STUDIES ON THE RENEWABLE ENERGY GENERATING POTENTIALS OF SOME AGRICULTURAL PLANT RESIDUES GENERATED FROM FARMING IN KATSINA STATE

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Abstract

The renewable energy producing potentials of six agriculturally generated residues have been studied with the aim of determining the suitability of each plant residue for use as a feedstock in energy generation systems. The physical, proximate and energy-related parameters were determined for each biomass. Results obtained revealed the following data: **Moisture contents (MC):** Maize stalk (6.24%), Maize cob (2.10%), Sugarcane bagasse (2.32%), Cotton stalk (8.87%), Millet stalk (7.86%) and Sorghum stalk (9.12%). **Bulk density** (ρb)**:** Maize stalk

[redacted]

(120.12 kgm^{-3}), Maize cob (160.24 kgm^{-3}), Sugarcane bagasse (84.12 kgm^{-3}), Cotton stalk (178.40 kgm^{-3}), Millet stalk (118.60 kgm^{-3}) and Sorghum stalk (235.28 kgm^{-3}). **Volatile Matter Content (V):**

Key words: Energy, Bulk density, Net calorific value, Fuel value index, Agricultural residue, Volatile matter, Fixed carbon.

Maize stalk (78.21%), Maize cob (78.16%), Sugarcane bagasse (76.44%), Cotton stalk (83.10%), Millet stalk (87.56%) and Sorghum stalk (90.10%). **Ash Content (Ash C):** Maize stalk (18.22%), Maize cob (12.10%), Sugarcane bagasse (18.12%), Cotton stalk (18.24%), Millet stalk (11.63%) and Sorghum stalk (17.82%). **Fixed Carbon (FC):** Maize stalk (20.56%), Maize cob (19.23%), Sugarcane bagasse (18.11%), Cotton stalk (26.40%), Millet stalk (18.24%) and Sorghum stalk (20.15%). **Net Calorific Value (q_{net}):** Maize stalk (307.10GJ/kg), Maize cob (308.18 GJ/kg), Sugarcane bagasse (307.21 GJ/kg), Cotton stalk (308.68 GJ/kg), Millet stalk (288.02 GJ/kg) and Sorghum stalk (276.76 GJ/kg). **Fuel Value Index (FVI):** Maize stalk (2.60 MJ/kg), Maize cob (14.77 MJ/kg), Sugarcane bagasse (14.75 MJ/kg), Cotton stalk (13.90 MJ/kg), Millet stalk (45.18 MJ/kg) and Sorghum stalk (4.77 MJ/kg). Based on the values of the FVI obtained in this research, it was concluded that all the agricultural residues tested are generally potentially good for materials for use as feed stocks in energy generation systems.

Introduction

In the last few decades, there has been increasing interests in energy generation from biological materials because of its environmental benefits and ease of accessibility (Alhassan, et. al., 2019). The use of these waste materials as feedstock in energy generation plants has been applied in many industrial processes. The availability of these wastes is key to the sustainability of such a process. In order to enhance environmental sustainability, there have been efforts at identifying alternative and renewable sources of energy capable of meeting increasing global demand. This is because in spite of the serious efforts already made in making electricity available, an estimated 1.2 billion people representing 17% of the

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global population are still without adequate access to electricity (IEA, 2015) due to climatic and geographical conditions which prevent easy access to rural or isolated areas causing hindrances to the extension of power grids to these places. An alternative to this problem are the renewable energy sources which are increasingly becoming the sources of electricity for isolated systems in rural areas (IEA, 2015).

Today, most of the developed economies utilize all waste streams in the energy system as feedstock for renewable energy production (Nikolau, et.al.,2003; Riva, et.al., 2014). However, the underdeveloped countries are still lagging behind in adopting the right technology of utilizing biomass and agricultural residues as alternative renewable energy resource (Vimal, 1979: Webb, 1979). Efficient utilization of biomass and agricultural wastes to generate bio-energy can also contribute in solving energy crisis and reducing complete dependence on fossil based resources (Bepp,1985; Bhattacharya, et.al., 1993).

