ANSF APPLIED AND NATURAL SCIENCE FOUNDATION

Journal of Applied and Natural Science
16(2), 883 - 889 (2024)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Biogas production from water hyacinth (*Eichhornia crassipes*) harvested from River Wouri, Douala, Cameroon

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Article Info
https://doi.org/10.31018/jans.v16i2.5631
Received: April 13, 2024
Revised: June 05, 2024
Accepted: June 11, 2024

How to Cite
Wirngo, H.Y. *et. al.* (2024). Biogas production from water hyacinth (*Eichhornia crassipes*) harvested from River Wouri, Douala, Cameroon. *Journal of Applied and Natural Science*, 16(2), 883 - 889. https://doi.org/10.31018/jans.v16i2.5631

Abstract
Over the past three decades, growing global interest has been in replacing fossil fuels with clean energy from renewable resources. As a result, biogas generation from biodegradable organic waste has become increasingly popular, and water hyacinth is a menace wherever it exists. This study aimed to assess the effectiveness of water hyacinth (*Eichhornia crassipes*) from River Wouri as a biogas substrate. Equal volumes (700 mL) of water hyacinth and poultry-based inoculum were prepared, each with a duplicate. The 8 substrates were placed in 1-liter plastic and incubated in a water bath at 37± 2 °C for 106 days. The substrates were subsampled before and after incubation to analyse the dry matter, moisture, volatile solids, ash contents, and pH. The volume of biogas produced from each digester was collected in plastic bags and measured every three days; hence, the methane produced was calculated. Results indicated an increase in the moisture contents of the substrates, while pH levels remained unchanged after incubation. The rate of destruction of volatile solids increased with the level of added inoculum. Biogas production started almost immediately for all the samples and largely followed a dome shape over the incubation period. Cumulative methane produced were 10.23, 11.84, 5.88, and 0.71 LCH_4/kgVS, respectively, for 100% water hyacinth, 90% water hyacinth, 80% water hyacinth and 0% water hyacinth. This study demonstrates the effectiveness of the weed in biogas production, which could be an important method to manage River Wouri while generating renewable energy.

Keywords: Anaerobic biodigester, Biogas, Inoculum, Methane, Water hyacinth

INTRODUCTION

Human existence is deeply intertwined with the environment, where human activities impact nature, leading to outcomes that affect humanity (Kumar, 2018; Pawanjeet, 2021). Over the years, humans have harnessed environmental components like water for bioenergy production and agricultural irrigation to produce food and raw materials for diverse usage. However, these activities have resulted in environmental degradation, characterized by harmful alterations or undesirable changes in the environment (Wang and Dong, 2019; Patel *et al.*, 2021). It includes land, water, and air pollution, destruction of ecosystems, and wildlife extinction. According to the World Health Organization (WHO), 25% of people who work outdoors are vulnerable to health problems: in 2019, 6.7 million deaths were a result of air pollution (WHO, 2023). Population growth, economic expansion, and the consumption of non-renewable energy resources, along with pollution, are key factors contributing to environmental degradation (Sarkodie, 2018; Wang and Dong, 2019; Sadiku *et al.*, 2020). This degradation manifests as climate change, rising sea levels, water, air, or land pollution, and biodiversity loss (Tyagi *et al.*, 2014). Excessive reliance on non-renewable energy sources such as fossil fuels, natural gas, and petroleum products has led to environmental pollution and resource depletion. To address these issues, scientists have explored renewable energy sources such as biomass, hydro, solar, and wind (Maradin, 2021).

