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## RESEARCH ARTICLE

## PRODUCTION AND CHARACTERIZATION OF BIO-BRIQUETTES FROM BIOCHAR DERIVED PYROLYSIS OF RICE HUSK

Ige, Ayodeji Rapheal<sup>a\*</sup>, Elinge, Cosmos Moki<sup>a</sup>, Aliyu, Muhammad<sup>a</sup>, Gwani Mohammed<sup>b</sup>, Ambursa Murtala M<sup>a</sup><sup>a</sup>Department of Pure and Applied Chemistry, Kebbi State University of Science and Technology, Aliero, Kebbi State, Nigeria<sup>b</sup>Department of Physics, Kebbi State University of Science and Technology, Kebbi State, Nigeria\*Corresponding Author Email: [igeayodeji2@gmail.com](mailto:igeayodeji2@gmail.com)

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## ABSTRACT

The exploit of biomass for bio-fuel production is becoming trendy as a waste management option. This study is aimed to investigate the physico-chemical and combustion properties of briquettes obtained from pyrolyzed biochar of rice husk. The rice husk biochar briquette bonded with cassava starch as binder were molded and analyzed. Proximate analysis, ultimate analyses, Scanning Electron Microscopy (SEM), FT-IR, calorific values, density and compressive strength, among other properties, were determined for the fabricated briquettes. A high heating value of 39.72 MJ/Kg was recorded for rice husk biochar briquette and 28.45 MJ/Kg of raw rice husk briquette respectively. The ash contents of 3.89 % and 4.52 % were recorded for raw rice husk briquette and rice husk biochar briquette respectively. It took rice husk biochar briquette approximately 13 minutes to boil 1000 cm<sup>3</sup> of water, while raw rice husk briquette boiled same quantity of water in 17 minutes. The finding of this study shows that the biochars obtained from the pyrolysis of rice husk are more suitable for fuel briquette production than the raw rice husk.

## KEYWORDS

Pyrolysis, Rice husk, Biochar, Briquette, Cassava starch

## 1. INTRODUCTION

The benefits of biomass as a tool for providing sufficient energy have aroused interest of using it as a better option of renewable energy (Zhao and Li, 2016; Chin et al., 2015). Biomass in general, can displace most of other fuel or source of energy, from the fact that biomass fuels have a significant part to play in meeting our energy needs. It is a unique part with the realization of the finite limitation of the fossil resources; a sense of urgency has therefore developed in the exploration of alternative energy and feedstock sources (Onifade et al., 2017).

Pyrolysis is a thermo-chemical conversion of the agricultural biomass by direct thermal decomposition in the complete absence of oxygen which produces three important products which are bio-char, bio-oil and non-condensable gases respectively (Bridgwater, 2012). The biochar is an intermediate solid residue, which is formed in the pyrolysis of most biomass. The char is believed to contribute to the formation of polycyclic aromatic hydrocarbon (PAHs) during biomass pyrolysis, particularly at low temperature (Sharma et al., 2004). The type of biochar depends on different variables: the nature biomass being used, particle size, residence time, the temperature and rate of heating. High and low temperatures have an unequivocal effect on char yields. It has been noticed that at low temperature, biochar has an amorphous carbon structure with a lower aromaticity than the biochar produced at high temperature (Joseph et al., 2010).

Biochar in their natural form are bulky materials, they have low bulk density, low heat release and generate excessive amounts of smoke (Akowuah et al., 2012). It is estimated that the highest bulk density of

unprocessed biochar is around 250 kgm<sup>-3</sup> (Demirbas, 2001). This makes its transportation and storage about five times more costly and also less efficient source of fuel than alternatively using it in the form of briquettes or pellets (Aruna et al., 1997).

