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Can the seasonal variability affect the BMP of fruit and vegetable waste?

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Abstract Fruit and vegetable waste (FVW), largely produced in open markets, is characterized by highly putrescible materials, thus being a proper substrate for anaerobic digestion. This study investigated the effect of the seasonal variation of FVW, on the biochemical methane potential (BMP). To this end, FVW with an average composition between the wastes collected from open markets in Amman (Jordan) and Sfax (Tunisia) was considered. Three sets of batch BMP tests were carried out using three seasonal FVW compositions under mesophilic conditions (34°C). The selected fruits and vegetables were chopped until reaching a particle size of 10 mm. Sewage sludge was used as inoculum, and the batch experiments were performed with an inoculum/substrate ratio of 2 (g VS basis). VFAs, TS and VS content, COD, TAN, pH and alkalinity were monitored. Results show a final methane yield of 493.1 ± 27.7, 394.2 ± 69.6 and 373.3 ± 32.4 NmL CH_4 g SV^{-1} for the winter, spring and summer composition, respectively. Due to the high biodegradability of all substrates, more than 80% of the total methane production occurred in the first 7 days, with a simultaneous reduction of the soluble COD and VFAs. For the highest performing substrate, a 40% reduction of VS was observed.

Keywords: anaerobic digestion, open market waste, methane, energy recovery

1. Introduction

Fruit and vegetable waste (FVW) is produced in large amounts in world wholesale markets (Edwiges et al., 2018). It has been estimated that more than 1748 million tons of FVW are wasted per year (Chatterjeeet al., 2020). The FVW produced in local open markets in Sfax (Tunisia) and Amman (Jordan) varies from 3 to 5 and 10 to 12 tons per day, respectively. The need for a proper management of market waste pushes towards the implementation of sustainable strategies through the recovery of energy and nutrients rather than landfilling. Nonetheless, recovery strategies are affected by the physical and chemical waste characteristics (Chatterjeeet al., 2020).

In this context, anaerobic digestion (AD) could be adopted to treat FVW for biogas production due to its high moisture and volatile solid content (Chatterjeeet al., 2020). AD gives the opportunity of both complying with the EU policies for greenhouse gases reduction and producing renewable energy (Scotto di Perta et al., 2019). However, FVW is characterized by a heterogeneous composition that can vary according to the season (Arhoun et al., 2019). Therefore, in this study, the effect of the seasonal variation of FVW on its biochemical methane potential (BMP) is evaluated.

This work was carried out within the CEOMED project (http://www.enicbcmed.eu/projects/ceomed), which involves 5 Mediterranean countries, and aims to recycle the FVW produced in the open markets located in Tunisia and Jordan, with the installation and operation of 2 pilot-scale anaerobic digesters.

2. Materials and methods

2.1. Substrate preparation

Three seasonal FVW compositions have been investigated: winter-autumn, spring and summer.

Figure 1. Fruits and vegetables chopped at a particle size of 10 mm (from left: winter-autumn, spring and summer).

They were selected in order to be representative of the average composition between the wastes collected from open markets in Amman (Jordan) and Sfax (Tunisia) (Table 1). The selected fruits and vegetables were chopped until reaching a particle size of 10 mm (Figure 1) and then stored in plastic bags at − 20 °C (Holliger et al., 2016), in order to reduce the composition fluctuations during the experimental period.

