Influence of coffee-derived phenolic compounds, initial loading, and biochar on anaerobic digestion of coffee pulp

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Abstract

Coffee pulp (CP), a by-product of wet coffee-cherry processing, contains organic matter suitable for biogas production through anaerobic digestion (AD). However, its high phenolic content may influence methane production. Batch digestion assays using whole CP, individual phenolic compounds [5-O-caffeoylquinic acid (5-CQA) and caffeic acid (CFA)], and CP phenolic extract were conducted under mesophilic conditions. Co-digestion experiments with Avicel microcrystalline cellulose and ethanol were performed to evaluate phenolic interactions with degradable substrates. Increasing initial loading (2–12 g VS/L) reduced methane yields from CP by approximately 20%, due to substrate overloading and transient volatile fatty acid accumulation, whereas lower loadings (2–4 g VS/L) supported rapid and stable methane production at inoculum-to-substrate ratios ≥ 2.0:1. Both 5-CQA and CFA were anaerobically biodegradable and contributed to methane formation during co-digestion. Ethanol digestion exhibited high tolerance to phenolic compounds, showing additive or synergistic interactions, whereas cellulose digestion was more sensitive, with prolonged lag phases and increasing antagonistic effects, particularly in the presence of CFA. CP phenolic extract produced lower methane yields than comparable systems supplemented with pure 5-CQA, indicating that inhibition resulted from combined effects of multiple phenolic constituents rather than individual compounds. At the tested dosage of 5 g/L, woody green-waste biochar did not improve methane production across the evaluated CP loadings, suggesting that the dominant process constraints were not alleviated under the investigated conditions. Overall, methane production under batch conditions was governed primarily by initial loading, phenolic composition, and substrate type, whereas biochar addition at the tested dosage had no effect.

Keywords

Coffee Pulp; Phenolic Compounds; Chlorogenic Acids; 5-O-Caffeoylquinic Acid; Caffeic Acid; Biochar; Anaerobic Digestion