Degraded water endangers human and aquatic life, raising concerns about the future of water resources. The invasion of water bodies by water hyacinth results in the alteration of the physical, biological, and chemical properties of water bodies alongside water quality and quantity changes. Water hyacinth was first reported in Brazil in 1816 in the Amazonian basin of South America (Basaula *et al.*, 2021) and spread to other parts of the world after the cotton exhibition of 1887 (Carlini *et al.*, 2018). Despite originating in Brazil, water hyacinth easily adapts to various environments, thriving in extremes of climatic zones from tropical deserts to rainforests. The plant's name, "water hyacinth" is derived from its aquatic habitat and its flowers' resemblance in color to garden hyacinths (Ayana, 2021). Water hyacinth was introduced as an ornamental plant to many parts of the world due to its beauty, which bears beautiful bright multi-petal flowers (Rezania *et al.*, 2015).

However, thick mats of water hyacinth float on the water's surface, preventing the entry of sunlight to deeper regions of the water, and affecting phytoplankton and other aquatic plants. In addition, studies have shown that decomposing water hyacinth increases water turbidity, decreases dissolved oxygen levels, and results in significant water loss due to evapotranspiration (Villamagna and Murphy, 2010; Ayana, 2021). Moreover, they can affect the structure and functions of aquatic ecosystems by out-competing existing aquatic plants, interfering with predator-prey relationships disrupting aquatic food chains and food webs (Hijdra *et al.*, 2014; Ayanda *et al.*, 2020; Dechassa and Abate, 2020). In addition, aside from the ecological impacts, literature search reveals that it obstructs waterways, limits access to fishing areas, local markets, healthcare facilities, and farms, serves as a host to disease vectors and poisonous snakes, reduces fishing frequency and fish catch, impedes sand exploitation activities and restricts recreational activities (Waithaka, 2013; Rezania *et al.*, 2015; Su *et al.*, 2018; Ayanda *et al.*, 2020; Li *et al.*, 2021).

Water hyacinth eradication methods face several challenges, including poorly executed mechanical control leading to re-infestation, exhausting manual eradication, secondary effects of chemicals on non-target organisms, and slow and ineffective biological control (Güereña *et al.*, 2015; Adelodun, 2022; Karouach *et al.*, 2022). The high cost associated with water hyacinth management highlights the need for sustainable management practices. Biomass, including water hyacinth, animal dung, and biodegradable wastes, can be used as substrates for biogas production (Sawyerr *et al.*, 2020). This biomass forms the basis for bioenergy generation, relying on microorganisms to degrade biodegradable substances into less harmful products such as carbon dioxide and biogas, which can be used for heating and other energy conversion processes (Bamgboye, 2010; Adeleye *et al.*, 2013). The energy potential of water hyacinth has been established by Bamgboye (1994), who found the weed to be suitable. Pretreating the plant by chopping, grinding, and blanching will enhance biogas production (Lucas and Bamgboye, 1998, 1999, and 2001). Over the years, other methods such as the use of different chemicals and microbes, have been applied to improve biogas pretreatment for biogas production (Barua *et al.*, 2018; Rezania *et al.*, 2019; Manigandan *et al.*, 2023). Given the challenges of managing water hyacinth in Cameroon and its potential for energy production, there is a need to evaluate its effectiveness in producing biogas.

Previous studies in Cameroon on water hyacinth have mainly focused on its socio-economic impacts (Kenfack *et al.*, 2019). However, there is limited experimental research on valorization methods identified in the literature and limited literature on assessing the effectiveness of water hyacinth as a raw material for bioenergy production (Nwamo *et al.*, 2022). Biogas production using water hyacinth as a substrate offers a dual benefit of eradicating the water weed and providing an alternative clean energy source. The present study aimed to assess the effectiveness of water hyacinths (*Eichhornia crassipes*) from River Wouri, Douala, as a raw material for biogas production.

MATERIALS AND METHODS

Substrate preparation

Water hyacinth (*Eichhornia crassipes*) used for biogas production was harvested from River Wouri in Douala-Cameroon. After harvesting, the thick root system was cut off and discarded. The remaining part consisting of the stolon, stem, leaves, and flowers were put in a jute bag and transported to the Waste to Energy/ Resource Laboratory in the University of Buea, Southwest Region, Cameroon, for biogas production. Pretreatment of the water hyacinth included shredding and grinding to increase the surface area for microbial action and to improve hydrolysis (Bamgboye, 1994; Adelekan and Bamgboye, 2009). The shredded plant was then mixed homogeneously then the inoculum was added. The poultry inoculum, containing indigenous methanogenic bacteria, was sourced from a local biogas plant situated within a poultry farm on the university premises. No other microbes were added.

