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Physicochemical Characterization of Water Hyacinth (*Eichhornia crassipes*) as a Sustainable Feedstock for Biofuel Production

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KeyWords

Anaerobic digestion; Carbon–nitrogen ratio; Elemental composition; Moisture content; Renewable energy. Physicochemical properties; Sustainable biofuel feedstock; Volatile solids; Water hyacinth.

ABSTRACT

This study presents the physicochemical characterization of *Eichhornia crassipes* (water hyacinth) as a potential renewable feedstock for biofuel generation. The biomass was harvested from freshwater sources, followed by thorough cleansing to remove dirt, sediment, and attached debris. The cleaned material was chopped and ground to enhance uniformity and increase surface area, ensuring accurate and representative physicochemical analysis. Comprehensive proximate and ultimate analyses were conducted to evaluate its suitability for anaerobic digestion and biodiesel production via transesterification processes. The proximate analysis revealed a moisture content of 43.08%, ash content of 8.00%, volatile solids of 75.50%, and lipid content of 6.24%, indicating high organic matter availability and favorable biodegradability. The pH of the biomass was measured using a calibrated pH meter in a homogenized aqueous slurry, providing insight into its chemical environment and suitability for microbial activity. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values further confirmed the high degradable organic fraction of the biomass. The ultimate analysis showed a carbon-to-nitrogen (C/N) ratio of 25.57, which falls within the optimum range for stable anaerobic digestion. The moderate nitrogen content and significant volatile solids suggest balanced nutrients capable of supporting efficient microbial activity, while the relatively low ash content indicates minimal inorganic interference during thermal and biological conversion. Overall, the physicochemical results, combined with detailed preparation and measurement protocols, demonstrate that *Eichhornia crassipes* possesses favorable chemical, elemental, and processing characteristics suitable for efficient biogas and biodiesel production, validating its potential as a sustainable lignocellulosic resource for integrated bioenergy systems.

1. Introduction

Water hyacinth (*Eichhornia crassipes*) is a free-floating perennial aquatic macrophyte that has become one of the most problematic invasive species across tropical and subtropical regions. Originating from the Amazon River Basin, it has proliferated extensively in Africa and Asia, including Nigeria, due to its rapid vegetative propagation and high adaptability to nutrient-rich waters. Its uncontrolled growth has resulted in severe ecological, economic, and environmental challenges, such as obstruction of waterways, interference with hydropower generation and irrigation systems, and degradation of aquatic biodiversity. The dense mats formed by the plant restrict sunlight penetration, lower dissolved oxygen levels, and alter the physicochemical properties of water bodies, leading to habitat loss and disruption of aquatic ecosystems Ekon et al, 2023.

Despite these challenges, water hyacinth presents a promising renewable biomass resource due to its high growth rate, nutrient composition, and significant annual yield potential. In Nigeria's Niger Delta region alone, the estimated biomass of water hyacinth exceeds 3.2 million tons per year (Elenwo & Akankali, 2023). This enormous biomass availability highlights its potential as an abundant, low-cost, and sustainable feedstock for biofuel production if properly harnessed. The plant's morphology characterized by broad leaves, spongy petioles, and fibrous roots supports rapid nutrient uptake, enabling it to thrive in polluted waters and convert nutrients into biomass efficiently (Kunatsa, et al 2020).

Water hyacinth's biochemical composition, consisting of cellulose, hemicellulose, lignin, proteins, and extractives, makes it suitable for multiple bioenergy conversion processes. Its relatively high volatile solids and organic matter contents, coupled with a moderate carbon-to-nitrogen (C/N) ratio, provide favorable conditions for microbial degradation during anaerobic digestion ((Flores et al 2024). The presence of lipids and fatty acids also enhances its potential as a feedstock for biodiesel production through transesterification. Thus, water hyacinth can serve as a dual-purpose substrate for biogas and biodiesel production, offering an environmentally friendly approach to waste-to-energy conversion. (Abebe et al 2021)

In addition to its biochemical richness, the physicochemical characteristics of water hyacinth such as moisture content, ash content, volatile solids, and elemental composition are crucial parameters that determine its suitability for biofuel applications. High volatile solids and organic carbon fractions enhance biogas yield, while moderate ash content minimizes inorganic interference during digestion and combustion processes. Understanding these parameters through proximate and ultimate analyses provides essential baseline data for optimizing conversion efficiency and reactor performance in both anaerobic and thermochemical processes. (Rahman et 2010).