Table 1. Fruits and vegetables in the winter-autumn, spring and summer.

	winter-autumn	spring	summer
Fruit	% ww	% ww	% ww
Apple	5%	5%	5%
Apricot		7%	
Cherry			6%
Grape			6%
Grapefruit	5%		
Kiwi			5%
Lemon	2%	3%	4%
Loquat		7%	
Melon			6%
Mandarin	6%		
Orange	12%		
Peach		4%	7%
Pear	4%	6%	6%
Pomegranate	1,5%		
Strawberry		7%	
Watermelon		4%	8%
Vegetables	% ww	% ww	% ww
Beans (green)	2,5%		
Broccoli	4%	3%	
Cabbage leaves	3%	3%	3%
Carrot leaves	2%	3%	5%
Cauliflower leaves	2%	2%	4%
Celery		4%	
Coriander	2%	2%	4%
Courgette/ Zucchini	2%	2%	2%
Cucumber	7%	8%	14%
Eggplant	15%	10%	5%
Fennel	25%	20%	10%
TOT	100%	100%	100%

2.1. Inoculum

The sewage sludge used as inoculum (Table 2) was collected at the municipal wastewater plant of Cuma (Campania region, Italy). Table 2 summarizes the physical-chemical characteristics of the inoculum. Before starting the tests, the sludge was pre-incubated under mesophilic conditions (34°C) for more than one month in order to reach a stabilization of the methanogenic activity (Holliger et al., 2016).

Table 2. Physical-chemical characteristics of the inoculum used

Parameter	Inoculum
TS (g/kg)	9.57±1.28
VS (g/kg)	6.48±0.78
pH	7.22±0.04
Total Alcalinity (mg $CaCO_3$/l)	1267.64±25.54
N-NH_4^+ (mg/l)	276.92
N (%)	0.054±0.011

2.2. BMP tests set-up

The batch experiments were performed in 500 ml GL 45 glass bottles (Schott Duran, Germany). For each of them, an inoculum/substrate ratio of 2 (g VS basis) was used in order to avoid any accumulation of volatile fatty acids (VFAs).

Three sets of batch BMP tests were carried out under mesophilic conditions (34°C). The temperature was kept constant during all the trials by submerging the bottles in a hot water bath (Esposito et al., 2012).
Set 1 was carried out as a sacrifice test with the winter – autumn substrate and was also devoted to evaluate the biodegradability of the FVW. Set 2 and 3 were conducted using all three seasonal FVW compositions.

2.3. Analytical Methods

TS and VS content, soluble chemical oxygen demand (CODs), total ammoniacal nitrogen (TAN), total alkalinity (TA) were measured according to the Standard Methods (APHA, 2005). The carbohydrate content was measured according to Dubois et al. (1956). The protein content was evaluated as described by Lowry et al. (1951). pH was measured with a pH/ION 340i pH meter (WTW, Germany). VFAs were analyzed using a High-Performance Liquid Chromatography (HPLC), with a Dionex (Sunnyvale, USA) LC 25 Chromatography Oven equipped with a Metrohom (Herisau, Switzerland) Organic Acids column (Metrosep Organic Acids - 250/7.8). The biogas composition was monitored using a Star 3400 gas chromatograph (Varian, USA). Methane production was measured by means of a volumetric displacement method, as described by Esposito et al. (2012).

3. Results and discussions

3.1. Substrates characterization

In terms of composition, the percentage of fruit and vegetable varied according to the season, as also found by Arhoun et al. (2019). Specifically, fruit constituted 36, 43 and 53% of the winter-autumn, spring and summer substrates, respectively.

Table 3. Physical-chemical FVW characteristics

Parameter	winter-autumn	spring	summer
Moisture (%)	88.44±0.35	88.34±1.93	88.56±1.06
TS [g/kg]	115.63±3.51	116.6±19.29	114.42±10.60
VS [g/kg]	105.48± 2.69	108.39± 18.99	107.08± 10.17
COD_t [mg/gVS]	1707.68±169.82	1206.76±78.29	1275.83±32.80
COD_s [mg/gVS]	828.56±4.46	717.17±0.00	962.51±8.80
Carbohydrates [mg/gVS]	773.21±71.43	693.52±100.43	734.17±154.57
Soluble Carbohydrates [mg/gVS]	577.06±89.15	612.13±62.04	648.85±0.00
Proteins [mg/gVS]	196.99±33,17	118.72±15.56	86.28±5.01
Soluble Proteins [mg/gVS]	64.78±3.30	37.38±2.81	51.26±3.25

