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Anaerobic Digestion of Food Wastes under Different Concentrations of Total Solids

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ABSTRACT

Fourth different concentrations of total solids B1, B2, B3, and B4 were prepared using food wastes, calcium carbonate and starter in four digesters to biogas production. The data showed colonies of total coliform bacteria were not detected the 14^{th} day. Fecal coliform bacteria were not detected through the 7^{th} day. Meanwhile, counts of *Salmonella* and *Shigella* were rapidly decreased throughout the anaerobic digestion period to be completely undetected onthe 14^{th} and 21^{st} days for all fomenters. A digested slurry of B3 and B4 exhibited (the highest) records of volatile fatty acids compared to the digested slurry of B1 and B2, respectively. The pH values were favorable to biogas generation and methane production, this was observed at different fermentation periods in both B1 and B2. The toxicity of pH is more pronounced in the fermentors, especially in B3 and B4. Accumulation of ammonia during anaerobic fermentation was 385.52, 462.68, 870.24 and 925.88 ppm in B1, B2, B3, and B4, respectively where it was not reach to level of toxicity or even inhibitive of methanogenic bacteria. The digested slurry of B4 exhibited the highest recorded of volatile fatty acids compared to the digested slurry of other digestions .The Cumulative biogas and methane were higher in B2, B1 than B3, and B4. Biogas and methane production rates (L /Kg) volatile solids consumed were 958.79,755.76, 213.19 and 141.76 for biogas, meanwhile methane was 501.57, 367.82 , 25.36 and 13.41 in digesters B2, B1, B3 and B4, respectively.

Keywords: Anaerobic digestion, Biogas, Food wastes, Total solids

Introduction

The environmental challenges related to the global population growth and the global energy demand are continuously promoting research efforts to develop innovative technologies aimed at producing energy from non-conventional sources (Lay *et al*., 1997 and Mussoline *et al.,* 2013). Food wastes are variably sourced from residential, commercial establishments, institutional and industrial activities, its characterized with high contents of moisture (about 70–80% of water) and biodegradable organics (about 18–31% of total solids) and account for 40–50% of the weight of municipal solid waste (MSW), according to the eating behaviors of populations in various countries (Zhang *et al*., 2011and 2013) which make the reuse of it is a favorable option for energy recovery and cost-effective municipal solid waste reduction using anaerobic digestion technology. In Egypt, food wastes are generated at an ever-increasing with the excessive population growth and their activities which attains about 50% vegetables and fruits, 40% fish wastes and 30% milk, in addition to amount of wheat losses and waste reaches 1.5 million tons/per annual (Elmenofi *et al*., 2015).

Anaerobic digestion is biochemically processed in a successive multi-stagesby which the biodegradable and high molecular weight organic matter succumb to hydrolysis acidogenesis, and methanogenesis and each is metabolically functioned through the activities of fermentative bacteria, producing small molecular weight substrates (Veeken and Hamelers, 1999; Guo *et al.,* 2014). Based on the total solids (TS) content of feedstocks, three main types of anaerobic digestion technologies have been developed including 1) Conventional wet (≤10% TS); 2) Semi-dry (10–20% TS) and 3) Modern dry (≥20% TS) processes.

The dry anaerobic digestion, pronounced as ‘‘high-solids’’ technology, has become attractive and was applied widely because it requires smaller reactor volume, lower energy requirements for heating, less material handling, and so on (Forster-Carneiro *et al.,* 2008; Duan *et al*., 2012). The TS contents of solid waste influences anaerobic digestion performance, especially biogas and methane

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production efficiency (Pavan *et al.,* 2000). Abbassi-Guendouz *et al*., (2012) found that the methane production slightly decreased with TS concentrations increasing from 10 to 25% TS in batch anaerobic digestion of cardboard under mesophilic conditions.

The present study aimed to investigate the effect of different total solid concentrations on biogas production from food wastes by using a batch system.

Materials and Methods

1. Materials

1.1. Food wastes:

Large quantities of food wastes (FW) were collected from Kentucky Fried Chicken (KFC) restaurant, El-Tahrir, Cairo Governorate, Egypt. Random samples from the collected wastes were picked up to determine their chemical analysis as shown in Table (1).

1.2. Starter:

Starter was taken from an old operating biogas digester at Training Center for Recycling of Agricultural Residues (TCRAR), Agric., Res. Center at Moshtohor, Kalubia Governorate**.** Representative samples of FW and the starter were taken and analyzed for several chemical parameters. The results are shown in Table (1).

Table 1: Chemical and physical characteristics of food wastes and starter

Character	Food wastes	Starter
Moisture content (%)	74.10	99
Total solids (%)	25.90	1.00
pH 1:10 raw material: water (w/v)	4.60	7.66
EC1:10 raw material: water (dS.m^{-1})	2.50	10.09
Ammoniacal –N (ppm)	366	125.00
Volatile fatty acids (meq/kg fresh weight)	54	26
Volatile solids (VS)%	94.25	30.00
Organic carbon (OC) %	54.67	17.4
Total nitrogen (N)%	2.25	1.35
C/N ratio	24.30:1	12.89:1
Total phosphorus (%P)	0.76	0.50
Total potassium (%K)	1.05	0.65

1.3. A laboratory bath experiment

Twelve units of batch anaerobic digestion were used in this study. Each digester had a total volume of 3 liters with an active volume 2.50 liters Figure (1).

