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Biogas Production from Jew's Mallow Processing Wastes and Cattle Dung Using Batch Feeding System.

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Biogas production via the anaerobic digestion of Jew's mallow processing wastes (JMPW) and cattle dung (CD) was studied. Obtain results showed that the populations of anaerobic saccharolytic, proteolytic, cellulose decomposers and acid producing bacteria were higher in digested slurry of JMPW than cattle dung. Colonies of total coliform bacteria were not detected at the 35th day. Fecal coliform bacteria were not detected at the 28th and 35th day for JMPW and CD, respectively. Counts of *Salmonella* and *Shigella* were rapidly decreased throughout the anaerobic digestion period to be completely undetected at the 14th and 28th day for JMPW and CD, respectively. Digested slurry of JMPW exhibited higher records of volatile fatty acids compared to the digested slurry of CD. Accumulation of ammonia during anaerobic fermentation of either JMPW or CD (1273 and 275 ppm, respectively) didn't reach the level reported to be toxic or even inhibitive to methanogenic bacteria. Cumulative biogas was higher in case of JMPW than CD. While, methane percentage in produced biogas was higher in case of CD than JMPW. Biogas production rates per kg volatile solids either added or consumed were (215.33, 826.47 and 160.79, 797.79) for JMPW and CD, respectively. While, methane production rates per kg volatile solids either added or consumed were (123.84, 475.31 and 98.74, 489.88) for JMPW and CD, respectively.

Key words: Biogas, Anaerobic digestion, Jew's mallow, Batch feeding.

There are many food processing wastes in Egypt emanating large quantities of solid wastes. These wastes are either uneconomically utilized or disposed off as they are, thereby causing serious of pollution problems. In vegetable processing, the solid residues range from 100 kg / ton in tomato canning to 670 kg / ton in pumpkin and squash canning. While, the range in fruit processing is from 150kg / ton in cheery canning to 450 kg / ton in pineapple canning (Woodroof and Luh, 1975). Biomethanation of food processing wastes is the best suited treatment as the process not only adds energy in the form of methane, but also results in highly stabilized effluent which is almost neutral in pH and is odorless.

Weiland (1992) reported that larger quantities of solid organic residues are accumulated during the processing of vegetables in agro- industry. Generally, these residues may be anaerobically digested for biogas generation becomes the principal purpose from these residues.

Methane production rates during the conventional anaerobic digestion of organic materials depending on the initial solid concentration which ranged between 6 – 9% for optimum biogas production (Varel *et al* 1977; El-Housseini 1983 and Zaghloul , 1993) . Baserga (1998) reported that although biogas production units on farms were run mainly on slurry; cost benefit studies show that if the organic wastes are fermented for biogas generation the cost of wastes disposal is significantly improved.

The present investigation was carried out to study the potentiality of biogas production from Jew's mallow – processing wastes in comparison with cattle dung.

Materials and Methods

Materials.

Jew's mallow processing wastes: Large quantities of jew's mallow-processing wastes (JMPW) were collected from the united company for food industry (Montana). Qualubia Governorate, Egypt.

Cattle dung: Cattle dung was collected from the experimental station at Faculty of Agriculture, Moshtohor, Zagazig Univ., Banha Branch.

Starter: A spent slurry of previously digested cattle dung derived from an active household biogas digester at the Training Center for Recycling of Agricultural Residues (TCRAR), Moshtohor, Qualubia Gover; Soils & Water and Environment Research Institute, Agric. Research Center was used as a seeding inoculum (starter).

Digesters: Two units of batch anaerobic digestion were used in this study. Each digester had a total volume 50 liters with an active volume 40 liters.

Representative samples of JMPW, CD wastes and the starter were taken and analyzed for several chemical parameters. The results are shown in Table (1).

Table 1. Initial chemical analysis of raw materials used in the study.

Parameters	Unit	Raw materials		
		Jew's mallow	Cattle dung	Starter
pH	-	5.17	8.10	7.44
Ammoniacal Nitrogen	Ppm	46.48	560.13	131.93
Volatile fatty acids	Meq/l	103.01	119.20	24.48
Total solids	%	11.50	16.03	7.80
Volatile solids	%	86.40	81.78	73.40
Organic carbon	%	50.11	47.43	42.57
Total nitrogen	%	3.61	1.70	1.66
Total phosphorus	%	0.78	1.30	1.09
Total potassium	%	0.23	0.94	0.34
C/N ratio	-	13.88:1	27.9:1	25.64:1

Experimental procedures.

Potentiality of biogas production from jew's mallow- processing wastes.

Batch experiment using conventional digesters was conducted to study the productivity of biogas from Jew's mallow processing wastes in comparison with a digester run on pure cattle dung and to study the behaviour of different microbial groups during the anaerobic digestion period. Before feeding the digesters, appropriate weights of well mixed fresh wastes (Jew's mallow) were mixed with tap water to reach 8 % total solids. Starter was added at a rate of 25% to each digester. The digesters were incubated in a walk-in-incubator at 35 ± 1°C for 45 days.

Analytical methods.

Chemical analysis.

