Decentralised system for demand-oriented collection of food waste - assessment of biomethane potential, pathogen development and microbial community structure

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Introduction

In 2019, approximately 17% or 931 million tonnes of the food produced worldwide was disposed of in households, food service and retail (UNEP, 2021). Various options exist for the disposal of food waste (FW), including incineration, landfilling and biological treatments such as composting and anaerobic digestion (AD). Considering the high energy potential, AD is often the preferred process (Pramanik *et al.*, 2019). The produced biogas may be used for the generation of electricity, as fuel for vehicles, or can be injected into the public gas grid (Abanades *et al.*, 2022). All these options are important and can help meeting the European Union's green deal targets of reducing greenhouse gas emissions by 55% compared to 1990, and increasing the share of energy from renewable sources to at least 40% by 2030 (European Commission, 2021).

FW from commercial kitchens would represent a promising substrate for biogas production. Nevertheless, a proper strategy for the collection and storage of the waste material is needed. It is well known that FW can contain pathogenic microbes potentially posing a risk to human health. A high level of odour nuisance is another factor to watch out for, especially if the FW is stored for a long period of time. Therefore, this study investigated a novel system for the storage of FW from commercial kitchens, consisting of a crushing unit and a tank. In the crushing unit, the FW is shredded on-site with the addition of water, and transferred to a storage tank. The pre-treated FW is then removed from the tank via suction and transported by tanker to an AD plant.

In this study (Wehner *et al.*, 2023), the storage of FW is examined in detail in terms of demand-oriented collection and subsequent biogas production. It focused on the evaluation of FW storage under practical related aspects, such as the occurrence of pathogens, possible safety hazards and on the energy potential. The main hypothesis is that appropriate storage conditions are able to maintain the biomethane potential (BMP) of FW while reducing the pathogen load.

Materials and methods

Fresh FW was collected from a canteen at the Universität Innsbruck (Austria). Before application, the material was homogenised to a particle size of < 12 mm, and water was added to keep the material pumpable. The storage experiments were conducted in batch and fed-batch mode, with two-litre laboratory flasks being used as storage tanks. In addition to the storage strategy, also the factor storage temperature was evaluated and three different conditions (5 °C, 20 °C and 30 °C) were compared. Physico-chemical properties including pH, total solids, volatile solids, and organic acids were measured weekly using sludge material from the storage flasks. In addition, BMP was determined, and the head space gas was analysed in order to assess CO_2, CH_4, and H_2 levels. Pathogens (*Escherichia coli*, *Salmonella enteritidis*, *Enterococcus faecalis*, *Clostridium perfringens*) were counted after cultivation on selective agar plates, and the microbial communities were characterized based on 16S rRNA amplicon sequencing.

Results and discussion

In the course of the experiment, more and more organic acids were formed, accompanied by a constant drop in pH. The organic acid spectrum was dominated by lactic acid (LA, 40-80%), with its percentage gradually increasing over the course of the experiment (Wehner *et al.*, 2023). A high LA content usually has a stabilizing effect on the waste material, a mechanism that we know from ensiling. With regard to pH and acid concentration, a clear temperature dependence was observed. Samples stored at 20 and 30 °C showed a stronger increase in organic acids and decrease in pH than samples stored at 5 °C. Similar findings were reported by Tang *et al.* (2016) where the highest LA yields (0.46 g/g-TS) were obtained at 37 °C compared to 25 °C conditions.

Despite fluctuations, the BMP remained constant or even increased over the entire test period (Wehner *et al.*, 2023). This is in line with Lü *et al.* (2016), who stored FW for 12 days in batch systems and found that longer storage generally led to an increased BMP. Both studies indicate that storing FW for 1-2 weeks has the potential to increase the BMP of the material, and that even longer storage is possible. This is important in terms of a highly flexible decentralized collection and storage strategy, where the FW is collected upon demand for a flexible biogas production and demand-oriented energy generation (Aichinger *et al.*, 2015).

Headspace gas analysis revealed that CO_2 accounted for up to 62%, while O_2 was detected with a maximum of 12%. The majority of residual gas was likely N_2, as the reactors were frequently opened for sampling and, in case of the fed-batch systems, also for feeding. H_2 and CH_4 were either undetectable, or only marginally detected in the storage gas. These results indicate that the storage of FW does not pose any risk for the formation of explosive gases, at least not under the conditions investigated in this study (Wehner *et al.*, 2023).

During the first two weeks of the trial, 95% of all pathogens (only 87% in the case of *Clostridium* sp.) were removed, irrespective of storage strategy and temperature. Afterwards, there was no further reduction. Temperature showed a strong effect, and the higher the temperature, the better the hygienisation. At 30 °C, for example, all pathogens were inactivated within the first two weeks. Hence, we concluded that storing FW has a sanitizing effect at any temperature, but 20 °C or even 30 °C are recommended for material that is regularly contaminated with pathogens (Wehner *et al.*, 2023). Apart from pathogens, microbial communities were clearly dominated by LA bacteria such as *Lactobacillus*, *Levilactobacillus*, *Leuconostoc*, *Lactococcus*, or *Streptococcus*. Temperature played here again a fundamental role and shaped totally unique microbial communities. As a result, most LA was produced via the heterofermentative process at 5 °C and 20 °C, and via the homofermentative process at 30 °C.

Conclusion

Decentralised storage of FW represents a promising approach for the future. The material can be collected in a simple and odourless way, picked up as needed and then sent for further recycling, e.g., for the demand-oriented production of biogas. This study showed that storage can be carried out without problems at 5-30 °C and for a period of up to two weeks. There was no loss of energy-rich substrate that would subsequently be missing in a biogas plant. The increased LA production not only effectively inactivated pathogens, but also pre-hydrolysed the FW, which subsequently meant an advantage in biogas production.

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