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Comparative Evaluation of Carbonaceous Additives for Enhancing Methane Production

A. Maragkaki[1], E. Maragkaki[2], G. Daskalakis[1], V. Lolou[2], L. Lombardi[3], M.R. Rodero[4], R. Munoz[4], A. Lazari[5], S. Saxioni[5], K. Karakitsou[5], T. Lolos[2], C. Tsompanidis[2], G. Louloudakis[1], D. Papadimitriou[1] and T. Manios[1]

[1]*Laboratory of Solid Waste & Wastewater Management, School of Agricultural Science, Hellenic Mediterranean University - Educational and Research Committee, Heraklion, 71401, Crete, Greece*
[2]*ENVIROPLAN SA, 23 Perikleous & Iras Str, Gerakas Athens, 15344, Greece*
[3]*Niccolò Cusano University - Rome, Italy*
[4]*Institute of Sustainable Processes, University of Valladolid, C/Dr. Mergelina s/n., 47011, Spain*
[5]*DEPA Commercial S.M.S.A., 92 Marinou Antipa Avenue, Irakleio Athens, 141 21, Greece*

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Abstract

Rising global energy demand, mounting concern over greenhouse gas emissions, and the finite nature of fossil resources have driven substantial research effort in recent decades towards sustainable fuel alternatives (Masoumi et al., 2021). Technologies built on renewable feedstocks and operating within the biological carbon cycle offer a route to carbon neutrality, the state in which carbon released equals carbon captured by sinks. Biochar and hydrochar illustrate this principle well: both are generated from renewable organic residues and serve a range of environmental functions. Reported applications include use as solid fuels, adsorbents, soil amendments, additives in anaerobic digestion and composting, and precursors for catalysts (Cavali et al., 2022). Carbonaceous additives derived from organic residues offer a circular pathway to intensify anaerobic digestion (AD), yet the influence of feedstock and thermochemical route on their performance remains insufficiently resolved. This study compared biochars (BC) and hydrochars (HC) produced from aloe vera leaves and algae as additives during the mesophilic AD of food waste (FW). Batch reactors operated at 37 °C for 60 days with a 1:1 inoculum-to-substrate ratio and an additive dosage of 10 g L^{-1}. Hydrochars consistently outperformed biochars, increasing cumulative biogas production by 18 - 35% against 10 - 14% for biochars, relative to the control. The aloe vera hydrochar (HA) achieved the highest response, raising total biomethane yield to 304 mL g^{-1} VSs, dissolved chemical oxygen demand removal to 42.5%, and volatile solids removal to 37.1%. Characterization by SEM-EDS and XRD linked this performance to HA's elevated electrical conductivity (8.52 mS cm^{-1}), coherent porous microstructure, and calcium-rich buffering fraction, all of which favour microbial colonization and direct interspecies electron transfer (DIET). By contrast, the algae biochar showed no appreciable enhancement, attributed to a high KCl content that likely induced ionic stress. The findings identify hydrochar, and feedstock selection, as decisive levers for optimizing methane recovery, and support the integration of residue-derived carbonaceous materials into sustainable waste-to-energy systems.

Keywords: =anaerobic digestion, biochar, hydrochar, DIET

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