Waste streams for sustainable generation of bioplastic precursors through targeted acidogenic fermentation

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Introduction

The utilization of heterogenous waste materials as precursors for the production of Volatile Fatty Acids (VFAs) has garnered considerable attention in the realm of sustainable bioproduction. This approach holds promise as it aligns with the principles of circular economy, providing a dual benefit of waste valorization and the generation of valuable chemical building blocks (Vázquez-Fernández *et al*, 2022). One of the primary reasons for the interest in using waste as VFA precursors stems from the environmental imperative to reduce reliance on fossil fuel-based processes. VFAs, such as acetic, propionic, butyric or valeric acids, are versatile compounds with applications ranging from bioplastics to biofuels (Agnihotri *et al*, 2022). By harnessing waste materials—ranging from agricultural residues to industrial by-products—as substrates for acidogenic fermentation, this approach not only mitigates environmental impact but also contributes to waste management strategies. Moreover, the use of waste as feedstock provides an opportunity to move away from the consumption of edible raw materials, a crucial step in addressing global food security concerns. The versatility of VFAs as chemical building blocks further enhances their appeal, as they find applications in diverse industries, including food, pharmaceuticals, and bioplastics. However, the implementation of waste-derived VFA bioproduction is not without its challenges. The heterogeneous nature of waste streams and the potential presence of impurities introduce variability in terms of organic composition, posing a significant challenge in optimizing fermentation processes (Ramos-Suarez *et al*, 2021). The need for effective pretreatment methods for certain types of waste, such as lignocellulosic biomass, adds an additional layer of complexity to the bioproduction process (Wang *et al*, 2023). Many research groups are actively investigating ways to enhance the efficiency and reliability of waste-derived VFA bioproduction. The focus includes understanding and manipulating the microbial consortia involved in acidogenic fermentation (Ram, and Nikhil, 2023), optimizing operational parameters to maximize yield and specificity of VFAs (targeting on specific acids) (Varghese *et al*, 2022), and developing robust metabolic models for predictive control (Li *et al*, 2023), among others.

The ELLIPSE project (Figure 1) is one of these research initiatives, focused, in this case, on the valorization of selected waste streams from the pulp and paper industry, slaughterhouses, and sludge, to generate cost-effective biodegradable bioplastics, known as PHAs (polyhydroxyalkanoate). The primary objective revolves around maximizing propionic and valeric acid production during the initial acidogenic fermentation stage; hence, the necessity arises for targeted acidogenesis. This strategic approach seeks to utilize VFAs derived from organic wastes as substrates for the subsequent fermentation stage, enhancing the production of PHBV (poly(3-hydroxybutyrate-co-3-hydroxyvalerate) copolymers, the most common PHA, enriched in valerate. The project's multi-stage process further includes the transformation of PHBV into practical demonstrators such as mulch film, paper coatings, and personal care sector bottles. Additionally, a controlled-release fertilizer formulation will utilize nitrogen and phosphorus recovered from the digestate, using PHBV as a matrix. The comprehensive approach of the ELLIPSE project emphasizes circularity through various recycling strategies, marking a significant stride in sustainable bioplastic production.

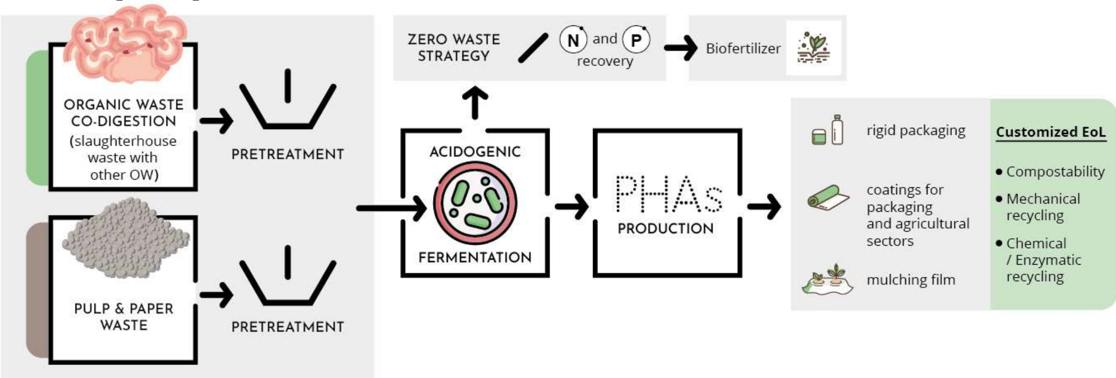

Figure 1. ELLIPSE project concept (ellipse-project.eu).