Daily biogas yield was estimated according to (Maramba *et al.*, 1978). Methane content was determined by gas-liquid chromatography according to Wujick and Jewell (1980). Carbon dioxide content was estimated by means of Orsat's apparatus as the method described by Hamilton and Stephen (1964). Total solids, volatile solids, organic carbon, total phosphorus, different microelements and volatile fatty acids (VFAs) were determined according to the standard method recommended by APHA (1992). The hydrogen ion concentration was directly measured by using 1: 5; slurry: water mixture, using glass electrode pH meter. Ammoniacal nitrogen and total nitrogen were determined by kjeldhal method according to Black *et al.* (1965). Total potassium was determined by flame photometer according to Dewis and Freitas (1970).

Bacteriological analysis.

Anaerobic saccharolytic bacteria were counted on skim milk liquid medium, anaerobic proteolytic bacteria were counted on ox heart liquid medium and acid producing bacteria were counted on nutrient broth medium according to Cunningham (1954). Anaerobic cellulose decomposers were counted on Omelianskey's medium according to Allen (1959). Counts of abovementioned groups of bacteria were estimated by using Most Probable Number (MPN) technique (Cochran, 1950). Coliform group bacteria (total and 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).

Results and Discussion

Anaerobic digestion of Jew's mallow processing wastes (JMPW) and cattle dung (CD).

Biogas generation from Jew's mallow processing wastes and cattle dung by anaerobic digestion in conventional anaerobic digester was monitored throughout 45 days by using the batch operating system. The bacteriological changes, chemical changes, quantity and quality of biogas produced were also determined.

1- Bacteriological changes.

A. Behaviour of different bacterial groups during anaerobic digestion of JMPW and CD wastes.

Behaviour of heterofermentative and homofermentative saccharolytic bacteria is presented in Table (2). Obtained data over the whole digestion period show that the digesting slurries of both Jew's mallow and cattle dung contained higher populations of anaerobic heterofermentative saccharolytic than homofermentative saccharolytic bacteria. Counts of anaerobic saccharolytic bacteria (hetero and homo–fermentative) gradually decreased during the first 21 days then exhibited a rapid decrease. The lowest counts being recorded at the late period of the experiment.

Populations of anaerobic saccharolytic bacteria determined in JMPW digested slurry were higher than CD digested slurry and this was true all over digestion periods. This is probably due to much higher level of polysaccharides with plant nature material (JMPW) compared to CD wastes which contain only the water soluble organics (Stevenson, 1982).

With respect to anaerobic proteolytic bacteria, it was found that digested slurry of JMPW exhibited much higher counts than digested slurry of CD. Their counts gradually increased with the increasing of anaerobic digestion time to reach their maximum records (9.2×10^4 and 3.3×10^4 cell / g dry weight of JMPW and CD, respectively) at the 21st day, then decreased thereafter till the end of the experiment. Similar trend was observed for the two wastes under investigation. These results are in agreement with Siebert and Toerien (1969) and Hobson and Shaw (1974) who reported that proteolytic bacteria were found to be ranging between 10^4 - 10^5 cells/ml digested slurry in anaerobic digesters during biomethanation process.

Obtained results also show that populations of anaerobic cellulose decomposers gradually increased throughout the experimental period to reach their maximal values on days 14 and 21 for JMPW and CD being 2.9×10^4 and 1.9×10^4 cells /g dry weight, respectively. Counts of anaerobic cellulose decomposers were gradually decreased thereafter towards end of the fermentation period.

The early proliferation of anaerobic cellulose decomposers were accompanied by the depletion of oxygen and presence of ample supply of cellulosic materials. As anaerobic digestion proceeded, the amount of their metabolic substrates began to decrease and resulted in a significant decrease in their counts. On the other hand, their higher bacterial counts noticed during digestion of JMPW compared to CD might be due to the higher cellulose content of JMPW than CD. Counts of these bacteria were ranged between $1.2 \times 10^3 - 2.8 \times 10^4$ cells/g dry weight.

Table 2. Periodical changes in microbial population (x 10^3 cells/g dry weight)during anaerobic digestion of Jew's mallow processing wastes(JMPW) and cattle dung(CD) for 45 days.

Digestion period (days)	Anaerobic saccharolytic				Anaerobic proteolytic		Anaerobic cellulose decomposers		Anaerobic Acid producers	
	Hetero		Homo							
	JMPW	CD	JMPW	CD	JMPW	CD	JMPW	CD	JMPW	CD
Initial	162	24.2	8.640	12.20	17.1	9.20	14.10	12.8	1800	1600
3	135	20.8	6.540	3.700	26.8	21.2	19.20	13.3	3900	2100
7	100	18.1	4.700	2.500	39.0	23.8	22.10	14.0	6800	4400
14	117	16.4	2.910	1.700	81.0	26.1	28.68	16.2	7500	5400
21	92.0	9.80	1.600	1.200	92.0	32.5	11.80	19.1	9500	6600
28	21.0	4.10	0.360	0.110	78.0	14.6	5.200	4.60	1208	1800
35	7.00	1.80	0.145	0.093	70.0	11.3	1.600	1.64	110.0	140
45	3.50	0.86	0.072	0.020	64.0	9.80	1.480	1.20	74.00	80.0

Similar results were recorded by Hobson and Shaw (1974), El-Housseini (1983) and Zaghloul (1993) who reported that counts of anaerobic cellulose decomposing bacteria ranged between $2.1 \times 10^3 - 1.6 \times 10^4$ cells/g dry weight during anaerobic fermentation for biogas generation from different organic wastes.

