Assessment of the biological methane potential of different food residues from a market in Ghana for local residues valorization and biogas production

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Fuel supply for cooking and heating is one of the major problems in Ghana (Africa). Firewood and liquified gas petroleum are the most used fuels, but their use has a high environmental impact, due to deforestation and CO_2 emissions. Therefore, more sustainable and accessible energy technologies need to be developed. Anaerobic digestion (AD) is a well-establish energy bioprocess that allow to obtain biogas and digestate trough organic waste anaerobic fermentation. Digestors are technologically simple, affordable and could be installed easily, for example by taking advantage of pre-existing infrastructure such as septic tanks with minor modifications. The obtained biogas is composed of CO_2 and methane (CH_4) and can be used for both heating and cooking purposes, as well as electricity production. The proportion of each gas in the biogas mixture depends on different factors such as temperature, pH, type of substrate, etc. Digestate is the solid fraction remaining after the AD and is a valuable fertilizer in terms of its chemical composition (N, P, K).

Within SESA project, novel waste-to-energy solutions for clean cooking were tested, potentially applicable to Africa for energy access in different demonstrations sites. Among other energy solutions, sustainable substrates for AD were tested at Leitat, based on the local waste substrates potentially available at the demo site in Ghana. Fruit and vegetable residues from a local market and molasses, a subproduct of sugar refinement, were assessed in terms of Biological Methane Potential (BMP), a test used to determine the potential of a substrate to produce CH_4 under anaerobic conditions. Fruits and molasses are both easily degradable substrates, which might be a problem due to the fast degradation of organic matter into volatile fatty acids (VFA). Accumulation of VFA would result in a decrease of the pH and in an organic overload, inhibiting the methanogenesis(Filer, Ding, y Chang 2019). Higher ratios between inoculum and substrate (I/S ratio) could reduce inhibition risk, as there would be more microorganism consuming the VFA.

For BMP assays we used the Automatic Methane Potential Test System (AMPTS-II, BPC Instruments, Sweden). The used inoculum was sewage sludge from the anaerobic digester of the local wastewater treatment plant. The used substrates were fruit waste (mix with plum, melon and watermelon) and molasses from beet (Toro sugar factory, Zamora, Spain) to emulate the waste available in Ghana. All experiments were carried out in Schott bottles with a working volume of 350 mL. After mixing inoculum and substrate, the bottles were flushed with N_2 for 10 minutes to create anaerobic conditions in the head-space. The bottles were incubated at 37 ºC (Holliger et al. 2016) and continuously mixed at 60 rpm. The produced CH_4 was measured by a series of MilliGas counters, after bubbling the biogas in a CO_2 absorption solution of NaOH 3 M. Each experiment ended when the gas flow recorded was lower than 5 mL per bottle per day. In addition, blank experiments (just inoculum) and positive controls (inoculum and cellulose microcrystalline at I/S ratio 2) were done in triplicate, to assess the endogenous CH_4 production and the inoculum activity. We worked with two different I/S ratios (calculated in terms of volatile solids (VS) concentration), for both substrates. First, we started with ratio 2 (recommended for an initial evaluation of the substrate) and then with ratio 4, more suitable to acid substrates or with high content of sugar and carbohydrates (Wang et al. 2015). Lastly, based on the BMPs obtained individually we tested a co-digestion between the substrates (75% fruits and 25% molasses), with I/S ratio 4.

Table 1. Experiments scheme for the three substrates with two different I/S ratios.

	I/S 2	**I/S 4**
Molasses	M2 (x3)	M4 (x1)
Fruits	F2 (x3)	F4 (x1)
Molasses:Fruits (25:75)	-	MF4 (x3)

Adopting an I/S ratio of 2, the reactors were operated for 15 days and during the experiment we had a significative increase in the VFA content from 3.60±0.78 to 14.45±2.01 g/L (M2) and from 4.51±1.68 to 52.85±12.68 g/L (F2). Accordingly, the pH dropped in both cases. The test F2 did not produce any CH_4 and just one of the M2 triplicates produces CH_4. The M2 reactor accumulated 504 NmL of CH_4 and the BMP was 140,58 NmL CH_4/ g VS, rather low in comparison with other studies. The average VS removal was 49% in test M2 and 51% in test F2, due to the breakdown of the solids into smaller soluble organic compounds, like VFA. The average COD removal was 25% in test M2 and 3% in test F2. These results indicates that the accumulation of VFA led to a methanogenesis inhibition in both cases. The lower COD removal in the fruits is explainable due to the extreme decrease in the pH, where a final pH of 5.23±0.02 was reached, inhibiting the growth activity of the methanogenic microorganisms. Likely, only the first steps of the anaerobic digestion process took place, i.e. hydrolysis and acidogenesis, causing an organic overload due to the fast and uncompensated production of VFA. Thus, the ratio I/S 2 seems insufficient to avoid inhibition. Other studies with molasses obtained higher BMPs with higher I/S ratios and associate this phenomenon to the composition of molasses which is mainly simple sugars. Similar for fruit residues, the lower initial pH and high biodegradable compounds usually force to work with higher ratios.

