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An assessment of duckweed as a potential lignocellulosic feedstock for biogas production

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ABSTRACT

Due to the complicated structure of lignocellulosic plant cell wall, their utilization for biogas production via anaerobic digestion has not been widely adopted. Alternative to this is to use aquatic plant materials as feedstock for biogas production. In this context, duckweed, an aquatic plant may prove to be a promising new energy source for bioenergy as well efficient CO_2 sequestration. This study entails a detailed characterization of duckweed to evaluate their potential as an alternate feedstock to cattle dung for biogas production. The duckweed was characterized for volatile matter, moisture content, ash content and carbon, hydrogen, and nitrogen (CHN) content. Property analysis of duckweed was also done by Fourier transform spectroscopy and thermogravimetric analysis. The volatile matter of duckweed was found to be 84.24± 0.2% with a lignin content of 12.2%, which is very encouraging for biogas production. Co-digestion of duckweed (DW) with cattle dung (CD) in varying ratios (DW:CD = 90:10, 75:25, and 50:50 respectively) in batch type anaerobic digesters was performed at 37 °C temperature for 55 days. The cumulative biogas production for CD (100%), DW/CD (90:10), (75:25) and (50:50) was found to be 11,620, 305, 11,695, and 12,070 mL, respectively, which indicated that duckweed can be a potential lignocellulosic feedstock when co-digested with cattle dung at an optimum ratio of 1:1. Methane content of the biogas from co-digested feedstock is comparable to the biogas from cattle dung alone.

1. Introduction

Worldwide the consumption of renewable energy is on the rise. Concerns for energy security, efforts to mitigate the environmental impact of conventional fuels, and improvements in living standards and renewable technologies are the ingredients of sustainable energy usage (Edenhofer et al., 2012). In this context, bioenergy is recognized as a potential player, which can lead a central role in promoting renewable alternatives. According to recent report by Ren21, Renewables 2015 Global Status Report (2015), the total primary energy demand from biomass in 2014 was approximately 16,250 Wh (58.5EJ). Various bioenergy production technologies, such as bioethanol, biodiesel, biomethane, etc., that use biomass as a substrate are receiving worldwide attention. As a sustainable energy source, biogas is one of the prospective alternatives identified so far which is economically feasible, as it has the lowest financial input of output energy, unlimited in potential and eco-friendly in nature. Furthermore, from a socio-economic point of view, biomass waste can serve as feedstock for biogas production and hence significantly reduces the cost (Jain et al., 2015). Biogas can be readily converted to electrical and thermal energy via a co-generator, typically for onsite consumption (Wickham et al., 2016). It can be produced from different types of organic materials, such as industrial wastewater, food waste, sewage sludge and agricultural waste (Sawatdeenarunat et al., 2015). According to Tufaner and Avşar (2016), anaerobic mono-digestion of cattle dung usually causes poor performance and stability, but cattle dung may resolve any imbalance and improve biogas production when it is combined

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synergistically with other waste.

Materials rich in lignocellulose, such as plant residues, represent the most promising renewable organic feedstock for biogas production, as their production does not compete for arable land (Chandra et al., 2012). The source of lignocellulosic biomass can be generally divided into three categories, namely agricultural wastes, annual and perennial dry energy grasses, and forestry waste (Loow et al., 2015, 2016). However the main hindrance in anaerobic digestion of agriculture waste is slow biodegradation rate because of its chemical composition and structure of ligno-cellulosic materials. The nature of lignocellulose material limits their application in anaerobic digestion (Sawatdeenarunat et al., 2015; Zhang et al., 2016). The utilization of aquatic weed and algae has been proposed as a potential feedstock for biogas production.

Anaerobic co-digestion of solid waste is regarded as a clean energy as it is able to convert energy directly from organic waste by action of microorganism. Co-digestion could enhance biogas production, methane yield and organic matter degradation due to added benefits such as diluted inhibitory compounds and a more balanced carbon-to-nitrogen ratio thereby increasing the economic feasibility of treatment plants (Wickham et al., 2009). This may be the main reason why there is increasing interest in this line of research.