The process of briquetting can be adjusted to improve the quality of the briquette through pyrolysis of the agricultural biomass. Few studies on the pyrolysis of agricultural biomass for briquette production have been reported. A group of researchers reported the effect of pyrolysis temperature on charcoal briquettes from biomass waste (Sri and Tutik, 2020). The results showed that the best characteristics of charcoal briquettes was obtained rubber seed shells, the temperature pyrolysis of 600°C, with the moisture content of 7.4%, ash content of 3.55%, volatile matter content of 13.44%, fixed carbon of 75.92% and calorific value of 29.76MJ/Kg. Idris et al., reported kinetic modeling of the pyrolysis of biomass for the development of charcoal briquette and obtained calorific value of 25.95MJ.Kg (Idris et al., 2016). Ifa et al., reported the best properties of bio-briquettes produced from pyrolysis of cashew nut waste with the moisture content of 5.30%, ash content of 5.08%, volatile matter of 18.40%, fixed carbon of 72.27 and calorific value of 29.51MJ/Kg (Ifa et al., 2019).

To date, only a few numbers of research studies have been performed to indicate the potential of pyrolyzed rice husk biochar as briquetting feedstock. Alkogo et al., reported assessment of the potential of charred briquettes from rice husk and obtained 25.72% for fixed carbon and 24.90MJ/Kg for calorific value from slow pyrolysis (Alkogo et al., 2021). Therefore, there is need to investigate the proximate, physico-chemical and combustion properties of the briquette produced from the biochar left over obtained from the pyrolysis of rice husk.

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## 2. MATERIAL AND METHODS

### 2.1 Material

The both raw rice husk and biochar left over from the pyrolysis of rice husk. A previous research investigated the effects of pyrolysis process conditions on the product yield of rice husk bio-oil using a fabricated fixed reactor (Ige et al., 2021). Box-Behnken factorial experimental design with three independent factors (pyrolysis temperature, biomass particle size, and pyrolysis residence time) and three levels (1, 0, +1) of the RSM was used. The selected three levels for each of the independent factors were based on the results of preliminary studies. The factors optimized were pyrolysis residence time in the range of 30-120 min, biomass particle size, 1.0-4.0mm mesh, and pyrolysis temperature, 500-650 °C, respectively. The bio-oil yield of 38.39% for rice husk occur at a temperature of 650 °C, particle size of 2.03 mm and time of 81.18 minutes were obtained from validation experiments conducted at the levels of the process variables predicted. The leftover biochar were collected for the production of briquette. The biochar and raw rice husk were sieved with 2mm wire mesh to reduce the particle size into fine particles and were stored in air-tight containers until further use.

### 2.2 Briquette Production

The briquettes were produced using a fabricated briquetting machine which works on 10 ton hydraulic jack that press a chamber of a cylindrical mould confining the slurry. The length and the breadth of briquettes are 94 mm and 61 mm respectively as shown in Figure 1 and 2. Few studies have established that cassava starch binder is the best for briquette production (Ige et al., 2018; Onuegbu et al., 2012). Cassava starch was procured from Kuto market, Abeokuta, Ogun State and was used as binder as shown in Figure 3. The dried samples of biochar from rice husk and raw rice husk were weighed, mixed in ratio 4:1 thoroughly with water to form slurry and fed into the mould to produce briquette and the briquettes were sun dried for two weeks.



Figure 1: Rice Husk Briquettes



Figure 2: Rice Husk Biochar Briquettes



Figure 3: Cassava starch

### 2.3 Elemental Analysis Determination

The elemental analysis of the raw and biochar samples was determined by the element analyzer (CHNS analyzer ASTM D5291 method) and Oxygen

was calculated according to Sallau et al., procedure (Sallau et al., 2021).

### 2.4 Physico-Chemical Properties Determination

The ash content, moisture content, fixed carbon and volatile matter of the briquette samples were determined according to ASTM D-3172 specifications. The calorific value was determined using LECO AC 350 Bomb calorimeter according to ASTM D-5865M-19. Density was determined according to DIN 52182 and 51731 specifications described elsewhere (Krizan et al., 2009).

