters. Their counts are illustrated in Table 2. The number of total coliform bacteria were higher than fecal coliform bacteria (12.14 × 10^4 and 32.52 × 10^4 cfu/mL) and also higher than *Salmonella & Shigella* (1.35 × 10^4 and 6.41 × 10^4 cfu/mL) at initial of anaerobic digestion. After anaerobic digestion, the total and faecal coliform count as well as *Salmonella & Shigella* were not discovered. This may be due to one or more of the following: competition, animosity and anaerobic conditions. The results obtained are consistent with what was reported by **Afifi *et al.* (2020)** found no harmful bacteria were present in any of the biogas slurry produced from poultry manure through anaerobic co-digestion with kitchen refuses. According to **Estefanous *et al.* (2010),** the colonies of total coliform bacteria could not be discovered in the sample after 7 weeks, although faecal coliform bacteria could not be found after 6 weeks. By extending the time that municipal solid waste spends in the anaerobic fermentation process, *Shigella and Salmonella* are not found at the end of the fifth week of fermentation.

Changes of cellulose decomposers (aerobic and anaerobic) during of different mixtures of wastes at initial and after anaerobic digestion

The number of aerobic and anaerobic cellulose decomposing bacteria during of different mixtures of wastes at initial and after anaerobic digestion are displayed in Table 3. The collected data revealed that the number of aerobic and anaerobic cellulose decomposers bacteria at initial anaerobic digestion ranged between (0.35×10^3 and 1.95×10^3 MPN/mL)for aerobic cellulose decomposers bacteria and (0.02×10^3 and 0.47×10^3 MPN/mL) for anaerobic cellulose decomposers bacteria. After anaerobic digestion, the populations of aerobic cellulose-decomposing bacteria reduced across all fermenters. The highest numbers were in T1 (cattle dung, starter and water). On the other hand, after anaerobic digestion in all fermenters, the populations of anaerobic cellulose-decomposing bacteria increased. This may be due to one or more of the following: competition, animosity and anaerobic conditions. **El-Khayat *et al.* (2021)** documented the outcomes. They came upon similar findings.

Changes of acid producing bacteria (aerobic and anaerobic) during of different mixtures of wastes at initial and after anaerobic digestion

Changes of aerobic and anaerobic acid producing bacteria during of different mixtures of wastes at initial and after anaerobic digestion are presented in Table 3. In general, the results showed that the numbers of acid producing bacteria, whether aerobic or anaerobic were high numbers at the beginning of the anaerobic fermentation process, ranging between (0.25×10^6 and 0.87×10^6 MPN/mL) for aerobic acid producing bacteria and (0.18×10^6 and 0.69×10^6 MPN/mL) for anaerobic acid producing bacteria. The results also showed that T1 was recorded the highest numbers of acid producing bacteria (aerobic or anaerobic). In contrast, these numbers decreased after the anaerobic fermentation process in all treatments. The obtained outcomes concur with those that were reported by **El-Akshar (2000) and El-Khayat *et al.* (2021).** They discovered that the anaerobic acid-producing bacteria steadily rose with the progression of fermentation, peaked at the 21st day, and then gradually reduced until the anaerobic digestion process was completed.

Changes of volatile fatty acids, ammoniacal nitrogen and pH values during of different mixtures of wastes at initial and after anaerobic digestion

The anaerobic digestion method has the potential to be used in the manufacturing of fertilizers and biofuels. However, this method has significant operational limitations in terms of the physicochemical characteristics of the feedstock, such as the biodigester setup parameters (e.g., VFA, pH, and $NH4 – N$) that affect anaerobic digestion stability and performance. Data in Table 4 illustrates how the volatile fatty acid, ammoniacal nitrogen, and pH values changed throughout the initial and after anaerobic digestion. The results showed that the values of volatile fatty acids were highly concentrated at the beginning of the anaerobic digestion process in all treatments, where the concentrations ranged between 2850.21-1984.06 ppm. The results also showed that the highest concentration of volatile fatty acids was in T1 (cattle dung + starter + water) and the lowest concentration was in T2 (poultry manure + starter + water).

Table 3. Changes of cellulose decomposers and acid producing bacteria (aerobic and anaerobic) during of different mixtures of wastes at initial and after anaerobic digestion.

Treatments	**Cellulose decomposers**				**Acid producers**			
	Aerobic × 10^3 (MPN/mL)		**Anaerobic × 10^3 (MPN/mL)**		**Aerobic × 10^6 (MPN/mL)**		**Anaerobic × 10^6 (MPN/mL)**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
T1	1.95	0.21	0.47	2.06	0.87	0.13	0.69	0.19
T2	0.51	0.02	0.02	0.87	0.25	0.002	0.18	0.002
T3	0.49	0.09	0.05	1.65	0.65	0.06	0.35	0.08
T4	1.65	0.17	0.32	1.87	0.74	0.09	0.57	0.13
T5	1.35	0.19	0.38	1.57	0.47	0.03	0.46	0.05
T6	0.35	0.04	0.09	1.42	0.39	0.01	0.39	0.03
T7	1.29	0.14	0.31	1.25	0.42	0.005	0.29	0.007

Table 4. Changes of volatile fatty acids as acetic acid, ammoniacal nitrogen and pH during of different mixtures of wastes at initial and after anaerobic digestion.