Globally, several studies have reported the use of water hyacinth as a bioenergy substrate. For instance, Rahman et al. (2010) demonstrated that the plant could yield up to 4,000 L of biogas per ton of dry matter, with methane concentrations averaging 60%. Similarly, its lipid fraction has been identified as a viable raw material for biodiesel production meeting ASTM fuel standards. However, despite this growing body of research, localized studies that characterize water hyacinth from Nigerian aquatic

environments are limited. Variations in nutrient availability, water quality, and climatic factors influence the plant's physicochemical properties, making regional characterization essential for accurate process design and yield prediction.

Therefore, this study aims to conduct a comprehensive **physicochemical characterization of water hyacinth** to evaluate its potential as a sustainable feedstock for biofuel production. Proximate parameters such as moisture, ash, volatile solids, and lipid content, alongside ultimate (elemental) composition, were analyzed to establish its suitability for anaerobic digestion and transesterification processes. The results provide critical insights into the energy potential, degradability, and conversion efficiency of *Eichhornia crassipes*, offering a scientific basis for its valorization into renewable energy resources and contributing to sustainable environmental management in Nigeria and beyond.

2.0 Materials and Methods

2.1 Feedstock Preparation

Fresh water hyacinth (*Eichhornia crassipes*) was harvested from Oxbow Lake, Yenagoa, Bayelsa State, Nigeria (latitude 4°55'N, longitude 6°16'E). The harvested biomass was manually cleaned to remove debris, roots, and associated impurities, ensuring that only uncontaminated shoot and leaf portions were retained for analysis. The cleaned biomass was chopped into small segments of approximately 2–3 cm in length to enhance handling and facilitate uniform particle size reduction.

To improve the surface area available for microbial and enzymatic activity, the chopped biomass was pulverized using a high-speed rotary grinding machine operating at approximately 1500 revolutions per minute (rpm). The pulverized sample was then air-dried to a constant weight to reduce moisture content and improve storage stability. The resulting fine powder was stored in airtight containers at room temperature until required for proximate and ultimate analyses.

2.2 Analysis of Biomass

The physicochemical characteristics of water hyacinth were determined through **proximate, ultimate, and biochemical analyses** to evaluate its potential as a biofuel feedstock. These analyses provided information on its organic content, energy potential, and elemental composition, essential for determining its suitability for biogas and biodiesel production.

2.3 Proximate Analysis

Proximate analysis determines the fundamental composition of biomass, including moisture, volatile matter, ash, and fixed carbon. All determinations were conducted according to **ASTM (American Society for Testing and Materials) standard procedures** as outlined by Marquez-Montesino et al. (2015). The analysis provides insights into the thermal behavior and energy yield potential of the biomass.

2.4 Determination of Moisture Content

A clean, dry petri dish was preheated in an oven and allowed to cool in a desiccator. Approximately 2 g of the water hyacinth sample was weighed into the petri dish, and the combined weight was recorded. The sample was dried in an oven at **105°C for 2 hours**, followed by intermittent heating until a constant weight was

achieved. (Márquez-Montesino, 2015)

The percentage of moisture was calculated using Equation (1)

$$\% \text{Moisture} = \text{Loss due to removal of volatile matter} \frac{\text{Initial weight} - \text{Dry weight}}{\text{Initial weight}} \times 100 \quad 1$$

2.5 Determination of Ash Content

Ash content represents the inorganic residue remaining after complete combustion of organic matter. A 2 g portion of the dried sample was placed in a pre-weighed porcelain crucible (W_1) and incinerated in a **muffle furnace at 800°C for 1 hour**. The crucible was cooled in a desiccator and reweighed (W_2).

The ash content was determined using Equation (3.26)

$$\% \text{ of Ash} = \text{Weight of ash left} \times \frac{100}{\text{Wt of sample taken}} \quad 2$$

All measurements were carried out in triplicate, and average values were recorded.

2.6 Determination of Volatile Matter

Volatile matter was determined by heating 2 g of the dried sample in a silica crucible covered with a vented lid to avoid oxidation. The sample was heated in a **muffle furnace at 825°C for 7 minutes**. After cooling in a desiccator, the weight loss was recorded.

The apparent volatile matter was calculated as:

$$\text{Apparent volatile matter} = \frac{\text{Initial weight} - \text{Dry weight}}{\text{Initial weight}} \times 100 \quad 3$$

The actual volatile matter was obtained by subtracting the moisture content from the apparent value.

2.7 Fixed Carbon Determination

Fixed carbon was calculated by difference, representing the fraction of carbon remaining after moisture, ash, and volatile components were deducted, as shown in Equation (3.28):

$$\text{Fixed carbon}\% = 100 - (\text{moisture}\% + \text{ash}\% + \text{volatile matter}\%) \quad 4$$

Fixed carbon gives insight into the char-forming potential of the biomass during thermal conversion.

