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Impact of biodegradable bioplastics on anaerobic co-digestion of household organic waste and wastewater sludge

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Abstract. The growing adoption of biodegradable bioplastics, such as Mater-Bi (MB) and Crystalline Polylactic Acid (CPLA), as substitutes for conventional plastics has raised questions about their environmental behaviour. This research investigates how these two materials degrade during anaerobic co-digestion with organic fractions of municipal solid waste (OFMSW) and thickened sewage sludge (TWAS). Laboratory-scale semi-continuous tests were carried out to evaluate biomethane production, process performance, and the extent of degradation at different bioplastic concentrations. Results showed that both materials degrade only partially, with MB showing greater weight loss (23%) than CPLA (15%) over six weeks. The degradation of MB was mainly attributed to abiotic mechanisms rather than microbial activity. Additionally, increasing the concentration of bioplastics in the feed negatively influenced process stability, causing a drop in methane yield and a rise in volatile fatty acids. Despite these effects, phytotoxicity tests suggested the digestate might still be usable in agriculture. However, the influence of bioplastics on the final digestate quality needs further investigation. Overall, the findings highlight the need for better-performing biodegradable materials and improved strategies for managing bioplastics within anaerobic digestion systems, especially when aiming for sustainable waste treatment and safe agricultural reuse.

Keywords: Anaerobic digestion; Biodegradable plastic; Crystalline polylactic acid; Mater-Bi; Organic fraction of municipal solid waste

1. Introduction

Plastic has become essential in modern society, but its widespread use has brought increasing environmental concerns, especially given the low global recycling rate—only 9% according to 2019 data (OECD, 2022). Much of the remaining plastic ends up in landfills or the environment, where it persists for centuries, breaking down into micro- and nano-plastics that contaminate ecosystems and enter food chains (Habumugisha et al., 2024). In response, bio-based and biodegradable plastics are gaining interest. However, they currently make up just 1% of total plastic production (Plastics Europe Market Research Group (PEMRG) and European Association of Plastics Recycling and Recovery Organisations (EPRO), 2021). Recent regulations encourage their use by banning single-use plastic items (Folino et al., 2023). However, limited research exists on their actual behaviour in anaerobic digestion (AD), particularly in semi-continuous conditions, which more closely reflect industrial-scale operations (Dolci et al., 2022). This study evaluates the anaerobic co-digestion of OFMSW and sewage sludge with two common bioplastics, Mater-Bi (MB) and crystalline PLA (CPLA), assessing degradation (differentiating biotic and abiotic influence), and digestate phytotoxicity. Previous studies have reported partial degradation under thermophilic conditions (Kosheleva et al., 2023), but semi-continuous trials have not been performed. This research fills that gap to inform sustainable waste treatment and improve digestate quality for agricultural reuse (Azarmanesh et al., 2023).

2. Materials and methods

Anaerobic digestion experiments were carried out using inoculum collected from a full-scale biogas plant treating agricultural waste in Candidoni (Calabria, Italy). Before use, the digestate was sieved and pre-incubated under mesophilic conditions. The substrate was composed of a 50:50 mixture (based on VS) of synthetic OFMSW and thickened waste-activated sludge (TWAS), sourced from a municipal WWTP. OFMSW was prepared to reflect typical Italian composition (Pangallo et al., 2021) and dried at 35°C before being ground and stored. Bioplastics tested were Mater-Bi bags and CPLA cutlery, both commercially available and certified compostable(Jan-Georg et al., 2022). The semi-continuous anaerobic digestion setup included four 1.9 L reactors (A–D), operated at 35°C. Reactors were fed five days per week. Bioplastics were added at 2%, 4%, and 8% (VS basis) to assess their influence on process performance. Methane production was continuously recorded, while digestate was analysed weekly for pH, TS, VS, VFA, and FOS/TAC

(APHA et al., 2012). Abiotic degradation was also tested by incubating bioplastic pieces in buffered water solutions at different pH levels. Digestate phytotoxicity was evaluated via soil cultivation trials on *Brassica oleracea* plants under controlled conditions (Vaish et al., 2022).

3. Results and discussions

In stable conditions (Phase I), MB had minimal impact on methane yield, while a higher loading in Phase II caused process acidification and methane inhibition. In contrast, CPLA improved methane production (+12%) at moderate doses and assured process stability even at higher loading rates (Figure 1). MB showed notable abiotic and biological degradation, especially at pH 6, while CPLA remained largely intact, due to its high crystallinity. Phytotoxicity tests showed that MB digestate at high concentrations reduced plant growth, whereas CPLA digestate had limited effects, with only slight reductions in stem diameter at higher doses. In conclusion, MB is more degradable but may destabilize AD and affect digestate quality, while CPLA is more stable but less degradable (Censi et al., 2022)

4. Conclusions

This study shows that MB caused strong acidification and low methane yield at high loads, while both bioplastics showed poor biodegradability. MB's mass loss was mainly abiotic, raising concerns about micro-bio-plastic formation. These results highlight the need for more research on end-of-life bioplastics management, and careful digestate quality monitoring when bioplastics are present in waste subjected to AD.

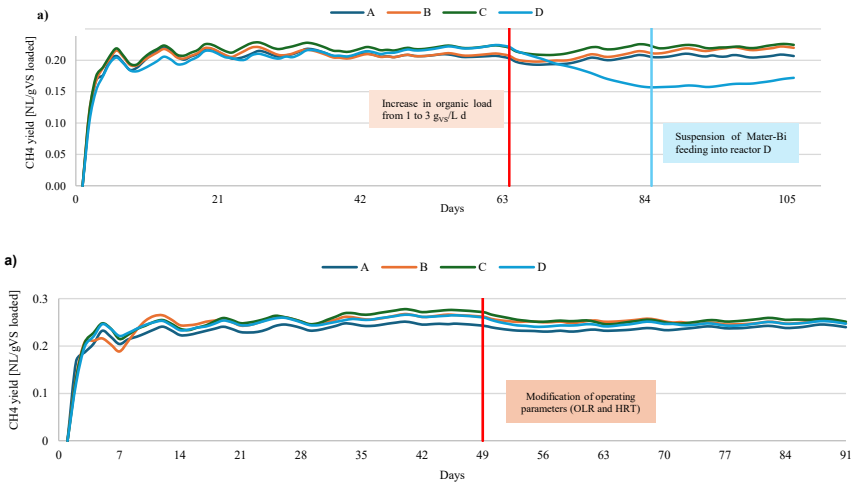

Figure 1. AcoD results of CH4 yield on (a) Mater-Bi, (b) CPLA.

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