Co-fermentation of organic waste and sewage sludge after cavitation for VFAs production and subsequent biomethanization

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In the urban context, the two main waste streams are sewage sludge (SS) and food waste (FW), which are destined to grow with the increasing world population. At the present, in Europe 13 million tonnes (dry matter) of sewage sludge and 78 million tonnes of food waste are generated, which need to be recovered with a circular economy approach in the frame of the EU Green Deal (Collivignarelli et al., 2019).

This study focuses on the transformation of these waste streams into high-added value compounds and biogas in mesophilic conditions through the acidogenic co-fermentation for VFAs production and by testing the BMP of the initial substrates, of the fermentation effluent and of its solid-rich fraction. The solid-rich fermentation effluent would be the only waste overflow of the fermentation process if the VFAs produced are separated from the slurry for other potential uses, such as the PHAs synthesis. Therefore this approach, in a frame of urban-biorefinery concept, would allow to drive the renewable carbon sources into more profitable routes than the sole biogas production.

In order to reduce the size of the substrate and to enhance the solubilization of the organic compounds, a pre-treatment of hydrodynamic cavitation has been tested on the mixture of FW and SS. To our knowledge, hydrodynamic cavitation has been performed on SS only (Bhat & Gogate, 2021), while studies on a mixture with food waste are still to be carried out.

The substrates used in this study were the biological sludge collected from the wastewater treatment plant (WWTP) located in Fusina (Venice, Italy) and the seasonal vegetable scraps from the fruit and vegetable wholesale market located in Marghera (Venice, Italy). The inoculum consisted of anaerobic digestate collected from the Treviso (Italy) WWTP, where the wastewater sludge and the organic fraction of municipal solid waste are anaerobically co-digested. All the three matrices were recurrently collected during the study period.

The mixture was made from the two substrates in a 1:1 ratio on a TVS basis, i.e. at a volumetric fraction of 73-77% of sludge and 27-23% of vegetable scraps, according to Valentino *et al.* (2019) and Moretto *et al*. (2020). The hydrodynamic cavitation of the mixture was performed twice, with the summer scraps and the autumnal scraps, applying the parameters listed in table 1.

Table 1. Parameters applied in the hydrodynamic cavitation.

	Time (min)	**Rotation velocity (rpm)**	**Pression (bar)**	**$Q_{mixture}$ (L/min)**
1st cavitation	27	1550-1650	1,40	12-30
2nd cavitation	30	1240	1,8-2	50

All the matrices were characterized in terms of total solids and volatile solids (TS and VS), soluble chemical oxygen demand (sCOD), VFAs (COD_{VFA}), total COD (tCOD), cations (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}), pH and alkalinity. All analyses were performed according to the APAT, IRSA-CNR (APAT, 2003) and APHA, AWWA, WET methods (APHA, 2012).

The fermentation tests were conducted at T=37°C with a laboratory fermenter with 4L of working volume, authomatically stirred at 14 rpm. The VFAs yield was determined for the cavitated and untreated mixture by carrying out a first exploratory batch test in duplicate and it was optimized in a second batch test, after which the reactors were fed in a semi-continuous manner. All the parameters applied are listed in table 2.

Table 2. Parameters applied in the fermentation tests.

	OL (kg_{tCOD}/m^3)		**F/M (kg_{tCOD}/kg_{TVS})**	
	cavitated	**untreated**	**cavitated**	**untreated**
1st batch	21,4	22,4	2,86	2,95
2nd batch	33,4	34,8	9,51	9,92
	OLR (kg_{TVS}/m^3 d)		**HRT (days)**	
	cavitated	**untreated**	**cavitated**	**untreated**
Semi-continuous	8	8	5	6,6

The BMP tests were conducted at T=42°C in bottles with a working volume of 0,5 L on the single substrates (organic waste and biological sludge), on the mixture of organic waste and biological sludge cavitated and non cavitated in a 1:1 ratio on TVS basis, and finally on the fermentation effluent of the two mixtures and on its solid-rich fraction. The OL was maintained between 4,5 and 5 kg_{TVS}/m^3, the F/M between 0,36-0,48 VS/VS.

