Pretreatment of Lignocellulosic Biomass with Tannery Wastewater for Solid-State Anaerobic Digestion

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Lignocellulosic biomass (LB) is the most abundant material globally, with an annual production of 180 x 10^9 t (Paul and Dutta, 2018). Lignocellulosic biomass is also an attractive resource for biorefining processes such as fermentation and anaerobic digestion (AD) (Zheng et al., 2014). However, in economically developing countries, the management of LB from agricultural crop residues is a major challenge. In these regions, the majority of LB materials are burnt directly on farmland or at waste dump sites. For example, 180 x 10^6 t of rice paddy waste was burnt on farm in 2018 (FAO, 2021). Nigeria accounts for 1% of total rice paddy waste that is burnt globally. The consequences of this practice include an increase in the production of greenhouse gases that negatively impact the climate and a reduction in local air quality that increases respiratory diseases.

Therefore, valorising LB resources into biofuels for renewable energy production would mitigate greenhouse gas emissions, by reducing uncontrolled burning of LB and replacing fossil fuels, benefit local economies, and promote energy security (Bhatia et al., 2020). Anaerobic digestion is a process that can achieve these goals by producing a high calorific value biogas and also a nutrient-rich digestate, that can be recycled to farmland as a fertiliser resource, thus contributing to the circular economy for nutrients. However, the structural complexity of LB prevents hydrolytic enzymes and bacteria from accessing and degrading the polysaccharide molecules by AD. Therefore, different pretreatment methods have been investigated to increase the microbial degradation of LB by AD. For example, calcium hydroxide ($Ca(OH)_2$) pretreatment is an effective approach (Sierra et al., 2009, Gu et al., 2015, Mustafa et al., 2018), however, chemical treatment technologies represent a major challenge in developing regions such as Nigeria . The high cost and restricted availability of pure chemicals represent a significant constraint to the economic and operationally viability and feasibility of an LB-AD system. Therefore, alternative, locally available and low-cost alkali sources are required for pretreatment of LB for AD under these circumstances.

Alkaline industrial wastes, such as tannery wastewater, could serve as alternatives to commercial alkali chemicals for LB pretreatment. This approach could: (1) reduce operating costs of the AD plant, (2) improve AD performance, and (3) provide greater economic and environmental returns. For example, Vazifehkhoran et al. (2018) investigated the potential of tannery wastewater as a chemical pretreatment to increase methane (CH_4) yields from AD of wheat straw (WS) and obtained a specific yield of 314 ml CH_4 g^{-1} VS that represents 23% increase compared to untreated control. Leather tanning generates wastewater at three primary stages of the process, including: soaking, beamhouse and tanning operations. Tannery beamhouse wastewater (TBWW), for example, represents a significant proportion, equivalent to more than 50% of the total wastewater generated in leather tanning, and is a major environmental and water pollutant. However, TBWW is highly alkaline (>10,000 mg L^{-1}) and high in organic matter (>10,000 mg l^{-1} COD) (Thorstensen, 1992) and segregated TBWW could therefore be potentially suitable as an alkaline pretreatment for LB.

The aim of the research reported here is to determine the effectiveness of TBWW for alkaline pretreatment, and organic matter co-digestion, for solid-state mesophilic AD of LB typically produced in Kano, Nigeria. In Phase 1, controlled experiments based on a batch biomethane potential (BMP) procedure were conducted to determine the optimum $Ca(OH)_2$ loading rate (the main source of alkali in TBWW) and pretreatment time to maximise solubilisation of WS fibres (Figure 1). In Phase 2, the effect of TBWW (collected from an operational tannery in Kano, Nigeria (pretreatment on the fibre content and biogas generation from AD of WS, rice straw (RS), sugar cane bagasse (SCN) and corn stover (CS), under ambient environmental conditions in Nigeria was evaluated (Figure 2).

Lignin and cellulose contents were not affected by $Ca(OH)_2$ pretreatment (Figure 1a). However, the hemicellulose content decreased with $Ca(OH)_2$ pretreatment at 5%, by up to 50% compared to untreated control, but no further changes were observed with increasing loading rates. The lignin fibre fraction was unaffected by pretreatment time (Figure 1b). Similarly, cellulose content was unchanged up to 7 d, however, a small decrease ($p<0.05$) was observed after 14 d. By contrast, hemicellulose fibre content deceased by 40% after 1 d compared to untreated control, and continued to decrease slowly to a value of 50% with increasing pretreatment time up to 14 d.