In most parts of the African continent, agricultural residues are currently utilized mostly for domestic heating and as feeds for domestic animals (Demirbas and Ayhan, 2001; Purohit, et.al, 2006). However, the energy contents of most of the agricultural wastes represents potential for bio-fuel production or combined heat and power production (Demirbas and Ayhan, 2005; Demirbas, et.al., 2009). In Nigeria, millions of people live in remote areas/villages and a significant number of these villages are not supplied with natural gas and electricity which are the major energy requirements (Loehr, 2012). Since the agricultural wastes are widely distributed and locally available, each area or village can produce its own electricity and heat from the available agricultural wastes given the appropriate technology. In addition, the distributed electricity production can contribute towards mitigating the severe energy crisis in the country (Dincer, 2000).

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Agricultural wastes can be classified based on their provenance into four main classes: wastes from soil plantations, waste from food industry, breeding, and slaughter wastes (Obi, 2016). Renewable energy obtained from biological sources is known as bio-energy. Bio-energy have since found applications as a source of heat and electrical energy, or as an automobile or vehicular fuel (Henniges and Zeddies, 2006; Int, Energy Outlook, 2016). This form of energy is one of the most rapidly increasing renewable energy technologiesAvcioglu, et.al., 2019). Organic materials that contain bio-energy are called biomass. Typical examples are woody biomass and residues, agricultural crops and residues, sewage, industrial residues, animal residues, aquatic plants, landfill gas, and municipal solid wastes. Bio-energy is developed and stored in plants through photosynthetic process while the animals get it by consuming the plants.

Biomass combustion involves a series of chemical reactions in which carbon is oxidized to carbon dioxide and hydrogen is oxidized to water (Demirbas, 2007). Agricultural residues are good fuels for combustion, since they are rich in hydrogen and carbon. Ideally, the hydrogen and carbon would split off and combine with the oxygen in the air to produce water vapor, carbon dioxide and release heat energy (Sadaka and Johnson, 2010). The generalized equation for the combustion of biomass fuel is:

$$\text{Fuel} + \text{Oxygen} \rightarrow \text{Carbon Dioxide} + \text{Water Vapor} + \text{Heat} \quad (1)$$

Complete combustion of biomass requires a certain volume of air which consists of about 21% oxygen and about 79% nitrogen and so the product of stoichiometric combustion of biomass in air will include carbon dioxide, water vapor and nitrogen.

For the biomass, the stoichiometric equation for the combustion is given by [58]:

$$\text{Biomass} + \text{Air} \rightarrow \text{Carbon Dioxide} + \text{Water Vapor} + \text{Nitrogen} + \text{Heat} \quad (2)$$

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Issues related to energy security, climate change, modern bio-energy technologies, bio-fuel trade, employment, and local investment in energy sector have been very fundamental in modern economics of energy analysis (Alhassan, et.al., 2019). Results of recent researches have shown that no modern-aged economy has succeeded at reducing poverty level significantly without effectively increasing the provision, availability, and usage of energy supply (Nnaji, et.al., 2010).

The physicochemical characteristics of biomass make it an attractive source to be harnessed for energy (Escalante, et al., 2010). Clean, renewable energy resources for use in transportation vehicles and for electricity generation are an important strategy to combat climate, economic, environmental, and security challenges posed by fossil fuel use. Bioenergy derived from biomass, including plant materials and manure, to produce renewable fuels for vehicular transportation and to generate electricity provides a sustainable, low-carbon alternative to fossil fuels and enables communities to benefit from locally available resources. It is one of several elements of a comprehensive climate strategy that can cut projected U.S. oil use to half by 2030, and help put the nation on track to phase out the use of coal in electricity generation.

Perennial herbaceous plants derived biomass present agro ecological benefits such as high organic carbon content and reduced soil erosion that are not readily obtainable from annual row crops. The species studied in the present research are the most commonly generated biomass in northern Nigeria (Muntean, et.al., 2018). Typical examples are:

Sorghum (Sorghum bicolor (L). Moench), which is a very promising plant for use in energy application, since it is a multipurpose plant from the genus of about 25 species of flowering plants of the grass family (Poaceae) (https://ro.wikipedia.org/wiki/sorghum bicolor, 2022. Sorghum crops are more valuable compared to cotton and corn considering its lower energy intake and higher energy production (Drozyner, et.al., 2013: Rai, et.al., 1997). It is used as a natural and cost-effective fuel source in local communities (Almodares and Hadi, 2009). There is therefore an increased interest of farmers to expand their cultivated land and produce more sorghum in Nigeria, due to its potential application in the manufacturing industry as biomass for the production of renewable energy, electricity, and heat, as a resource for achieving the desired level of renewable energy production in the current dispensation.