Treatments	**Volatile fatty acids (ppm)**		**pH**		**NH_4-N (ppm)**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**
T1	2850.21	509.49	7.06	7.85	195.00	53.00
T2	1984.06	1325.02	7.11	7.65	450.00	120.00
T3	2584.09	875.61	7.09	7.95	315.00	65.00
T4	2687.41	625.24	7.25	7.87	229.00	63.00
T5	2410.03	951.76	7.18	8.02	435.00	110.00
T6	2251.17	1087.94	7.05	7.79	489.00	135.00
T7	2009.72	1298.07	7.13	7.83	405.00	97.00

The results also showed that the anaerobic co digestion process of kitchen wastes with cattle dung wastes gave a concentration of volatile fatty acids, in contrast to the mono-anaerobic digestion of poultry manure. Then, following anaerobic digestion, VFA levels fell. This decrease may be related to methane bacteria consuming VFAs during anaerobic digestion. The obtained results were consistent with those of **Ali *et al.* (2020), Afifi *et al.* (2020), El-Khayat *et al.* (2021) and Ali *et al.* (2022)** they reported that the concentration of VFAs dropped with increased fermentation, possibly as a result of the VFAs that were transformed into CO_2 and CH_4 by methane bacteria.In this experiment, the pH values were low at the beginning, as these values ranged between 7.05 - 7.25 in all fermenters, then these values increased at the end of the anaerobic fermentation process in all fermenters, where the values ranged between 7.65 – 8.02. This may be due to $CaCO_3$ buffer in the initial wastes mixture and the natural decomposition of this material. These results were similar to those reported by **Maria *et al.* (2019), Afifi *et al.* (2020), El-Khayat *et al.* (2021) and Ali *et al.* (2022).** They discovered similar results. Due to the action of acid-producing bacteria (VFA generation) in the biodigester during biogas production, pH values changed frequently **(Ali *et al.*, 2020)**. **Ali *et al.* (2022)** found that showed that there was a progressive rise in VFA concentration and a reduction in pH throughout the early stages of AD. The relationship between pH values and VFA variations was often inverse. **Kothari *et al.* (2014)** observed that the pH level has a direct impact on the AD process. They found that the pH range of 6.6 to 8.2 is ideal for the growth and activity of bacteria that produce CH_4. The rate of methanogen development is significantly slowed at pH levels below 6.6, and as a result, methanogenic bacterial activity decreases.

In contrast, the results showed that the concentration of NH_4–N in all treatments ranged from 195 to 489 ppm at the start of the fermentation process and fell to between 53 and 135 ppm after the anaerobic fermentation process. These reductions could be the result of bacteria cells converting organic nitrogen through transformation or volatilization. These outcomes concur with those mentioned by **Estefanous *et al.* (2010), Afifi *et al.* (2020) and El-Khayat *et al.* (2021).** They came upon similar findings.

Changes of some chemical properties during of different mixtures of wastes at initial and after anaerobic digestion

Changes of the percentages of total nitrogen, total phosphorus and total potassium during of different mixtures of wastes at initial and after anaerobic digestion were illustrated in Table 5. The obtained results revealed that the percentage of total nitrogen, total phosphorus and total potassium were increased after anaerobic digestion. These increases could be the result of the total and volatile solids being consumed, which then produces products like CH_4, CO_2, and others. These results are in agreement with those reported by **Estefanous *et al.* (2010), Afifi *et al.* (2020) and El-Khayat *et al.* (2021).** They discovered similar results. According to **Shen *et al.* (2013)**, an insufficient C/N ratio of the input (substrates) decreases organic matter while increasing TN content and VFA formation. Their accumulation in the digester diminishes biogas and CH_4 output. The mineralization and breakdown of organic nitrogen may be the cause of the increase in TN during the AD process. According to **Rajagopal *et al.* (2013)**, elevated ammonium nitrogen levels cause VFA accumulation and injury to CH_4-producing bacteria. For microbial nutritional homeostasis, the ideal C/N ratio is essential. This may help to explain why, at the conclusion of HRT, biogas output declined at low C/N ratios. Due to the variation in OM, TN, and minerals (macro- and/or micro-nutrients) of organic substrates, AD of the sole substrate in this context is not an effective technique when compared to co-digestion process. This variation increases the possibility that microbial populations may develop and enhance their metabolic processes, leading to an improvement in the output and quality of fertiliser and biogas. In order to increase biogas productivity, it is possible to combine organic wastes with a high carbon content with other wastes, such as animal dung or food wastes, to achieve the right VFAs concentration and C/N ratio. This will encourage the growth of the bacterial population in the biodigester, specifically the CH4-producing bacteria and the acid-producing bacteria (**Ali *et al.*, 2022)**.

Table 5. Changes of some chemical properties during of different mixtures of wastes at initial and after anaerobic digestion.

Treatments	Total nitrogen (%)		Total phosphorus (%)		Total potassium (%)	
	Initial	Final	Initial	Final	Initial	Final
T1	1.11	1.67	0.52	0.81	0.69	0.97
T2	2.85	3.75	1.45	2.09	0.92	1.49
T3	1.59	1.85	0.40	0.67	0.87	1.21
T4	1.37	1.93	0.54	0.86	0.78	1.09
T5	1.75	2.41	1.21	1.89	0.97	1.65
T6	2.14	2.53	0.99	1.69	0.90	1.53
T7	1.99	2.34	1.19	1.93	0.80	1.19

Rate of organic material decomposition inside the digesters:

The changes of total solids (TS) and volatile solids (VS) during of different mixtures of wastes at initial and after anaerobic digestion were illustrated in Table 6. The obtained results revealed that the percentage of TS at the initial of the experiment for all treatments was about 10 % with a weight about 300 g. The percentage of VS at the beginning of the experiment also ranged between 60.36 - 92.66% with a weight ranging between 181.08 – 277.98 g. As the findings showed that after anaerobic digestion the amount of TS and VS were reduced in all treatments. These values were ranged between 4.57 – 5.68 % of TS and 18.15 – 120.78 % of VS after anaerobic digestion. The losses percentage of TS and VS after anaerobic digestion ranged between 43.17 – 54.31 % of TS and 54.13 – 89.98 % of VS. These reductions could be caused by the total solids and a volatile solid, which has taken the form of gases and water. The obtained outcomes concur with those that were reported by **Afifi *et al.* (2020) and El-Khayat *et al.* (2021)**. They found similar results.