Counts of acid producers gradually increased with the increase in fermentation period to reach their maximum records on day 21 and decreased thereafter till the end of the fermentation course. The same trend of results was observed for the two organic wastes under study.

Moreover, it was interesting to notice that records of anaerobic acid producers were higher in digested slurry of JMPW than digested slurry of CD. This was true up to day 21 of fermentation when 9.5-6.6 x 10^6 cells/g dry weight were recorded, respectively.

Thereafter, digested slurry of CD accommodated higher densities of anaerobic acid producers compared to digested JMPW. Similar results were reported by Summers *et al* (1987) and Zaghloul (1993) who found that counts of acid producing bacteria ranged between 10^6–10^7 cells/g dry weight during anaerobic digestion of agricultural wastes. Also, populations of acid producers increased with the increasing of fermentation period to reach their maximum records after 4 weeks of fermentation period and decreased thereafter when most of animal wastes and plant residues were anaerobically converted to biogas mixture.

As expected, populations of acid producing bacteria were parallel with populations of anaerobic cellulose decomposing bacteria for the two organic wastes under investigation as the latter provide simple sugars for growth and multiplication of acid producing bacteria.

B. Survival of pathogenic bacteria during anaerobic digestion of JMPW and CD wastes.

Counts of total and fecal coliform as well as *Salmonella and Shigella* are presented in Table (3). Obtained results show that digested slurry of CD initially contained higher numbers of different pathogenic bacteria compared to digested slurry of JMPW. These counts were rapidly decreased as anaerobic digestion progressed. Data also show that during the first part of fermentation period numbers of either total coliform or fecal coliform groups were higher compared to *Salmonella and Shigella* groups.

Table 3. Survival of total and fecal coliform and *Salmonella and Shigella* (x10^2 cells /g dry weight) during anaerobic digestion of JMPW and CD for 45 days.

Digestion period (days)	Total coliform		Fecal coliform		*Salmonella* and *Shigella*	
	JMPW	CD	JMPW	CD	JMPW	CD
Initial	28.00	4600	13.40	2600	2.80	12.10
3	19.60	2240	11.20	120.0	0.20	8.40
7	16.40	820.0	8.60	34.00	0.10	3.90
14	3.910	240.0	0.22	6.34	N.D	3.00
21	2.200	32.30	0.10	1.86	N.D	1.60
28	1.200	13.00	N.D	0.29	N.D	N.D
35	N.D	N.D	N.D	N.D	N.D	N.D
45	N.D	N.D	N.D	N.D	N.D	N.D

ND: Not detected.

Colonies of total coliform bacteria were not detected on day 35 and this was true for the two wastes under investigation. Undetection of fecal coliform was achieved on days 28 and 35 for JMPW and CD, respectively.

With regard to the behaviour of *Salmonella and Shigella,* data in Table (3) show that counts of these bacteria rapidly decreased throughout the anaerobic digestion period to be completely undetected on days 14 and 28 for JMPW and CD, respectively. These results are in accordance with the findings of several earlier investigators. Nasr (1980) reported that more than 95% of total and fecal coliform were destroyed after 28 days of anaerobic digestion at 37°C. Zehnder (1982)

reported a 100% destroyment of *Shigella dysenteriae* when the septic tank slurry was fermented at 37°C in less than 8 days, while *Salmonella typhi* and *Salmonella paratyphi* persisted up to 8 days and was killed at the rate of 99% thereafter. Zaghloul (1993) found that numbers of coliform group and *Salmonella and Shigella* showed rapid decrease during the fermentation period to disappear completely after 45 and 30 days, respectively.

2- Chemical changes during anaerobic digestion of JMPW and CD wastes.

A. Changes in volatile fatty acids (VFA), ammoniacal nitrogen and pH values.

Data graphically illustrated in Figure (1) show that concentration of volatile fatty acids increased by increasing the fermentation period to reach their maximum values on day 21 for JMPW as well as CD. On the other hand, the concentration of VFA was gradually decreased thereafter till the end of the experimental period. The increase of volatile fatty acids as the fermentation progressed could be attributed to the activity of acid producing bacteria which showed an increase in their counts with the increasing of fermentation period and reached their maximum records on day 21 for the two organic wastes (Table, 2).

Moreover, digested slurry of JMPW exhibited higher records for the concentrations of VFA as compared to digested slurry of CD all over the whole digestion period. Concentration of volatile fatty acids recorded in this study did not reach the levels reported to be toxic or even inhibitive to methanogenic bacteria as shown in (Figure, 1). Van Velsen *et al* (1979) mentioned that the methanogenic bacteria inhibited by volatile fatty acid concentration above 85 meq/l.

El-Shimi *et al* (1992) studied the biogas generation from food processing wastes. They found that the fermenters containing carrot wastes showed the highest accumulation of VFA (187 meq/l), while orange, legume and tomato wastes followed in order; producing concentrations of VFA 120.8, 58.1 and 48.3 meq/l, respectively.