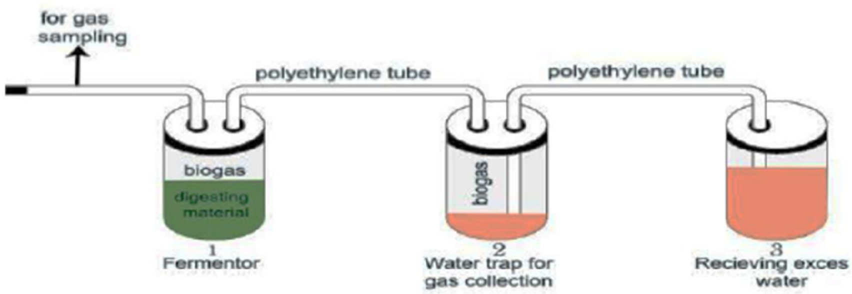

Fig. 1: Laboratory biogas digester units

1.4. Experimental procedures

A Laboratory batch experiment using a conventional reactor was conducted to study the productivity of biogas from food wastes under different concentrations of total solids, namely

2.5,5.0,7.5, and 10.0 %. Therefore, appropriate weights of well mixed with fresh 25% (V/V) of starter from active digester volume for each digester. Calcium carbonate was added also at the rate of 2 % of total solids to serve as a buffer. Initially, digested slurries were adjusted to pH 7.0 by 0.1 N solution of KOH as follows**:**

B1: Total solids adjusted 2.5% from food wastes + 25 % starter (V/V) of active digester volume + 2% $CaCO_3$ from TS.
B2: Total solids adjusted 5% from food wastes + 25 % starter (V/V) of active digester volume + 2% $CaCO_3$ from TS.
B3: Total solids adjusted 7.5% from food wastes + 25 % starter (V/V) of active digester volume + 2% $CaCO_3$ from TS.
B4: Total solids adjusted 10% from food wastes + 25 % starter (V/V) of active digester volume + 2% $CaCO_3$ from TS.

All treatments were run in triplicates. Therefore, 12 fomenters were constructed, sealed, incubated growth champer at 35 ± 1 Cº for long 42 days. Samples were taken weekly from the fomenters for determined pH, ammoniacal nitrogen (NH_4-N), total volatile fatty acids (VFAs), total solids (TS), volatile solids (VS), Organic carbon (OC) %, total nitrogen (TN), total phosphorus (TP) and total potassium (TK). Also, total and fecal coliform (as an indicator of pathogenic bacteria) meanwhile, pathogen bacteria representing *Salmonella* and *Shigella* were assayed in addition to, the gas yield was daily measured, while methane and carbon dioxide were measured every 3 days.

2. Methods

Daily biogas yield was estimated according to Maramba *et al.* (1978). Methane content and individual volatile fatty acids were determined by gas-liquid chromatography according toWujick and Jewell (1980).Carbon dioxide content was estimated using Orsat's apparatus as the method described by Hamilton and Stephen (1964). Total solids, volatile solids, organic carbon, total phosphorus, total potassium, and total volatile fatty acids were determined according to the stranded method byAPHA (1992).The hydrogen ion concentration was directly measured by1:5 sample: water mixture, using a glass electrode pH meter. Ammoniacal nitrogen was determined by the Kjeldahl method according to Black *et al.* (1981).

Coliform group bacteria (total & fecal) were counted on MacConkey's bile salt agar medium and *Salmonella and Shigella* were counted on S.S agar medium according to (Difco Manual, 1977).

Statistics analysis

The experiment was arranged in a completely randomized block design and data were analyzed according to methods described by Snedecor and Cochran (1980). The averages were compared using L.S.D. values.

Results and Discussion

1. Survival of pathogenic bacteria

The total and fecal coliform group as well as *Salmonella & Shigella* (SS) were presented in Table (2). The highest counts of total, fecal coliform group and *Salmonella & Shigella* were in the starting experiment where, total coliform bacteria range from 2.10 to 13.20 $x10^3$cfu/g, meanwhile fecal coliform was range from 0.11 to 3.20$x10^2$cfu /g while, *Salmonella* and *Shigella* were ranged from3 to 20 x 10^2cfu/ g during the zero time. These counts were rapidly decreased as anaerobic digestion progressed.

Also, data showed that during the first part of the fermentation period numbers of either total or fecal coliform groups were higher than *Salmonella and Shigella* groups. The colonies of total coliform bacteria were not detected at the 3-week sample but the fecal coliform bacteria was not appeared at the second week. Also, *Salmonella* and *Shigella* were not detected after second week in B1, B2 and B3 treatments. In contrary, B4 achieved 1.2 $x10^{-1}$cfu/g during the second week then pathogen bacteria not detected after this period (second week) in all treatments anaerobic digestion.