Daily and cumulative biogas production during of different mixtures of wastes at initial and after anaerobic digestion:

Daily biogas production either liter/digester/day or liter/liter/day during of different mixtures of wastes at initial and after anaerobic digestion are depicted by Fig. 1. The results gathered indicated that no biogas was produced by the fermented materials on the first day. Anaerobic bacteria need a lag time (almost one day) before they can start producing biogas from the substrates they use to ferment. The results showed that there were fluctuations in the daily biogas production in all treatments, as the daily biogas production started after the 2nd day of the beginning of the experiment in some fermenters and others after different time periods, then it was observed that the daily biogas production increased until it reached the highest daily biogas production on day 26th as in treatments (T1, T4, T5, T6 and T7) and on day 28th as in treatments (T2 and T3). On the other hand, the results also showed that the highest cumulative biogas production was in (T1) and the lowest cumulative biogas production was in (T2). The

Table 6. Changes of total solids and volatile solids during of different mixtures of wastes at initial and after anaerobic digestion.

Treatments	**Total solids (TS)**						**Volatile solids (VS)**					
	as %		**as g**		**Losses**		**as %**		**as g**		**Losses**	
	Initial	**Final**	**Initial**	**Final**	**%**	**g**	**Initial**	**Final**	**Initial**	**Final**	**%**	**g**
T1	10.00	4.57	300.00	137.07	54.31	162.93	60.36	13.24	181.08	18.15	89.98	162.93
T2	10.00	5.68	300.00	170.50	43.17	129.50	79.75	64.37	239.25	109.75	54.13	129.50
T3	10.00	4.76	300.00	142.80	52.40	157.20	92.66	84.58	277.98	120.78	56.55	157.20
T4	10.00	4.66	300.00	139.68	53.44	160.32	73.55	43.19	220.65	60.33	72.66	160.32
T5	10.00	4.93	300.00	147.75	50.75	152.25	61.54	21.91	184.62	32.37	82.47	152.25
T6	10.00	5.11	300.00	153.40	48.87	146.60	78.11	57.19	234.33	87.73	62.56	146.60
T7	10.00	5.34	300.00	160.17	46.61	139.83	65.44	35.27	196.32	56.49	71.22	139.83
LSD (0.05)		2.39		8.32	6.42	7.57	7.53	6.95	33.02	5.13	5.20	5.57

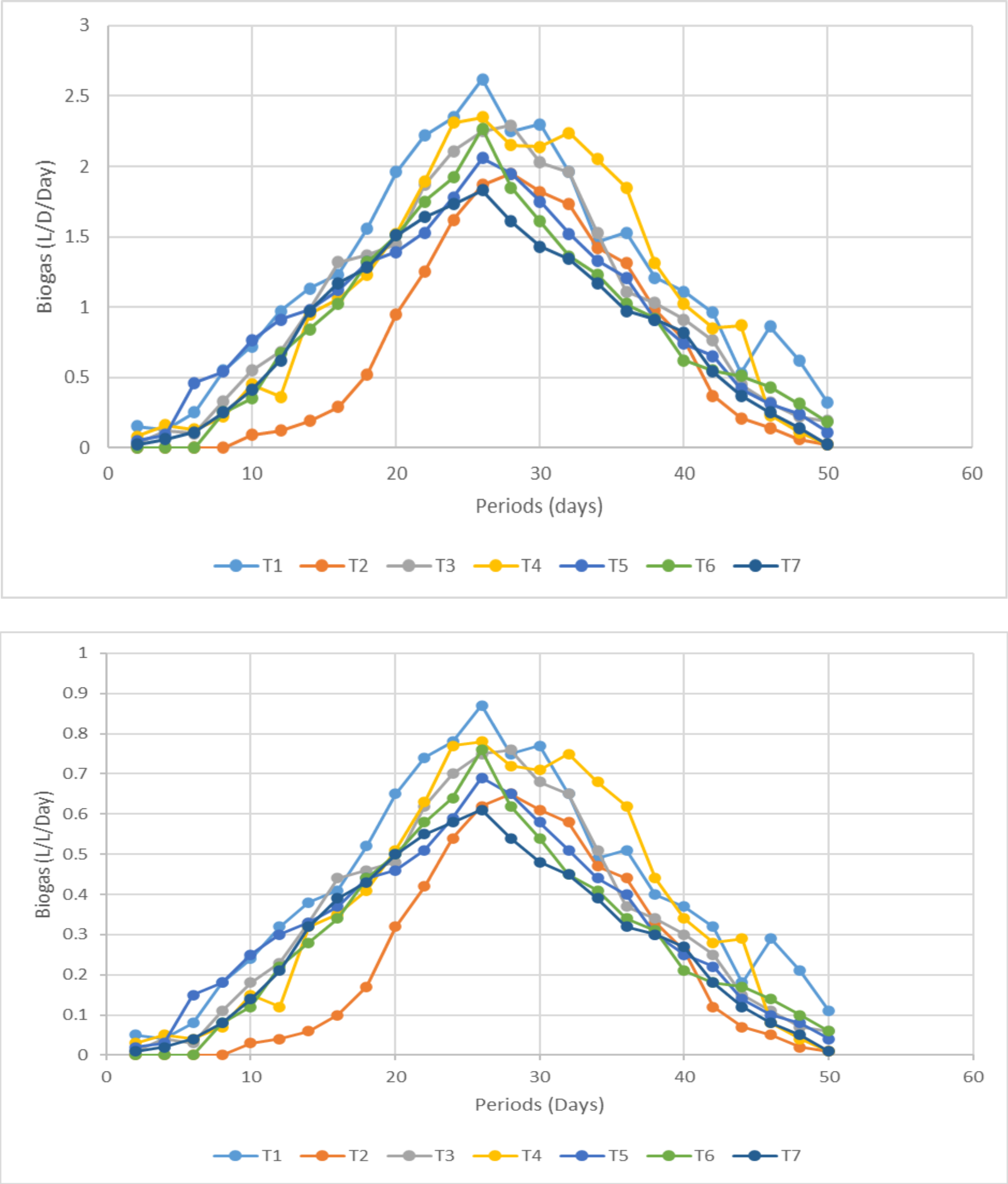

Fig. 1. Daily biogas production either liter/digester/day or liter/liter/day during of different mixtures of wastes at initial and after anaerobic digestion.