Regarding the periodical changes in ammoniacal nitrogen concentration, data graphically illustrated in Figure (1) clearly indicate that the concentrations of NH_4-N gradually increased by increasing the fermentation period for both JMPW and CD wastes. The increase of NH_4-N concentration over progression of anaerobic digestion process could be attributed to the ammonification of organic nitrogen compounds by ammonifiers. Accumulation of ammonia during anaerobic fermentation of either JMPW or CD did not reach the levels reported to be toxic or even inhibitive to methanogenic bacteria. The lowest concentration of NH_4 -N for toxicity is given by Chengdu (1979) to be higher than 1500 ppm.

Also, detection of NH_4-N during anaerobic fermentation was conducted by El-Shimi *et al* (1992) and Zaghloul (1993). They found that the NH_4-N concentration in digested animal wastes was higher than that produced from digested plant residues. As well as they reported that the ammoniacal nitrogen concentration increased in digested slurry by progression in the anaerobic digestion process.

Regarding the periodical changes in pH values in digested slurry of JMPW and CD, data graphically illustrated in Figure (1) show that pH values in digested slurry of the two organic wastes under investigation decreased with the increase of fermentation period till day 21. Then, pH values increased till the end of the experimental period regardless the type of digested wastes.

The decrease in pH values during the first part of fermentation period could be attributed to the increase in volatile fatty acid concentration produced at the beginning of anaerobic digestion while, the higher pH values found during the late fermentation periods to the higher production of ammonia during the same periods (Figure, 1).

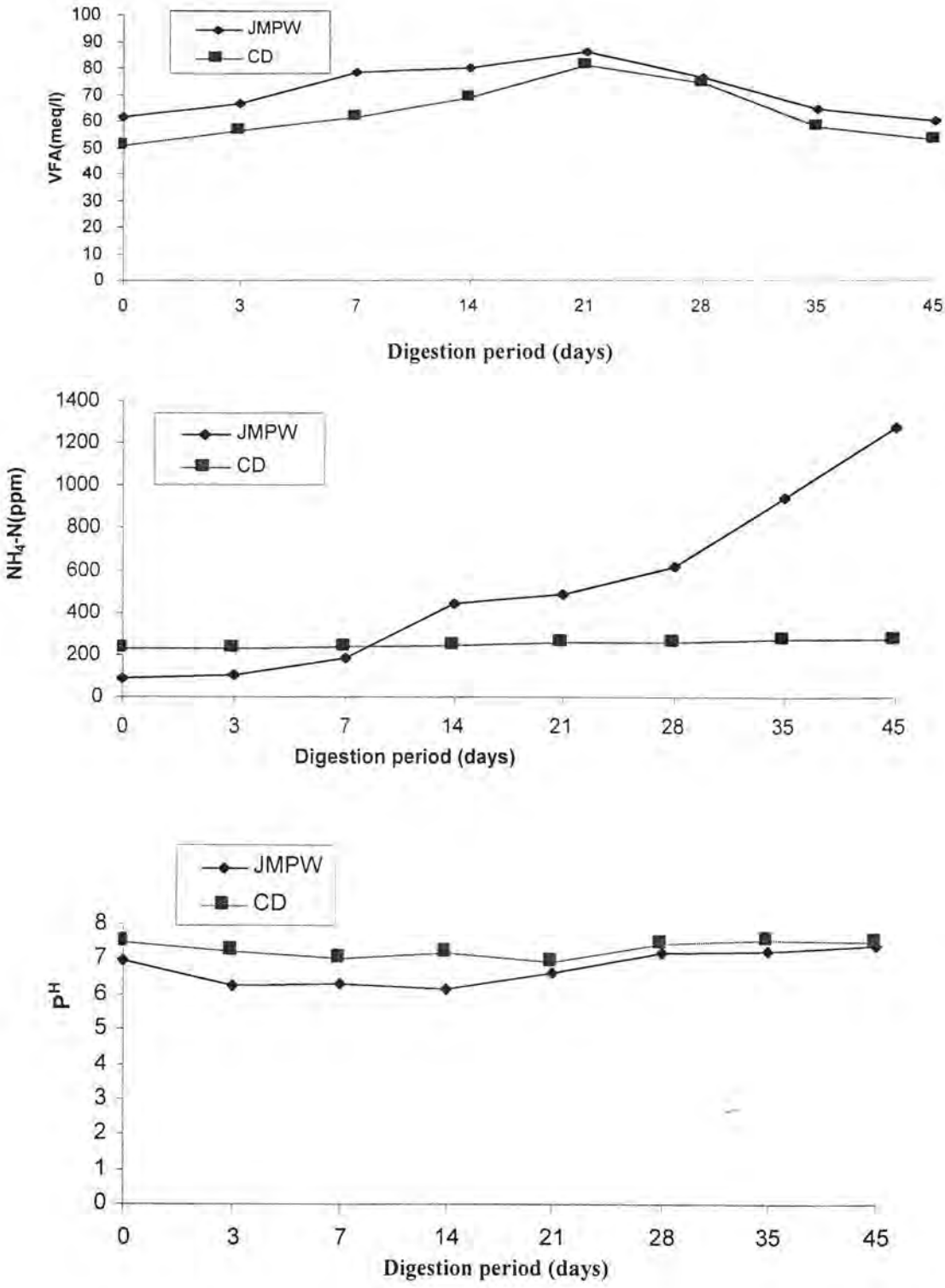

Figure (1): Periodical change in volatile fatty acids, ammoniacal nitrogen and pH values during anaerobic digestion of jew's mallow processing wastes (JMPW) and cattle dung (CD) for 45 days.