These results were almost in agreement with El-Akshar (2000), He found that the fecal coliform bacteria are almost completely absent in the end product resulting from dry anaerobic fermentation. Also, Estefanous *et al*. (2010) and El-Khayat (2014) found that the colonies of total coliform bacteria were not detected after 6weeks sample but the undetected of faecal coliform bacteria was achieved after the 5 weeks. *Salmonella &Shigella* were not detected at the fifth week of fermentation by increasing the anaerobic fermentation time of municipal solid waste.

Table 2: Changes in the counts of total, fecal coliform and pathogenic bacteria (cfu/g.DW) during of anaerobic digestion of food wastes during 6 weeks.

Treatments	Periods (week)						
	0	1	2	3	4	5	6
	Total coliform ($x10^{-3}$) cfu/g						
B1	2.10	0.10	0.08	ND	ND	ND	ND
B2	7.25	0.85	0.19	ND	ND	ND	ND
B3	11.52	1.11	0.93	ND	ND	ND	ND
B4	13.20	2.10	1.10	ND	ND	ND	ND
	Faecal coliform ($x10^{-2}$) cfu/g						
B1	0.11	0.01	ND	ND	ND	ND	ND
B2	0.75	0.05	ND	ND	ND	ND	ND
B3	1.50	0.80	ND	ND	ND	ND	ND
B4	3.20	1.32	ND	ND	ND	ND	ND
	***Salmonella & Shigella*($x10^{-1}$) cfu/g**						
B1	3.00	ND	ND	ND	ND	ND	ND
B2	10.00	2.00	ND	ND	ND	ND	ND
B3	14.00	2.80	ND	ND	ND	ND	ND
B4	20.00	11.00	1.20	ND	ND	ND	ND

- ND: Not detected

2. Physical and Chemical Parameters

2.1. Volatile fatty acids

The present results in Table (3). show that the volatile fatty acids in the digesting slurries where, its represent the majorportion of the intermediate substrate from which the methane generated. In this respect, VFAs increased gradually until the third week it had been shown 50.90 and 60.40 meq/L in fomenters contained B1 and B2,respectively.

Table 3: Changes of volatile fatty acids, pH, and ammoniacal–nitrogen during anaerobic digestion periods.

Treatments	Periods (weeks)						
	0	1	2	3	4	5	6
	VFAs (meq/L)						
B1	10.00	25.14	36.00	50.90	46.90	30.40	20.00
B2	11.30	30.62	40.50	60.40	52.30	46.10	37.00
B3	21.45	68.10	120.00	150.90	180.25	190.85	200.60
B4	27.60	75.20	156.00	166.00	200.00	220.00	232.25
LSD 5 %	5.0355	4.661	5.1316	5.1957	5.499	5.043	5.4786
	pH						
B1	7.04	6.45	6.12	6.62	6.95	7.50	8.20
B2	6.95	6.31	6.00	6.50	6.90	7.00	7.40
B3	6.76	5.40	5.10	5.00	5.30	4.90	5.80
B4	6.50	5.00	4.80	4.50	4.70	4.85	5.60
LSD 5 %	0.2981	0.3470	0.437	0.8036	1.516	0.527	0.4043
	NH_4-N (ppm)						
B1	68.70	110.00	200.40	275.05	326.05	381.21	385.52
B2	86.64	150.60	275.35	320.10	447.44	580.20	462.68
B3	116.48	225.00	322.00	411.01	529.31	610.11	870.24
B4	152.32	280.05	420.60	521.00	688.32	710.25	925.88
LSD 5 %	4.2599	5.5609	5.0189	4.374	5.5108	5.336	6.216

Thereafter, VFAs values were dropped gradually to end of digestion period as due to its consumption by the methane-forming bacteria. On the other hand, the accumulation of VFAs in the other fermenters (B3 and B4) continued towards the end of the experiment to reach maximum values 200.60 and 232.25meq/L., respectively. Zhang *et al.* (2014); El-Khayat (2019) reported that the concentration of VFAs decreased by increasing the fermentation periods this may be due to the VFAs are converting into CO_2 and CH_4 by methane bacteria.

2.2. Hydrogen Ion Concentration (pH)

The changes in pH values in the four fermenters at different anaerobic digestion periods observed in Table (3) shown an inverse high level of VFAs and low values of pH were recorded at the same time. When the consumption of VFAs was started, the pH values were turned to increase towards alkalinity as shown in the fermentors contained B1 and B2, this may be due to $CaCO_3$ buffer in the initial wastes' mixture and the natural decomposition of this materials. While the toxicity of pH is more pronounced in the fermentors loaded with high concentrations of total solids B3 and B4. These results were similar to the reported by Kvasauskas and Baltrėnas (2008) who found that the pH changed from 6.6 to 7.10 in the course of sewage sludge biodegradation. Also, Budiyono *et al.* (2010) found that there was an increase in pH before and after digestion. The same trend was obtained by El-Khayat (2014)who found that the pH values increased at the end of anaerobic digestion.