results also showed that the anaerobic co digestion of kitchen waste with cattle dung as in (T4) gave a high amount of cumulative biogas compared to the amount of cumulative biogas resulting from the mono-anaerobic digestion of kitchen waste as in (T3). The results obtained are in line with those published by **Ali *et al.* (2022)**, who investigated the techno-economic consequences of anaerobic co-digestion of water hyacinth (WH) and cattle dung (CD) to optimise their mixing ratios for increasing methane (CH_4) generation. The highest concentration of biogas and CH_4 was obtained at a 1:1 mixing ratio. By 111.3 and 173.6% more than CD, the co-digestion technology enhanced biogas and CH_4 generation. The highest daily CH_4 content was 67.11% on day 13. According to **Afifi *et al.* (2020)**, the biogas yield was at its highest with starters, poultry manure, and kitchen waste in the digester from the sixth to the fifteenth day of the process. During this time, the digester reached its highest daily biogas yield (220 L/day). Additionally, they discovered that digester contents including kitchen waste, poultry manure, and starter had a higher cumulative biogas yield (500 L cumulative biogas yield/day) than other digesters after a fermentation time of about 42 days.

Daily and cumulative methane production during of different mixtures of wastes at initial and after anaerobic digestion:

Daily methane production either liter/digester/day or liter/liter/day during of different mixtures of wastes at initial and after anaerobic digestion are illustrated by Fig. 2. The results showed that the daily methane production started after the 2nd day of the beginning of the experiment in some fermenters and others after different time periods. The results also showed that the daily methane production, whether (liter/digester/day) or (liter/liter/day), was gradually increasing until it reached its highest production daily on day 26th as in fermenters (T1, T4, T5, T6 and T7) and on day 28th as in fermenters (T2 and T3). Then, the daily methane production began to decrease until the end of anaerobic digestion. In the same context, the results showed that the highest cumulative methane production was produced from T1 (cattle dung, starter and water) and on the other hand, the lowest cumulative methane production was caused by T2 (poultry manure, starter and water). The results also showed that the anaerobic co digestion of kitchen waste with cattle dung as in (T4) gave a high amount of cumulative methane compared to the amount of cumulative methane resulting from the mono-anaerobic digestion of kitchen waste as in (T3). The acquired results are in agreements with those reported by **Estefanous *et al.* (2010), Afifi *et al.* (2020), El-Khayat *et al.* (2021) and Ali *et al.* (2022)**. They came upon similar findings.

Gases quality of methane and carbon dioxide

The evaluation of the gas characteristics and the resulting findings are shown in Fig. 3. In order to evaluate the biogas gas produced from the experiment, a chemical analysis of the resulting gas was conducted to find out its chemical composition of methane and carbon dioxide, as they are the two main components of biogas. The obtained results showed that the percentage of methane gas increased gradually until it reached its highest concentration on day 26th as in the treatments (T1, T4, T5, T6 and T7) and day 28th as in the treatments (T2 and T3) and then gradually decreased until the end of the experiment. The increased activity of lytic bacteria for organic matter may be responsible for the elevated methane percentages that were seen throughout the period of 26 to 28 days. On the other hand, it was found that the percentage of carbon dioxide gas took an opposite path to methane gas, where it was found that the concentration of carbon dioxide gas was initially high and then gradually decreased until it reached its lowest concentration after about 26th days, as in the treatments (T1, T4, T5, T6 and T7) and after 28th day as in the treatments (T2 and T3) and then after it increased gradually until the end of the experiment. The results also showed that the highest average percentage of methane gas production was from treatment T1 (cattle dung, starter and water) and the lowest average percentage of methane gas production was from treatment T2 (poultry manure, starter and water). The results also showed that the anaerobic co digestion of kitchen waste with cattle manure and starter (T4) improved the average percentage of methane gas compared to the mono anaerobic digestion of kitchen waste (T3). This finding was in accordance with that