Generally, fermenting slurries of JMPW and CD showed a pH range favourable to biogas generation and methane production. The favourable values of pH for methanogenic bacteria were recorded by many investigators (Zehnder *et al* 1981; Panti and Jui, 1985; Sarada and Nand, 1989 and Ghaly, 1996) who reported that the optimum pH for methanogenic bacteria ranged between 6.5 – 8.05.

B. Changes in total solids, volatile solids and total nitrogen.

Data in Table (4) clearly show that the concentration of abovementioned parameters decreased throughout the fermentation course. The loss percentages of total solids, volatile solids and total nitrogen were 21.25; 26.05; 22.27% and 16.30; 20.16; 12.77% for JMPW and CD, respectively. Such losses recorded in this study especially in total and volatile solids most probably occurred in the form of gases and water.

It is worthy to notice that the loss percentages of both total and volatile solids were higher in case of JMPW than CD. The higher losses in total and volatile solids which occurred in case of anaerobic digestion of JMPW compared with CD may be due to the high activity of heterofermentative saccharolytic, anaerobic proteolytic, anaerobic acid producers and anaerobic cellulose decomposers which showed higher populations during anaerobic digestion of JMPW than CD as previously shown in (Table, 2).

Table 4. Changes of total solids, volatile solids and total nitrogen content during anaerobic digestion of Jew's mallow processing wastes (JMPW) and cattle dung (CD).

Digested wastes	Total solids (Kg/digester)			Volatile solids (Kg/digester)			Total nitrogen (g/digester)		
	Initial	Final	Loss %	Initial	Final	Loss %	Initial	Final	Loss %
JMPW	3.20	2.52	21.25	2.61	1.93	26.05	127.36	99.00	22.27
CD	3.19	2.67	16.30	2.58	2.06	20.16	56.78	49.53	12.77

Also, it was conceptually assumed that during the anaerobic digestion almost all of the carbon of volatile solids or organic matter destroyed was evolved as carbon dioxide and methane (Wohlt *et al,* 1990). The loss percentages of total and volatile solids from the two organic wastes used in the present study are within the range recorded by many investigators (Sax *et al,* 1980; El-Shimi *et al,* 1992; Sarada and Joseph 1994). They reported that the loss of total and volatile solids during anaerobic digestion of different food wastes depend on the applied system, type of residues, starter amendment, incubation time and temperature. In addition, Dinsdale *et al* (1996) reported that 58% reduction in volatile solids was observed in batch system during anaerobic digestion of wastewater containing significant levels of coffee grounds.

A reduction in total nitrogen content during anaerobic digestion of JMPW and CD was also observed which could be attributed to the volatilization of ammonia and loss by denitrification under anaerobic conditions. The loss percentage of total nitrogen from digestion of the two organic wastes are within the range recorded by many investigators. The average loss in total nitrogen during anaerobic fermentation of pig manure was about 10% (Velsen, 1979). El-Housseini (1983) and Aly (1985)

found that nitrogen loss during biogas generation ranged between 8 and 28% according to type of digester and organic waste used.

C. Changes in macro and micro-nutrients content.

Changes in concentrations of total nitrogen, total phosphorus, total potassium as well as micro- nutrients (iron, zinc, manganese and copper) are presented in Table (5). Results show that the percentages of macro and micro – nutrients in the digested slurries of JMPW and CD increased at the end of the fermentation period. This increase is likely to be due to the consumption of total and volatile solids during anaerobic digestion to produce biogas mixture (CH_4 and CO_2) and other products.

These results are in agreement with the findings of El-Housseini (1983), El-Shimi *et al* (1992) and Estefanous *et al* (1997). A similar increase in concentration of micro- nutrients was reported by (Zaghloul, 1993) at the end of digestion period compared to their initial concentration.

Table 5. Concentration of macro and micro - nutrients before and after anaerobic digestion of (JMPW) and (CD).

Digested wastes	Macro – nutrients					
	Total nitrogen %		Total phosphorus %		Total Potassium %	
	Initial	Final	Initial	Final	Initial	Final
JMPW	3.98	4.10	0.78	0.91	0.20	0.26
CD	1.78	1.95	0.99	1.02	0.38	0.88

	Micro – nutrients							
	Iron (ppm)		Zinc (ppm)		Manganese (ppm)		Copper(ppm)	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
JMPW	280	540	60	78	40	56	18	26
CD	210	420	68	114	34	42	15	28

D. Biogas production.

a. Rate of biogas production.

Biogas production rate estimated as (liter/liter/day) and cumulative yield (liter/digester) during the fermentation period of JMPW and CD are graphically illustrated in Figure (2). Obtained data show that the fermented materials poor biogas generation was observed at the beginning. It seems that, substrates conversion to biogas by anaerobic bacteria exhibits a lag period during the first day which other bacterial groups than methanogenic bacteria activate substrate degradation as a prerequisite for biogas generation from complex substrates.