Experimental setup

Eight 1L plastic air-tight containers were used as anaerobic digesters. The plastic containers were washed with clean water to remove impurities. A hole was drilled into the lid of each bottle, and a pipe was fitted into the lid with the other end connected to a 500 mL saline bag for biogas storage. It was ensured that there were no leakages from the bottles through the pipes to the saline bags. Water hyacinth and inoculum were mixed in various proportions and put in each plastic bottle as presented in Table 1. Before putting the substrates in the bottles, they were subsampled and frozen for dry matter and volatile solid content analyses. The digesters were placed in an electric water bath maintained at 37± 2 °C (Fig. 1). Four months was the exact duration for the digestion experiments.

Dry matter and volatile solid contents measurement

The pH, moisture, volatile solid, dry matter, and ash content of the water hyacinth and poultry inoculum were determined at the experiment's beginning and end following standard Method 1648 of the US Environmental Protection Agency (2001), as indicated in Telliard (2001) and utilized by Ngwabie *et al.* (2019).

Measuring biogas volume and methane produced during the anaerobic digestion.

Depending on how quickly the saline bags filled up, the volume of biogas produced was measured every 3-5 days using a Ritter Volumetric Gas Flow Meter (Gehäuse/Trommel, Germany). After measuring the volume of biogas in each saline bag, gas samples were collected using a syringe and transferred to labeled evacuated vials. The empty saline bags were then reconnected to the plastic bottles. The vials were stored at a temperature of 4.0 °C and later sent to the International Livestock Research Institute to measure CH_4, N_2O and CO_2 concentrations through gas chromatography to determine the quantity of methane (combustible part of biogas) from the impurities.

Statistical data analysis

Data was entered in Excel and imported into the R Project for statistical computing. The mean values (biogas volume, CH_4 concentration, CH_4 volume) for each substrate mixture and its replicate in Table 1 were calculated. The cumulative CH_4 volume (mL) was further computed and standardized with the initial volatile solid content (g) in the corresponding bottle. ANOVA was used to assess the difference in CH_4 production from the different mixtures of water hyacinth and inoculum.

RESULTS AND DISCUSSION

Characteristics of water hyacinth and poultry inoculum substrate mixtures during incubation

The pH values of the substrates ranged from 6.06 to 6.86, while the pH of the digestate was observed to be between 6.38 and 6.85. A comparative analysis of the

Table 1. Substrate composition for anaerobic digestion

Substrate mixture	Volume of each bottle (mL)	Volume of mixture in each bottle	
		Water hyacinth (mL)	Inoculum (mL)
100% water hyacinth (with replicate)	1000	700	0
90% water hyacinth 10% inoculum (with replicate)	1000	630	70
80% water hyacinth 20% inoculum (with replicate)	1000	560	140
100% inoculum (with replicate)	1000	0	700

