The impact of organic matter content on the carbon monoxide (CO) production during food waste composting: the comprehensive lab-scale evaluation

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Although biorefinery processes have developed, integrating 'conventional' composting with the production of biochemicals remains overlooked. Nonetheless, net carbon monoxide (CO) emissions have been detected during the composting of various fractions of organic waste (Sobieraj et al., 2023a). As a valuable chemical, it is utilized across various industries, including the pharmaceutical and food industry, metallurgy, fuels, and aromatic compounds production (Sobieraj et al., 2023a). Given the unavoidable generation of CO due to the high organic carbon content in biowaste, utilizing this CO offers a promising opportunity to align with the goals of a circular economy and the biorefinery model.

CO is typically produced through a thermochemical process such as biowaste gasification. However, this method demands energy-intensive, costly, and time-consuming drying of the raw material. Consequently, composting biowaste could emerge as a more economically and ecologically viable alternative for CO production. Despite this potential, no dedicated studies have yet explored this approach. While few studies have examined the effects of temperature and aeration on CO production from composting (Sobieraj et al., 2023b; Stegenta-Dąbrowska et al., 2019), there is no data on how the organic matter content (OMC) in composted waste affects CO levels. Therefore, the research aimed to examine the CO concentration during composting of food waste in laboratory conditions under controlled aeration and temperature conditions depending on the organic matter content in the bioreactor.

A model food waste mixture, prepared based on (Valta et al., 2019), was composted (Fig. 1). To regulate the organic matter content within the bioreactor, the food waste was combined with a mineral material, gravelite, with ratios: 1:0, 1:1, and 1:2 (waste:gravelite, W:G, v/v), corresponding to 95, 40 and 20% dry OMC. As a control, gravelite alone was also composted (ratio 0:1). The composting process lasted 7 days and was conducted in 1-L bioreactors with forced aeration. Aeration was provided daily for 1.5 minutes using an oxygen concentrator (OxyFlow-10, GESS, Poland) at a flow rate of 10 $dm^3 \cdot min^{-1}$, immediately after the first gas concentration measurements. The bioreactors were placed in thermostatic cabinets (ST3, POL-EKO, Wodzisław Śląski, Poland) maintained at temperatures of 45°C, 60°C, and 70°C. Each bioreactor had a metal cap featuring two connectors and silicone tubing. One connector remained sealed, while the other was opened and closed using a Mohr clamp to allow connection to a portable gas analyzer (DP-28, Nanosens, Wysogotowo, Poland). Gas concentration measurements for CO (ppm), CO_2 (%), and O_2 (%) were taken twice daily at 9:00 AM and 4:00 PM. The substrates and the material collected after 7 days were analyzed for dry matter content, dry organic matter content, elemental composition (C, H, N, S), and respiratory activity (AT_4).