The early slight generation of biogas that occurred in this study could be attributed to the addition of digested cattle dung (starter) at the commencement of fermentation. Such starter provided the fermentation process with active bacterial agents and nutritional requirements.

Regarding the produced biogas mixture from JMPW during anaerobic digestion period, data show that the biogas production was high at the beginning up to the fifth day, then decreased and showed fluctuation thereafter. High peak of biogas production rate (0.5 L / L / day) was observed on day 18 and gradually

decreased thereafter down to 0.27 L/L/day on day 32 where it was maintained at this level till end of digestion period.

On the other hand, the produced biogas from anaerobic digestion of CD was low at the beginning, then increased thereafter and showed fluctuation till the end of the experimental period. Biogas production rate from digested CD wastes showed slightly decrease after day 16 till day 30. Thereafter, biogas production rapidly decreased with the increasing of fermentation period to reach the minimum level at the end of fermentation time. Also, data showed some differences between the two organic wastes in their activity for cumulative biogas. The cumulative biogas yield was higher in case of JMPW than CD wastes. The duration of high biogas production rates was for JMPW 43 days and 30 days for CD wastes. The higher and longer production rates of biogas in case of anaerobic digestion of JMPW can be attributed to the higher populations of anaerobic saccharolytic, proteolytic, cellulose decomposers and acid producing bacteria in JMPW than CD wastes as previously discussed in Table (2).

Regarding the effect of starter addition on biogas production, Chengdu (1979) and Marty (1984) stated that the ruminant wastes contain sufficient populations of anaerobic cellulose decomposers, anaerobic acid producers and methane forming bacteria. Also, they reported that if the fresh raw materials that introduce the fermenters have only a few seeding bacteria, the fermentation period would be very long and could not produce biogas immediately or produce just little amount of gas.

Also, El-Housseini (1983) found that garbage mixed 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 proliferation of fermenting bacterial populations to effective counts.

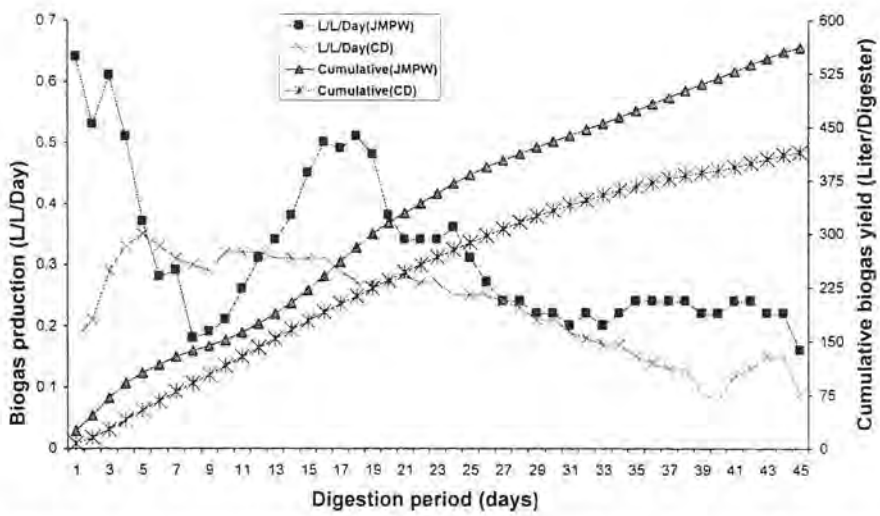

Figure (2): Daily and cumulative biogas production during anaerobic digestion of jew's mallow processing waste and cattle dung for 45 days.

b. Daily and cumulative methane yield.

The daily and cumulative methane production during the fermentation course is graphically illustrated in Figure (3). It is clear that the methane gas was produced in considerable amounts after the first day of fermentation from the two

organic wastes under investigation. Evolution of methane exhibited fluctuation with anaerobic digestion periods with the same trend for both digested wastes. The daily methane production rate (L/L/day) showed an increase over the period between days 16-19 and days 19-23 of fermentation period for JMPW and CD, respectively. Daily methane production rate and cumulative yield gradually decreased till the end of the experimental period. Also, data clearly show that the daily and cumulative methane production during anaerobic digestion were higher in case of JMPW than CD and this result was observed all over the experimental period.

The higher cumulative of methane yields in case of JMPW could be attributed to the high activity of microbial populations especially anaerobic cellulose decomposers as well as acid producers which exhibited much higher records in the digested slurry of JMPW compared to CD (Table, 2). Brummeler and Koster (1990), Zaghloul (1993) and Estefanous *et al* (1997) found that the maximum production rate of methane (L/L fermented material/day) was achieved at the period ranged between the 3rd and the 4th week according to the type of digested waste and initial total solids.

c. Components of biogas mixture.

The different gases produced during anaerobic digestion of both JMPW and CD wastes are determined and graphically illustrated in Figure (4). The methane percentage in produced biogas mixture gradually increased with increasing fermentation period to reach its maximum values after 27 and 30 days for JMPW and CD being 73.1% and 75%, respectively. The high methane percentages which observed during the period ranged between 27-30 days could be attributed to the high activity of lytic microorganisms for organic matter during the same period as previously discussed (Table, 2). Nevertheless, obtained results previously graphically illustrated in Figure (1) also showed the suitable concentrations of volatile fatty acids which represent the ample supply for methanogenic bacteria which were observed on day 28 of fermentation period.