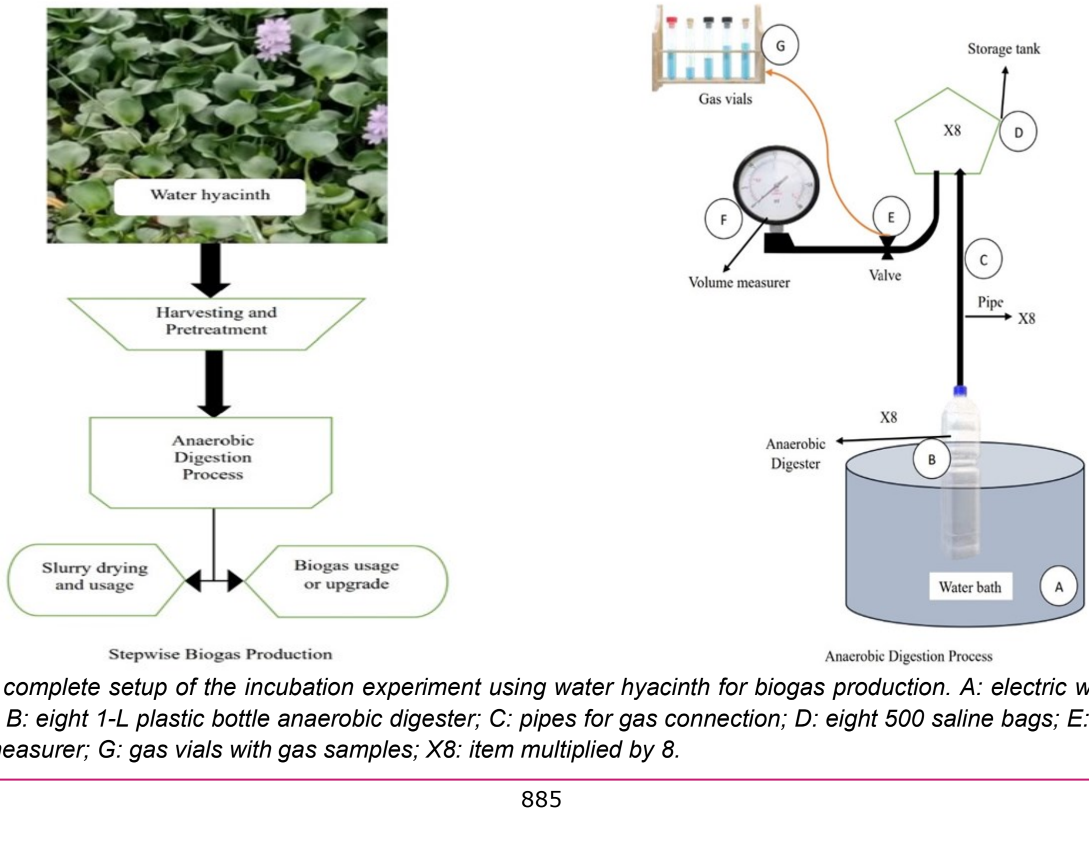

Fig. 1. *A complete setup of the incubation experiment using water hyacinth for biogas production. A: electric water bath 37± 2 °C; B: eight 1-L plastic bottle anaerobic digester; C: pipes for gas connection; D: eight 500 saline bags; E: valve; F: volume measurer; G: gas vials with gas samples; X8: item multiplied by 8.*

pH levels of the digestate, as well as similar studies on water hyacinth incubation by Okewale and Adesina (2019), showed that the pH levels were slightly acidic. Therefore, assessing the effect of these pH levels on biogas production is imperative. The moisture contents decreased (94 to 89%) with the increasing quantity of inoculum added to water hyacinth before incubation (Table 2). The same trend was observed after incubation. This was due to the low initial moisture content (77%) of the inoculum used in the incubation experiments. As expected, the trend was reversed for the dry matter contents. The volatile solid content also decreased with the increased quantity of added inoculum. This was likely also because of the low initial volatile solid content of the inoculum (86%) that was used.

The destruction rate of volatile solids (mixtures of water hyacinth and poultry inoculum) increased with the increase in the quantity of added inoculum. Indeed, volatile solid destruction increased from 9 to 32% as the inoculum rose from 0 to 20% in the water hyacinth incubation experiment (Table 3). The increasing trend in volatile solid destruction is expected to translate to increasing biogas production and methane production compared to results from raw dairy manure (Ngwabie *et al.*, 2019; VanderZaag *et al.*, 2018). In a similar experiment using cow dung as a co-substrate to water hyacinth (*Eichhornia crassipes*), it was also shown that higher biogas production is favored by lower volatile solid (Manigandan *et al.*, 2023).

