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Potential Usage of Selected Agro-Residue as a Biofuel Production Sources: Physiochemical Evaluation Approach

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This article present physiochemical characterization of commonly available agricultural waste residues on dry basis for: (Corn cob, Coconut shell, Cashew nut, Palm kernel shell and Cassava stem) with the view to evaluate their respective suitability for biofuel production using thermochemical conversion process. The investigated respective biomass feedstock milled samples was analyzed in the laboratory for fuel physiochemical characterization. The physiochemical characterization carried out on each biomass waste sample are Proximate Analysis, Ultimate Analysis, Elemental composition analysis and determination of their respective Higher heating Value(HHV). The obtained results revealed that of all the biomass samples characterized, the Coconut shell (CNS), Corn cob(CC) and Cassava stem(CS) samples proved to

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possess the most suitable characteristics for better bio-oil production. Palm kernel shell(PKS), Coconut shell(CNS) and Cashew nut(CN) due to their obtained low ash content, adequate hardness and fairly high fixed carbon content are generally regarded to be a potential source for making quality grade charcoal (bio-char) using Pyrolysis process. Gasification process is found desirable to producing high yield of bio-gas for Corncob(CC) and Cassava stem(CS) biomass samples due to their respectively obtainable high value of moisture content: (13.4%wt and 15.10%wt.) and fixed carbon contents of (67.94%wt and 74.13%wt) in this study. Moreover, among all other biomass sample investigated in this study, Coconut Shell(CNS) in comparison to all other samples characterized attained highest HHV of 31.2 MJ/kg. Negligible amount of Sulphur and Nitrogen which could resulted to lower emission of SO_2 and NO_2 if use directly for heating purposes aftermath application of any of the thermochemical conversion processes is also observed for the biomass waste samples analyzed independent of their types. These results show that the characterized biomass samples could be a suitable candidate for alternative energy fuels production in terms of quality and environment concern.

Keywords: Biomass waste; physiochemical characterization; biofuel production; thermochemical conversion processes.

1. INTRODUCTION

The use of renewable energy sources is becoming increasingly necessary, if we are to achieve the changes required to address the impact of global warming. As pointed out in the study of Danso-Boateng and Osei-Wusu [1], the major problem related to meeting the demand of world's total energy of about 865 exajoules per year (EJ/y) by 2040 is the dependence on fossil fuels, as their uses increase Greenhouse gas (GHG) emissions and contribute to air pollution and climate change. It should be highlighted that the modern energy-demanding lifestyle coupled with depletion of fossil fuel resources and the adverse environmental impact of greenhouse gas emission presents an overwhelming need for exploring and exploiting new sources of energy that are both renewable and eco-friendly. To achieve this objective, biomass stands a greater chance of prevailing as a good source for alternative energy fuels which in turn can be a solution for waste management. Tripathi et al. [2] recap biomass as one of the most important and potential source of energy that is readily available with high carbon content, low ash content, low emission, low moisture content and renewable in nature. Demirbas, [3] also reported biomass as the most widely existing material and its total growth on earth each year is equivalent to 10 times of the current total world energy consumption. Similarly, according to Özbay et al. [4], biomass is the only renewable energy source that can be converted into any form of fuel comprising solid, liquid, and gaseous. Findings from the studies of (Jackson, et al. [5]; Meza, et al. [6]; Zhu and Pan. [7]) revealed that the pre-processing and pre-treatment of biomass also increases the potential gain of biomass to bioenergy efficiency since once treated, biomass resources can be converted to energy using a variety of processes to generate electricity, fuel for vehicles, residential and commercial heating, as well as provide process heat for industrial facilities. With advancements in biomass technologies in place, energy producers seek sustainable supplies of biomass feedstock to ensure long-term success. It should be reported that biomass has been an important source of fuel for cooking and heating in many developing countries. Such feedstocks can come from the forestry and agricultural communities. Recently, several innovations and technology advancements have come from the biomass industry. Advancements within the industry are primarily focused on the areas of harvesting, collection, storage, pre-treatment, and conversion of biomass to bio-based products. The potent of characterizing the biomass feedstock for optimum biofuel production yield is the major concern in this study. The purpose of this research is to determine the optimum biofuel product yielded using the available thermochemical biomass conversion processes based on literature search and to investigate bioenergy production processes while identifying different agricultural residue that can best yield a particular product of energy required or needed as alternative source of fuels such as (biogas, bio-oil, or bio char). As also reported in the study of Danso-Boateng and Osei-Wusu [1], thermochemical processed biofuels and bioenergy generation technologies have gain research and technical attention over the past years due to their ability to process diverse biomass feedstocks to produce a variety of bioenergy sources including direct heat energy, solid, liquid and gaseous biofuels such as biochar, bio-oil and syngas. In this research, physiochemical characterization of biomass feedstock comprised agro-residues from PKS, CC, CNS, CN and CS (wt%) on dry basis was conducted to evaluate their suitability for optimum biofuel production. The physiochemical characterization carried out on each biomass waste sample are Proximate Analysis, Ultimate Analysis, Elemental composition analysis and determination of their respective Higher heating Value (HHV). The potent of the characterized biomass feedstock for optimum biofuel production yield using biomass conversion processing means aforementioned are also discussed.