2.3. Ammoniacal– Nitrogen

Data of ammoniacal - nitrogen (Table 4) indicate that ammoniacal –nitrogen showed a gradual increase in NH_4-N levels to reach a maximum after 5 weeks of incubation and then declined in B1 and B2, while B3 and B4 exhibited a continual increase by the time of digestion. The level of ammoniacal - nitrogen was directly proportional to the totalsolid's concentration of the digestion slurry.

There is a negative relation between the level of ammoniacal – nitrogen and the pH. However, the maximum level of NH_4-N 925.88 ppm was exhibited by B4. Still level of ammonia is not injurious for the digestion and methanogenic bacteria. These results are agreement with those reported by El-Akshar (2000) and Estefanous *et al*. (2010). They found that the concentration of NH_4-N increases alone with anaerobic digestion to reach its high values after four weeks, being 1200 mg/L, and then decreased to 325 ppm after eight weeks of digestion.

2.4. Total solids, volatile solids, and total nitrogen.

Total solid (TS), volatile solids (VS), and total nitrogen (TN) were determined at the initial and final of the experimental period in Table (4).

Table 4: Changes of total, volatile solids and total nitrogen content during anaerobic digestion of food wastes during 42 days.

Treatments	Total solids (g/digester)			Volatile solids (g/digester)			Nitrogen content (g/digester)		
	Initial	Final	Losses %	Initial	Final	Losses %	Initial	Final	Losses %
B1	62.50	24.71	60.46	51.96	14.17	72.73	1.01	0.43	57.43
B2	125.00	86.90	30.48	110.10	72.00	34.60	2.16	1.56	27.78
B3	187.50	134.26	28.39	168.94	115.70	31.51	3.47	2.64	23.92
B4	250.00	182.14	27.14	227.75	159.89	29.80	5.00	3.79	24.20
LSD 5%	4.43	4.77	5.10	5.60	5.05	5.26	2.67	1.15	4.69

Data clearly show that the concentration of the above-mentioned parameters decreased throughout the digestion course. The loss percentages of total solids were 60.46, 30.48, 28.39 and 27.14 % in B1, B2, B3, and B4, respectively. Also, the loss percentages of volatile solids were 72.73, 34.60, 31.51and 29.80 in B1, B2, B3, and B4, respectively. Meanwhile, the loss percentages of total nitrogen were 57.43, 27.78, 23.92 and 24.20 in B1, B2, B3, and B4, respectively. Such decrements recorded in this study especially in total and volatile solids occurred in the form of gases and water. Dinsdale *et al.* (1996) reported that a 58% reduction in volatile solids was observed in the batch system during anaerobic digestion of wastewater containing significant levels of coffee grounds. In this respect, Estefanous *et al.* (2010) and El-Khayat (2014)found that during anaerobic digestion the total solids, volatile solids, and total nitrogen were decreased due to a high substrate conversion rates to biogas and methane in the digestion process. Ugwuoke *et al*. (2015) mentioned that the total solid of any given biogas feedstock specifically contributes to the execution of the system and ltw1accumulative of biogas amid anaerobic digestion. There is a reverse connection between the total solid content and an accumulative of biogas.

2.5. Total nitrogen, phosphorus and total potassium

Changes in concentrations of total nitrogen, phosphorus and potassium were determined in the initial and the final of the anaerobic digestion period, the obtained results are tabulated in Table (5).

Table 5: The concentration of total nitrogen, phosphorus and potassium initial and final anaerobic digestion of food wastes.

Treatments	Total nitrogen (%)		Total phosphorus (%)		Total potassium (%)	
	Initial	Final	Initial	Final	Initial	Final
B1	1.61	1.73	0.27	0.32	1.02	1.22
B2	1.73	1.80	0.45	1.10	1.13	1.30
B3	1.85	1.97	0.56	1.25	1.20	1.39
B4	2.00	2.18	0.63	1.31	1.27	1.46
LSD 5%	0.57	0.51	0.22	0.18	0.32	0.179

The results showed that the digestion of food wastes was increased at the end of the digestion period. This may be due to the consumption of total and volatile solids during anaerobic digestion to produce gases (CH_4 and CO_2) and other products These results are in agreement with the findings of Estefanous *et al*. (2010) found that the concentrations of nitrogen, phosphorus, and potassium in the end product were increased, this may be due to a decrease in total solids. The percentage of phosphorus. potassium and total nitrogen were increased at the end of the fermentation period. This increase is likely to be due to the consumption of volatile solids during anaerobic digestion to produce gases (CH_4 and CO_2) as reported El-Khayat (2019).

