Valorization of *Sargassum spp*. through Anaerobic Digestion: effects of non-chemical pretreatments and Fe_2O_3 nanoparticles on bio-methane production

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Sargassum spp. blooms have become a significant environmental challenge in Caribbean coastal regions, disrupting ecosystems, local economies, and public health. Despite these impacts, this macroalgal biomass holds considerable potential for innovative applications such as biogas production via anaerobic digestion (AD) and wastewater treatment. This study investigates two complementary strategies to enhance methane production from *Sargassum spp*. biomass.

First, non-chemical pretreatments—including microwave irradiation, sonication, and water washing at 40°C—were evaluated to overcome the low biodegradability caused by lignocellulose and calcite in the biomass structure. Morphological changes were characterized using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FT-IR) and scanning electron microscopy (SEM). The biochemical methane potential (BMP) was assessed with an automated methane potential test system (AMPTS® II). Untreated biomass yielded 72.25 NmL CH_4/g VS. Microwave pretreatments decreased methane yield by 26.06%, likely due to the formation of recalcitrant compounds. Sonication induced a 5.28% increase in yield, attributed to cavitation effects that alter cellular structure. Water washing resulted in the most substantial improvement, enhancing methane yield by 20.76% over the control. Nevertheless, none of these pretreatments scenarios alone generated a positive economic return based solely on electricity sales from the biogas produced.

Secondly, the effect of iron oxide (Fe_2O_3) nanoparticles on the AD process of *Sargassum spp.* biomass was explored. Nanoparticles were added at concentrations of 5, 10, and 50 mg/g substrate. The control sample produced 80.25 ± 3.21 NmL CH_4/g VS. Addition of 5 and 10 mg/g Fe_2O_3 nanoparticles increased methane production by 24.07% and 26.97%, respectively, suggesting enhanced microbial activity likely via direct interspecies electron transfer (DIET), which facilitates more efficient methanogenesis. Conversely, the highest nanoparticle concentration (50 mg/g) inhibited methane production, reducing yield by 38.97%, indicating toxicity at elevated doses.

Sargassum spp. biomass represents a promising feedstock for sustainable biogas generation, particularly when coupled with effective pretreatments and optimized Fe_2O_3 nanoparticle dosing. Future work should focus on integrating these strategies to improve process efficiency and economic viability for large-scale applications.

Keywords: *Sargassum spp., Anaerobic digestion, pre-treatment methods, Fe_2O_3*