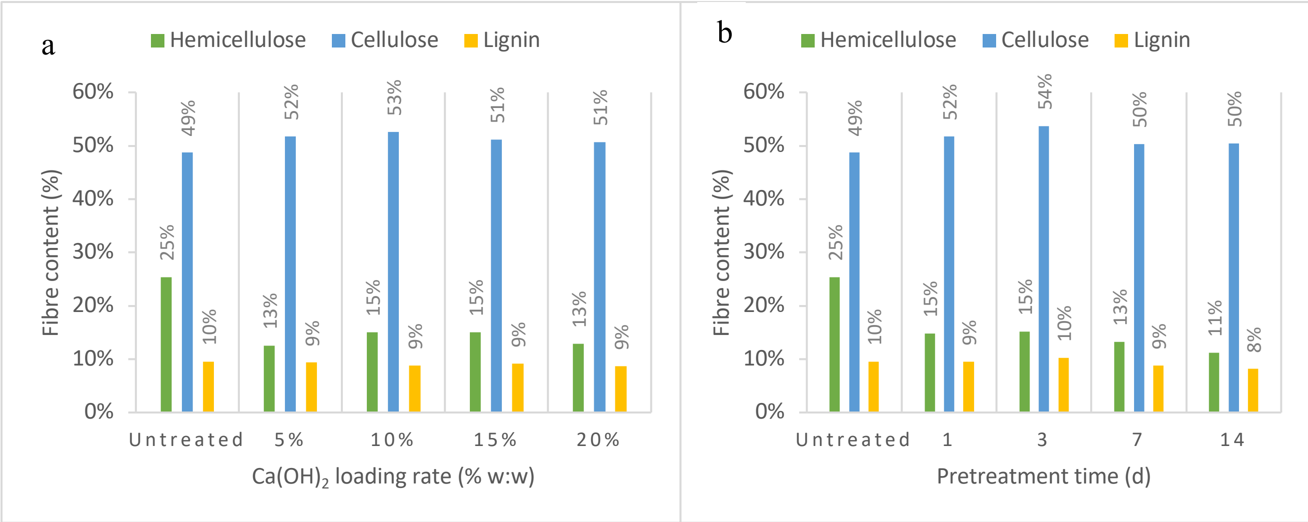

Figure 1: Effect of (a) $Ca(OH)_2$ loading rate for 7 d and (b) pretreatment time on WS fibre content at 5% $Ca(OH)_2$ loading rate

Figure 2a shows the accumulated biogas response of BMP tests of 5% $Ca(OH)_2$ pretreated WS for 7 d for two inoculum/substrate ratios (ISR) (1 and 2) incubated at 35 d at 35 °C; the control treatment was untreated WS at ISR of 2. The specific biogas yield increased at a faster rate initially for the control to an accumulative value of 94 ml gVS^{-1} which was similar to $Ca(OH)_2$ pretreated WS using ISR of 1 (92 ml gVS^{-1}). The highest specific biogas yield (108 ml gVS^{-1}) was obtained with $Ca(OH)_2$ pretreatment and ISR of 2 representing an increase equivalent to 10% compared to the untreated control. Figure 2b shows the accumulative specific biogas yield obtained for TBWW pre-treated substrates (WS, RS, SCN and CS). The highest biogas yield was measured for RS, equivalent to 11.3 ml gVS^{-1}, compared to WS and CS which gave specific yields of 8.95 ml gVS^{-1} and 3.17 ml gVS^{-1}, respectively. The smallest yield, 0.93 ml gVS^{-1}, was obtained for pretreated SCN (which may be explained by the high lignin content of this LB source. TBWW contains a large concentration of sulphide which is potentially inhibitory to the AD process, nevertheless, methanogenic activity was observed. Further research is ongoing to apply a precipitation technique to produce sulphide free TBWW for LB retreatment to increase the potential biogas yield from the process.

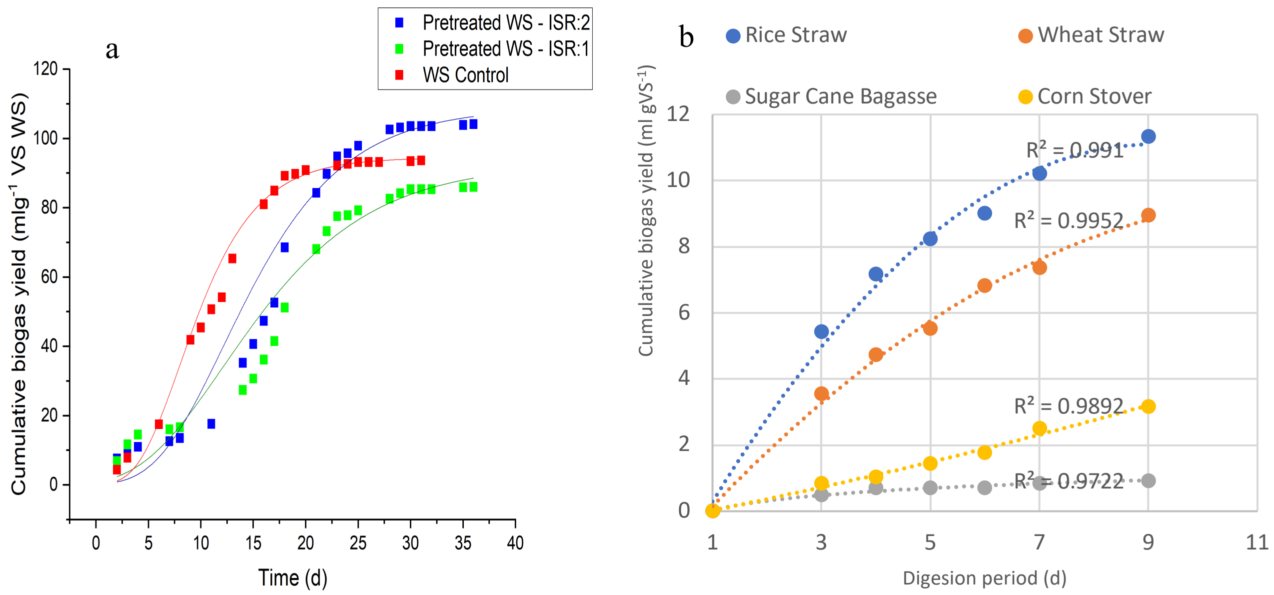

Figure 2: Cumulative biogas yield of (a) 5% $Ca(OH)_2$ pretreated WS for 7 d (b) TBWW pretreated substrates for 7 d

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