Food waste and waste activated sludge co-fermentation to enhance VFA production

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Organic wastes are generated in huge quantities daily being excellent biomaterials that can be used as biomass feedstock in biorefineries to produce volatile fatty acids (VFA) in acidogenic fermentation. VFA production has paid more attention than general treatments as incineration, landfill, composting or anaerobic digestion due to the wide range of VFA uses (Zhou et al., 2018). The acidogenic fermentation is a biological process based on hydrolysis, acidogenesis and acetogenensis. The first step, hydrolysis, breaks down the complex organic matter such as proteins, carbohydrates and lipids in monomers as amino acids, sugars, glycerol and some fatty acids. In the subsequent steps, bacteria transform these monomers in VFA through different metabolic pathways. An organic urban waste widely used as feedstock in acidogenic fermentation is food waste (FW) being a promising carbon source with a high concentration of organic matter that can be bioconverted in VFA. Nevertheless, this substrate is also characterized by complex biodegradable substances that could limit the fermentation. Specifically, the acidogenic fermentation of FW is restricted by hydrolysis as rate-limiting step (Cheah et al., 2019) due to its complex polymers composition (Zhou et al., 2018). Moreover, FW is usually characterized by a low alkalinity, so its co-fermentation with another substrate that provides alkalinity to the mixture, such as Waste Activated Sludge (WAS) could be interesting to enhance VFA production without the use of external reagents to control the pH. In fact, Feng et al. (2011) and Li et al. (2018) reported that the addition of FW to WAS increased fermentation yields when compared to sludge fermentation.

Moreover, to improve the FW hydrolysis, different strategies could be carried out, such as the application of pre-treatments. The biological pre-treatment could use enzymatic bacteria to break the cellular wall, making the bacteria more susceptible to microbial attack (Wagner et al., 2018) without reagents addition and low energy demands. The pre-treatment of waste activated sludge (WAS) at 55 ºC during a relatively short period of time (i.e. 2.5 hours) could lead to the release of hydrolytic compounds that could solubilize particulate organic matter. Therefore, the co-treatment of FW and pre-treated WAS could enhance the FW solubilization and, therefore, its acidogenic fermentation. Hence, double beneficial effect is allowing with biological pre-treatment that increase the FW solubilization and the co-fermentation of FW and WAS improving the hydrolysis.

This study focuses on the study of the improvement of VFA yield and distribution of FW fermentation using its co-fermentation with pre-treated and non-pre-treatment WAS at different mixtures in VS basis. Moreover, the synergies that are carried out in this process will be investigated.

Batch fermentation assays were performed to check the effect of co-fermentation of FW with pre-treated Waste Activated Sludge (WASp) and non-pre-treated Waste Activated Sludge (WAS) without inoculum addition. The FW used was formulated combining: 30% vegetables, 30% fruits, 20% carbohydrates 10% meat and 10% fish and seafood (in weight basis) using ingredients available all year-round to ensure its reproducibility. The synthetic FW was shredded (Bosch, MMB66G5M) and mixed with deionized water to adjust the total solids (TS) and volatile solids (VS) content around 15.0%-15.5% in weight (Xiong et al., 2019; Abreu et al., 2019). The WAS used was collected from the thickener of secondary reactor of a municipal WWTP of the Barcelona Metropolitan Area. WAS pre-treatment was carried out by placing 1L-bottles with 900 mL of effective volume maintaining the temperature at 55 ºC in incubator during 2h 30 min in order to release hydrolytic substances inside WAS (obtaining the WASp). Batch fermentation assays were performed in bottles of 250 mL with 150 mL of effective volume mixing FW and WAS in different proportions in VS basis: (i) 50% FW + 50% WAS/WASp, (ii) 30% FW + 70 % WAS/WASp and (iii) 10% FW + 90 %WAS/WASp. Furthermore, WAS, WASp and FW fermentation were analysed as controls. The conditions were performed in triplicates at 35 ºC for 14 days analysing VFA production and distribution, COD_{VFA}, soluble COD (sCOD) and pH.

The analysis of TS, VS, sCOD were performed in accordance to the Standard Methods for the Examination of Water and Wastewater (APHA, 2012). The pH was determined using a pH electrode (PHEL-GB3-001) connected to multimeter (Crison, MultiMeter MM 41). The VFA concentration and its distribution were analysed by gas chromatography (Shimadzu GC 2010 plus) equipped with capillary column (Nukol™, 15 m x 0.53 mm x 0.5 µm) with flame ionization detector (FID) and He as carrier gas.

Batches were also carried out to check the synergistic effect of co-fermentation of FW and WAS/WASp. First of all, two assays comparing WAS and WASp were carried out as shown in Figure 1 and Figure 2, respectively. An increase of VFA production is observed in the first four days of WASp, indicating that the use of WASp could enhance VFA production at short retention times. Hence, mixtures with WAS and WASp were done to check if WASp provide an improvement in the VFA yield. As can be seen in Figure 2, the improvement is appreciable in mixture 30%FW+70%WASp with value of 538 mgCOD/gVS compared to 420 mgCOD/gVS obtained with WAS. The highest proportion of FW (50% FW) lead to a decrease of pH, yielding the lowest VFA production and no beneficial effect of using WASp was observed.

