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Compositional Assessment of Selected Plant-based Substrates for Biogas Production

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Authors' contributions

This work was carried out in collaboration between all authors. Author OTE design the study, wrote the first draft of the manuscript. Authors NAA and OTN performed the statistical analysis, managed the analyses of the study. Author AEA managed the literature searches, wrote the protocol. All authors read and approved the final manuscript.

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ABSTRACT

Enormous quantities of plant biomass are generated annually, as agricultural wastes. Lignocellulose is the main structural constituent of plants and represents the primary source of renewable organic matter on earth. This study was carried out to evaluate the lignocellulose composition, proximate and selected physicochemical characteristics of some selected plant-based substrates for biogas production. The substrates were: Corn cobs, Rice straw and Water hyacinth (*Eichhorniacrassipes*). They were collected, cut, dried for 72 hours at 32^0C, milled and subjected to hemicellulose, lignin and cellulose compositional analyses, using the standard Sox let extraction method. Standard methods were employed for proximate and physicochemical analyses. Results of the compositional evaluation showed that corn cob has the highest percentages of cellulose (42.0%), while extractives content was least (2.18%) in Rice straw. For the proximate analysis, the percentage carbohydrates (24.22) and ash (24.40) were highest in rice straw, while fat content had the least values of 0.65% recorded in corn cobs. The results of the physicochemical analysis showed that Rice straw had the highest values of TS (94.55%) and phosphorus (928.57mg/kg), Corn cob had the highest TVS

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(85.53%) and organic carbon (50.46%) while Water hyacinth recorded the highest Nitrogen content (2.33%). They are good substrates for energy generation, and lignocellulosic biomass holds a huge potential to meet the current energy demand of the modern world. The knowledge of the lignocellulosic composition of the biomass would help in choosing appropriate pretreatment measures to achieve better hydrolysis which would translate to higher biogas yield.

Keywords: Lignocellulose; physicochemical; proximate; corn cobs; rice straw; water hyacinth; biogas.

1. INTRODUCTION

Biomass is complex organic substance stored as biological energy, primarily through photosynthesis such as wood, aquatic weed, animal excreta, shrubs and wastes obtained as a result of agricultural activities [1]. Biomass rich in lignocellulose is a substrate with high energy yield, when used for biogas production. Lignocellulose is the primary component of plants, and is principally composed of cellulose, hemicellulose and lignin. Biogas production is a process which involves the degradation of organic material/biomass in an anaerobic environment. This process engages different microorganisms performing degradation in four basic steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis [2]. The use of lignocellulose biomass in the production of biogas is encouraged because of its advantage in waste treatment which helps to keep our environment clean and also provide alternativesourceenergy.

Maize cob and rice straw are agrowastes that persist in the environment, after harvest. Water hyacinth (*Eichhorniacrassipes*) is an invasive aquatic plant that grows rapidly and causes obstructions in water bodies, due their ability to form mats [3].

Considering their menace in both land and aquatic environments, including the fact that their use is sustainable, as they do not compete with food supply, it is imperative to devise a means of channeling these wastes to a more beneficial path in our society. Therefore, it is necessary to assess the lignocellulose, proximate and physicochemical characteristics of these plant substrates, for biogas production.

2. MATERIALS AND METHODS

2.1 Sample Collection

Maize cob was obtained from within Owerri metropolis, rice straw from Ihite-Uboma, in Imo state, while water hyacinth was collected from river Nun Amassoma, Bayelsa state. All plant substrates were collected using surface-sterilized polyethene bags.

2.2 Sample Preparation

The substrates were cut, dried for 72 hours at 32°C, aseptically milled and sent to the Lab for analyses.