Sugarcane is also produced many parts of Nigeria especially in the north. It is one of the world's most important crops and represents 21.1 % of the total global crop production with Brazil being the largest world producer produced 632.127 million tons in 2014/2015 (Figueroa-Rodriguez, et.al., 2019). Literature survey showed that the sugarcanes by product, called bagasse, have been extensively studied, due to its high potential for bioenergy production (Dollarose, et.al., 2021).

Figure1: Different Agricultural and Forest Residues for Energy Generation

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Figure1: Heaps of Agricultural and forest (Plants) Residues

Figure2: Dumping of Agricultural Solid Wastes in Public

Materials and Methods

The four agricultural by-products were dried naturally for eight weeks before other procedures were carried out. The measurements were performed in the Laboratory in accordance with European Union Standards for solid biofuel. Biomass samples were reduced to smaller particle, ground into powdered form using mortar and pestle. The samples of about 0.6-0.8 g were weighed with an analytical balance and dried at 105±2°C in a ventilated oven until constant mass was obtained. The prepared raw materials were placed in crucibles and stored in a desiccator at room temperature until the analyses were carried out. The determination of calorific value of agricultural wastes and was performed in accordance with the ASTM D5865 Standard Test Method for Gross Calorific Value of Coal and Coke (ASTM D5865, 2013) and standard operating procedure Parr 6000 Calorimeter (Parr Instrument Company, 6200, 2014). The experiments were carried out in a bomb calorimeter under an oxygen pressure of 35 atmospheres and high purity of about 99.995 %. For each material, three determinations were made, in order to verify if the difference in calorific value between them was lower than 120 J/g, according to literature protocols (Cioabla, et.al., 2016). The determinations of the parameters affecting the calorific value (moisture, ash content) were also performed using standard analytical procedures.

Determination of Moisture Content

For each sample, 1 gram will be weighed and put in a pan and oven-dried for 24 hours at a temperature of 130°C.

The moisture content of the sample was determined using the gallenkamp oven; model P165.

An empty crucible was first weighed and 10g of the sample was put into it and the crucible and contents were kept in an oven at 110 °C until a constant mass was obtained. The moisture content (M.C.) of the sample was then computed using the formula:

$$\text{Moisture content} = \frac{\text{Initial Weight} - \text{Final Weigth}}{\text{Initial Weight}} X100\% \qquad (1)$$

Determination of Ash content

Ash content is another important test for determining biomass fuel properties. The ash content of the samples were determined based on a method described by CEN/TS 14775:2004 (Alalwan, *et.al.,* 2019). A sample (sample mass > 1 g) was initially ashed at 250˚C until volatiles are burnt off slowly (to avoid losing entrained particles with fast burning). Then, heating the sample at 250˚C - 550˚C in 60 min with defined temperature rise of 5˚C·min^{-1} and then a heating regime was followed to finish with an ashing temperature of 550˚C ± 10˚C for at least 2 hours. The weight of the residual ash was determined and used to calculate the percentage ash in the sample using the formula:

$$\text{Ash Content } (\%) = \frac{\text{Weight of ash}}{\text{Weight of carbon}} \text{x } 100\% \qquad (2)$$

The ash content measurements were repeated three times for each sample.