2.8 Determination of pH

To assess acidity or alkalinity, 10 g of ground water hyacinth was added to 100 mL of distilled water, stirred thoroughly, and allowed to stand for 1 hour. The mixture was decanted, and pH was measured using a calibrated **digital pH meter (Model: Hanna HI 2211)** at room temperature. The pH value provides an indication of the potential microbial suitability for anaerobic digestion.

2.9 Elemental Composition (Gas Chromatography Analysis)

Elemental composition was analyzed using **Gas Chromatography–Flame Ionization Detection (GC–FID)**.

Two grams of the pulverized sample was mixed with 6 g of sodium sulfate and extracted using 300 mL of *n*-hexane. The filtrate was concentrated and purified using **silica solid-phase extraction (SPE)**.

The purified extract was analyzed on a **Buck M910 GC system** equipped with a VF-5 capillary column (30 m × 0.25 mm, 0.25 μm film). The injector and detector temperatures were 250°C and 280°C, respectively. The oven temperature was programmed from 120°C (4 min hold), ramped at 10°C/min to 180°C (2 min hold), and then 5°C/min to 300°C. **Helium** served as the carrier gas at a flow rate of 1.0 mL/min.

Calibration was done using analytical standards, and the elemental carbon, hydrogen, nitrogen, sulfur, and oxygen contents were computed on a dry weight basis to establish the **C/N ratio**, an indicator of biomass stability and biodegradability. (Adebayo et al 2012).

2.10 Crude Fibre Analysis (AOAC, 1990)

Crude fiber was determined according to **AOAC (1990)** procedures. Approximately 2 g of defatted sample was sequentially digested in **1.25% H₂SO₄** and **1.25% NaOH** under reflux for 30 minutes each, filtered, washed, dried, and incinerated.

The crude fiber percentage was calculated using Equation (3.29)

$$\% \text{ crude fibre} = \frac{\text{weight of fibre}}{\text{Weight of sample}} \times 100 \quad 5$$

2.11 Crude Fat Determination (Soxhlet Extraction Method)

The lipid content was determined using the **Soxhlet extraction technique** with petroleum ether (boiling point 40–60°C) as solvent. About 2 g of dried sample was extracted for **6 hours under reflux**. The solvent was recovered, and the flask was dried at 105°C for 1 hour, cooled, and weighed.

The percentage of crude fat was determined using Equation (3.30):

$$\% \text{ fat} = \frac{\text{wt of flask + oil} - \text{wt of flask}}{\text{Weight of sample}} \times 100 \quad 6$$

2.12 Chemical Oxygen Demand (COD) Determination

COD was measured using the **APHA (1998)** dichromate reflux method to estimate the oxidizable organic content. A 10 mL sample aliquot was treated with **0.1 M K₂Cr₂O₇**, **0.01 M HgSO₄**, and **H₂SO₄ containing Ag₂SO₄** and refluxed for 45 minutes. After cooling, ferroin indicator was added, and titration was performed with **ammonium iron(II) sulfate** until a distinct reddish-brown endpoint was observed. A blank sample was also analyzed for correction. (Kunatsa et 2020)

2.13 Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) Determination

The **Winkler titration method** was employed for DO analysis. Manganous sulfate and alkaline-iodide-azide reagents were added to the sample, forming a precipitate that was later dissolved with concentrated sulfuric acid. The released iodine was titrated with **0.0125 M sodium thiosulfate** using starch indicator.

For **BOD determination**, the initial DO (D₁) was recorded immediately after collection, and the sample was incubated in the dark at 20°C for five days. The final DO (D₅) was then measured. The BOD was calculated using Equation (3.31):

$$\text{BOD(mg/L)} = D_1 - D_5$$

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these parameters helped to quantify the biodegradable organic matter, reflecting the feedstock's potential for microbial decomposition during biogas production

3.0. Results and Discussion

3.1 Physicochemical Characterization of Water Hyacinth (*Eichhornia crassipes*)

The physicochemical properties of *Eichhornia crassipes* were analyzed to determine its suitability as a sustainable feedstock for biofuel production. The results of the proximate and ultimate analyses are presented in Tables 4.1 and 4.2. These parameters are essential for evaluating the biochemical and energy potential of the biomass, particularly for processes such as anaerobic digestion and transesterification.