The hydrodynamic cavitation pre-treatment increased the sCOD of the mixture by 39% and 43% after the first and the second treatment, respectively. In the semi-continuous fermentation process, this resulted in a 20% higher maximum activity of 1,01 $gCOD_{VFA}/gVS_{(0)}$ d for the cavitated, while the untreated mixture reached a value of 0,84 $gCOD_{VFA}/gVS_{(0)}$ d. The yields were similar between the two conditions, with values of 0,53 ± 0,07 $gCOD_{VFA}/gVS_{(0)}$ for the cavitated and 0,52 ± 0,06 for the untreated mixture.

In the semi-continuous process, the concentration and profile of the VFAs was kept stable for 3,8 HRTs for the cavitated mixture, reaching a mean concentration of 12,94 ± 0,63 $gCOD_{VFA}/L$, and for 2,6 HRTs for the untreated mixture, reaching a mean concentration of 18,23 ± 0,51 $gCOD_{VFA}/L$. The pH showed a stable performance, with mean values of 5,508 ± 0,138 for the cavitated and 5,361 ± 0,059 for the untreated mixture.

Therefore, pH control was not needed, thus allowing to save chemicals and costs. The profile of the VFAs was similar between the two conditions, except for the valeric acid, accounting for 6,6 ± 1,1 % in the untreated and absent in the cavitated mixture. Interestingly, both VFAs profiles showed a stable high molar fraction of VFA with odd number of C-atoms if compared to the total $[C3/(C3+C2)]_{VFA}$, accounting for 0,53 ± 0,04 for the cavitated and 0,48 ± 0,04 for the untreated mixture.

The results obtained emphasize that a good acidogenic performance took place respect to similar works found in literature: the concentration obtained of 18,23 ± 0,51 $gCOD_{VFA}/L$ was close to 19,5 $gCOD_{VFA}/L$ produced in similar conditions by Valentino *et al.* (2019), which used richer substrates, i.e. squeezed OFMSW and thickened activated sludge. The yields of both mixtures were higher than those in Valentino *et al*. (2019), who reached 0,41-0,44 $gCOD_{VFA}/gVS_{(fed)}$. A higher $[C3/(C3+C2)]_{VFA}$ ratio of 0,48-0,53 was obtained in this study if compared to 0,20 ± 0,02 obtained by Valentino *et al*. (2019) and to 0,38 ± 0,03 reached by Moretto *et al.* (2019), who optimized the fermentation process achieving 39 ± 3 $gCOD_{VFA}/L$. The $[C3/(C3+C2)]_{VFA}$ ratio is a pivotal characteristic since affects the composition of the microbial synthetized biopolymer, such as the polyhydroxyalkanoates (PHA), and, in turn, their market applications (Bengtsson *et al.*, 2010).

The results of the BMPs were consistent with similar works found in literature. In particular, the solid-rich fermentation effluent showed an SGP of 0,42 ± 0,0 m^3/kgTVS for the cavitated and of 0,34 ± 0,01 m^3/kgTVS for the untreated mixture, which was slightly lower than the value of 0,44 ± 0,02 m^3/kgTVS obtained by Moretto *et al.* (2020) in a continuous process. However, it should be considered that the author diluted the solid-rich fermentation effluent with SS, therefore adding readily degradable organic material to the slowly degradable COD left in the solid-rich fermentation effluent.

In conclusion, this work demonstrated that vegetable scraps and SS can be treated with an integrated approach consisting of the fermentation, which allows to recover high-added value VFAs from the liquid fraction, also suitable for PHAs synthesis, and of the anaerobic digestion of the solid fraction, which enables to recover energy in the form of biogas.

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