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Synergy of Siam weed (*Chromolaena odorata*) and poultry manure for energy generation: Effects of pretreatment methods, modeling and process optimization

S.O. Dahunsi [a], S. Oranusi [b,*], J.B. Owolabi [c], V.E. Efeovbokhan [d]

[a] Biological Sciences Department, Landmark University, Nigeria
[b] Biological Sciences Department, Covenant University, Nigeria
[c] All Saints University College of Medicine, Kingstown, Saint Vincent and the Grenadines
[d] Chemical Engineering Department, Covenant University, Nigeria

HIGHLIGHTS

- Co-digestion of Siam weed and poultry manure generated huge biogas.
- The study established the appropriate pre-treatment method for the substrates.
- Modeling and optimization was done using the Response Surface Methodology.
- The optimized conditions for maximal biogas yield were established.

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ABSTRACT

The co-digestion of *Chromolaena odorata* with poultry manure was evaluated in this study. Two samples of the weed: (A: which was pre-treated with mechanical, chemical and thermal methods) and (B: which was pretreated using mechanical and chemical methods only) were separately digested with poultry manure. Biogas generation started from the 2nd to 4th and 4th to 7th day for samples 'A' and 'B' respectively. The most desired actual biogas yield from samples 'A' and 'B' were 3884.20 and 2544.70 (10^{-4} m^3/kg VS) respectively and the gas composition was 68 ± 2% Methane and 20 ± 2% Carbon dioxide for sample A while it was 62 ± 3% Methane and 22 ± 2% Carbon dioxide for sample B. In all, there was a 38.06% increase in gas generation in 'A' over 'B'. The coefficient of determination (R^2) for the Response Surface Methodology (RSM) model (0.9009) was high suggesting high accuracy in the modeling and prediction. The worldwide usage of *C. odorata* is encouraged.

1. Introduction

Globally regarded as 'one of the world's worst weed', Siam weed (*C. odorata*) is an invasive plant species known for its negative impact on agricultural systems, the economy and biodiversity conservation in its areas of dominance (Perrings et al., 2010). As common for most invasive plant species, *C. odorata* constitutes huge threat to both the natural and derived ecosystems in its introduced habitats. It is known for its capability to smother existing native plant communities and by so doing has generated huge attractions in different agricultural systems worldwide (Adebayo and Uyi, 2010).

C. odorata has been noted to have originated from Mexico, the Caribbean and Brazil all in tropical Central and South America, from where it has spread to other localities due to its effective short- and long-distance dispersal mechanisms. It is often found in disturbed land areas, grasslands, fallow areas and forestry plantations where it forms pure stands when fully established (Gautier, 1992). *C. odorata* was introduced to Southern Nigeria in 1937 from Sri Lanka. Presently, it has reached alarming population in Nigeria (Uyi et al., 2013) and other African countries like Cameroon, Ghana etc (Djietror et al., 2011a, 2011b). It has over the last few decades been regarded as one of the worst weeds in Nigeria and West Africa.

C. odorata have in the past been put to some uses including as a fallow species in crop rotations, as medicine, in soil fertility improvement and as potential pesticide (Alisi et al., 2011). Several

* Corresponding author.
E-mail address: solomon.oranusi@covenantuniversity.edu.ng (S. Oranusi).

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control measures ranging from chemical, mechanical and biological have been applied to control the plant due to its presence over large areas and its invasive nature (Zachariades et al., 2013). However, none of the methods have been practically found sustainable in terms of cost (Uyi et al., 2014). At present, there are no control or proven management strategies in place to check the spread of the weed in Nigeria and other countries. Therefore, this study is an attempt to utilize this weed for energy generation since green plants are natural sinks for enormous energy as a result of photosynthesis. Its abundance and invasiveness in several locations around the world is an indication that a veritable and environmental-friendly usage needs to be sought for the weed.

Anaerobic digestion (AD) is a technology for the conversion of organic materials into biogas which is subsequently used for electricity and mechanical energy generation, heating and other forms of energy utilization (Leite et al., 2016). The biogas generation in AD is brought about by the hydrolysis and subsequent fermentation of feedstock by diverse group of microorganisms carrying out several biochemical reactions in an anoxic environment (Chuichulcherm et al., 2016; He et al., 2016; Ismail and Talib, 2016).

Agricultural wastes and grasses are usually burnt off since they are mostly seen as solid wastes. However, the advent of the AD technology now makes these materials constitute low cost suitable candidates for the biotechnological production of biogas (Guenther-Lübbers et al., 2016; Othman et al., 2016). Previous investigations have specifically identified grasses as rich energy substrates and highly effective in greenhouse gas control than first generation biofuel resources when fully exploited for biogas production (Riggio et al., 2015). Biogas generation from poultry manure has been extensively investigated on with some success recorded. However, major setbacks were reported due to its low C/N ratio and high amount of total ammonia. The best approach to its usage therefore is co-digestion with other high energy-yielding substrates as earlier suggested by Dalkilic and Ugurlu (2015).