2.6. Biogas and methane production rates

The productivity of biogas and methane per unit of digester volume for both total solids and volatile solids added are presented in table (6). The B2 treatment showed higher productivity of biogas 36.53 liters than the recorded for B1 (28.56 liters), but they exhibited nearly almost productivity of methane 19.11 and 13.90 liters. Production rates both biogas and its methane content were indirect proportional to the concentrations of total and volatile solids loaded to the digesters therefore, the rates of biogas were decreased from 549.65 to 42.24 (L/kg VS added) relative to increase VS from B1 to B4 respectively.

Similarly, the B1 treatment showed a higher rate of methane production 267.51 (L/kg VS added) than that calculated for B2 (173.57 L/kg VS added).While the biogas and methane production rates based on either total or volatile solids consumed were the highest in the case of B2 could be attributed to the high activity of lytic microorganisms. Cho *et al.* (1995) found that the methane yields of cooked meat, cellulose, boiled rice, fresh cabbage, and mixed food wastes were 482, 356, 294, 277, and 427 liters CH4/kvolatile solid added. In this respect, El-Akshar (2000) found that the biogas production rates per kg of volatile solids either added of consumed were (215.33, 826.47 and 160.79, 797.79) for Jews mallow processing wastes and cattle dung respectively. Also, they found that the methane production rates per kg of volatile solids either added or consumed were (123.84, 475.31 and 98.74, 489.88) for Jews mallow processing wastes and cattle dung respectively. The biogas and methane production rates were 420.68-liter biogas and 176.50-liter methane /kg volatile solids added and 987.20-liter biogas and 706.00-liter methane /kg VS consumed for municipal solid waste (Estefanous *et al*., 2010)

Table 6: Solids destruction and production during anaerobic digestion of food wastes for 42 days

Treatments	Biogas production				Methane production			
	Total biogas production L/digester	Rate of biogas production (L /Kg)			Total methane production (L)	Rate methane production (L /Kg)		
		TS	VS			TS	VS	
		Add	Add	Consumed		Add	Add	Consumed
B1	28.56	456.96	549.65	755.76	13.90	222.40	267.51	367.82
B2	36.53	292.24	331.79	958.79	19.11	152.88	173.57	501.57
B3	11.35	60.53	67.18	213.19	1.35	7.20	7.99	25.36
B4	9.62	38.48	42.24	141.76	0.91	3.64	4.00	13.41
LSD %5	3.26	6.39	5.28	5.39	4.10	3.468	4.41	5.04

3. Biogas produced and it's component

3.1. Daily and cumulative biogas production.

The daily production of biogas either liter/digester/day or liter/liter /day during the anaerobic digestion period (42 days) of food wastes waste are given in Figs (2 and 3).

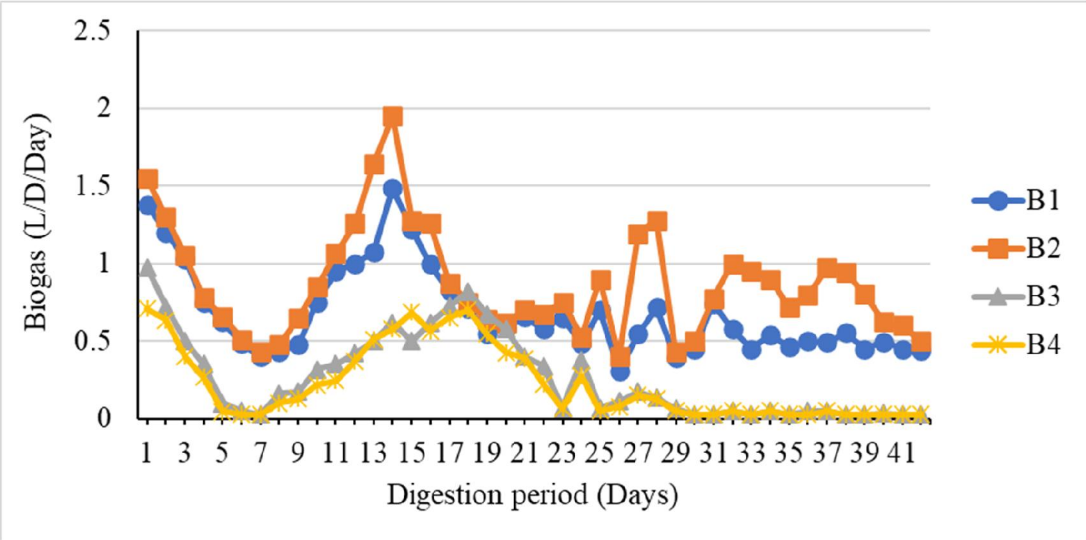

Fig. 2: Daily biogas production during anaerobic digestion of food wastes for 42 days.