Biogas and methane production

The trend in biogas production is shown in Fig. 3. On the first week of the incubation experiment, biogas production increased with increased added inoculum. Biogas production during this period likely came from the inoculum. In the second week, biogas production from 100% inoculum dropped, and production from water hyacinth started. The trend was generally dome-shaped, with peak production after about a month of incubation. Biogas production also dropped as the volatile solids in the substrates were degraded towards the end of the experiment. The drop in biogas production between days 64 and 73 in Fig. 2 resulted from a drop in the temperature of the water bath below 37 °C due to power failure. For 100% water hyacinth, the cumulative biogas production was slightly higher (462mL/g) compared to 412mL/g (Oduor *et al.*, 2022) and 406 mL/g (Rashama *et al.*, 2023) who used food wastes and cow dung as co-substrates. However, the other mixtures had higher cumulative biogas values produced for both studies and the current one due to the action and type of inoculum. The duration of anaerobic digestion of water hyacinth from River Wouri under the same mesophilic conditions of the authors was slightly higher (106 days) than the others.

The cumulative methane produced from the biogas expressed as a function of the initial volatile solid in each bottle is presented in Fig. 3. In the first ~30 days, considered the lag phase, methane production in all samples was less than 1 LCH_4/kgVS. After the lag phase, the cumulative methane production exhibited a logarithmic growth as expected for water hyacinth samples that had inoculum. It was interesting to note that the cumulative methane production decreased with increasing level of added inoculum (from 0 to 20% inoculum). However, as anaerobic digestion progressed, the effect of the inoculum became important at the substrate, with 10% of the inoculum performing better. In-

Table 2. Characteristics of the substrate before and after incubation experiments

Substrate	MC (%)	DM (%)	VS (%)	Ash (%)	
100% water hyacinth	94	6	95	5	Before incubation
90% water hyacinth 10% inoculum	92	8	92	8	
80% water hyacinth 20% inoculum	89	11	92	8	
100% inoculum	77	23	86	14	
100% water hyacinth	94	6	95	5	After incubation
90% water hyacinth 10% inoculum	94	6	94	6	
80% water hyacinth 20% inoculum	92	8	82	18	
100% inoculum	83	17	91	9	

MC: moisture content; DM: dry matter; VS: volatile solids

Table 3. Volatile solid destruction rate during anaerobic digestion of water hyacinth with added inoculum

Substrate	Initial volatile solid content (g)	Final volatile solid content (g)	Volatile solid destruction (%)
100% water hyacinth	42.86	38.88	9.28
90% water hyacinth, 10% inoculum	48.06	40.81	15.02
80% water hyacinth, 20% inoculum	67.29	45.44	32.47
100% inoculum	139.93	108.49	22.46

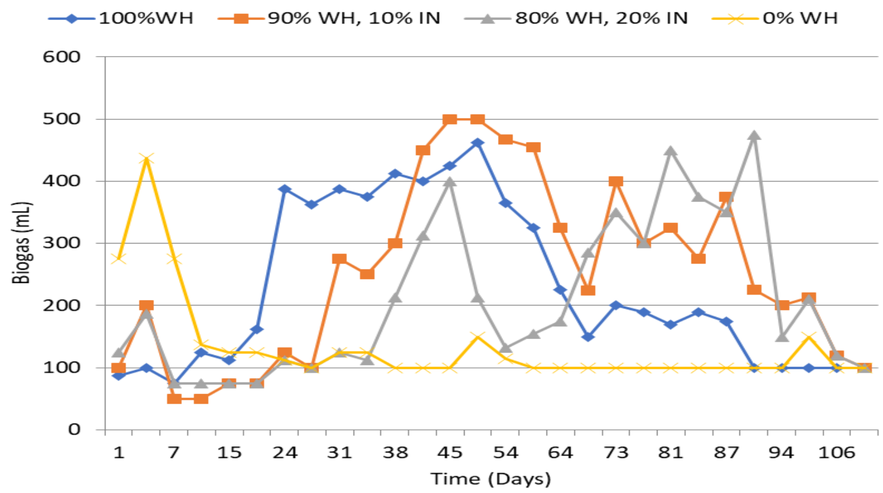

Fig. 2. *Trend in biogas production from water hyacinth with added inoculum (WH: water hyacinth, IN: inoculum)*