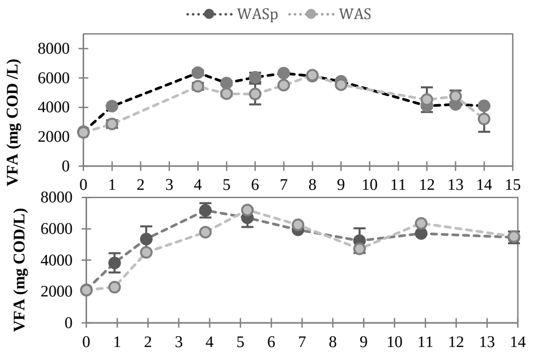

Figure 1: VFA production of WAS and WASp in two assays

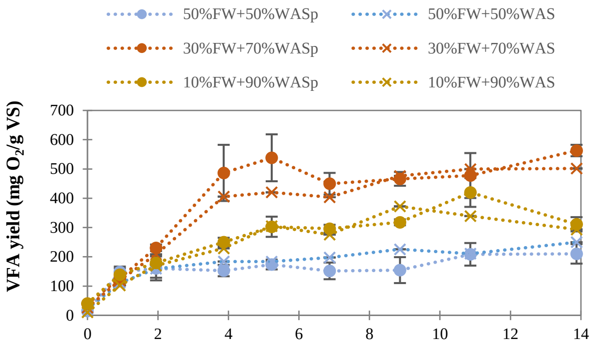

Figure 2: VFA yield of mixtures of FW with WASp and WAS

The assays showed a clear synergistic effect between FW and WAS. As is shown in Figure 3, the mixtures 50%FW + 50%WAS and 30%FW + 70%WAS are very favourable with a maximum VFA yield of 488±25 and 419±49 mgCOD/gVS at 8th day, respectively, compared to 68 and 70 mg COD/gVS calculated theoretically from the VFA yield of FW and WAS controls (mono-fermentation without pH control). However, in the mixture 10%FW + 90%WAS the synergistic effect is less present than in the other two cases with a maximum VFA yield of 175 mg COD/gVS at 8th day compared to the theoretically calculated VFA yield of 71 mg COD/gVS from the monofermentation of substrates. This fact is because very little amount of FW has been added in the mixture and there is not such a clear improvement effect. Even so, the mixtures achieved a huge improvement of 713%, 600% and 247% in the mixtures 50%FW+50%WAS, 30%FW+70%WAS and 10%FW+90%WAS, respectively, in the maximum production day when compared to the mono-fermentation of substrates (without pH control). Co-fermentation results are promising and will be further studied with more discontinuous and continuous assays.

On the other hand, the distribution obtained in this experiment is also important. As shown in Figure 4, the VFA of different mixtures changed depending on WAS:FW proportion on VS basis and pH. First of all, it is important to highlight that the samples with more WAS proportion had a distribution with acetic (25%), propionic (32%) and butyric (16%) acids as majority VFAs. In this case, the obtained pH values between 6 and 7 (without external pH control) played a crucial role. Furthermore, the sample with 70% of WAS maintained the acetic acid proportion of 25% but increased the butyric content to 40% and decreased the propionic proportion to 15% at pH 5. Finally, the sample with 50% of WAS had less acetic (18%) and propionic (7%) acids but increased a little bit the butyric proportion (42%). Unlike the other mixtures, the valeric acid (13%) and caproic (13%) increased in spite of pH at 4.75.

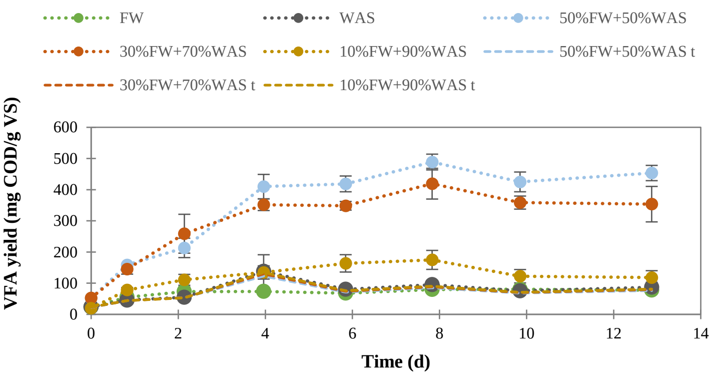

Figure 1: VFA yield in the mixtures and synergic effect

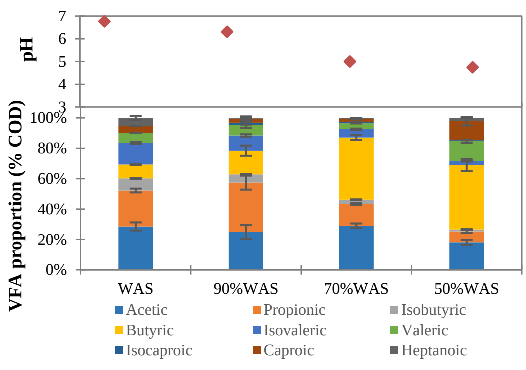

Figure 2: VFA distribution and pH

As general conclusion, the co-fermentation of FW and WAS at 35 ºC used in the study show: (i) in short-term analysis, the WASp seems to have a (limited) positive effect in VFA production if pH is between 5.5 and 7.0 (ii) the mixture of WAS and FW has an important synergic effect with a maximum yield of 489±25 mg COD/gVS in the mixture 50%FW + 50%WAS, (iii) all mixtures show a high VFA production improvement compared to the mono-fermentation values of FW and WAS, (iv) when FW doses are increased, the percentage of butyric and propionic acids increased and decreased, respectively, (v) the co-fermentation of FW and WAS could be used to tune the VFA production and profile.

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