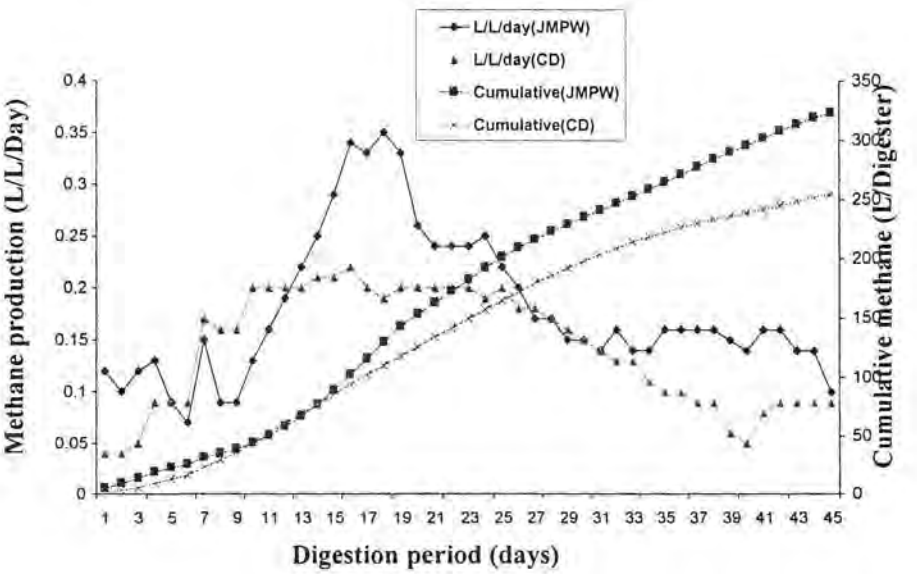

Figure (3): Daily and cumulative methane production during anaerobic digestion of jew's mallow processing waste and cattle dung for 45 days

On the other hand, carbon dioxide percentages of the produced biogas gradually decreased with increasing of fermentation period to reach their minimum percentage on days 27 and 30 being 26% and 23.4% for JMPW and CD, respectively. Average methane percentage was 60.71% and 62.77%, whereas the average carbon dioxide percentage was 37.80% and 35.65% for JMPW and CD, respectively. Similar results were observed by many investigators (Alaa El-Din *et al.*, 1984; Hanafy *et al.*, 1990; Zaghloul, 1993 and Estefanous *et al.*, 1997) who reported that composition of produced biogas from anaerobic fermentation of animal wastes and crop residues ranged between 60-70% (methane) and 25-30% (CO_2) with small quantities of other gases (H_2S, H_2, NH_3 and N-oxides).

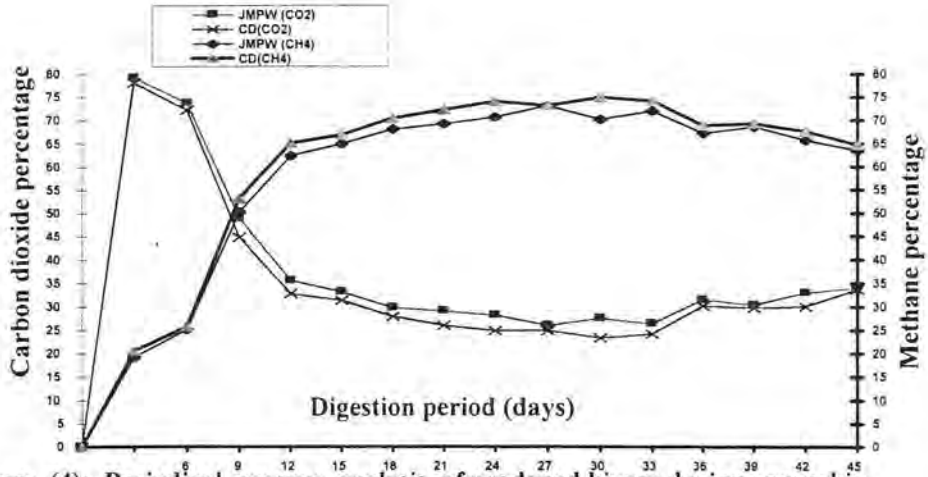

Figure (4): Periodical gaseous analysis of produced biogas during anaerobic digestion of jew's mallow processing wastes and cattle dung for 45 days.

Moreover, data graphically illustrated in Figure (4) show that the average percentage of methane was higher in case of anaerobic digestion of CD than JMPW. Similar results were observed by Hobson *et al* (1981) and Zaghloul (1993) who stated that the methane percentage of produced biogas from fermenting plant residues ranged between (60.00 – 66.5%), while Alaa El- Din *et al* (1984) and Kalyuzhnyi *et al* (1998) found that the methane percentage ranged between 72.1–79.81% of produced biogas from the fermentation of animal wastes and sewage sludge.

d. Rate of organic substrate conversion to biogas and methane.

Data presented in Table (6) show conversion rate of organic substances presented in both wastes to biogas and methane. These data were calculated as liter/kg total solids added as well as liter/kg volatile solids added or consumed for both JMPW and CD.