Compressive strength of the briquette sample was determined using an ELE tritest 50 compression machine according to D 3173-878 specifications (Wilaipon et al., 2007). The water boiling test was examined by recording the time taken for a given mass of 500 g of the briquette sample to first boil 1000 cm<sup>3</sup> of water under similar conditions (Onuegbu et al., 2011). Afterglow and ignition propagation were determined using Oladeji et al., (Oladeji et al., 2009). The burning rate at which briquettes of various fuel samples were burnt was determined by Equation 1 below as suggested by Prasad, et al., (Prasad et al., 1983):

$$m_f = \frac{w_i \times w_f}{t} \quad (1)$$

Where;  $m_f$  = Burning rate (kg/hr),  $w_i$  = initial weight of fuel before combustion (kg),  $w_f$  = final weight of fuel after combustion (kg),  $t$  = total boiling/cooking time (hour).

### 2.5 FTIR (Fourier Transform Infrared Spectroscopy)

Infrared spectra of raw and biochar rice husk were measured on AVATAR 330 Fourier Transform infrared (FT-IR).

### 2.6 Scanning Electron Microscopy

The micro-structure of the raw and biochar rice husk were analyzed by Scanning Electron Microscopy (SEM). The samples were first transferred to capsules and coated with Palladium (Pd) at 30 mA and analyzed in a JEOLJFC-5510LV Scanning Electron Microscope (Oyibo et al., 2020).

### 2.7 Statistical Analysis

The average of all the parameters analyzed was computed by pair T-test using Graph Pad Prism® (Version 6.04) and results were presented as mean ± SEM.

## 3. RESULTS AND DISCUSSION

The results of the proximate of the raw samples (rice husk and pyrolyzed biochar samples rice husk) were shown in Figure 4. The results obtained were compared well with the findings reported by Lasode et al., and Prins et al., (Lasode et al., 2014; Prins et al., 2006). The lower moisture obtained for biochar rice husk may be due to dehydration while undergoing pyrolysis. It was reported that a high concentration of volatiles will be released during pyrolysis at high temperature and part of the volatiles could be trapped within the carbon matrix of biomass, forming secondary char that contributes to a high C % (Shu-Hong et al., 2014).

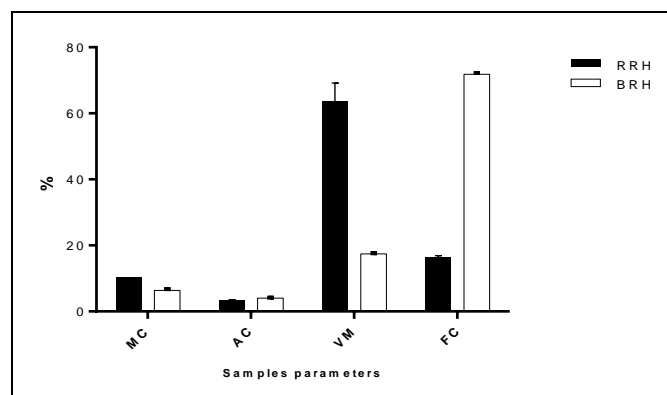


Figure 4: Proximate Properties of Raw and Biochar Rice Husk

The heating values of the raw samples (rice husk and pyrolyzed biochar samples rice husk) were shown in Figure 5. The heating values of the raw and biochar samples were less than the heating value (35.48MJ/Kg) reported for chestnut shell biochar (Jiang et al., 2018). The heating values obtained are suitable for solid fuel production. The heating values were compared well with ASTM standard of coal 30.00MJ/Kg.