* TS – total solid; VS – volatile solid; COD_t - Total COD; COD_s - Soluble COD;

As it is possible to observe from Table 3, the TS and VS content was similar for all the substrates, as well as the moisture content, which accounts for more than 88% for all the seasons. VS content represents 91, 93 and 94% of TS for winter-autumn, spring and summer, respectively, indicating that the selected FVW is particularly suitable to anaerobic organic conversion (Arhoun et al., 2019). Indeed, Chatterjee et al. (2020) indicated that a waste with VS content > 90% and high moisture content is decomposed in a short time and easily via AD. Each substrate had a similar total carbohydrate content but differed for the total proteins content, which was higher for the winter substrate.

3.2. CH_4 production from FVW

The cumulative bio-methane production per grams of VS (Figure 2) can be described as a reverse L shaped curve, characterized by an initial phase with a high bio-methanation rate (103 Nml CH_4/g SV d), which progressively decreased as the organic solids content in the batch bottles was reduced (Esposito et al., 2012). Specifically, VS content decreased from 7.6 to 4.4 g/kg, resulting in a VS reduction of 42%. Moreover, no drops in pH occurred during the test and it remained within the optimal range of 6-8.

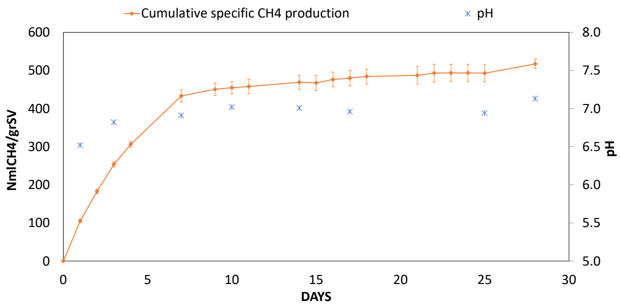

Figure 2. Specific cumulative methane production of winter-autumn substrate and pH trend.

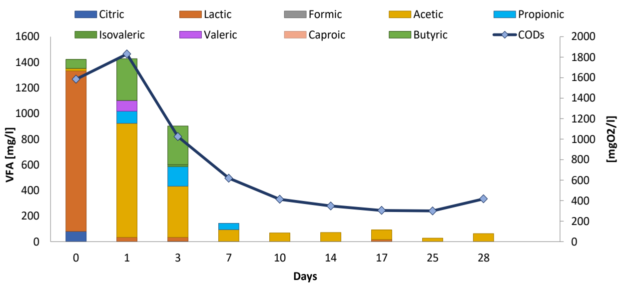

Figure 3. VFAs and soluble COD trends.

As shown in the figures above, the amount of VFAs decreased as the soluble COD was degraded. With regard to the single VFA produced, it is possible to observe a high concentration of citric and lactic acid on day 0, which were principally converted in acetic and butyric acid after the first day. More than 84 % of the methane produced occurred in the first 7 days from the beginning of the trial, in correspondence with a great reduction in terms of VFAs. After day 7, only a low concentration (< 200 mg/l) of acetic acid was detected.

3.3. Effect of the seasonal composition

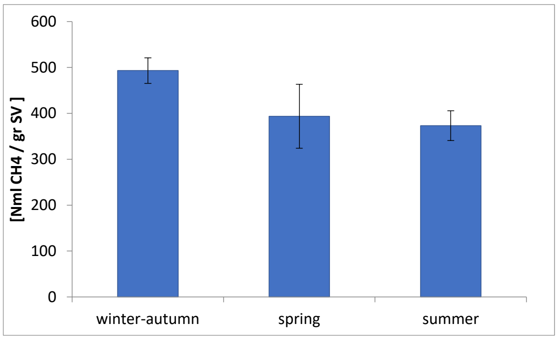

Figure 4. Specific cumulative methane productions.