2.2.1 Plant substrates lignocellulose determination

The extraction of Extractives, hemicellulose, lignin and cellulose components was done using the Volatilization gravimetric method as described by Adila et al. [4]. The percentage Extractives was determined using Soxhlet extractor, by adding 150ml of acetone to 2g of the substrates and heating to 70°C for 4hrs.Constant weight of the substrate was obtained at 105°C and the extractives calculated using the following equation:

$$A – B= E\ (g)$$

A= Mass of substrate
B=Mass of substrate residue after drying
E= Amount of extractive (g)

Hemicellulose was obtained by adding 500mol/m^3 of NaOHinto 150ml of water containing 2g of the substrate and heating for 3hrs, filtered and washed to neutrality. Constant weight was achieved at 105°C and the equation below was used to determine the hemicelluloses content.

$$B – C = H\ (g).$$

Where:

B=Mass of free-extractive
C= Mass of residue after dying
H=Amount of hemicellulose

Lignin content was achieved by adding 72% H_2SO_4 to 2g of the substrate and shaken intermittently for 2hrs at room temperature, then heating for 1hr at 121^{0}C. It was allowed to cool and then filtered. The acid insoluble lignin was determined by drying at 105°C and incinerating at 575°C in a muffle furnace, while the acid soluble lignin was obtained by measuring the absorbance of the acid hydrolyzed samples at 320nm. The lignin content was calculated by summation of insoluble and soluble lignin content.

The cellulose content was obtained by the equation below:

$$(A - B) + (B - C) + D + E + 2g$$

Where:

(A-B) = amount of extractive
(B-C) = amount of hemicellulose
D = amount of lignin
E = amount of cellulose
2g = mass of substrate used

2.2.2 Determination of proximate composition

The moisture, crude protein, ash, fat, crude fiber and carbohydrate contents were analyzed using the standard official methods of Association of Analytical Chemists [5].

2.2.3 Determination of the physicochemical characteristics

The physicochemical characteristics of the total solids(TS) and total volatile solids (TVS)were determined using the standard method of APHA [6], whileorganic carbon(OC) was determined using Walkey-Black Chromic Wet Oxidation method as described by Tambuwal & Ogbiko(2018).Total Nitrogen (TN),Total Phosphorous (TP),iron (Fe), nickel (Ni), cobalt (Co), molybdenum (Mo), potassium (P) and arsenic (As) were analyzed using Atomic Absorption Spectroscopy (AAS, model-ICP-MS, Thermo Scientific iCAP Q).

3. RESULTS AND DISCUSSIONS

3.1 Lignocellulose Composition of Plant Substrates

The lignin content of rice straw was the highest (14.8%) while that of maize cob was the least (2.73%) (Fig. 1). Thevalues of hemicellulose, cellulose and extractives of the plant biomass obtained showed thathemicellulose, cellulose and extractive recorded the highest values in maize cobwhile water hyacinth had the least values of hemicellulose and cellulose. The ash content of water hyacinth (*Eichhorniacrassipes*) was the highest while corn cob has the least value.Fale do conteúdo de Ash do water hyacinth que foi muito elevado quando comparado aos demais.

Hemicellulose, lignin, and celluloseare the major components of plant biomass, and also provide the main carbon source for the anaerobic microorganisms [7].Biogas production is greatly affected by the availability and digestibility of cellulose and hemicellulose as well as the association of lignin with the carbohydrates [8].