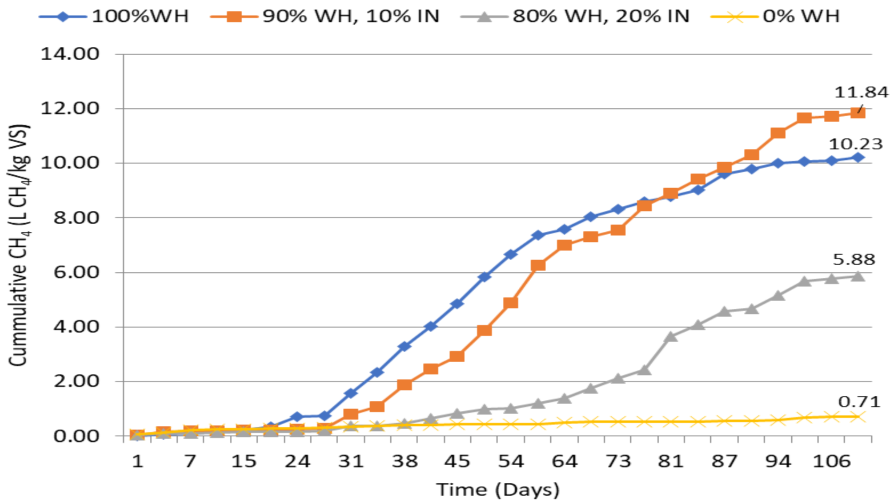

Fig. 3. *Cumulative methane production from water hyacinth with added inoculum (WH: water hyacinth; IN: inoculum)*

deed, the substrate 90% water hyacinth reached a peak value of 11.84 LCH_4/kgVS followed by 100% water hyacinth with 10.23 LCH_4/kgVS and by 80 % water hyacinth which was 5.88 LCH_4/kgVS. As such, water hyacinth can potentially be used for biomethane production. In addition, the proportion of inoculum for optimal methane production from water hyacinth needs to be assessed. These results showed the effectiveness of water hyacinth from River Wouri in producing biogas as a substitute fuel, which follows a similar pattern with other studies using food wastes as co-substrate for the same species of water hyacinth.

Conclusion

Biogas can be produced from water hyacinth harvested from River Wouri, Cameroon, with added poultry inoculum containing indigenous methanogenic bacteria to reduce the lag phase and boost productivity. The optimal level of added poultry inoculum was 10% and water hyacinth 90%. The rate of volatile solid destruction after incubation increased with the increasing quantity of added inoculum. The present study also showed that water hyacinth has the potential to be used for biomethane production. It serves as the baseline of anaerobic digestion experimental data in the context of water hyacinth from River Wouri in Cameroon since the focus on locally available and problematic biomass has been underexplored. The present approach reflected a sustainable solution for waste management and energy production. Although the current study identifies the optimal ratio of water hyacinth and optimal poultry inoculum for biogas production, it may also be beneficial to examine the possibilities of the kinds or concentration levels of inoculum for biomethane production.

ACKNOWLEDGEMENTS

The authors express gratitude to the Pan African University, Life and Earth Sciences Institute (including Health and Agriculture), Ibadan, Oyo State, Nigeria, for funding the research. We also thank the University of

Buea, Cameroon, for providing an environment enabling us to carry out incubation experiments in the Waste to Energy/ Resource Laboratory, Environmental Science Department

Conflict of interest

The authors declare that they have no conflicts of interest.

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