The Lemnaceae, commonly called duckweed, is a monocotyledonous family of five genera and 37 species. The tiny, free floating, aquatic weed is native to temperate and subtropical regions worldwide (Xu et al., 2012). Duckweed grows faster than most other plants on Earth, with species having doubling times of 2–3 days under ideal growth conditions (Yu et al., 2014). Duckweed can achieve these rapid growth rates utilizing nutrient-rich wastewater, thus preventing the environmental release of potentially polluting compounds via plant assimilation. Cheng and coworkers have studied duckweed production in swine wastewater for a decade and have reported non optimized growth rates of up to 0.2 kg dry weight (DW) m^{-2} $week^{-1}$ under field conditions (Cheng et al., 2002). Duckweed biomass contains organic nitrogen as protein and free amino acids, and starch, both of which are useful in a fermentable feedstock. The other benefits of duckweed included as a CO_2 sequestration agent. Assuming a duckweed carbon content of 40%, 57.3–155.3 tonnes of CO_2 can be removed from the atmosphere by 1 ha of duckweed pond in a year, which makes duckweed a highly competitive candidate for CO_2 sequestration (Landolt and kandeler, 1987). Duckweed has been reported as potential feedstock for bioethanol production and the results reported that theoretical ethanol yield of duckweed has been reported to be 6.42×10^3 L ha^{-1}, about 50% higher than that of maize-based ethanol production (Xu et al., 2011). Due to relatively high level of starch (a favorable composition of cell-wall carbohydrates) and lack or low level of lignin reduces the pretreatment and enzyme dosages thereby significantly improving the economics of bioethanol production. Recently, *Lemna minor* (duckweed species) was reported to have great potential as feedstock for production of bio-oil and bio-char (Muradov et al., 2010, 2012). Another possible use of duckweed biomass is the production of biogas. It is especially well suitable for this purpose as it contains very small amounts of lignin (a major component of wood) which otherwise would make microbial degradation difficult. The resulting liquid waste after biogas production still contains almost all nutrients from the green plants and can be further used, as fertilizer for duckweed growth. It has been reported that methane production from duckweed was higher than that from grass and water spinach (Cu et al., 2015). Ramaraj and Unpaprom, (2016) also reported biogas production from duckweed.

In this work, the physico-chemical property of duckweed has been characterized by proximate and ultimate analysis and also using techniques such as Fourier transform infrared (FTIR), thermogravimetric analysis (TGA) and fibre analysis. Biogas production using duckweed and cattle dung (DW:CD = 75:25, 50:50, and 90:10 respectively) in lab scale batch bioreactors was assessed at ambient room temperature.

2. Materials and methods

2.1. Preparation of samples

Duckweed samples were collected from Amingaon village ponds close by to Indian Institute of Technology Guwahati (IITG) campus, Guwahati-39, Assam, India. A known volume of cattle dung (5 kg) was procured locally for the experiment. Fresh duckweed samples have been utilized for the biogas batch reactor. All the samples were air dried and grounded in a high speed rotary cutting mill prior to the use for characterization.

2.2. Proximate analysis

Proximate analysis is one of the most important characterization methods for biomass to biofuel conversion. This includes moisture, ash, volatile matter and fixed carbon contents of the raw biomass. The procedure to estimate the amount of total solids, moisture and ash present in biomass was adopted from the National Renewable Energy Laboratory (NREL) protocol. American Society for Testing and Materials (ASTM) D 271-48 was followed for volatile matter determination. Fixed carbon was determined by difference from summation of ash, volatile and moisture content. Lignin, cellulose and hemicellulose were determined by Van Soest method in a fibre digestion unit (Make:Pelican, Model:Fibra plus unit). All the protocols have been mention in Yadav et al. (2016).

2.3. Ultimate analysis

The basic elements of any biomass are carbon, hydrogen and nitrogen. Ultimate analysis was done in a CHN analyzer (Make:-LECO, Model:Truspec CHN). The test method covers the determination of carbon in the range of 50 ppm or 0.005%–50%, hydrogen in the range of 200 ppm or 0.02%–50% and nitrogen in the range of 80 ppm or 0.08%–100% (Yadav et al., 2016).

2.4. Heating value

The heating value of the samples were measured in an adiabatic oxygen bomb calorimeter as per IP-12 and IS-1305 (Parr 1341 Plain Jacket, USA) using the procedure described in ASTM manual (Yadav et al., 2016).

2.5. Thermogravimetric analysis

Thermogravimetry provides a rapid method for determining the temperature assisted decomposition profile of a material and the kinetics of its thermal decomposition. Thermogravimetric analysis (TGA) measurements were performed on a Mettler TGA/SDTA 851 thermogravimetric analyzer. Approximately 5 mg of the prepared sample was placed in an alumina crucible and heated in nitrogen atmosphere between 10 and 800 °C at a rate of 10 °C min^{-1} (Yadav et al., 2016).

2.6. Fourier transform infrared spectroscopy

Fourier transform infrared spectroscopy (FTIR) spectra of all the lignocellulosic biomasses were obtained using a Shimadzu IR Affinity (Shimadzu, Japan) by mixing 1% sample with finely ground