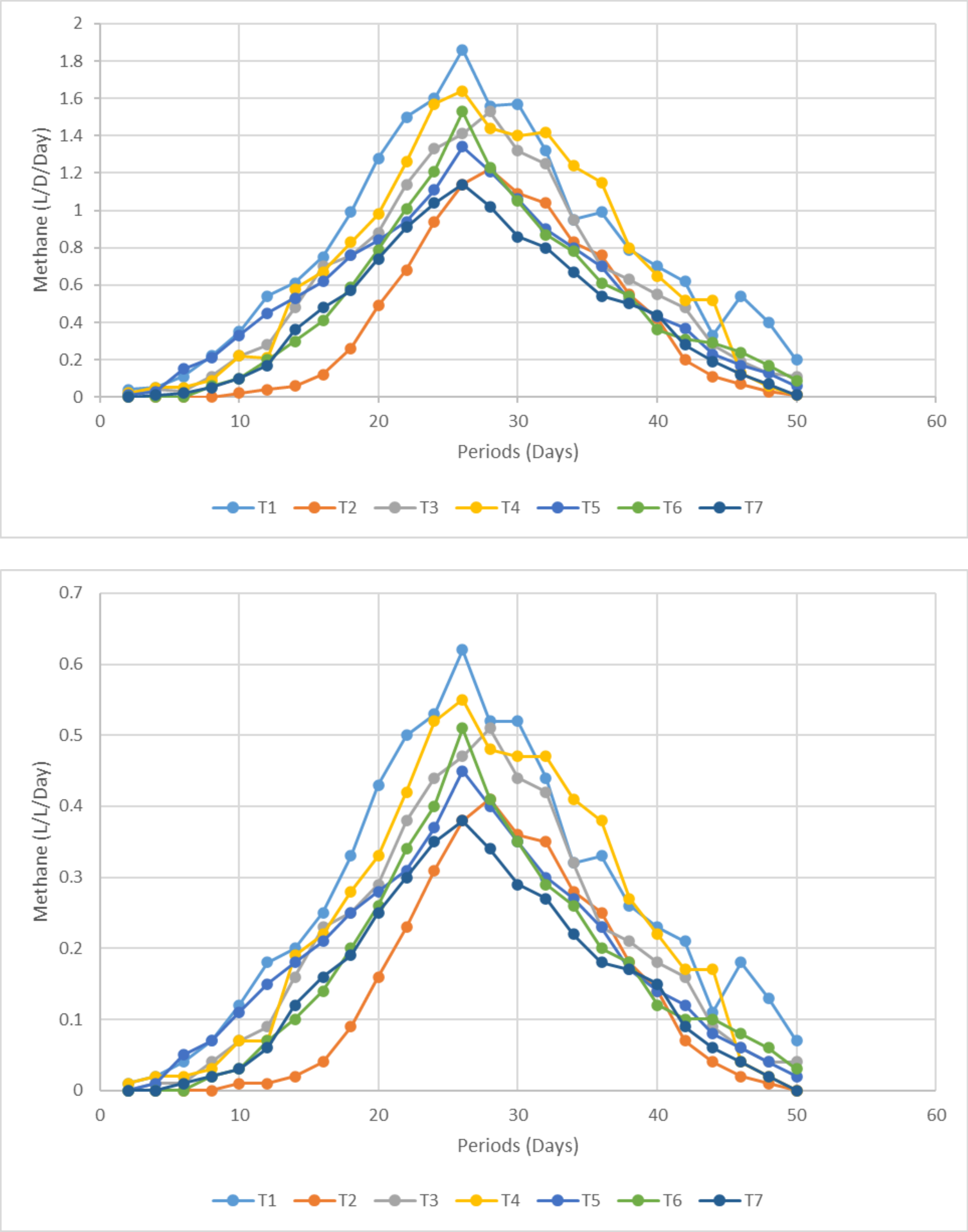

Fig. 2. Daily Methane production either liter/digester/day or liter/liter/day during of different mixtures of wastes at initial and after anaerobic digestion.

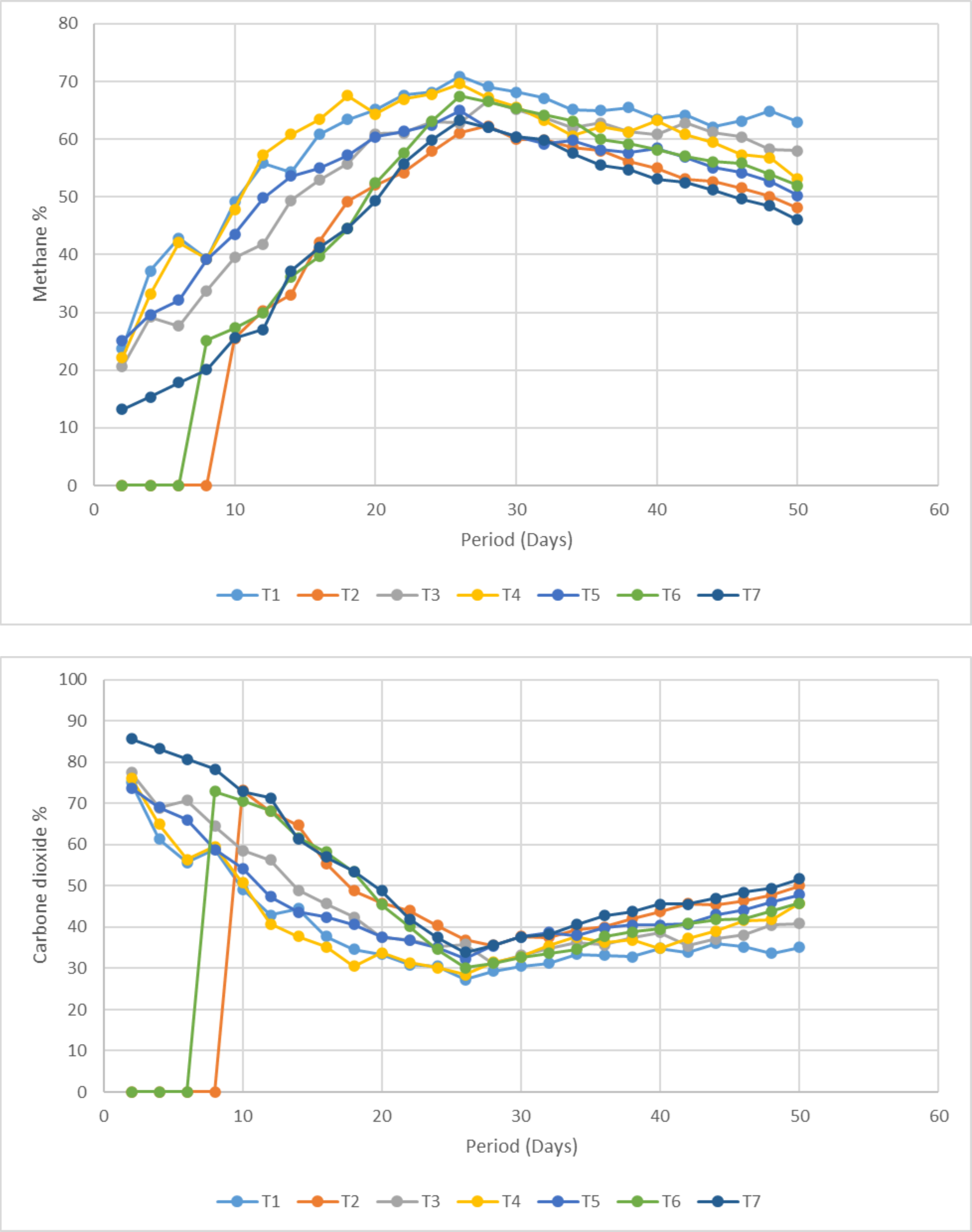

Fig. 3. Periodical gaseous analysis of produced biogas during of different mixtures of wastes at initial and after anaerobic digestion.

obtained by **Afifi *et al.* (2020), El-Khayat *et al.* (2021) and Ali *et al.* (2022)**. They came upon similar findings.