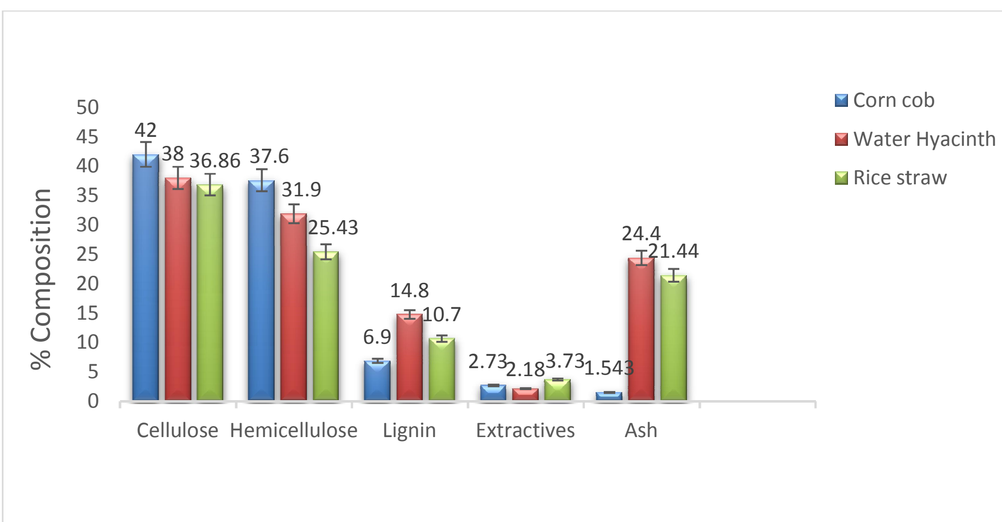

Fig. 1. Lignocellulose contents of plant substrates

The lignin content of the test plant substrates in this studyindicates they are not outrageous, hence, after pretreatment, should favour biogas production, considering its toxicity to methanogens.Moreover, less lignin content attributes to easy degradability by microorganisms for increased biogas yield as lignin confers resistance to the plant substrates.

The highcellulose content of the plant substrates suggests that they are good substrates for biogas production. Shiratori et al. [9] observed that the fermentation products from cellulose include carbon dioxide, hydrogen, acetate, lactate, ethanol and a small amount of formate. The acetate is utilized by microorganism to produce methane. However, cellulose resistance to digestion because of hydrogen bond should be handled with pretreatment, hence allowing enzymes' easy access and digestion.

The hemicellulose content of thetestplant substrates from this study were above average which contributes to methane yield in biogas production when degraded by microorganisms.

3.2 Proximate Composition of Substrates

The percentage carbohydrates (24.22) and ash (24.40) were highest in rice straw, while the least values of 9.21% and 1.54% respectively, were recorded in corncobs. Water hyacinth recorded the highest fat (6.83%) and crude protein (14.58%) contents, with the least values of 0.65% and 5.67% respectively, recorded in corn cobs. However, corn cobs recorded the highest values of moisture (12.93%) and crude fiber (70.00%) as shown in Fig. 2.

These results show that all the energy-yielding macronutrients are present in these substrates, with crude fiber and carbohydrate being the most abundant.The test plant substrates were low in fat content which make them good substrates for biogas production. Kim & Kim [10] aforementioned that materials with high fat content can be difficult to degrade properly and prevent biogas production. However, the carbohydrate content of the substrates showed they are effective biogas production material. This supports Osiboteet al. [11] who reported that substrate rich in carbohydrate content produce more of propionate which removes hydrogen for methane production during degradation for improved biogas production.

3.3 Physicochemical Characteristics of the Substrates

The percentage Total solids (TS), Total volatile solids (TVS), Total Nitrogen (TN), and Organic Carbon (OC) contents were within the range of 94.55-87.07%, 85.53-70.82%, 2.33-0.91%, and 50.46-41.90% respectively. For the elemental analysis, Total Phosphorus(TP), Iron(Fe), Nickel(Ni), Molybdenum(Mo), Arsenic(As), Cadmium(Cd) and Lead(Pb) were within the range of 928.6-457.0mg/kg, 538.0-298.0mg/kg, 0.977-0.143mg/kg, 0.98-0.60mg/kg, 1.84-0.06mg/kg, 1.341- 0.027mg/kg, 8.29-0.44mg/kg.

Water hyacinth had the highest values of Cd, Pb, Ni, Mo and As, while rice straw and maize cob recorded the highest value for TP. However, values obtained from maize cob were the lowest of all the elemental analysis, except for Fe.

