Apple pomace anaerobically co-digested with swine manure for organic waste valorisation

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The world apple production has increased by 4% from 2017, to a total of 86.44 million of tons in 2020 (Shahbandeh, 2022). Around 30% of this amount is used by the apple processing industry for the production of juice, cider and jelly (Dhillon et al., 2013a). After the processing, 25% of the fresh apple fruit turns into waste, as skin, seeds and pulp, known as apple pomace (AP). This represents millions of tons of waste, and the majority of these residues goes to landfilling, incineration or composting, generating major environmental and human health problems (Dhillon et al., 2013a). To address this, innovative approaches are emerging in the frame of the bioeconomy, to use the AP as a by-product to obtain valuable resources, such as animal feed, organic acids or pectin, among others (Dhillon et al., 2013a). In this line, anaerobic digestion (AD) is a mature and profitable technology that has been pointed as an excellent choice for food and beverage industry waste valorization (EC, 2020), and in particular for apple waste (Awasthi et al., 2021).

In the AD process, it has been stated that co-digestion of N rich wastes, such as swine manure (SM) with C rich residues, like AP, can provide a balanced C/N ratio, and helps to avoid inhibition by ammonia inside the reactors. Also, the co-digestion of AP with residues with a high buffering capacity, such as SM, will provide a more stable AD process and also valuable nutrients (Awasthi et al., 2021). However, the use of AP as a co-substrate for AD process, and its effects on energy production has been studied only in few works (Llaneza-Coalla et al., 2009; Kafle and Kim, 2013; Riggio et al., 2015; Molinuevo-Salces et al., 2020). In this line, the aim of the present study was to assess for the first time the anaerobic co-digestion of different proportions of AP and SM under semi-continuous operation and mesophilic conditions, for 240 days, and to compare the results of biogas production and methane yield with the AD of SM alone under the same conditions.

The AP was obtained from the Regional Research and Development Service of Asturias (SERIDA), (Asturias, Spain), as solid fresh residue from the cider production. After the transportation to ITACyL, it was stored at 4ºC in plastic containers for further utilization. The AP had a concentration of 268.7 ± 14.5 g of total solids (TS) kg^{-1}, and 265.4 ± 14.4 g volatile solids (VS) kg^{-1}. The SM was a centrated collected after centrifugation from a farm in Narros de Cuéllar (Segovia, Spain), transported to ITACyL and stored at 4ºC for further utilization. The SM presented a pH of 7.2 ± 0.1, 41.8 ±7.1 g TS L^{-1}, 30.6 ± 4.5 g VS L^{-1}, 139.1 ± 94.9 g total chemical oxygen demand (TCOD) L^{-1}, 36.2 ± 2.2 g soluble chemical oxygen demand (SCOD) L^{-1}, 4762 ± 62 mg N total Kjeldahl nitrogen (TKN) L^{-1}, and 3607 ± 308 mg N total ammoniacal nitrogen (TAN) L^{-1}. The inoculum used, from the municipal wastewater treatment plant in Valladolid (Spain), had a concentration of 10.9 ± 0.1 g VS L^{-1}.

The experiment was designed to assess the effect of different proportions of AP in combination with SM in the feed in the AD performance. The performance of the AD process was evaluated in terms of stability, methane production and biodegradability. The stability of reactors was measured using the IA/PA ratio, considering a stability reference value of 0.3 (Ripley et al., 1986). For that, it was measured the total alkalinity (TA) and the partial alkalinity (PA) of the effluent two times a week, and then IA (intermediate alkalinity) was calculated by subtracting PA to the TA. Methane volumes were converted to standard temperature and pressure (0ºC and 101.325 kPa), and methane yields were calculated as mL of CH_4 produced per g of VS added in the fed mix daily. There were used two identical continuously stirred reactors (R1 and R2), with a working volume of 5 L, for the digestion of SM and the different mixes of SM and AP. The reactors were initially filled with inoculum, and for the subsequent daily feeding it was used an initial organic loading rate (OLR) of 1.04 g VS L^{-1} d^{-1} (based on Molinuevo-Salces et al., 2020) and a hydraulic retention time (HRT) of 25 days for both reactors. R1 was fed with SM alone and R2 was fed with a mix of 85% of SM and 15% of AP (on VS basis). Under these operational conditions, a destabilization of both reactors was observed during this initial period, with IA/PA ratios over 1. Therefore, the OLR was decreased to 0.78 g VS L^{-1} d^{-1} and the HRT was increased to 33 days from day 26 (periods I and II). In period I (days 27 – 138), R1 was fed with SM alone and R2 with a mix with a percentage of AP of 15% (on VS basis), and it was observed a stabilization of both R1 and R2 in day 48 (IA/PA ratios of 0.35 and 0.33, respectively). In period II (days 139 – 240), R1 was fed with a mix of SM and 7.5% of AP (on VS basis) and R2 with a mix of SM and 30% of AP (on VS basis).

They were obtained similar specific methane yields ($p<0.05$) when digesting SM alone and up to 15% of AP in the feed mixture (Table 1). However, with a 30% of AP added in the feed (on VS basis) it was observed that the specific methane yield significantly decreased. This could be caused by a lower biodegradability of the mix due to the presence of lignocellulosic compound of the AP residues, as it was reported in previous works (Dhillon et al., 2013b; Labatut et al., 2011).

We can conclude that, as the co-digestion of SM with up to 15% of AP (on VS basis) presented comparable specific methane yields than those of the digestion of SM alone, AP could be an interesting co-substrate to be used in the AD process combined with livestock wastewaters, thus valorizing these organic wastes especially the apple residues in a growing food sector.

Table 1. Performance of the reactors according to the percentage of AP

		Apple pomace (%)	Biogas (mL day^{-1})	Specific methane yield (mL g^{-1} VS day^{-1})	VS reduction (%)
R1	Period I	0.0	3057 ± 1255	421.6 ± 153.6	30.3 ± 16.4
	Period II	7.5	3529 ± 542	412.3 ± 62.6	44.3 ± 15.9
R2	Period I	15.0	2827 ± 1135	381.8 ± 134.1	35.9 ± 10.5
	Period II	30.0	3029 ± 1130	341.9 ± 7.1	39.7 ± 14.5

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