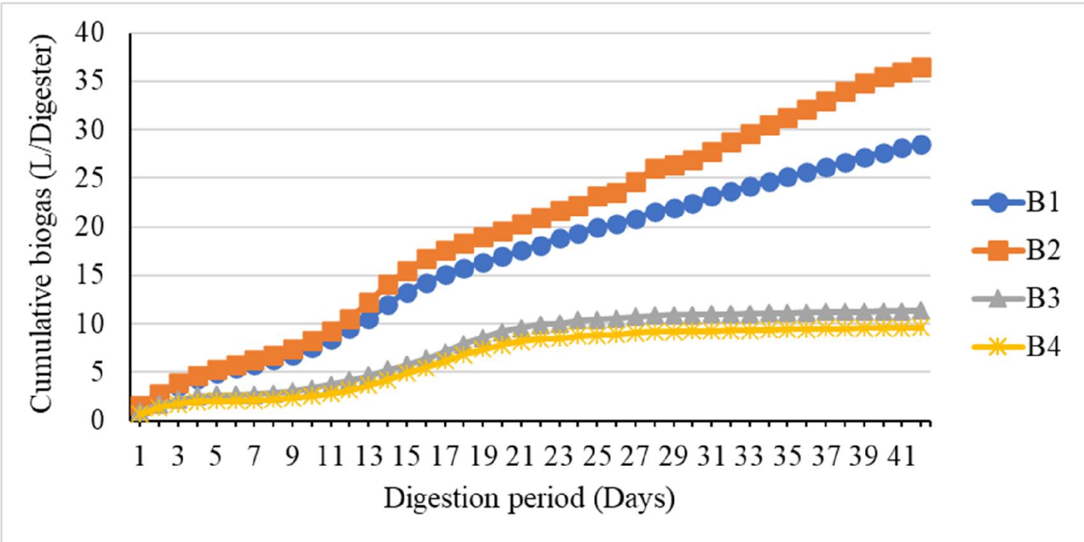

Fig. 3: Cumulative biogas production during anaerobic digestion of food wastes for 42 days.

The achieved results indicated that the production of biogas started from the first day of anaerobic digestion and increased reached to the highest production at 14 days of anaerobic digestion, where it's recorded 1.485-1.950 liter/digest/day and 0.594 -0.780 liter/liter/day from B1,B2 respectively .while during 18 days it's recorded 0.825-0.700 liter/digest/day and 0.328-0.280 liter/liter/day from B3,B4 respectively., and then slowly to reach the minimum level at the end of the digestion course. The cumulative biogas production recorded 28.555, 36.528, 11.350, and 9.615liter/digester from B1, B2, B3, and B4, respectively.

El-Housseini (1983) found that the garbage mixing with sewage sludge produced biogas within the first day whereas, moistening the garbage with water required 9 to 23 days to generate the biogas such period was needed for the proliferation of fermenting bacterial population's effective counts. Vindis *et al*. (2008) studied biogas production with the use of mini digester and reported that the highest biogas and methane yield was achieved in the case of (75% sugar beet + 25% maize). On contrary, the lowest biogas yield was in the case of (50 % sugar beet + 50% maize), after twenty days the anaerobic digestion is mostly finished. However, after 35 days the amount of biogas was very low. Almoustapha *et al*. (2009) reported in their study that although biogas production began on the 8^{th} day, the gas became combustible only on the 11^{th} day. As of the 48^{th}, the day the biogas production began to decline steadily. The total volume of biogas produced after 65 days was $151.4m^3$, which is, $2.6m^3$/ day. Budiyono *et al*. (2010) reported that biogas production was very slow at the beginning and the end period of observation.

3.2. Daily and cumulative methane production

Daily and cumulative methane during the production of digestion course are recorded in Figures (4 and 5).The methane gas was produced on a considerable amount after the first day of fermentation from the four mixtures of food wastes under consideration. The daily methane production either L/D/day or L/L/day showed generally an increase up to about 14 days in (B, B2) and 18days in (B3, B4) of the fermentation period.

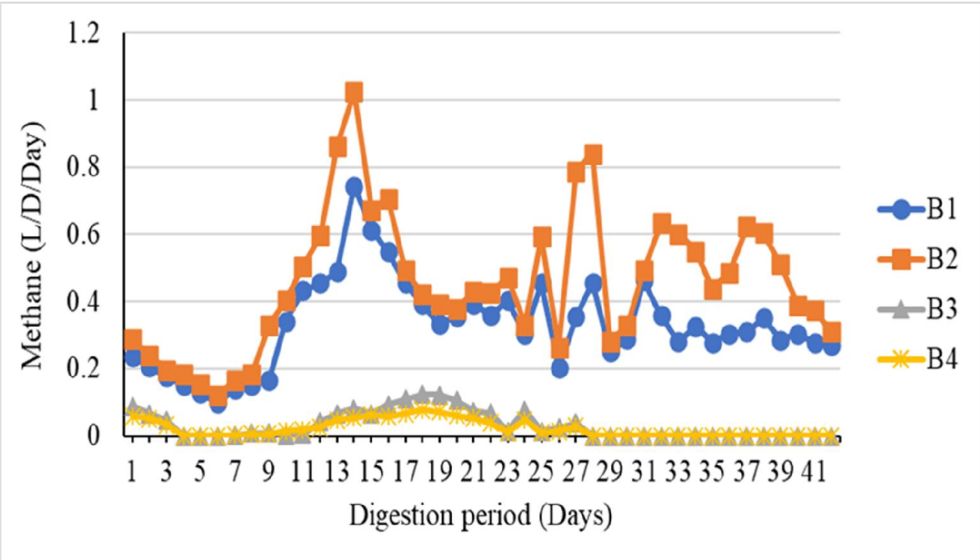

Fig. 4: Daily methane production during anaerobic digestion of food wastes for 42 days.