Prior to anaerobic co-digestion, pretreatment of substrates using different methods such as mechanical, chemical, thermal and others has been widely reported as an efficient approach to increase their accessibility to microbial bioconversion and also improve methane production (Lalak et al., 2016; Li et al., 2016a, b; Serrano et al., 2016). This is necessary because most lignocellulosic materials are highly recalcitrant to biodegradation and subsequent bioconversion by AD microorganisms due to their abundant lignin and cellulose matrix (Carrere et al., 2016). Similarly, optimization of process parameters is important in bioenergy generation (Montingelli et al., 2016) and the Response Surface Methodology (RSM) has been successfully utilized in the modeling of biogas from different substrates (Emeko et al., 2015). This study therefore aims at evaluating the usage of one of the world's worst weed (*C. odorata*) for biogas generation in co-digestion with poultry dropping. This is the very first time Siam weed will be reported as a viable substrate for bioenergy generation coupled with use of different pretreatment combinations. Since no permanent solution has been documented for the weed's invasion across the world and the challenges it poses to Agriculture, this research proposes a permanent solution to this barrier after which the plant will no longer be regarded as a weed but an energy biomass.

2. Methodology

2.1. Sample collection for the study

The vegetative portion of *C. odorata* and fresh poultry manure were both collected from the Teaching and Research Farms of Landmark University, Omu-Aran, Kwara State, Nigeria where the experiment also took place. In order to have adequate microbial flora in the AD systems, the inoculum (bovine rumen contents) were collected from the slaughter slab of Landmark University's Cafeteria. Considering the lignocellulosic nature of the plant, it was pre-treated using two different methods in order to establish the most appropriate pre-treatment method for the biomass. The first sample labeled 'A' was pre-treated using the combination of mechanical, thermal and chemical (Na OH) pre-treatment earlier described (Dahunsi et al., 2016a,b). In doing this, a hammer mill was employed to crush the biomass into mesh sizes of ⩽20 mm and was then heated in the CLIFTON, 88579 water bath (NICKEL-ELECTRO Ltd., ENGLAND) at 80 °C for one hour since thermal pre-treatment at higher temperature has been reported to have adverse effect on the AD system (Liu et al., 2012). Chemical pre-treatment was then followed with 3 g/L sodium hydroxide (Na OH). The choice of Na OH was premised on earlier reports that among other widely used alkalis, Na OH has produced the best result for thermo-chemical pre-treatment of AD substrates (Li et al., 2015). The second sample labeled 'B' was pre-treated using the described mechanical and chemical (Na OH) methods only. The twenty-five-litre volume digesters earlier used (Dahunsi et al., 2016a,b) were employed in this study. Each digester setup comprises an air-tight tank furnished with a mechanical iron stirrer in-built for appropriate substrate mixing. A liquid displacement apparatus for gas collection was equally attached to the digestion tank (Dahunsi and Oranusi, 2013).

2.2. Design of experiment

The CCRD was employed in the experimental design for the AD of pre-treated samples of *C. odotata* and poultry manure to biogas because of its efficiency in biofuel process improvement (Emeko et al., 2015). A total of 50 experimental runs were generated via the five-level-five-factors design used. Based on their importance in the success of AD process, five independent factors (Temperature (°C), pH, Retention time (days), Total solids (g/kg) and Volatile solids (g/kg) designated as X_1, X_2 X_3 X_4 and X_5 respectively were selected for the biogas modeling and optimization study. In most previous studies till date, temperature for most mesophilic AD has been varied between 30 and 40 °C (Tampio et al., 2016). Likewise, pH range of between 6.5 and 8 has been severally reported to be best for AD microbial operations. The range of retention time for mesophilic AD has equally been given to be from 20 to 30 days based on the ambient temperature. It has been documented that liquid AD efficiency is achieved when the total solids content is <15% and ⩾4% (Tampio et al., 2016). It was therefore on the basis of the prescribed values in literature that the working ranges were chosen in this optimization study (Table 2) so as to document the optimal process conditions for the most efficient AD using *C. odorata* and poultry manure as substrates.

2.3. Biochemical and residual methane potential tests

In order to determine the potential methane production of the substrates at standard temperature and pressure (STP), the biomethane potential test was carried out following already prescribed methods (Dahunsi et al., 2016a,b). The experiment ran anaerobically in a batch system for 30 days using two 250 ml flasks for the experiment and a blank making three in all and in triplicate with an inoculum to substrate ratio of 3 according to earlier protocol (Ghasimi et al., 2016a,b). Collection of produced gas from the digesters was constantly carried out and the methane content was analyzed chromatographically. The same method was employed for carrying out the Residual methane test carried out solid digestates.

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