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**COMPREHENSIVE CHARACTERIZATION OF SOME SELECTED BIOMASS FOR BIO-OIL PRODUCTION**

BY

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**ABSTRACT**

This study presents a comprehensive characterization of four biomass, corn stover, iroko sawdust, elephant grass, mahogany bark, to aid appropriate selection for bio-oil production. The proximate, ultimate, and compositional analyses were carried out following the American Standard for Testing and Materials (ASTM) standards. The results of moisture content of the various biomass range of 0.40 – 1.30% with corn Stover, iroko sawdust, elephant grass and mahogany bark recording 0.40, 0.42, 0.86 and 1.30% respectively. Amongst the biomass, mahogany bark recorded the highest value of 1.30% while corn stover was the lowest.

mahogany bark exhibited favorable characteristics for bio-oil production as indicated by its higher volatile matter (79.96%), low ash content (3.39%), moisture content (1.30%), and high fixed carbon content (15.35 %). Also, all samples showed favorable ignition and flammability properties. The low nitrogen (<0.13%) and sulfur (<0.05%) contents in the samples make them environmentally benign fuels as a lower percentage of NOx and SOx will be released during the production of the bio-oil. These results are contributions to the advancement of a sustainable

and efficient carbon-neutral energy mix, promoting biomass resource utilization for the generation of energy. . The cellulose content ranged from 40.12-42.16.56% with corn stover having the highest value (42.16%). The quantities of cellulose and hemicellulose obtained here is in consonance with the values of cellulose (48%) and hemicellulose (29%) reported by Mullen *et al.*, 2010. This is an indication that corn stover will be most suitable for biomass pyrolysis because a relatively higher bio-oil yield can be expected as cellulose and hemicellulose contents are the two main biomass components that favours high yield of bio-oil. The HHV value ranged from 19.80-22.80 MJ/kg in the biomass samples studied. Corn stover has the highest value (22.80MJ/kg) whereas the elephant grass had the least value HHV (19.70MJ/kg).

Keywords: Biomass, Hemicellulose ; Cellulose ; Lignin ; Bio-oil.

**INTRODUCTION**

Biomass recognized as a global renewable energy source has been identified to supplement declining conventional bio-oil resources. Therefore, other forms of energy such as biomass have significant potential to offset traditional energy sources (Srivastava 2021). In 2016, renewable energy accounted for 18.2% of the 576 exajoules (EJ) of total primary energy supply (TPES), of which 13% came from biomass (IEA 2017, REN21 2018). Advances in the Structural Composition of Biomass (Srivastava 2021). It is composed primarily of cellulose, hemicellulose, lignin and smaller amounts of elements of oxygen, hydrogen and carbon with high-energy content ( Isahak et al., 2012). Biomass (plant materials) is a promising eco-friendly alternative considered to play a significant part in the future energy systems globally. Renewable energy such as biomass is huge and limitless

The conversion of biomass to bio-oill can be achieved broadly through various means, physical, biological, biochemical and thermochemical means. Researchers like (Okonkwo et al., 2018); (Achebe et al., 2018), used the biological process for the production of methane, which is a major constituent of biogas. However, pyrolysis among the thermochemical process for converting biomass to energy has attracted more interest in the production of liquid fuel due to its advantages in versatility in application like turbines, boilers, combustion engines, etc., transportation, and storage (Jahirul et al., 2012). The production of liquid fuel (bio-oil), biochar and non-condensable gases

**Characterization of the Biomass**

After pretreatment of the sample at the Department of Science Laboratory Technology, Delta State Polytechnic, Otefe, Oghara, the sample was transported to Lighthouse Petroleum Engineering Company Laboratory for characterization. Characterization was done before experimentation to determine the physicochemical (proximate and ultimate) properties, structural compositions (cellulose, hemicellulose and lignin) and other properties of the biomass feedstock. The proximate and physical analysis was to evaluate the percentages of the fixed carbon, moisture content, ash, volatile matter (VM) and pH of the feedstock using the American Standard for Testing and Material (ASTM) standard as described by Ibikunle *et al.*, 2019 and Kumar *et al*. 2020. The chemical and ultimate analysis was carried out to determine the carbon, hydrogen, oxygen, nitrogen, sulphur and heating values using the American Standard for Testing and Material (ASTM) standard as described by Kristin *et al.*, 2020. Furthermore, components analysis was carried out to estimate the amount of cellulose, hemicellulose and lignin in the substrates using also the ASTM standard as described by Kristin *et. al.*, 2020.