Adopting an I/S ratio of 4, the reactors were operated for 20 days and during the experiment a decrease in the VFA concentration was measured in test F4 and an increase in the pH of both reactors. Only test F4 produced CH_4 and achieved a total of 1792 NmL of CH_4 accumulated at the end of the experiment and a BMP of 836.27 NmL CH_4/ g SV. The average VS removal was 48% in M4 and 36% in F4, due to the breakdown of the solids into smaller soluble organic compounds. The average COD removal was 28% in test M4 and 18% in test F4. The BMP obtained is higher to other BMPs for fruits and vegetables residues, that usually ranges between 260-450 NmL CH_4/ g SV (Edwiges et al. 2018). Differences between BMPs in fruits are big because the different composition and structure, the high value we obtain could be a synergy between produced by mixing different whole fruits (seeds, peels, pulp), as normally the studies only work with specific parts of the fruit. The BMP obtained is high compared with other fruits residues used in AD and show great potential to produce biogas. The lack of production in test M4 could be due to an operation error and as we did not have any replicate to confirm the achieved result.

Finally, fruits and molasses (75% fruit, 25% molasses) were combined with I/S ratio 4 to study a synergy that allows to exploit both. This I/S ratio was chosen as it gave the best results in the previous experimental phase. During the 10 days of operation, it was observed an increase of the pH from 6.99±0.02 to 7.49±0.02 and a decrease in the VFA content from 1.91±0.65 to 0.22±0.01 g/L. A total of 520.50±58.9 NmL of CH_4 was accumulated with a BMP of 441.54±45.98 NmL of CH_4 /g SV.

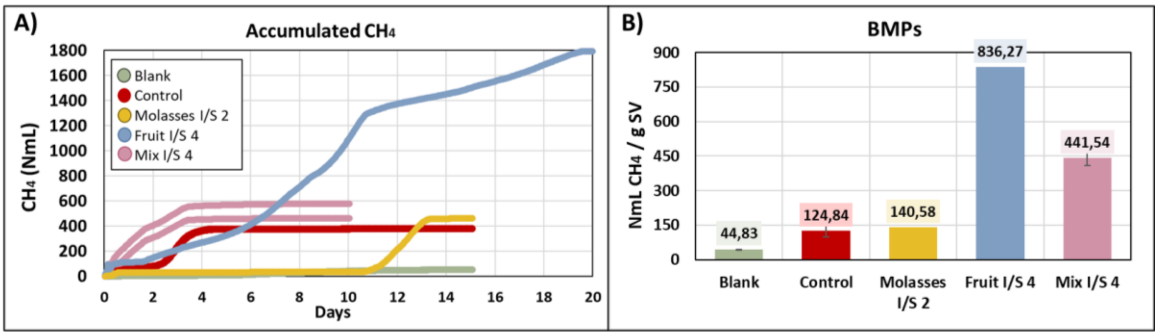

Figure 1. CH_4 production results. A) Accumulated CH_4 during the experiments for the blank (green), positive control (red), molasses with ratio I/S = 2 (yellow), fruit with ratio I/S = 4 (blue) and the mix (75% fruit and 25% molasses) with ratio I/S = 4 (pink). **B) BMPs** obtained for the blank (green), positive control (red), molasses with ratio I/S = 2 (yellow), fruit with ratio I/S = 4 (blue) and the mix (75% fruit and 25% molasses) with ratio I/S = 4 (pink).

The BMP was lower with the mixture of both substrates, than the one obtained with the individual digestion of fruits, but is in range with other BMPs done with molasses (350-450 NmL of CH_4 /g SV) (De Vrieze et al. 2015). While the combination of the two substrates could not improve the CH_4 production, it resulted in a faster degradation of the organic load, compared to single substrates. This would allow to reduce the HRT in field applications, therefore treating higher quantities of residues maintaining the same reactor size. Besides, there is room to make more combinations, study other seasonal fruits and ascertain the BMP of the molasses individually in future research.

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