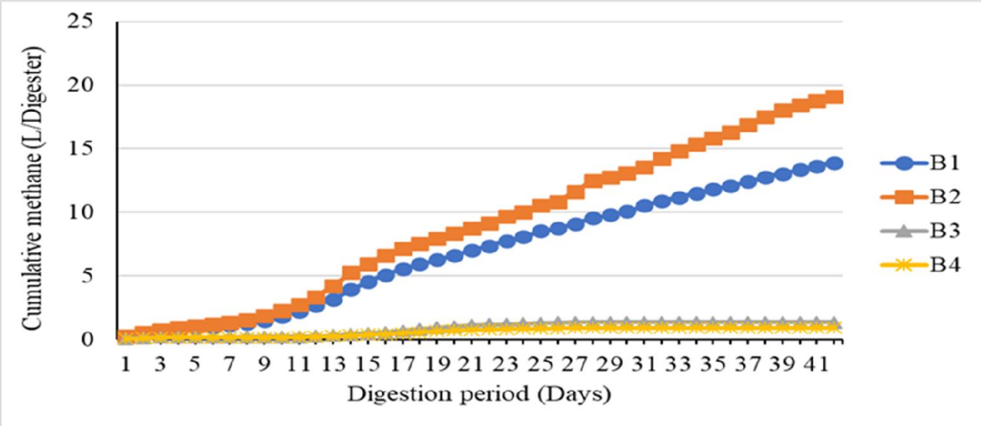

Fig. 5: Cumulative methane production during anaerobic digestion of food wastes for 42 days.

Daily methane production and cumulative were gradually decreased until the end of the experimental period. Data clearly show that the daily and cumulative methane production during anaerobic digestion was in the order from the highest to the lowest in B2, B1, B3, and B4. Estefanous *et al.* (1997) found that daily methane production and cumulative were gradually decreased until the end of the experimental period. Data clearly show that the daily and cumulative methane production during anaerobic3rdand 4thweek according to the type of digested waste and initial total solids. Amon *et al.* (2007) measured methane production at a commercial biogas plant for 1 year. Specific methane production was not constant throughout the year. When the dairy cattle diet changed from winter feed to summer feed, specific methane production increased. Winter feed consisted mainly of hay. In spring and summer fresh clover grass was fed. Kvasauskas and Baltrėnas (2008) found that during the first several days, the amount of methane remained to drop due to the drop in temperature.

3.3. Methane and Carbone dioxide gas quality

The gas qualities were evaluated and the obtained results are presented in Figs. (6, 7 and 8). The methane percentage in the produced biogas was gradually increased with the increasing fermentation period to until reached its maximum values at 27 days, where it's recorded 65.20, 66.00, 21.45 and 18. 90 % for B1, B2, B3 and B4, respectively. On the other hand, carbon dioxide (CO_2) percentages of the produced biogas were gradually decreased with increasing of fermentation period for B1 and B2 while B3 and B4 were increased at the end of fermentation could be attributed to the high activity of lytic microorganisms for organic matter to produce high levels of VFAs and low values of pH.

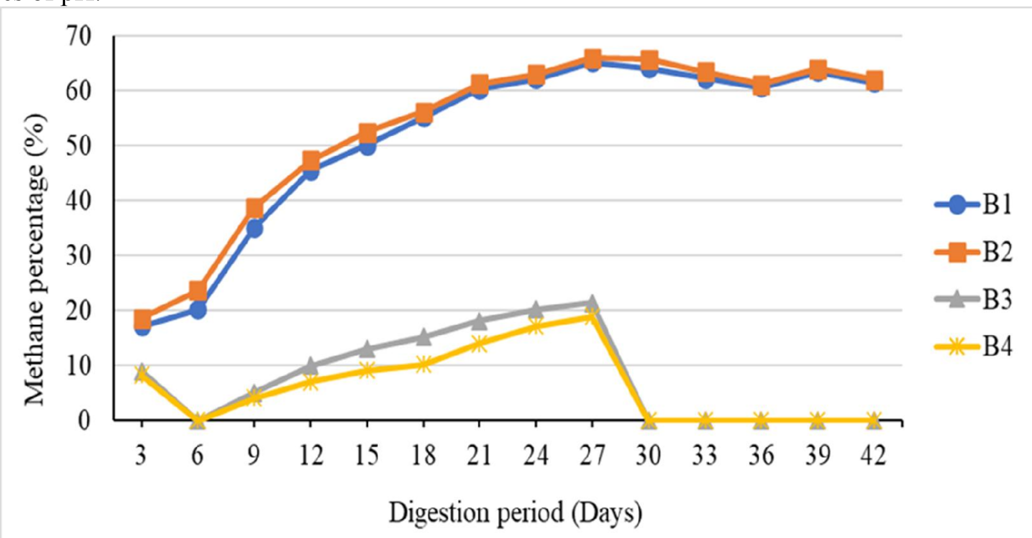

Fig. 6: Methane percentage during anaerobic digestion of food wastes for 42 days.