**Determination of Proximate Analysis**

Moisture content

The moisture content is an important property that affects the burning characteristics of biomass material. It has influence on the energy value of the fuel. The ASTM standard used to analyze the moisture content is ASTM E871-80. The moisture content of the samples was determined by drying at a temperature of 105°C in an oven and expressed in percentage of oven dry mass.

Procedure

An empty moisture dish was correctly weighed and recorded.

10g of the specimen was placed inside the dish and reweighed.

The dish with the specimen was placed in an oven of partial vacuum (less than 100mm Hg) at a temperature of 105°C for about 5 hours.

After which the dish was removed from the oven and gradually allowed to cool and weighed.

The process was repeated for an hour until we noticed a constant weight.

Calculation:

% moisture = [(weight in g of sample - weight in g of dry sample) X 100]

Weight of sample in g

Ash content

The ASTM standard used to analyze the ash content is E1755- II. The muffle furnace was used for this analysis. The ash fraction contains all the mineral elements jumbled together.

Procedure

5g of the prepared sample was placed in a crucible.

After which it was placed in an oven at 100$^{o}$C for 24 hours.

It was then removed and transferred to a muffle furnace where the temperature was increased further to 550±5$^{o}$C.

This increased temperature was maintained for another 8 hours

Finally, the crucible was removed from the furnace and transferred to a desiccator to cool, weighed and recorded.

Calculation:

The ash content was expressed in percentage dry basis using the expression below

$$\% \text{ ash content} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100$$

Volatile matter (VM)

High volatile matter content is an indication that biomass would ignite easily during pyrolysis process and this has influence in the thermal behavior of fuels as described . The VM was obtained by difference as shown in the equation below

$$\%, \text{VM} = \frac{\text{Initial mass of the sample - Final constant mass of the sample}}{\text{Initial mass of the sample}} \times 100$$

Fixed carbon

The fixed carbon was obtained from the equation below

% FC = 100 – (% moisture content + % volatile matter + % ash content)

In obtaining the fixed carbon ASTM D3174 – 76 standard method was used. The crucible cover used in performing the volatile matter last analysis was removed after which the crucible heated over Bunsen burner to allow all the carbon to burn. The difference in weight of the residue from the previous weight is the fixed carbon.

**Determination of Ultimate Analysis**

The ultimate analysis was performed to evaluate the percentage chemical elements of the sample and it consists of oxygen, carbon, Sulphur, nitrogen and hydrogen content as described by Ibikunle *et. al*., 2019.

The LECO CHN 2000 Elemental Analyzer with ASTM D529I standard was used in the elemental determination of Carbon, Hydrogen and Nitrogen while Oxygen was determined by difference.

2g of the biomass sample is weighed into platinum crucible.

Then the crucible containing the sample was placed in a leibig - pregle chamber containing sodium hydroxide and magnesium percolate.

The sample was ignited and burnt off to yield $CO_2$ and water.

Sodium hydroxide and magnesium percolate is used to absorb the $CO_2$ and water, respectively. The amount of carbon dioxide and water was calculated by difference

## RESULTS AND DISCUSSION

Table 1: Results of proximate analysis

| SAMPLE | MOISTURE CONTENT (%) | FIXED CARBON CONTENT (%) | VOLATILE MATTER CONTENT (%) | ASH CONTENT (%) |
|---|---|---|---|---|
| CORN STOVER | 0.40±0.2 | 26.60 ±0.2 | 69.04 ± 0.7 | 3.96 ± 0.2 |
| IROKO SAWDUST | 0.42±0.2 | 22.60 ±0.3 | 73.20 ± 0.2 | 3.78±0.1 |
| ELEPHANT GRASS | 0.86±0.4 | 14.00 ±0.4 | 79.24 ± 0.4 | 5.90 ±0.1 |
| MAHOGANY BARK | 1.30±0.05 | 15.35±0.2 | 79.96± 0.7 | 3.39 ±0.3 |