2. MATERIALS AND METHODS

The considered biomass feedstock consisted of agro-residues from PKS, CC, CNS, CN and CS. All the agro-residues samples as shown in Fig. 1

A. Palm Kernel shell **B. Coconut Shell** **C. Corncob**

D. Cashew Nut **E. Cassava Stem**

Fig. 1. Samples of all the characterized biomass feedstock

A. Milled PKS **B. Milled CNS** **C. Milled CC**

D. Milled CN **E. Milled CS**

Fig. 2. Milled version of all the characterized biomass feedstock samples

were collected from different farms in Akure, Ondo State in South West Nigeria.

All the biomass samples presented in Fig. 1 (A, B, C, D, and E) were air dried at ambient conditions to bring the moisture content in the range of 8-10% (w/w). The samples were also milled to smaller particle sizes using a knife mill as shown in Fig. 2 (A, B, C, D, and E).

In order to evaluate the suitability of the considered biomass feedstock in this study for biofuel production, the obtained respective biomass feedstock milled samples displayed in Fig. 2 was assayed for physiochemical characterization in the laboratory to obtain their respective fuel properties. The physiochemical characterization carried out on each biomass samples are Proximate Analysis using furnace for Volatile Matter (VM) and Ash Content (AC), while oven drier was used for the considered sample Moisture Content (MC) analysis. Presented in Table 1 is the obtained proximate analysis results of the analyzed biomass samples in this study. Ultimate Analysis was also performed using an elemental analyser (Thermo FlashEA 1112), according to the ASTM-D 5291 method to analyze the weight percentage of Carbon, Hydrogen, Oxygen, Sulphur and Nitrogen, as shown in Table 2, while their respective Elemental composition was determined to analyze their obtainable cellulose, hemicellulose, and lignin content respectively, using (fibre analyser) as presented in Table 3. The Energy content analysis (HHV) of the considered biomass samples in this work were obtained using (bomb calorimeter). It should be highlighted that all the characterization carried out in this work were determined experimentally in the Central Research Laboratory of Federal University of Technology, Akure using the standard procedure as detailed in Mogaji et al. [8]. The fixed carbon (FC) of the analyzed biomass samples were estimated theoretically using Equation (1) as follows:

$$FC = 100 - (MC + VM + AC) \quad (1)$$

3. RESULTS AND DISCUSSION

3.1 Characterization of Raw Biomass Wastes

3.1.1 Proximate analysis of biomass sample

Proximate analysis of the feedstock biomass presented in Table 1 showed the results of the proximate analysis obtained on a dry basis. It is interesting to point out that the characteristics of a particular type of biomass provide useful information in the evaluation of its suitability as biofuel feedstock in various applications. From Table 1 it can be noticed that among the biomass sample analyzed in this study, palm kernel shell is observed to have the highest amount of fixed carbon (88.33%), while corncob has the lowest (67.94%). Similarly, Corncob contain the highest ash content (9.40%) while the lowest in ash content is the palm kernel shell (1.28%).The observed lowest FC for corncob sample in this work is due to its obtainable high ash content value shown in Table 1, this finding is in agreement with the previous report in the study of Jayanti et al. [9] who observed that a high ash content in fuel may reduce its combustion efficiency and increasing the burning time. However, the CC biomass waste sample could be suitable for gasification processes to take place based on its obtainable (13.4%) MC in this study as justified by the finding of Lewandowski and Schmidt [10] who asserted that materials with MC beyond 20% would create technical difficulties linked to poor combustion conditions within the gasification system. Also in agreement with the report from previous research of Ferrara et al. [11], the observed high VM obtained for the CC, CNS, CN and CS rationalize these biomass waste samples suitable for pyrolysis process for conversion into bio-oil which can be upgraded into chemical feedstock and fuel. The obtained high FC contents for PKS, CN and CNS in addition to their low AC is in agreement with those observed in the study of Vassilev *et al*. [12]. This carbon in its free state will have a positive impact on their combustion properties by producing less char and burns as a solid material in the combustion system. The observed FC content of these biomass waste samples indicate their suitability for torrefaction process, a means of converting solid biomass wastes to value added solid fuel that could be applicable as an alternative/ environmental friendly fuel source in running thermal systems like boiler and heat treatment furnace system.