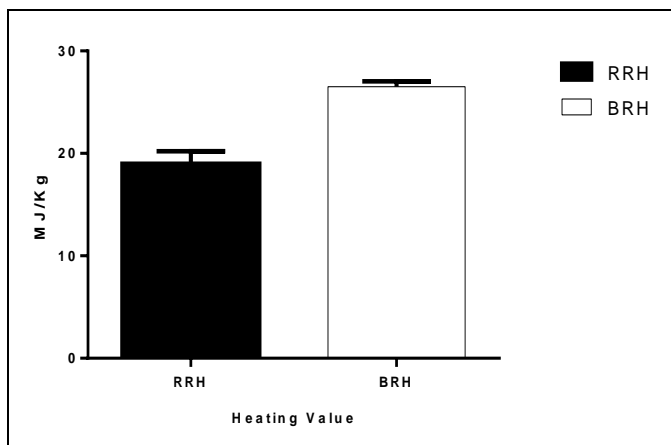


Figure 5: Heating Value of Raw and Biochar Rice Husk

Figure 6 showed the results of elemental analysis of the raw rice husk and biochar rice husk. High carbon content in fuel aids combustion. Studies of biomass structure have revealed that cellulose and hemicelluloses loses also have a significant influence on carbon and ash contents (Tripathi et al., 2016). The oxygen contents in biochar were reduced due to dehydration of biomass and the electronegativity nature of oxygen itself while undergoing pyrolysis. According to Ryemshak and Aliyu, low hydrogen content results in low amount of volatile matter (Ryemshak and Aliyu, 2014). The higher nitrogen content recorded for the raw rice husk shell could be attributed to the present of nitro compounds. Though the percentage nitrogen content obtained for the biochars are welcomed because high levels of nitrogen in fuels could lead to the formation of photochemical smog and also serious respiratory conditions.

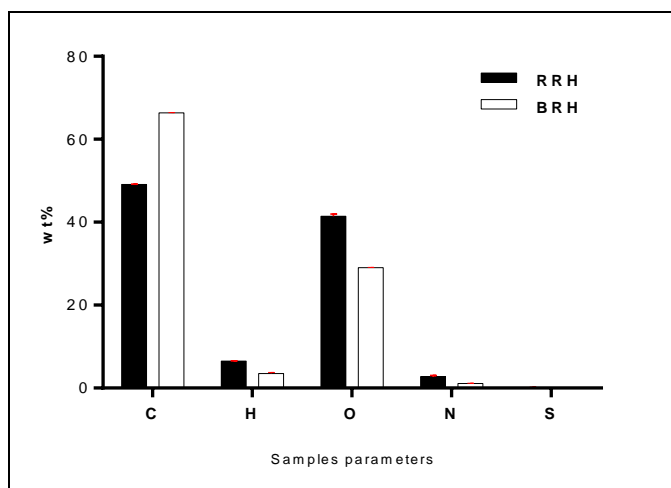


Figure 6: Elemental Analysis of Raw and Biochar Rice Husk

The results of moisture content obtained are compared well with that of biochar briquette produced from pyrolysis of palm kernel (1.75 %) as reported by Nurhayati et al., (Nurhayati et al., 2017). Moisture content value greater than 20% may have a marked effect on the stored or residual energy needed for the complete combustions of the fuel for water evaporation at the expense of the fuels calorific value. This may have an effect on the shelf life of the briquette. High ash content is an indicator that helps to determine the dust emission rate of a briquette. Its general value may appear in a range of 5-20%, the moisture content values obtained are considerable as shown in Figure 7. Any values above this may result to environmental pollution (Maninder et al., 2012; Olorunnisola, 2007).

High volatile matter content of 66.25 % was recorded for raw rice husk. The combustibility of a briquette fuel also depends on the volatile matter content. The higher the volatile matter of a fuel briquette the higher its combustibility, provided low ash content is recorded (Praveena et al., 2014).

The fixed carbon content measures the percentage of combustible carbon available after the removal of volatile matter. It is used to determine the heating value and as well act a heat heat generator during combustion. The high fixed carbon value of 69.36% observed in rice husk biochar briquette shows that the pyrolyzed sample will produce more heat than the non-pyrolyzed sample.