Table 2: Results of ultimate analysis

| SAMPLE | C (%) | H (%) | N (%) | O (%) | S (%) |
|---|---|---|---|---|---|
| CORN STOVER | 45.65±0.3 | 5.95± 0.3 | 0.69 ± 0.1 | 47.61±0.2 | 0.10± 0.3 |
| IROKO SAWDUST | 50.06±0.1 | 5.63± 0.3 | 0.04 ± 0.2 | 46.25±0.1 | 0.02 ±0.1 |
| ELEPHANT GRASS | 43.44 ±0.1 | 5.60± 0.3 | 0.68± 0.2 | 47.95±0.1 | 0.33± 0.1 |
| MAHOGANY BARK | 50.55 ±0.1 | 5.46 ±0.03 | 0.13 ±0.01 | 43.81 ±0.5 | 0.05± 0.01 |

Table 3: Biomass compositions and heating value

| | CORN STOVER | IROKO SAW DUST | ELEPHANT GRASS | MAHOGANY BARK |
|---|---|---|---|---|
| CELLULOSE (%) | 42.16 | 40.90 | 40.12 | 42.12 |
| HEMICELLULOSE (%) | 24.12 | 25.50 | 25.72 | 24.62 |
| LIGNIN (%) | 23.76 | 24.42 | 22.48 | 22.55 |
| HIGH HEATING VALUE (MJ/kg) | 22.80 | 19.80 | 19.70 | 20.60 |

Table 1 showed results of proximate analysis, table 2 showed results of ultimate analysis of corn Stover, iroko sawdust, elephant grass and mahogany bark. While table 3 showed the biomass composition and heating value. It can be observed that the values of cellulose is the highest followed by lignin and hemicellulose for the four biomass samples. The cellulose content ranged from 40.12-42.16.56% with corn stover having the highest value (42.16%). The quantities of cellulose and hemicellulose obtained here is in consonance with the values of cellulose (48%) and hemicellulose (29%) reported by Mullen *et al*., 2010. This is an indication that corn stover will be most suitable for biomass pyrolysis because a relatively higher bio-oil yield can be expected as cellulose and hemicellulose contents are the two main biomass components that favours high yield of bio-oil. The HHV value ranged from 19.80-22.80 MJ/kg in the biomass samples studied. Corn stover has the highest value (22.80MJ/kg) whereas the elephant grass had the least value HHV (19.7MJ/kg). This is in agreement with the 19-70MJ/kg heating value of corn stover reported by (Tumuluru *et al*., 2012). From the information reported, the work zeroed in on the choice of corn stover as it has the optimal properties of achieving best bio-oil production with respect to quantity and quality.

**Proximate analysis**

*Moisture content*

Moisture content of biomass is the quantity of water existing within the biomass, expressed as a percentage of the total material's mass. Moisture content of biomass in natural conditions depends enormously on the type of biomass, ranging from less than 15% in cereals straw to more than 90% as in algae biomass. This is an important parameter when using biomass for energy since it has a marked effect on and heating value on the other, high moisture content entails logistic issues as it increases the tendency to decompose which results in energy loss and tend to reduce energy and cost balances.

The results of moisture content of the various biomass range of 0.40 – 1.30% with corn stover, iroko sawdust, elephant grass and mahogany bark recording 0.40, 0.42, 0.86 and 1.30% respectively. Amongst the biomass, mahogany bark recorded the highest value of 1.30% while corn stover was the lowest.