Table 1: Proximate Analysis of Water Hyacinth

Parameter	Weight of Sample (g)	Weight of Crucible (g)	Weight of Crucible + Residue (g)	% Content
Moisture	2.031	17.018	19.049	43.08
Ash	2.059	30.709	30.874	8.00
Fat	2.067	28.768	28.897	6.24
Fiber	2.158	30.593	30.706	5.22
Volatile Solids	2.045	30.785	31.286	75.52

Parameter	pH	Adjusted pH	Calcium (ppm)	Potassium (ppm)	Phosphorus (ppm)
Water Hyacinth	6.2	6.8	13.787	19.289	12.787

Parameter	DO (mg/L)	BOD (mg/L)	COD (mg/L)
Water Hyacinth	1.20	610.00	871.00

Table 2: Ultimate Analysis of Water Hyacinth

Element	Concentration (%)
Carbon	41.2145
Nitrogen	1.6118
Oxygen	5.0570
Bromine	0.9955
Hydrogen	19.6156
Sulphur	0.1017
C/N Ratio	25.5698

The figure presents the elemental composition of water hyacinth, showing the relative proportions of carbon, hydrogen, nitrogen, oxygen, sulfur, and other trace elements. The dominance of carbon (41.21%) and hydrogen (19.62%) indicates a strong potential for bioenergy conversion, while the low sulfur content (0.10%) minimizes the risk of harmful gas emissions during anaerobic digestion.

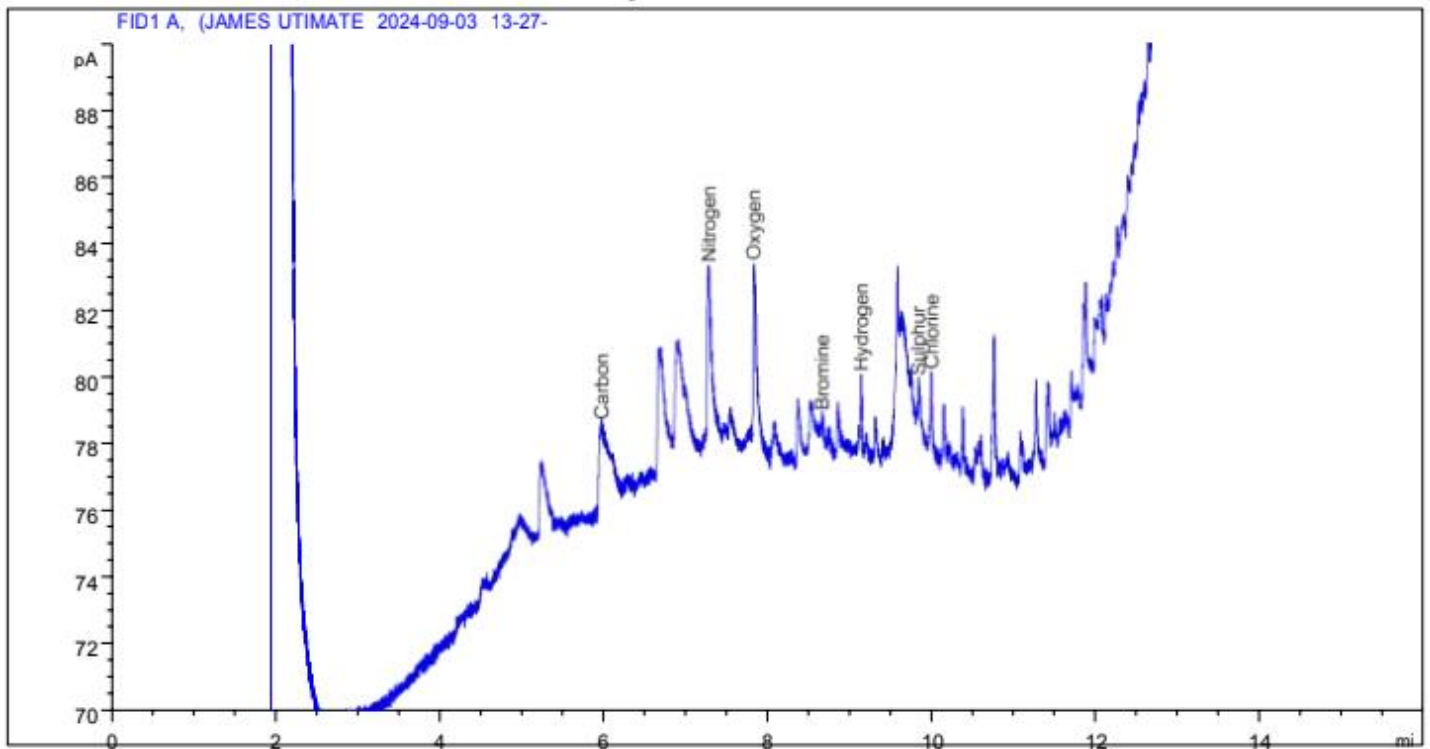


Figure 1: Ultimate Analysis of Water Hyacinth (*Eichhornia crassipes*)

Interpretation of Physicochemical Properties

3.2 Moisture and Volatile Solids

The moisture content of water hyacinth was 43.08%, which is within the typical range for aquatic macrophytes. This moderate moisture level indicates that the biomass is suitable for direct anaerobic digestion without extensive drying. The volatile solids (75.52%) represent the biodegradable organic fraction, confirming the substrate's high potential for biogas production.