Biogas and methane production rates

Data in Table 7 shows the generation rates of biogas and methane for various waste mixtures, calculated as liter/kg total solids added or consumed as well as liter/kg volatile solids added or consumed. The acquired data unmistakably demonstrate that the rates of biogas and methane production varied significantly depending on the kind of the various waste mixtures. The obtained results showed that the rate of biogas production as TS added ranged from 58.93 to 103.17 L/kg and the biogas production rate as VS added ranged from 73.90 to 170.92 L/Kg. The results also showed that the biogas production rate as TS or VS consumed ranged from136.53 to 189.96 L/Kg. However, the data obtained indicated that the rate of methane production as TS added varied from 33.60 to 66.23 L/kg, whereas the rate as VS added varied from 42.13 to 109.73 L/Kg. The outcomes also demonstrated that the biogas generation rate ranged from 77.84 to 121.95 L/Kg as TS or VS were consumed. Additionally, the findings that T1 had the highest biogas and methane production rates based on total solid or volatile solids added or consumed can be explained by the high activity of lytic bacteria of organic materials. The results also showed that anaerobic co digestion had an effective effect in increasing the rate of biogas and methane production (liter/kg), where the rate of gas production in T4 (cattle dung, kitchen waste, starter and water) was higher than T3 (kitchen waste, starter and water). The obtained results are consistent with those reported by **Rozy *et al.* (2017)** discovered that after 40 days of HRT, biogas production reached 44.9 L/kg under ideal circumstances. **Omondi *et al.* (2019)** obtained a 52 L/kg of WH CH_4 output. But when ruminal slaughterhouse wastes were also digested, CH_4 generation rose to 14.09 L/kg. This demonstrates the significance of co-digestion in raising CH_4 concentration and generation. **Zhang *et al.* (2017)** found that the CH_4 level changed in mesophilic conditions between 53 and 58%. The refractory nature of lignocellulosic wastes is altered by pretreatment of lignocellulosic substrates, however, and they become more vulnerable to microbial attack. Following co-digestion, the solids concentration decreased by 10.1%. CH_4 production increased noticeably (36.3%) after co-digesting municipal solid waste and pretreatment maize cob **(Surra *et al.*, 2018)**.

Conclusions

Fossil fuels are still the dominant source of energy in developing countries, despite being expensive and unsustainable from an environmental standpoint. In this study, kitchen waste, poultry manure, and cattle dung were used to produce biogas. From the results mentioned above, it was concluded that the anaerobic co digestion process of kitchen waste with cattle dung and poultry manure produced large amounts of biogas, and thus the problems of anaerobic mono digestion of kitchen waste or poultry manure were overcome.

References

Abbas, Y., Yun, S., Mehmood, A., Shah, F.A., Wang, K., Eldin, E.T., Al-Qahtani, W.H., Ali, S., Bocchetta, P. 2023. Co-digestion of cow manure and food waste for biogas enhancement and nutrients revival in bio-circular economy. Chemosphere, 311, 137018. https://doi.org/10.1016/j.chemosphere.2022.137018.

Table 7. Biogas and methane production during of different mixtures of wastes at initial and after anaerobic digestion.

Treatments	Biogas production					Methane production					
	Total Liter	L/Kg TS added	L/Kg TS consumed	L/Kg VS added	L/Kg VS consumed	% of biogas produced	Total Liter	L/Kg TS added	L/Kg TS consumed	L/Kg VS added	L/Kg VS consumed
T1	30.95	103.17	189.96	170.92	189.96	59.18	19.87	66.23	121.95	109.73	121.95
T2	17.68	58.93	136.53	73.90	136.53	42.84	10.08	33.60	77.84	42.13	77.84
T3	25.96	86.53	165.14	93.39	165.14	53.67	15.51	51.70	98.67	55.80	98.67
T4	27.55	91.83	171.84	124.86	171.84	57.33	17.51	58.37	109.22	79.36	109.22
T5	24.13	80.43	158.49	130.70	158.49	52.77	13.88	46.27	91.17	75.18	91.17
T6	22.49	74.97	153.41	95.98	153.41	46.20	12.75	42.50	86.97	54.41	86.97
T7	21.17	70.57	151.40	107.83	151.40	44.86	11.10	37.00	79.38	56.54	79.38
LSD (0.05)	4.96	5.376	5.118	5.411	4.488	5.92	2.99	4.41	4.77	5.58	4.15

ADP (Agricultural Development Program) 2016. Bioconversion of agricultural residues in to compost for improving crop productively and environmental protection project 2015-2016.

Afifi, M.M.I., Mahmoud, Y.I., Sendaaza, C. 2020. Biogas generation from co-digestion manure, poultry waste and kitchen refuses. N. Egypt. J. Microbiol. (55), 94-112.

Ajay, C.M., Mohan, S., Dinesha, P. 2021. Decentralized energy from portable biogas digesters using domestic kitchen waste: a review. Waste Manage., (125), 10–26.