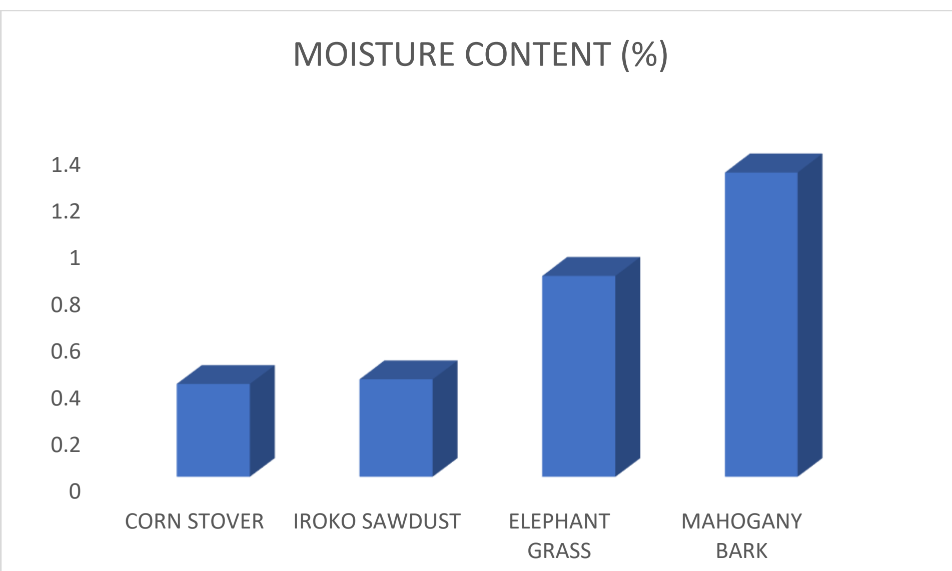


*Figure 1: Moisture content of biomass*

The heating value of a biomass feedstock represents the energy amount per unit mass or volume released on complete combustion. The heating value is seen in two different ways, the higher heating value (HHV) and low heating value (LHV). The HHV includes the latent heat contained in the water vapor that in practice cannot be used effectively, while the LHV excludes the heat of evaporation of the water formed from the hydrogen contained in the biomass feedstock and its moisture content. Thus, the LHV is the appropriate value to assess the energy available for subsequent use.

*Fixed carbon*

Fixed carbon is the solid combustible residue that remains after a sample is heated at 900 degrees Celsius for a period of 7 minutes and the volatile matter is expelled (Gautum et. al., 2020)

The fixed carbon content of this present study was found in the range of 14.00 – 26.60%. Corn stover, iroko sawdust, elephant grass and mahogany bark recorded fixed carbon content of 26.60, 22.60, 14.00 and 15.35% respectively. Corn stover recorded the highest fixed carbon (26.60%) while elephant grass was the lowest (14.00%).

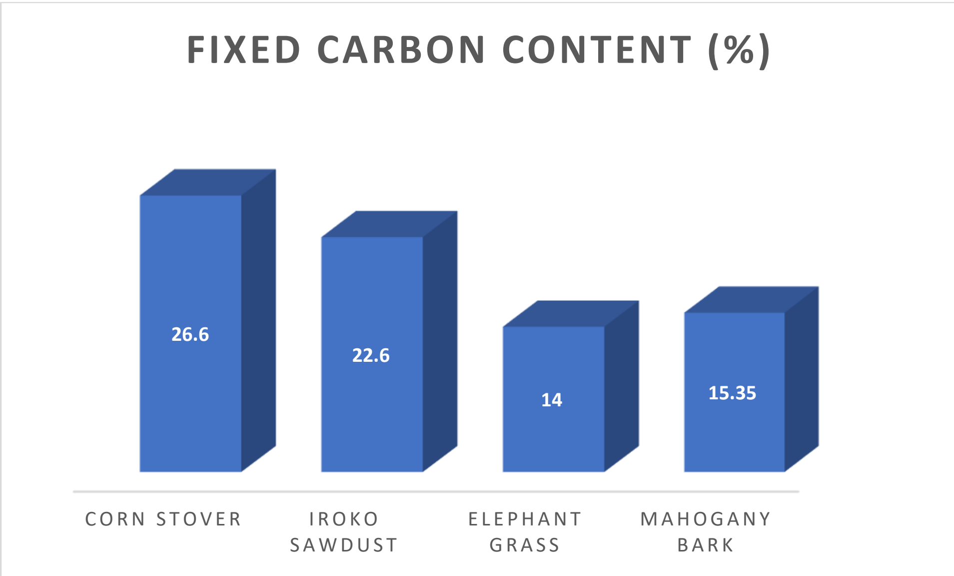


*Figure 2: Fixed carbon content of biomass*

The fixed carbon can influence the biological conversion of fuel. Woody biomass has a much higher fixed carbon content as compared to perennial crops. This justifies why elephant grass recorded the lowest value while corn stover which would be much in weight had the highest.

*Volatile matter*

The volatile matter of biomass is composed by condensable vapor and permanent gases (exclusive of water vapor) released when the biomass is heated to 925˚C for few minutes. During this heating, the biomass decomposes into gases and solid matter is left out as char.