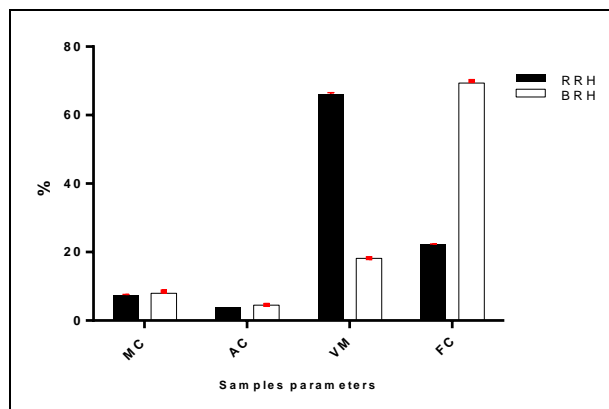


Figure 7: Proximate Properties of the Raw and Biochar Rice Husk Briquettes

The density values of 0.75 g/cm<sup>3</sup>, and 1.20 g/cm<sup>3</sup> were recorded for raw rice husk briquette and rice husk biochar briquette as shown in Figure 8. The obtained density value was observed to be compared well to the reported value of 0.89±0.06 g/cm<sup>3</sup> charcoal briquettes from water hyacinth (*Eichhornia crassipes*) and banana peel 0.60g/cm<sup>3</sup> (Wachira et al., 2015; Davies and Abolade, 2013). It is also expected that rice husk biochar briquette combustion rate maybe longer with the density value obtained compared to raw rice husk briquette sample (Olawale et al., 2014).

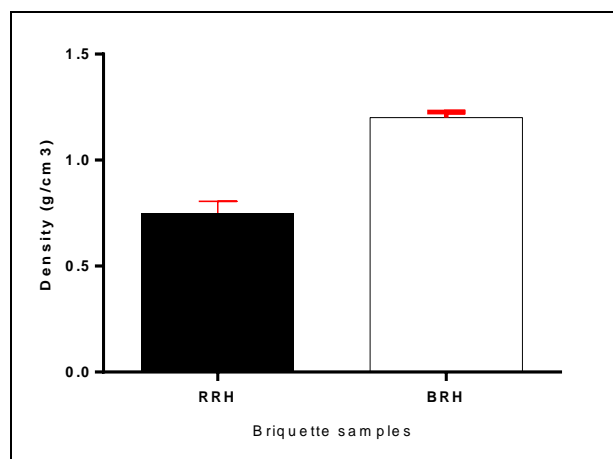


Figure 8: Density of the Raw and Biochar Rice Husk Briquettes

A compressive value of 1.10 N/mm<sup>2</sup> and 3.42 N/mm<sup>2</sup> were recorded for raw rice husk briquette and rice husk biochar briquette as shown in Figure 9. The compressive strength depends on the density, moisture content and lignin content of the biomass materials. The higher the density and decrease in moisture content was found to increase the compressive strength (Sotanne et al., 2010).

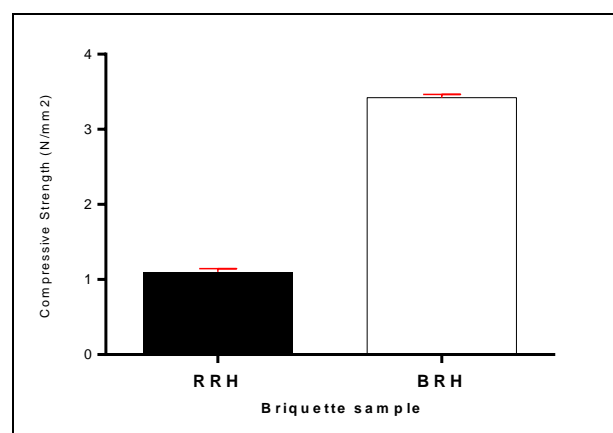


Figure 9: Compressive Strength of the Raw and Biochar Rice Husk Briquettes

Furthermore, heating value is regarded as one of the essential parameters to be considered thus, determining the usage of any potential fuel to serve its purpose. A high heating value of 39.72 MJ/Kg was recorded for rice

husk biochar briquette compared to 28.45MJ/Kg of raw rice husk briquette as shown in Figure 10. Although, the calorific value of the samples were observed to be considerably high as shown in Figure 10. The heating values of the briquette were improved due to the densification process as reported (Demirbas, 2013). From the results, rice husk biochar briquette recorded a higher heating value. The values obtained are compared well to those earlier reported from previous findings, for example; 11.99 MJ/kg watermelon peel briquette and  $32.61 \pm 0.81$  *Gmelina arborea* biochar briquette while lower than the heating value of 52.81MJ/Kg obtained for *C. gabunensis* sawdust briquette by Boasiako and Acheampong, (Adegoke and Ogunsanwo, 2017; Boasiako and Acheampong, 2016). However, this may be attributed to the high density, lower volatile matter, and high fixed carbon.