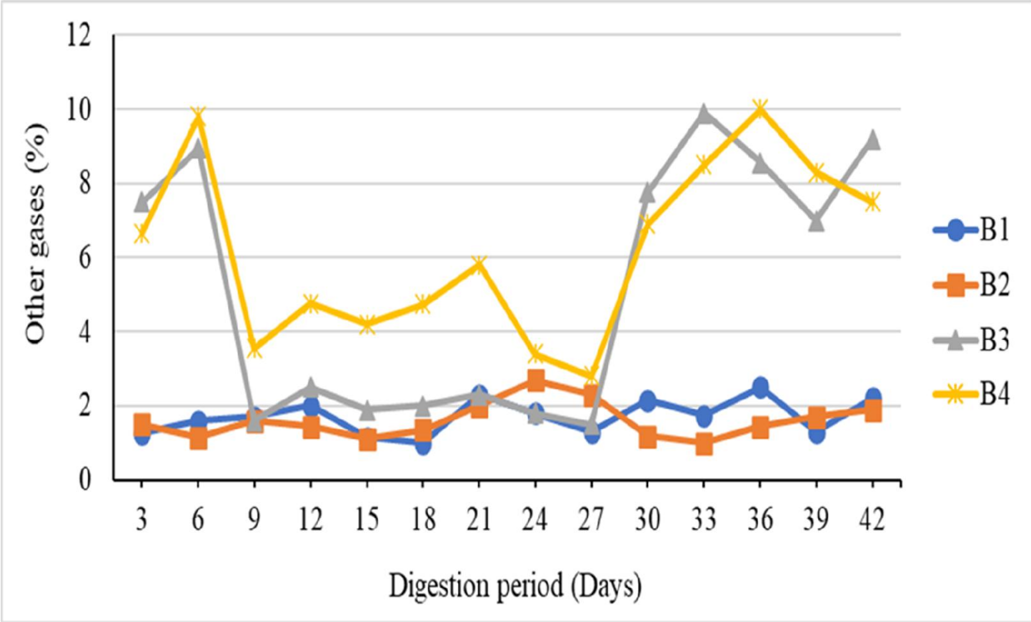

Fig. 7: Carbon dioxide percentage during anaerobic digestion of food wastes for 42 days

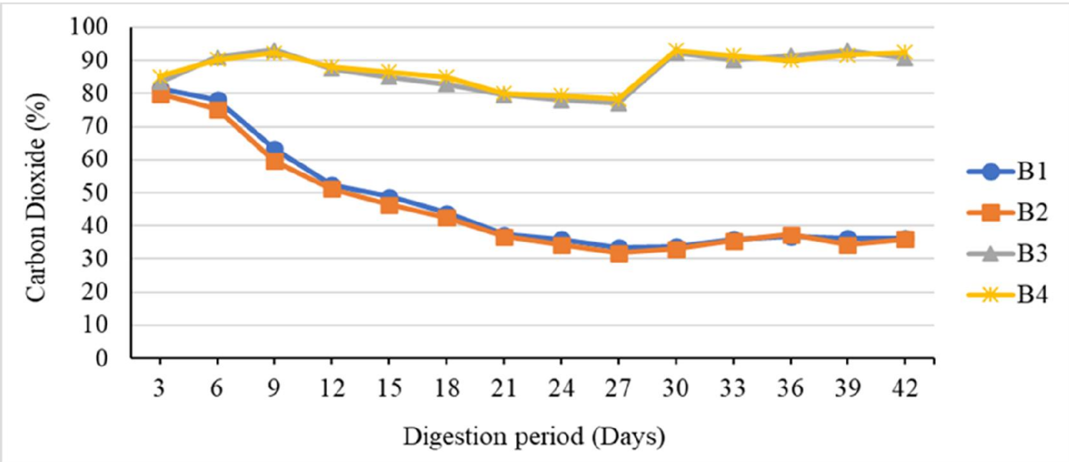

Fig. 8: Other gases percentage during anaerobic digestion of food wastes for 42 days.

Similar results were observed by many investigators. El-Akshar (2000); Estefanous *et al.* (2010) and El-Khayat (2014) found that the highest amount of biogas produced from Jew's mallow processing waste, mixed with cattle dung ranged between 60-70 % methane and 25-30 % CO_2 with small amounts of other gases (H_2S, H_2, NH_3, and N- oxides).

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