The volatile matters of this study were found to be 69.04, 73.20, 79.24 and 79.96% for corn stover, iroko sawdust, elephant grass and mahogany bark respectively.

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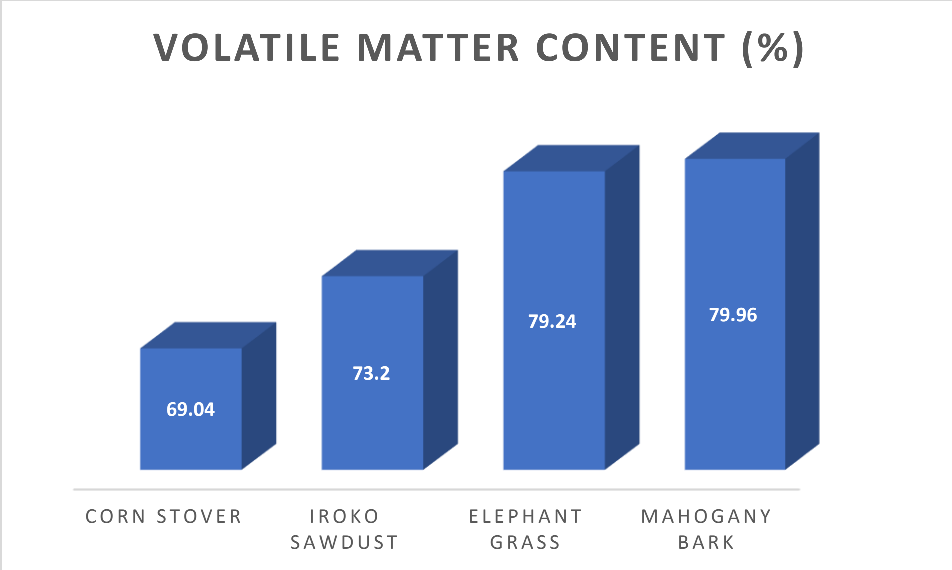


*Figure 3: Volatile matter content of biomass*

It is worthy to state that the presence of volatile matter in biomass influences fuel reactivity, it has been observed that an increase in the volatile matter content of the biomass sample causes, as a general tendency, an increase in the peak temperature. The peak temperature is the point on the burning profile at which the rate of weight loss due to combustion is maximum. The burning profile peak temperature is usually taken as a measure of the reactivity of the sample. The volatile matter content is also an important parameter for evaluating anaerobic digestion for biogas production (Cai et. al., 2017).



*Ash*

Ash is generally considered to be the residue remaining after the material has been incinerated. It therefore has no energy value and, being made up of the inorganic elements in the biomass, is of no direct value in hydrolysis technologies.

The ash contents of this study for corn stover, iroko sawdust, elephant grass and mahogany bark are 3.96, 3.78, 5.90 and 3.39% respectively