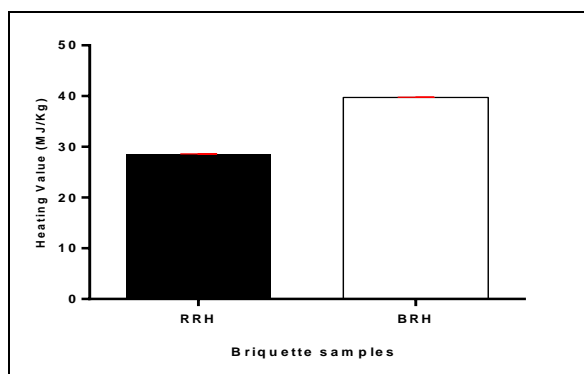


Figure 10: Heating Value of the Raw and Biochar Rice Husk Briquettes

The results of the ignition propagation are shown in Figure 11. The biomass briquettes have short ignition time and will catch fire easily. The density, porosity and moisture content of briquette have an influence on the ignition propagation value of such briquette (Adegoke and Fuwape, 2008).

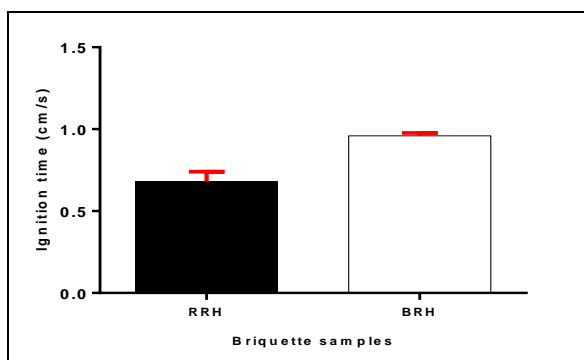


Figure 11: Ignition Time of the Raw and Biochar Rice Husk Briquettes

The results of the afterglow time are shown in Figure 12. The afterglow values for raw rice husk briquette and rice husk biochar briquette are 49 Sec, and 57 Sec respectively. It is noted that, the higher value recorded for rice husk biochar briquette could be attributed to the reduction in the porosity exhibited between inter and intra particles which does not enable easy infiltration of oxygen and outflow of combustion briquettes.

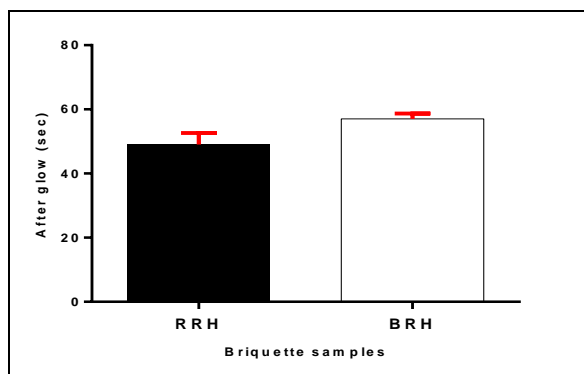


Figure 12: Afterglow of the Raw and Biochar Rice Husk Briquettes

The results of the combustibility test are presented in Figure 13. This was carried out to compare the cooking efficiency of the briquettes. It measured the time taken for each set of briquettes to boil an equal volume

of water under similar condition. From the results obtained, it was observed that, the higher calorific value recorded for rice husk biochar briquette actually reduced the time taken to boil the same quantity of water and improving the residence time for the briquettes to undergo complete combustion (Nwabue et al., 2017). Lubwama and Yiga, recorded time of 13 minutes to boil 1 liter of water at similar condition and Lubwama et al., recorded time of less than 25 minutes to 1 liter of water for 200g of briquette (Lubwama and Yiga, 2019; Lubwama et al., 2019).