3.1.2 Ultimate analysis of biomass sample

Ultimate analysis of the feedstock biomass waste samples presented in Table 2 revealed that cashew nut(CN) and corn cob(CC) possess highest nitrogen level of 1.26 and 1.09%wt. respectively while coconut shell(CNS), palm kernel shell(PKS) and cassava stem(CS) had low nitrogen levels of 0.28, 0.55 and 0.98%wt.

respectively. It interesting to point out that the observed Nitrogen content for all the biomass waste samples is almost negligible in value in comparison to their Carbon and Oxygen contents counterparts. Moreso, finding from the study of Obernberger and Thek, [13] asserted that Carbon Hydrogen and Oxygen content of the biomass are the main components of biomass fuels. The authors in their work described that Carbon and Hydrogen react during combustion in an exothermic reaction leading to formation of CO_2 and H_2O and therefore influence the gross calorific value of the fuel. In general, the ultimate analysis result showed that all the biomass waste samples characterized in this work possess high oxygen and carbon contents with low nitrogen, sulphur and hydrogen contents justifying that the investigated biomass waste samples would attain high heating value (HHV) and support combustion efficiency in thermal system. Similarly, with the observed low/negligible amount of nitrogen, sulphur and hydrogen content attained in the characterized biomass waste samples would makeup with production of more environmentally friendly alternative energy fuel by using any of the thermochemical conversion processes of the renewable energy technology.

3.1.3 Elemental composition of biomass sample

The result of elemental composition analysis of the biomass samples is shown in Table 3. The cellulose content was obtained highest for coconut shell(CNS) (45.98%wt) and lowest for palm kernel shell(PKS) (9.33%wt). According to Zhang et al. [14] bio-oil yields generally depend mainly on the cellulose content in the lignocellulosic biomass. thus, it is expected that lignocellulosic biomass such as coconut shell(CNS) with highest cellulose contents (45.98%) including cassava stem(CS) high cellulose content of (38.90%) among other biomass samples considered in this study will produce high yields of bio-oil by using pyrolysis process. It should be highlighted that, the carbohydrate composition of lignocellulosic biomass such as wood and agricultural residues is generally not much different, as observed in the present study. It can also be noticed from the Table 3 that the obtained physiochemical characterization for the Hemicellulose content of the analyzed biomass waste samples was found to be high in corn cobs (CC) (28.94 %wt.), cashew nut (CN) (22.36 %wt.) and palm kernel shell (PKS) (20.44 %wt.) with low content observed for Coconut shell(CNS) and cassava stem(CS) in the range of 10.31 and 15.32%wt. respectively. Similarly, high value of Lignin contents was attained for the PKS (49.95%wt), the CNS (27.40%wt.), and CS (22.71%wt.) while the CC sample is characterized with low content (7.5%wt.). The obtained result for the CC sample in this study is similar to those observed by Mullen et al. [15] who also reported low lignin contents of 3.30 %wt. for corn cobs and 6.3 %wt. for corn stover in their study. It should be highlighted that the obtained low lignin content for the CC in this study justify its suitability to yield more of bio-oil using pyrolysis process, this is due to the fact that a biomass sample with high lignin content may affect bio-oil yields since it promotes secondary reactions which result in char formation during combustion process.

Table 1. Proximate analysis of sample

Biomass wastes (wt%) on dry basis	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)
Corncob	13.4	9.26	9.40	67.94
Cassava stem	15.10	4.51	6.26	74.13
Coconut shell	7.33	6.02	1.56	85.09
Cashew nut	7.71	5.14	1.89	85.26
Palm kernel shell	8.07	2.32	1.28	88.33

Table 2. Ultimate analysis of sample

Biomass wastes (wt%) on dry basis	Nitrogen (%)	Sulphur (%)	Hydrogen (%)	Carbon (%)	Oxygen (%)
Corn cob	1.09	0.09	1.52	50.33	46.97
Cassava stem	0.98	0.14	1.59	52.07	45.22
Coconut shell	0.28	0.06	0.82	54.68	44.16
Cashew nut	1.26	0.12	0.87	54.51	43.24
Palm kernel shell	0.55	0.09	0.91	54.84	43.62