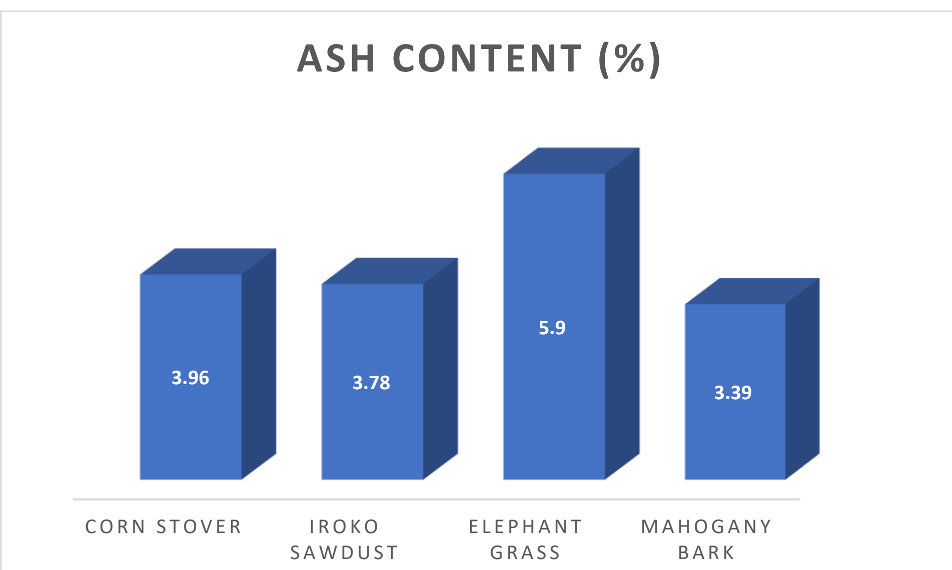


*Figure 4: Ash content of biomass*

The primary components of biomass ash are oxides of silica, aluminium, iron, calcium, magnesium, titanium, sodium and potassium. For example, knowing
the exact composition of the ashes of a biomass aids in predicting both its tendency to form deposits in the boiler components and the composition of the char produced during pyrolysis and gasification processes, which in turn also influence the combustion rate. The percentage and composition varies according to the type of biomass (Gianluca et. al., 2020).

Ultimate analysis

Ultimate analysis mainly focused on carbon, hydrogen, nitrogen oxygen and sulphur content. These elements are the major component of biomass and determine the fuel efficacy and the possible pollutant behavior (Singh et. al., 2017)

The presence of carbon, hydrogen, nitrogen, oxygen and sulphur in this study ranged from 43.44 - 50.55, 5.46 - 5.95, 0.04 - 0.69, 43.81 - 47.95 and 0.10 - 0.33% respectively.

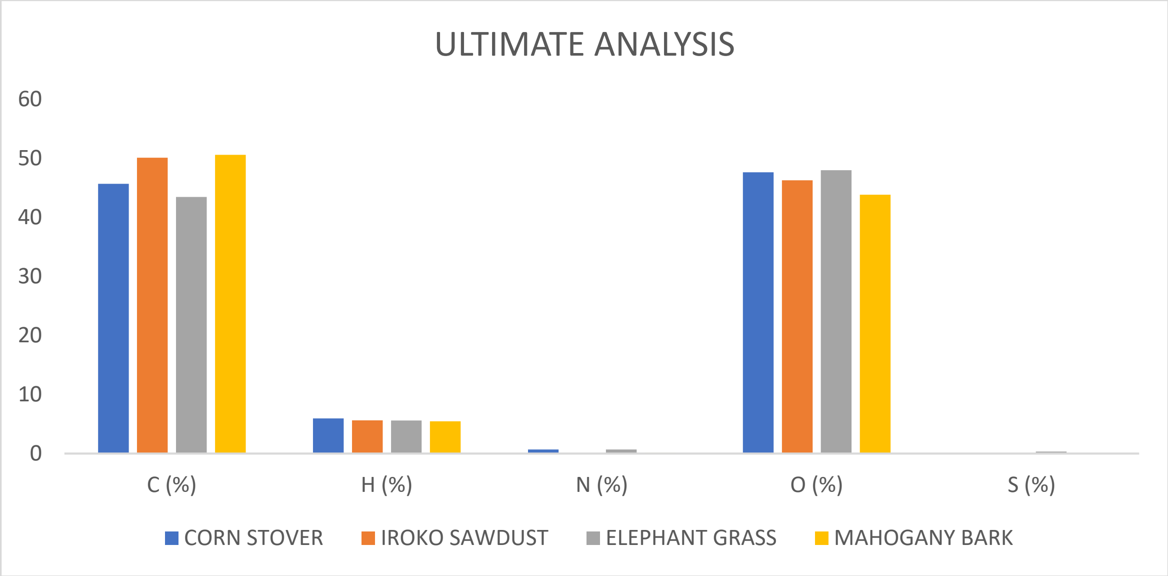


*Figure 5: Comparison of ultimate analysis parameters*

Amongst the ultimate parameters, carbon was in abundance. The maximum carbon content was recorded by mahogany bark (50.55%) while the least carbon was recorded by elephant grass (43.44%) though the difference between the two is low. Next in abundance in the analysis is oxygen for which the highest value was recorded by elephant grass (47.95%) while the least was mahogany bark (43.81%). The highest hydrogen content was corn stover (5.95%) while the lowest hydrogen was recorded by elephant grass (5.46%). There was no much difference in the presence of hydrogen in the biomass samples. The presence of sulphur and nitrogen were very small compared to carbon and oxygen. The low nitrogen content results in a reduction of NOx during combustion (Thomas,1997)

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