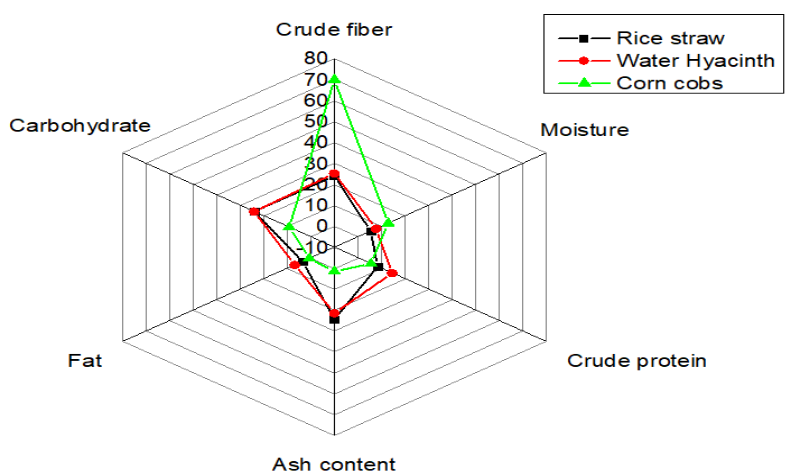

Fig. 2. Radar plot showing percentage proximate composition of the selected substrates

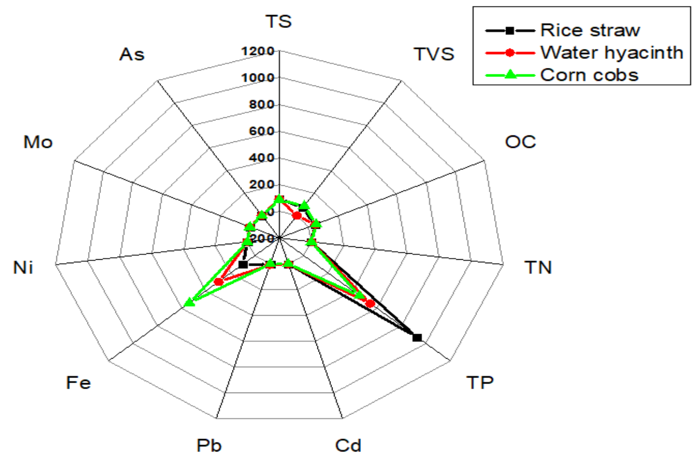

Fig. 3. Radar plot showing the physicochemical parameters of plant substrates

Thevalues obtained from water hyacinth (*Eichhorniacrassipes*), corn cob and rice straw indicate that they are good substrates for biogas production. Igoni et al. [12] reported that abundanttotal solid of municipal solid wastes in an anaerobic digestion process, correspond to high yield in biogas production. Ofoefule & Uzodinma [13] reported that in an anaerobic environment, the degradation of total solids and volatile solids by microorganisms translates to increase in biogas production. During anaerobic digestion the presence of elements such as Carbon, Nitrogen, Phosphorus, Cadmium, Nickel, Molybdenum, and Arsenic, are essential, as they enhance the fermentation process. According to Irvan [14], the presence of elements in an anaerobic process can enhance methanogens up to 42% and also increase degradation rate of volatile solids and volatile fatty acids. Nitrogen and phosphorus are the most common elements that an anaerobic digestion system needs, while trace elements were often reported to have stimulatory effect [15]. Therefore, plant substrates used in this research contained elements like iron, molybdenum, nickel, cadmium, arsenic, lead, phosphorus, nitrogen and carbon in their different values are of importance in biogas production. Nevertheless, these elements can also be toxic to the system and inhibit the process, when they surpass their threshold [16]. According to Chen et al.[17] low level of Nain anaerobic system helps in ATP formation and NADH oxidation but at high concentration, it interferes with the bacteria metabolism. However, the toxicity caused by elements is attributed toenzymatic function and structure disruption by binding with thiol and other groups in proteinmolecules or by displacing the naturallyoccurringmetal in the enzyme prosthetics.

4. CONCLUSION

The lignocellulose, proximate and physicochemical characteristics of biomass, gives an insight on the quality of the substrates,to be used for biogas production. An idea of the lignocellulosic content of the substrates would help in choosing the proper pretreatment method to be adopted, to achieve better degradation and hence improved product yield.

The proximate and physicochemical parameters determine the feed content and stimulants, upon which the biodegrading microorganisms will depend on, to yield the desired results.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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