Ali, S.S., Al-Tohamy, R.; Manni, A., Luz, F.C., Elsamahy, T., Sun, J. 2019. Enhanced digestion of bio-pretreated sawdust using a novel bacterial consortium: microbial community structure and methane-producing pathways. Fuel, (254), 115604.

Ali, S.S., Elsamahy, T., Abdelfattah, A., Mustafa, A.M., Khalil, M.A., Mastropetros, S.G., Kornaros, M., Sun, J., Azab, M. 2022. Exploring the potential of anaerobic co-digestion of water hyacinth and cattle dung for enhanced biomethanation and techno-economic feasibility. Fuel, (329), 125397. https://doi.org/10.1016/j.fuel.2022.125397.

Ali, S.S., Kornaros, M., Manni, A., Sun, J., El-Shanshoury, A.R., Kenawy, E.R. 2020. Enhanced anaerobic digestion performance by two artificially constructed microbial consortia capable of woody biomass degradation and chlorophenols detoxification. J. Hazard Mater, (389), 122076.

Ali, S.S., Mustafa, A.M., Sun, J. 2021. Wood–feeding termites as an obscure yet promising source of bacteria for biodegradation and detoxification of creosote-treated wood along with methane production enhancement. Bioresour Technol., (338), 125521.

Ali, S.S., Mustafa, A.M., Kornaros, M., Manni, A., Sun, J., Khalil, M.A. 2020. Construction of novel microbial consortia CS-5 and BC-4 valued for the degradation of catalpa sawdust and chlorophenols simultaneously with enhancing methane production. Bioresour Technol., (301), 122720.

Allen, O.N. 1959. Experiments in Soil Bacteriology.1st ed. Burges Publ. co. Minnesota USA, 117 p.

Amodeo, C., Hattou. S., Buffiere, P., Benbelkacem, H. 2021. Temperature phased anaerobic digestion (TPAD) of organic fraction of municipal solid waste (OFMSW) and digested sludge (DS): Effect of different hydrolysis conditions. Waste Manag., (126), 21–9. https://doi.org/10.1016/j.wasman.2021.02.049.

APHA; American Publich Health, Association. (1992). Standard methods for the examination of water and wastewater. 18th, Washington, D.C.

Awe, O.W., Zhao, Y., Nzihou, A., Minh, D. P., Lyczko, N. 2017. A Review of Biogas Utilization, Purification and Upgrading Technologies. Waste Biomass Valor, (8), 267-283.

Berghuis, B.A., Yu, F.B., Schulz, F., Blainey, P.C., Woyke, T., Quake, S.R. 2019. Hydrogenotrophic methanogenesis in archaeal phylum Verstraetearchaeota reveals the shared ancestry of all methanogens. Proc. Natl. Acad. Sci. USA, 116(11), 5037–44.

Böjti, T., Kovács, K.L., Kakuk, B., Wirth, R., Rákhely, G., Bagi, Z. 2017. Pretreatment of poultry manure for efficient biogas production as monosubstrate or co-fermentation with maize silage and corn stover. Anaerobe, (46), 138-145. http://dx.doi.org/10.1016/j.anaerobe.2017.03.017.

Chhandama, M.V.L., Chetia, A.C., Satyan, K.B., Ao, S., Ruatpuia, J.V.L., Rokhum, S.L. 2022. Valorisation of food waste to sustainable energy and other value-added products: a review. Bioresour Technol. Reports, (17), 100945.

Cochran, W. G. 1950. Estimation of bacteria densities by means of the "most probable number." Biometrics, (6), 105-116.

Cunningham, A. 1954. Practical Bacteriology. 2nd Ed. Oliver and Boyed, Edinburgh and London.

Deena, S.R., Vickram, A.S., Manikandan, S., Subbaiya, R., Karmegam, N., Ravindran, B. 2022. Enhanced biogas production from food waste and activated sludge using advanced techniques–A review. Bioresour Technol., (355), 127234.

Difico, Manual 1985. Manual of Dehydrated Culture Media and Reagents of Microbiology. 10th Ed. Difico Laboratories, Detroit, MI, USA.

El-Akshar, Y. S. 2000. Microbiological studies on anaerobic digestion of solid and liquid wastes. M.Sc., Thesis Fac. of Agric., Moshtohor, Zagazig University.

El-Khayat, R.M., Ali, F.F., Saad, S.M.M., Abou-Aly, H.E. 2021. Production of Biogas by Using Different Pretreatments of Rice Straw Under Aerobic and Semi Aerobic Conditions. 5th International Conference on Biotechnology Applications in Agriculture (ICBAA), Benha University, 8 April 2021, Egypt (Conference Online), 349-360.

Estefanous, A.N., El-Akshar, Y.S., El-Sayed, G.A.M., Amal, A. H. 2010. Anaerobic digestion of municipal solid waste to produce biogas and organic manure by using leachate recycling. Egypt. J. Biotechnol., (36), 65 – 80.

Flesch T. K., Desjardins, R. L., Worth, D. 2011. Fugitive methane emissions from an agricultural biodigester. Biomass and Bioenergy (35), 3927–3935.

Hagos, K., Zong, J., Li, D., Liu, C., Lu, X.J.R. 2017. Anaerobic co-digestion process for biogas production: progress, challenges and perspectives. Renew. Sust. Energy Rev., (76), 1485–1496.

Hamilton, L.F., Stephen, G.S. 1964. Quantitative chemical analysis. The Macmillan company, New York, 454-459.

Huang, W.P., Fooladi, H. 2021. Economic and environmental estimated assessment of power production from municipal solid waste using anaerobic digestion and landfill gas technologies. Energy Rep., (7), 4460– 9.

Jia, B. 2020. Enhanced anaerobic mono-and co-digestion under mesophilic condition: focusing on the magnetic field and Ti-sphere core–shell structured additives. Bioresour. Technol. (310), 123450.