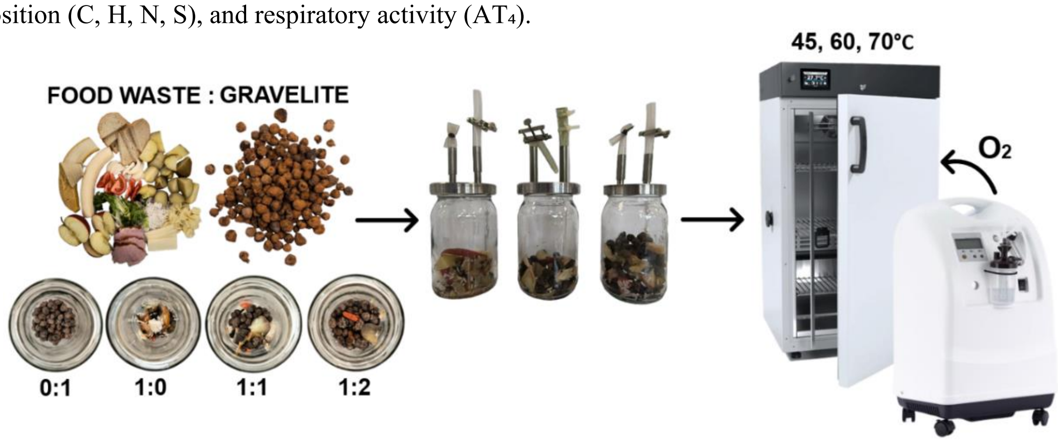

Fig. 1. Experiment matrix

Research indicated that the highest average concentrations of CO were obtained in the variant with the highest temperature, regardless of the W:G ratio used (Fig. 2). The peak CO production at 45°C and 70°C was recorded between the 3rd and 5th day of reactor incubation (approx. 800 and 1400 ppm for 45°C and 70°C, respectively). Interestingly, the variant with the optimal composting temperature (60°C) had the lowest CO yield (on average 131, 140, and 68 ppm for the 1:0, 1:1, and 1:2 ratios, respectively). The results showed that CO production during composting is positively correlated with OMC in the reactor, with the highest correlation coefficient obtained for the 45°C variant (r=0.47). The highest average CO concentrations were obtained for a W:G ratio of 1:2 in the 45°C and 70°C variants (412 and 655 ppm, respectively). In the former, the CO peak was indeed produced at a W:G ratio of 1:1, but the gas production was more stable throughout the process for the 1:2 variant and reached a higher average value (366 and 412 ppm for 1:1 and 1:2, respectively). Importantly, gravelite incubated alone did not produce CO in any variant (Fig. 2).

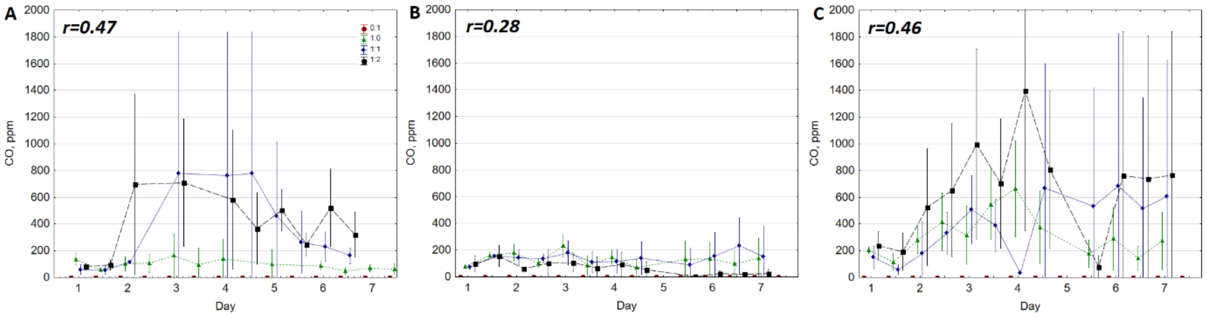

Fig. 2. CO concentration during composting at: A) 45°C, B) 60°C, C) 70°C; linear correlation coefficients indicated in the upper left corners at a significance level of $p < 0.05$

The changing CO concentration depending on OMC and temperature in the reactor during composting may be related to the dual nature of CO production: biological (based on bacterial activity) and abiotic (resulting from thermochemical processes). Literature suggests that in aerobic soil conditions, carbon compounds can undergo thermal degradation at relatively low temperatures (below 100°C), leading to CO emissions. As temperatures rise, this process intensifies, significantly affecting CO emissions in warm, carbon-rich ecosystems (Cowan et al., 2018). On the other hand, the study didn't report a linear relationship between CO concentration and either the process temperature or OMC in compost. The highest CO concentrations obtained for a W:G ratio of 1:2 and at 45 and 70°C highlight the biological CO production by bacteria. According to previous research, bacterial CO production in compost can exceed even 1000 ppm during a 4-day incubation (Sobieraj et al., 2024). Furthermore, the highest CO yield for the variant with a W:G ratio of 1:2 is the result of providing an optimal amount of organic matter for processing by the bacteria present in the compost. Changes in the composition of organic matter are noted to impact bacterial community dynamics and regulate the rate of carbon processing (Judd et al., 2006).

According to the research, since the concentration of CO was the lowest at the optimal composting process temperature (60°C), to focus this process on CO production, it should be conducted at a controlled temperature (prolonging the mesophilic and thermophilic phases at 45°C and 70°C) and with a determined OMC (approx. 20% dry OMC). Intensifying CO production by controlling these composting parameters could enable coupling this process with biorefinery processes in the future to obtain CO.

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