In the frame of the ELLIPSE project, this paper delves into the complexities of directed acidogenic fermentation, highlighting the significance of thoughtful waste stream selection, specific process conditions, and potential pre-treatments to enhance efficiency.

Factors affecting targeted VFA production from waste

The complex interactions in anaerobic reactors during acidogenic fermentation, with a focus on operational parameters and microbial communities, has been evaluated in this work (Figure 2). It is important to emphasize the significance of maintaining a balance in the variable organic loading rate (OLR) to regulate microbial composition effectively, specifically targeting methanogens and acidogenic microorganisms. The investigation scrutinizes the intricate relationships within anaerobic reactors during acidogenic fermentation, primarily focusing on specific facets such as pH, temperature, volumetric organic loading rate, hydraulic retention time (HRT), and the organic composition of waste. Notably, the pH and organic composition of waste emerged as pivotal factors influencing the distribution of VFAs. Concerning pH and organic composition, the study revealed distinct VFA outcomes based on substrate characteristics. Protein-rich substrates showcased a dominance of propionic acid at pH levels below 5.0, while a range between pH 5.0 and 11.0 led to acetic acid prevalence. The interplay between temperature and organic composition demonstrated varying VFA compositions, particularly in studies involving food waste. The OLR and HRT further emerged as critical parameters affecting microbial communities and, consequently, VFA distributions. Achieving a balance in OLR was underscored for effective regulation of microbial composition, targeting both methanogens and acidogenic microorganisms. Bacterial composition within anaerobic reactors, influenced by the organic composition of waste, pH, and temperature, played a central role in shaping VFA outcomes. However, the precise correlation between microbial communities and VFA synthesis remained elusive, necessitating further exploration.

Figure 2. Lab setup for monitoring VFA production from waste streams.

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References

- Agnihotri, S., Yin, D. M., Mahboubi, A., Sapmaz, T., Varjani, S., Qiao, W., ... & Taherzadeh, M. J. (2022). A glimpse of the world of volatile fatty acids production and application: a review. Bioengineered, 13(1), 1249-1275.

- Li, H., Tian, Y., Wang, H., Simeonov, I., & Christov, N. (2023). A volatile fatty acids adaptive observer-based hierarchical optimal controller design to maximum gas production of two-stage anaerobic digestion process. Computers & Chemical Engineering, 108524.

- Ram, N. R., & Nikhil, G. N. (2023). Assessment of microbial consortiums and their metabolic patterns during the bioconversion of food waste. Biomass Conversion and Biorefinery, 1-14.

- Ramos-Suarez, M., Zhang, Y., & Outram, V. (2021). Current perspectives on acidogenic fermentation to produce volatile fatty acids from waste. Reviews in Environmental Science and Bio/Technology, 20(2), 439-478.

- Varghese, V. K., Poddar, B. J., Shah, M. P., Purohit, H. J., & Khardenavis, A. A. (2022). A comprehensive review on current status and future perspectives of microbial volatile fatty acids production as platform chemicals. Science of The Total Environment, 815, 152500.

- Vázquez-Fernández, A., Suárez-Ojeda, M. E., & Carrera, J. (2022). Review about bioproduction of Volatile Fatty Acids from wastes and wastewaters: Influence of operating conditions and organic composition of the substrate. Journal of Environmental Chemical Engineering, 10(3), 107917.

- Wang, Q., Xin, W., Shao, Z., Usman, M., Li, J., Shang, P., ... & Chen, C. (2023). Role of pretreatment type and microbial mechanisms on enhancing volatile fatty acids production during anaerobic fermentation of refinery waste activated sludge. Bioresource Technology, 381, 129122.