Obtained results clearly show organic substrate conversion rates was differed according to the type of digested waste. These rates were higher for digested JMPW than digested CD wastes.

The higher substrate conversion rates to biogas and methane in the case of JMPW than CD could be attributed to the high activity of lytic microorganisms viz; anaerobic saccharolytic, proteolytic, cellulose decomposers as well as acid

producing bacteria which were observed with digesting slurry of JMPW compared to digesting slurry of cattle dung (Table, 2).

Table 6. Conversion rates of total and volatile solids into biogas mixture and methane gas during anaerobic digestion of jew's mallow processing wastes (JMPW) and cattle dung (CD).

Digested waste	Total Biogas production L/digester	Biogas production Rate of production (L/Kg)			Total Methane production L/digester	Methane production Rate of production (L/Kg)		
		TS Added	VS Added	VS Consumed		TS added	VS Added	VS Consumed
JMPW	562.0	175.63	215.33	826.47	323.21	101.00	123.84	475.31
CD	414.85	130.05	160.79	797.79	254.74	79.86	98.74	489.88

Similar results concerning the relation between the biogas production and TS, VS added or consumed were obtained by earlier investigators; Nipaney and Panholzer (1987) mentioned that the gas yield was 707 liters/kg VS consumed when the *Pistia stratiotes* was anaerobically digested to biogas generation. Summers *et al* (1987) observed that the excreta from dairy and fattening cows produced 170 liters/kg TS added when anaerobically digested. Zaghloul (1993) found that the biogas production rates were 813, 907, 627 and 294 liters/kg VS consumed for cattle dung, poultry manure, water hyacinth and tomato shoots, respectively. Also, he found that the methane production rates were 596, 638, 438 and 184 liter/kg VS consumed for abovementioned residues, respectively. Also, 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 liter CH_4/kg VS added, respectively.

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إنتاج البيوجاز من مخلفات التصنيع الغذائي للملوخية وروث الماشية باستخدام نظام التغذية دفعة واحدة .

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فى هذا البحث تم دراسة إنتاج البيوجاز بواسطة الهضم اللاهوائي لمخلفات التصنيع الغذائي للملوخية ومقارنة ذلك بروث الماشية ولقد أوضحت نتائج هذه الدراسة أن أعداد البكتريا اللاهوائية المحللة للكربوهيدرات وتلك المحللة للبروتينات والمحللة للسليولوز وكذلك البكتريا المنتجة للأحماض ظهرت بأعداد عالية فى محلول التخمير الخاص بمخلفات التصنيع الغذائي للملوخية عن محلول التخمير الخاص بروث الماشية .

انخفضت أعداد البكتريا المرضية (مجموعة بكتريا القولون والسالمونيلا ، الشيجيلا) انخفاضاً سريعاً خلال فترة التخمير حيث كان الزمن اللازم لاختفاء متسعمرات بكتريا القولون الكلية ٣٥ يوماً بينما الزمن اللازم لاختفاء مستعمرات بكتريا القولون البرازية ٢٨و ٣٥ يوماً عند تخمير مخلفات التصنيع الغذائي للملوخية وروث الماشية على التوالي . كذلك أظهرت النتائج أن أعداد بكتريا السالمونيلا والشيجيلا قد اختفت تماماً عند اليوم الرابع عشر والثامن والعشرون لمخلفات التصنيع الغذائي للملوخية وروث الماشية على التوالي .

أظهر محلول تخمير مخلفات التصنيع الغذائي للملوخية تركيزات عالية من الأحماض العضوية المتطايرة مقارنة بروث الماشية . كذلك أوضحت النتائج أن تركيز النيتروجين الأمونيومى كان (١٢٧٣ ، ٢٧٥ جزء فى المليون) فى محاليل التخمير لكل من مخلفات التصنيع الغذائي للملوخية وروث الماشية على التوالى وأن هذا التركيز لم يصل إلي مستوى السمية أو التثبيط لبكتريا الميثان .

بخصوص معدلات إنتاج البيوجاز والميثان على أساس كمية المادة العضوية المضافة أو المستهلكة فقد أظهرت النتائج أنه عند تخمير مخلفات التصنيع الغذائي للملوخية أنتجت كميات من البيوجاز أعلى من تخمير روث الماشية حيث وجد أن معدلات إنتاج البيوجاز لكل كيلو جرام من المادة العضوية المضافة أو المستهلكة هي (٢١٥,٣٣، ٨٢٦,٤٧ و ١٦٠,٧٩، ٧٩٧,٧٩) لمخلفات التصنيع الغذائي للملوخية وروث الماشية على التوالي .

أظهرت النتائج أن معدلات إنتاج الميثان كانت أعلى فى حالة روث الماشية بالمقارنة بمخلفات التصنيع الغذائي للملوخية حيث أوضحت النتائج أن معدلات إنتاج الميثان لكل كيلو جرام من المادة العضوية المضافة أو المستهلكة هى (١٢٣,٨٤ ، ٤٧٥,٣١ و ٩٨,٧٤، ٤٨٩,٨٨) لمخلفات التصنيع الغذائي للملوخية وروث الماشية على التوالي .