Determination of Calorific Value

The calorific values of the fuel samples were determined using the Parr oxygen Bomb-Adiabatic calorimeter. The calorific values were determined by weighing one gram of each fuel sample and transferring to the capsule; making sure the interior of the bomb including the support and crucible are properly cleaned and dried. A 10 cm long fuse wire was fixed to the two electrodes and the capsule containing the sample was carefully fixed into the electrode seat inside the bomb. The bomb head or cover was also carefully and tightly closed using a special vice and spanner and then connected to the oxygen cylinder at a pressure of 30psi (207 Kpa) The calorimeter bucket was filled with 1 liter of distilled water. The bomb was then carefully transferred into the bucket and ignition wires were pushed into the terminal socket on the bomb head; making sure no water is removed from the bucket with the fingers. The calorimeter jacket was covered and a thermometer facing down ward was inserted into the water. The stirrer was turned by hand to make sure it runs freely without touching the calorimeter jacket or the bucket, the drive belt was then slipped into the pulleys and the motor was started. The stirrer was allowed to run for 5 minutes to reach equilibrium before any measured run. The temperature was read and recorded at one minute interval for 5 minutes; at the end of the 6th minutes, the calorimeter bomb was fired by pressing the ignition button and holding it down until the indicator light goes out. The bucket temperature started rising rapidly during the first few minutes, then it became slower as the temperature approaches a stable maximum. After the final temperature reading; the motor was stopped, the drive belt removed and the calorimeter cover lifted. The knurled knob on the bomb head was carefully and steadily opened to release the gas pressure before removing the cap. The interior of the bomb was then examined for evidence of incomplete combustion; the bomb was then cleaned and dried. The whole procedure was repeated three times and temperature readings were taken for each sample. The mean time - temperature readings was found for each sample. The calorific values were computed using the formula;

$$\text{Calorific value} = \frac{\text{T X W}}{\text{Wgs}} \quad (2)$$

Where; T = corrected temperature rise, Wc= Energy equivalent of the calorimeter which is 2416 cal and Wgs = Weight of samples used.

Bulk Density

To determine the bulk density (ρb), an analytical balance was used. An empty cylindrical container (150 mL) was weighed. The container was filled with the sample and the material was slightly compacted to remove large void spaces. The container and the sample were then weighed together. The bulk density of the sample was calculated using the formula:

$$\text{Bulk density} = \frac{\text{Weight of dry material (g)}}{\text{Volume of picked dry material}} \qquad (3)$$

Volatile matter content

The volatile matter content (V) was determined through mass difference, for samples under investigation (three times determination), according to the following equation used for the calculation:

$$\text{Volatile Matter Content(V)} = \{\frac{100(\text{m2}-\text{m3})}{(\text{m2}-\text{m1})-\text{w}} \; x \; \frac{100}{(100-\text{w})}\}\% \qquad (4)$$

Where, m1= weight of empty vessel (in g); m2= weight of vessel with sample before heating(in g); m3= weight of vessel with sample after heating (in g); w = moisture content (in %). The volatile matter and ash content were corrected to dry basis by using the moisture content.

Fixed carbon, FC

The percentage fixed Carbon represent the residue left after removing the volatile matter and the ash from the substance. The percentage fixed carbon for each sample (in conformity with ASTM D3172 – 13) method was determined by subtracting the ash content (%) and volatile matter content (%) from 100.

Percentage Fixed Carbon (FC) = 100 – {Vd(%) + Ash C(%)} (5)

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Energy density

Energy density or caloric density was calculated from the bulk density and the calorific value of the biomass feed stock (Vijayanand, et.al., 2016; Lunguleasa, et.al., 2015). The energy density was calculated based on the formula:

$$\text{Energy density (ED) (mJ/m}^3\text{)} = \rho b \times CV \qquad (6)$$

Where, ρb = bulk density of the biomass (kg/m^3), CV = the calorific value of the biomass (MJ/kg).

Fuel value index

The fuel value index is the main parameter that indicates the potentiality of the biomass material for energy production. It is determined to establish the suitability of the agricultural by product for energy production. The procedure is described in (Sadiku, et.al., 2016; Deka, et.al., 2007).
Fuel value index was calculated based on the equation;

$$\text{FVI} = \frac{(\text{qnet} - \rho\text{b})}{(\text{Ash C} - \text{w})} \qquad (7)$$

Where, FVI = the fuel value index (GJ/m^3), qnet = the net calorific value (GJ/kg), ρb = the bulk density (kg/m^3); Ash C = the ash content (%) and w = the moisture content (%).