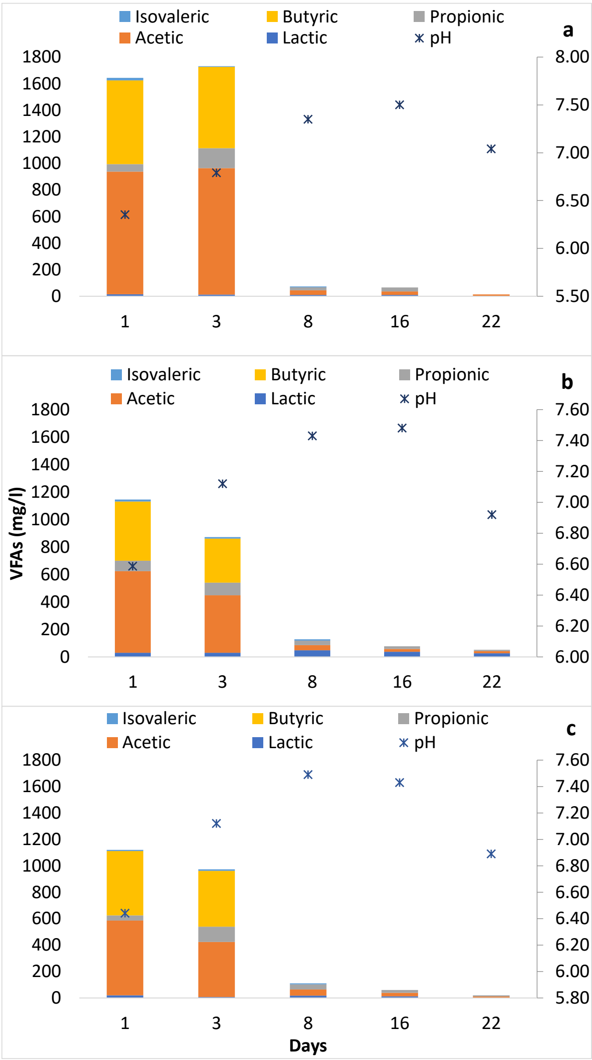

Figure 5. VFAs and pH trends for the winter-autumn (a), spring (b) and summer (c) substrates.

Figure 4 shows the specific cumulative methane production related to the different seasons. Results show a final methane yield of 493.1 ± 27.7, 394.2 ± 69.6 and 373.3 ± 32.4 NmL CH_4 g SV^{-1} for the winter-autumn, spring and summer composition, respectively. These values are comparable with the BMP of FVW in the study of Edwiges et al. (2018), which varies between 288 and 516 NmL CH_4 g VS^{-1}. Methane yield is consistent with the higher CODt of the winter-autumn substrate, which was 37% higher than for the other two seasons (Table 3).

Also the VFAs trend is in good accordance with these findings. Indeed, Figure 5 shows higher VFAs concentrations (>1600 mg/l) on day 1 for the winter-autumn substrate, which is almost everything consumed after the first week.

Table 4 reports the main parameters monitored during trial 3. Carbohydrate content directly affected the bio-methanation rate. Indeed, after the first 24 h, the soluble carbohydrates decrease by 97-98% for all the substrates. Proteins were instead degraded more slowly.