3.3 Ash and Mineral Composition

The ash content (8.00%) reflects the mineral residue remaining after combustion. A lower ash value indicates higher organic matter availability, favoring microbial degradation. The mineral analysis revealed the presence of essential macronutrients such as calcium (13.79 ppm), potassium (19.29 ppm), and phosphorus (12.79 ppm), which contribute to microbial activity and enhance digestion stability during biofuel conversion processes.

3.4 Fat and Fiber Content

The fat content (6.24%) suggests the presence of lipids that may contribute to both biogas and bio-diesel production, as lipids provide higher calorific value. The fiber content (5.22%) represents the lignocellulosic fraction, which is relatively low compared to terrestrial biomass, thus making the material more biodegradable under anaerobic conditions.

3.4 pH and Chemical Oxygen Demand

The natural pH of water hyacinth (6.2) was slightly acidic but was adjusted to 6.8 using wood ash to maintain a neutral environment suitable for anaerobic microorganisms. The high Biological Oxygen Demand (BOD = 610 mg/L) and Chemical Oxygen Demand (COD = 871 mg/L) values indicate a substantial amount of biodegradable organic matter, further validating the feedstock's potential for biofuel generation.

3.6 Elemental Composition (Ultimate Analysis)

The elemental composition of water hyacinth showed a high carbon content (41.21%) and moderate hydrogen (19.62%), both of which contribute to the substrate's energy potential. The nitrogen content (1.61%) yielded a C/N ratio of 25.57, which falls within the optimal range (20–30) for anaerobic digestion. This balance ensures efficient microbial metabolism and minimizes the risk of ammonia inhibition.

3.7 Sulphur and Bromine

The sulphur (0.10%) and bromine (0.99%) contents were low, reducing the likelihood of hydrogen sulfide (H₂S) generation during digestion, which can cause corrosion and reduce biogas quality. Low sulphur levels thus make water hyacinth a cleaner and safer biofuel substrate.

3.8 Overall Assessment

The combination of high volatile solids, favorable C/N ratio, moderate moisture content, and low ash and sulphur levels makes *Eichhornia crassipes* a promising renewable feedstock for sustainable biofuel production. Its nutrient-rich composition supports microbial growth and enhances biodegradability, confirming its suitability for biogas and biodiesel conversion processes.

4.0 Conclusion

4.1 Proximate and Ultimate Analyses

The physicochemical evaluation of *Eichhornia crassipes* demonstrates that this aquatic macrophyte possesses a favorable composition for renewable energy conversion. The proximate analysis indicated a moisture content of 43.08%, ash content of 8.00%, fat content of 6.24%, fiber content of 5.22%, and volatile solids content of 75.52%. These findings confirm that water hyacinth contains a high proportion of biodegradable organic matter, which serves as a vital substrate for microbial metabolism during anaerobic digestion. The relatively low ash value further implies limited inorganic residue, enhancing its efficiency as a biofuel feedstock.

The ultimate analysis revealed that water hyacinth is rich in carbon (41.21%) and hydrogen (19.62%), with moderate amounts of nitrogen (1.61%), oxygen (5.06%), and minimal sulfur (0.10%). The derived C/N ratio of 25.57 falls within the ideal range of 20–30, which is widely recognized as suitable for stable anaerobic digestion and efficient methane generation. This balanced nutrient profile promotes microbial activity while minimizing ammonia inhibition, ensuring optimal gas production. The results are consistent with research by; Ezekoye *et al*, 2021, Ekong *et al*, 2023, Weiland, 2010, Zhang *et al*, 2022).

Overall, the results affirm that *Eichhornia crassipes* has a biochemical composition that supports its conversion into renewable bioenergy carriers such as biogas and biodiesel. Its high volatile solids

content, favorable C/N ratio, and low sulfur level make it a clean and sustainable feedstock with minimal environmental drawbacks. Harnessing this invasive species for biofuel production not only mitigates its ecological impact on aquatic ecosystems but also contributes to the diversification of renewable energy resources, especially in tropical regions where its proliferation is widespread.

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