Results and discussion

The results of proximate analysis and fuel parameters of the biomass materials are presented in Table 1.

Table 1: Proximate and fuel Parameters of the Agricultural residues

\			Proximate Parameters (%wt, db)			q_{net}
FVI						
Sample	MC(%)	ρb(kgm^{-3})	V	A	FC	(GJ/kg)
(MJ/kg)						

Maize Stalk	**6.24**	**120.12**	**78.21**	**18.22**	**20.56**	**307.10**	**02.60**
Maize Cob	**2.10**	**160.24**	**78.16**	**12.10**	**19.23**	**308.18**	**14.77**
Sugarcane bagasse	**2.32**	**84.12**	**76.44**	**18.12**	**18.11**	**307.21**	**14.75**
Cotton Stalk	**8.87**	**178.40**	**83.10**	**18.24**	**26.40**	**308.68**	**13.90**
Millet Stalk	**7.86**	**118.60**	**87.56**	**11.63**	**18.24**	**288.92**	**45.18**
Sorghum Stalk	**9.12**	**235.28**	**90.10**	**17.82**	**20.15**	**276.76**	**04.77**

MC = Moisture content, ρb = Bulk density, V = Volatile matter, A = Ash content, FC = Fixed-carbon content, db = Dry basis, FVI = Fuel value index, q_{net} = Net Calorific Value.

Discussion

Table1presents the data obtained on the physical, proximate and energy-related parameters of the analysed agricultural residues (Maize stalk, Maize cob, Sugarcane bagasse, Cotton stalk and sorghum stalk) generated from farming activities. The Table revealed the results of the parameters as follows:

Moisture contents (MC): Moisture content or water content of a material represents the amount of moisture present in the material expressed as a percentage of the mass of the material. For the agricultural residues, the values obtained for the moisture contents were. Maize stalk (6.24%), Maize cob (2.10%), Sugarcane bagasse (2.32%), Cotton stalk (8.87%), Millet stalk (7.86%) and Sorghum stalk (9.12%). Cotton stalk appeared to have the highest moisture content of 8.87% and maize cob had the least, 2.10%. Moisture content is the most important factor that influences the calorific value of biomass (Nielson, et.al., 2009). Generally, lower heating values of biomass samples are caused by high moisture and ash contents.

Bulk density (ρb): Bulk density also known as apparent density or volumetric density is the property of powders, granules, and other divided solids. It is the mass of the many particles of that material divided by the total volume they occupy. Bulk density is an important parameter that influences the transportation and storage of a biomass material as well as feeding the material into the thermochemical conversion system (Natarajan, et.al, 1998). For this research, the values obtained for the agricultural residues were**:** Maize stalk (120.12 kgm^{-3}), Maize cob (160.24 kgm^{-3}), Sugarcane bagasse (84.12 kgm^{-3}), Cotton stalk (178.40 kgm^{-3}), Millet stalk (118.60 kgm^{-3}) and Sorghum stalk (235.28 kgm^{-3}). Sorghum stalk had the highest bulk density while sugarcane bagasse had the least. The calculated bulk density for the studied samples varies between 84.12 kgm^{-3}– 235.28 kgm^{-3}.

Volatile Matter Content (V): Volatile matter refers to all those components of the material (fuel) that are readily burnt in the presence of oxygen. They are usually a mixture of hydrocarbons, both, aromatic and aliphatic, short and long-chain and sometimes sulphur. In the present study, the values of the volatile contents obtained for the agricultural residues were: Maize stalk (78.21%), Maize cob (78.16%), Sugarcane bagasse (76.44%), Cotton stalk (83.10%), Millet stalk (87.56%) and Sorghum stalk (90.10%) with sorghum stalk having the highest value of 90.10% and sugarcane bagasse the least.

Ash Content (Ash C): The ash content of a material is a measure of the amount of inorganic noncombustible components in it. Here, the ash contents of the agricultural by-products were: Maize stalk (18.22%), Maize cob (12.10%), Sugarcane bagasse (18.12%), Cotton stalk (18.24%), Millet stalk

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(11.63%) and Sorghum stalk (17.82%). The residue with the highest ash content was cotton stalk while maize cob had the least value.