Table 3. Elemental composition of sample

Biomass wastes (wt%) on dry basis	Lignin (%)	Cellulose (%)	Hemicellulose (%)
Corn cob	7.50	25.01	28.94
Cassava stem	22.71	38.90	15.32
Coconut shell	13.74	45.98	10.31
Cashew nut	27.40	12.38	22.36
Palm kernel shell	49.95	9.33	20.44

3.1.4 Energy content analysis of the biomass sample

The use of biomass waste as a fuel for thermal and electrical applications requires knowledge of its heating value. Heating value reflects the energy content of a fuel in a standardized fashion. As reported in the open literatures, the energy content of a fuel is often expressed as higher heating value (HHV) or lower heating value (LHV). As pointed out in the study of Vargas-Morenoa et al. [16], higher heating value refers to heat released by complete combustion of a unit volume of fuel leading to the production of water vapour and its eventual condensation; at this point, the total released energy is measured. The energy contents of the investigated biomass samples in this study is obtained experimentally as HHV in the Central Research Laboratory of Federal University of Technology, Akure using bomb calorimeter. Presented in the Table 4.is the obtained HHV in this study. From the table, higher heating values of 31.17 MJ/Kg is obtained for coconut shell(CNS) in comparison to other biomass waste samples considered in this work. This behavior is due to its possession of high FC (85.09%) with low value of AC(1.56%) additional to the lowest/negligible contents of Nitrogen (0.28%), Sulphur (0.06%) and Hydrogen(0.82%) including its highest content of Cellulose (45.98%) obtained based on its physiochemical characterization results depicted in Tables 1,2 and 3 respectively. It should be highlighted that the obtained low FC contents for CC and CS in addition to their obtained high ash and moisture contents contributed to their respective fairly LHV observed in this work. It is also interesting to point out that the obtained physiochemical fuel properties for CNS contribute positively to its combustion efficiency and justify its highest energy content of 31.18% followed with 31.11% and 31.00% obtained for PKS and CN respectively in this study. It is interesting to point out that the obtained HHV for CNS in this study is in close match to that observed in the study of Basu [17].

Table 4. Energy content of biomass sample

Biomass wastes (wt%) on dry basis	HHV (MJ/Kg)
Corncob	26.42
Cassava stem	26.94
Coconut shell	31.18
Cashew nut	31.00
Palm kernel shell	31.11

4. CONCLUSIONS

Physiochemical characterization of biomass feedstock comprised agro-residues from PKS, CC, CNS, CN and CS (wt%) on dry basis was carried out to evaluate their suitability for optimum biofuel production in this research. The energy content of the analyzed biomass waste samples is characterized as (26.42, 26.94, 31.18, 31.00, 31.11) MJ/Kg for CC,CS,CNS,CN and PKS respectively. Among all the biomass samples characterized, the Coconut shell(CNS), Corn cob(CC) and Cassava stem(CS) samples proved to possess the most suitable characteristics for better bio-oil production if subjected to thermal degradation condition relating to pyrolysis process. This affirmation is due to their possession of high carbon, cellulose and volatile matter contents as reported in the open literatures and as similarly observed in the present study. Palm kernel shell(PKS), Coconut shell(CNS) and Cashew nut(CN) due to their obtained low ash content, adequate hardness and fairly high fixed carbon are generally regarded to be a potential source for making quality grade charcoal (bio-char) using Pyrolysis process. Similarly, Corncob(CC) and Cassava stem(CS) due to their respectively possessions of high value of moisture content: (13.4%wt and 15.10%wt.) and fixed carbon values of (67.94%wt and 74.13%wt) are found to be desirable in producing high yield of bio-gas during gasification process. Higher heating value (HHV) of 31.2 MJ/kg is also attained for Coconut Shell(CNS) in comparison to all other samples considered in this study. This result justifies the fairly higher values of Fixed Carbon, (85.09%wt) and highest Cellulose value (45.98 %) obtained for their respective Proximate and Elemental composition analysis carried out in this research. Additionally, elemental analysis of the analyzed biomass waste samples showed that the product contain negligible amount of Sulphur and Nitrogen which could resulted to lower emission of SO_2 and NO_2 if use directly for heating purposes aftermath application of either Torrefaction process for solid fuel production or Pyrolysis process for bio fuel production. This behavior is observed to be more pronounce with CNS containing 0.28% of Nitrogen and 0.06% of sulphur followed by PKS and CC biomass waste samples. The comparative analysis of physiochemical fuel properties of the biomass waste samples investigated in this work aid determining bio-oil, biogas and biochar fuels optimum yield while applying available thermochemical conversion process in the production of alternative energy fuels.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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