Jodice, R., Luzzati, A., Nappi, P. 1982. The influence of organic fertilizers, obtained from poplar barks, on the correction of iron chlorosis of *Luipinus albusl*. Plant and Soil, (65), 309 - 317.

Kothari, R., Pandey, A.K., Kumar, S., Tyagi, V.V., Tyagi, S.K. 2014. Different aspects of dry anaerobic digestion for bio-energy: An overview. Renew. Sust. Energ. Rev., (39), 174–95.

Li, Y., Jin, Y.Y. 2015. Effects of thermal pretreatment on acidification phase during two-phase batch anaerobic digestion of kitchen waste. Renewable Energy, (77), 550-557.

Maramba, F. D., Obias, E. D., Julian, B., Taganas, C., Alumbro, R. D., Judan, A. A. 1978. Biogas and waste recycling, the Philippine experience. Maya farms division, liberity flour mills, Inc. Metro Manila, Philippines.

Maria, L.V., Daniel, S., Affonso, C.G., Jr., Alfredo, R., Jéssica, M., Andréiada, P.S., Thiago, B.S. 2019. Production of biogas and biofertilizer using anaerobic reactors with swine manure and glycerin doses. J. Cleaner Production, (213), 176-184.

Omondi, E.A., Njuru, P.G., Ndiba, P.K. 2019. Anaerobic co-digestion of water hyacinth (E. crassipes) with ruminal slaughterhouse waste for biogas production. Int. J. Renew. Energy Dev., 8(3), 253–9.

Page, A. L., Miller, R. H., Keeney, D.R. 1982. Methods of Soil Analysis. Part 2. Soil Soc. Amer. Inc. Madison, Wisconsin, U.S.A., 310 p.

Paritosh, K., Mathur, S., Pareek, N., Vivekanand, V. 2021. Enhancing hydrolysis and syntropy simultaneously in solid state anaerobic digestion: digester performance and techno-economic evaluation. Bioresour. Technol. (338), 125538. https://doi.org/ 10.1016/j.biortech.2021.125538.

Rajagopal, R., Massé, D.I., Singh, G. 2013. A critical review on inhibition of anaerobic digestion process by excess ammonia. Bioresour. Technol., (143), 632–41.

Richards, L. A. 1954. Diagnosis and Improvement of Saline and Alkali Soil. U.S. Dept. Agric., (60) 50-75.

Rozy, R., Dar, R.A., ,Phutela, U.G. 2017. Optimization of biogas production from water hyacinth (Eichhornia crassipes). J. Appl. Nat. Sci., (9), 2062–7.

Sendaaza, C. 2018. Anaerobic digestion of organic waste: A kitchen waste case study. M.Sc., Thesis American Univ. Cairo, Egypt.

Shen, F., Yuan, H., Pang, Y., Chen, S., Zhu, B., Zou, D. 2013. Performances of anaerobic codigestion of fruit & vegetable waste (FVW) and food waste (FW): single-phase vs. two-phase. Bioresour. Technol., (144), 80–5.

Shirzad, M., Kazemi Shariat Panahi, H., Dashti, B.B., Rajaeifar, M.A., Aghbashlo, M., Tabatabaei, M. 2019. A comprehensive review on electricity generation and GHG emission reduction potentials through anaerobic digestion of agricultural and livestock/slaughterhouse wastes in Iran. Renew. Sustain. Energy Rev. (111), 571–594. https://doi.org/10.1016/j.rser.2019.05.011.

Sillero, L., Perez, M., Solera, R. 2023. Temperature-phased enhanced the single-stage anaerobic co-digestion of sewage sludge, wine vinasse and poultry manure: Perspetives for the circular economy. Fuel, (331), 125761. https://doi.org/10.1016/j.fuel.2022.125761.

Snedecor, G.W., Cochran, W.G. 1991. Statistical Method 7 th Ed Iowa State Univ. Press, Iowa, USA.

Solís, B., Guisasola, A., Flores-Alsina, X., Jeppsson, U., Baeza, J.A. 2022. A plant-wide model describing GHG emissions and nutrient recovery options for water resource recovery facilities. Water Res. (215), 118223. https://doi.org/10.1016/j. watres.2022.118223.

Su, G., Ong, H.C., Fattah, I.M.R., Ok, Y.S., Jang, J.H., Wang, C.T. 2022. State-of-the-art of the pyrolysis and co-pyrolysis of food waste: progress and challenges. Sci. Total Environ., (809), 151170.

Surra, E., Bernardo, M., Lapa, N., Esteves, I., Fonseca, I., Mota, J.P. 2018. Maize cob waste pretreatments to enhance biogas production through co-anaerobic digestion with OFMSW. Waste Manage., (72), 193–205.

Wujick, W. J., Jewell, W. J. 1980. Dry anaerobic fermentation. Biotechnology and Bioengineering Symp., (10), 43-65. Jon Willey &Sons, Inc. N.Y.

Yang, Y., Wang, M., Yan, S., Yong, X., Zhang, X., Awasthi, M.K., Xi, Y., Zhou, J. 2023. Effects of hydrochar and biogas slurry reflux on methane production by mixed anaerobic digestion of cow manure and corn straw. Chemosphere, (310), 136876. https://doi.org/10.1016/j.chemosphere.2022.136876.

Yu, Q., Yang, Y.F., Wang, M.W., Zhu, Y.H., Sun, C., Zhang, Y.B. 2021. Enhancing anaerobic digestion of kitchen wastes via combining ethanol-type fermentation with magnetite: potential for stimulating secretion of extracellular polymeric substances. Waste Manage., (127), 10–7.

Zhang, J., Li, W., Lee, J., Loh, K.C., Dai, Y., Tong, Y.W. 2017. Enhancement of biogas production in anaerobic co-digestion of food waste and waste activated sludge by biological co-pretreatment. Energy, (137), 479–86.