Fixed Carbon (FC): Fixed carbon represents the amount of non-volatile carbon that remain after complete burning of the material. In this research, the percentage fixed carbons obtained for these materials were: Maize stalk (20.56%), Maize cob (19.23%), Sugarcane bagasse (18.11%), Cotton stalk (26.40%), Millet stalk (18.24%) and Sorghum stalk (20.15%).

Net Calorific Value (q_{net}): The net calorific value of a material is the amount of energy which can be practically realized at constant atmospheric pressure. It is the most important parameter that is expressed on an 'as received basis' that is including the moisture content, because that is typically how the fuel will be burned. For the agricultural residues used in this study, the values obtained for the net calorific value were: Maize stalk (307.10GJ/kg), Maize cob (308.18 GJ/kg), Sugarcane bagasse (307.21 GJ/kg), Cotton stalk (308.68 GJ/kg), Millet stalk (288.02 GJ/kg) and Sorghum stalk (276.76 GJ/kg).

Fuel Value Index (FVI): The fuel value index (FVI) is a parameter which highlights the suitability of the studied agricultural residues for energy production. FVI depends upon calorific value, density, moisture, and ash content. A high value of the FVI reveals a good quality fuel, generally exceeding 500 GJ/m3(Mierzwa-Hersztek, et.al., 2019) . From Table 1 it can be seen that the FVI values obtained for these biomass materials were: Maize stalk (2.60 MJ/kg), Maize cob (14.77 MJ/kg), Sugarcane bagasse (14.75 MJ/kg), Cotton stalk (13.90 MJ/kg), Millet stalk (45.18 MJ/kg) and Sorghum stalk (4.77 MJ/kg). These values of the FVI are pictorially represented in the bar-chart of figure3. The values obtained in this research (in million Joules), indicates that all the agricultural residues tested are generally potentially very good for energy generation.

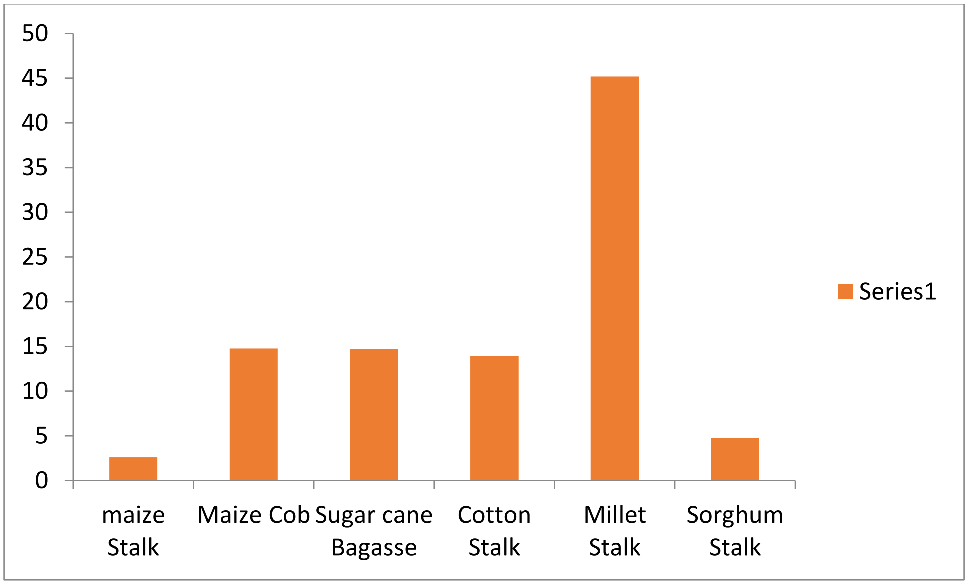

Figure 3: Fuel Value Indices of the Agricultural Residues

Summary and Conclusion

The results obtained in this research indicate that the six agricultural residues studied exhibited good physical, proximate and fuel properties. Conclusively all the agricultural residues tested are generally potentially good materials for use in the production of good quality animal feeds and as feed stocks in renewable energy generation. This will go a long way in mitigating the problem of green-house gases emissions and enhance environmental sustainability.

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