Table 4. Main parameters monitored during trial 3

DAYS	Soluble COD [mg O_2/l]		
	winter-autumn	spring	summer
0	3073.50±53.03	3051.00±403.05	3051.00±106.07
1	2185.50±53.03	1818.00±21.21	2118.00±42.43
3	2339.00±35.36	1569.00±63.64	1599.00±63.64
8	528.00±7.07	398.00±7.07	518.00±7.07
16	469.00±16.50	274.00±14.14	304.00±4.71
22	304.67±18.86	211.33±9.43	231.33±4.71
DAYS	**Soluble Proteins [mg/l]**		
	winter-autumn	spring	summer
0	442.03±4.08	273.38±19.57	352.84±6.14
1	337.70±29.60	189.05±15.48	165.27±7.31
3	205.68±51.80	187.48±6.95	191.98±3.07
8	265.95±4.01	278.40±45.58	240.37±5.46
16	212.54±4.15	75.25±2.27	75.25±1.76
22	77.73±4.30	76.28±5.54	54.93±2.31
DAYS	**Soluble Carbohydrates [mg/l]**		
	winter-autumn	spring	summer
0	2802.74±47.98	1887.26±509.29	2915.83±117.01
1	84.21±7.25	55.40±1.35	52.07±16.10
3	50.67±1.01	46.30±4.10	56.62±11.55
8	47.02±0.36	41.62±4.56	42.89±3.28
16	44.70±1.54	36.37±3.52	33.67±0.31
22	32.43±2.47	34.89±0.81	28.68±1.09

4. Conclusions

In conclusion, the results demonstrate that the selected FVW is an easily degradable material suitable for anaerobic digestion; confirming the possibility of recycling the FVW produced in the open markets located in Tunisia and Jordan throughout the recovery of energy rather than landfilling.

In terms of season variability, it was found that the percentage of fruit and vegetable varied according to the season, specifically, fruit constituted 36, 43 and 53% of the winter-autumn, spring and summer substrates, respectively. Nonetheless, similar TS and VS contents for all the substrates, as well as the moisture content (88 %) were observed. Differences in terms of chemical composition over the seasons, in particular a higher protein content of the winter-autumn substrate, seemed to affect the final methane yield, which was 493.1 ± 27.7, 394.2 ± 69.6 and 373.3 ± 32.4 NmL CH_4 g SV^{-1} for the winter, spring and summer compositions, respectively.

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References

APHA. (2005). Standard methods for the examination of water and wastewater. American Public Health Association, American Water Environment Federation: Washington, DC, USA.

Arhoun, B., Villen-Guzman, M., Gomez-Lahoz, C., Rodriguez-Maroto, J. M., Garcia-Herruzo, F., & Vereda-Alonso, C. (2019). Anaerobic co-digestion of mixed sewage sludge and fruits and vegetable wholesale market waste: Composition and seasonality effect. *Journal of Water Process Engineering*, **31**, 100848.

Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. T., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. Analytical chemistry, 28(3), 350-356.

Chatterjee, B., & Mazumder, D. (2020). New approach of characterizing fruit and vegetable waste (FVW) to ascertain its biological stabilization via two-stage anaerobic digestion (AD). *Biomass and Bioenergy*, 139, 105594.

Edwiges, T., Frare, L., Mayer, B., Lins, L., Triolo, J. M., Flotats, X., & de Mendonça Costa, M. S. S. (2018). Influence of chemical composition on biochemical methane potential of fruit and vegetable waste. *Waste management*, **71**, 618-625.

Esposito, G., Frunzo, L., Liotta, F., Panico, A., & Pirozzi, F. (2012). Bio-methane potential tests to measure the biogas production from the digestion and co-digestion of complex organic substrates. *The Open Environmental Engineering Journal*, 5(1).

Holliger, C., Alves, M., Andrade, D., Angelidaki, I., Astals, S., Baier, U., ... & Wierinck, I. (2016). Towards a standardization of biomethane potential tests. *Water Science and Technology*, **74**(11), 2515-2522.

Lowry, O. H., Rosebrough, N. J., Farr, A. L., & Randall, R. J. (1951). Protein measurement with the Folin phenol reagent. Journal of biological chemistry, 193, 265-275.

Scotto di Perta, E., Cervelli, E., di Campagna, M. P., & Pindozzi, S. (2019). From biogas to biomethane: Techno-economic analysis of an anaerobic digestion power plant in a cattle/buffalo farm in central Italy. *Journal of Agricultural Engineering*, **50**(3), 127-133.