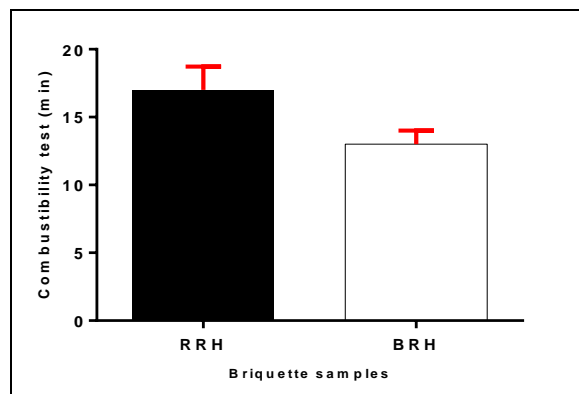


Figure 13: Combustibility Test of the Raw and Biochar Rice Husk Briquettes

The fuel burning rate was defined by the rate of amount of fuel burnt to the time taken to boil 100°C. as shown in Figure 14, the rice husk biochar briquette has the higher fuel burning rate of 1.40 Kg/hr while the raw rice husk briquette had the lower fuel burning rate of 1.10 Kg/hr. The briquettes with higher burning rate are economical as smaller amount of it is required to cook a given quantity of food (Tangsathitkulchai et al., 2016).

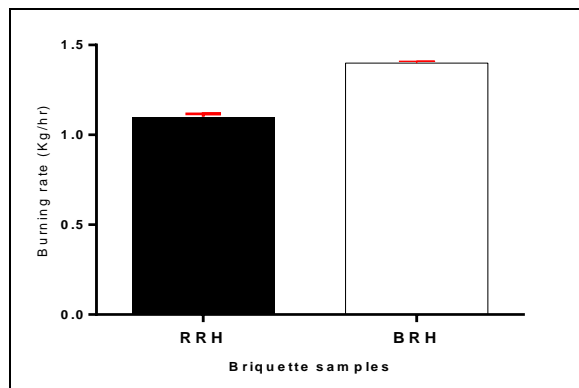


Figure 14: Burning Rate of the Raw and Biochar Rice Husk Briquettes

The FTIR was used to evaluate as well as to monitor the effects of pyrolysis on the adjoining bonds in the pyrolyzed fiber matrix. An absorption band which is characteristic of hydrogen bonded hydroxyl group was observed in the raw sample at  $3272\text{cm}^{-1}$  as shown in Table 1. The reduction of peaks at the range of  $1599\text{cm}^{-1}$ , which represents aromatic C=C stretching, shows that there is lignin decomposition after the pyrolysis as shown in Figure 15. The peak reduction was greatly noticed in biochar sample. The intensity of the hydroxyl peak (O-H) which decrease for the biochar sample indicates that the loss of hydrogen and oxygen atoms due to the breaking bond from hydroxyl group.

Table 1: FT-IR Characteristics of Raw and Biochar Materials				
RRH	BRH	Range ( $\text{cm}^{-1}$ )	Functional Group	Characteristics
3272	-	3570-3200	OH	Broad
2918	-	2935-2915	C-H	Methylene, Assy/Sym Stretch
2851	-	2865-2845	C-H	SP <sup>3</sup> Stretch
1640	1599	1650-1566	C = C	Cyclo Alkene Stretch
1417	-	1450-1335	C-H	Bending Vibration
1026	1067	1150-1000	C-H	C-O Stretch Vibration of Ester

RRH: Raw Rice Husk, BRH: Biochar Rice Husk

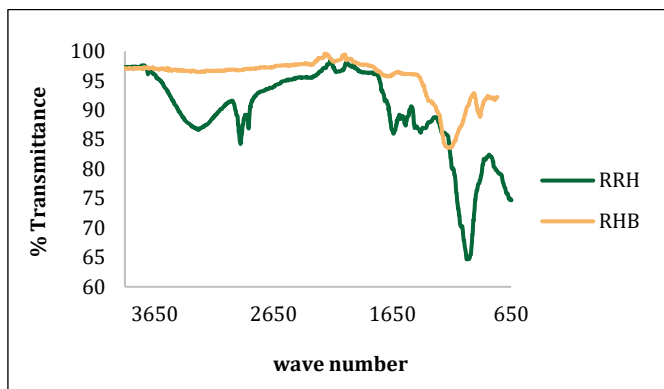


Figure 15: FTIR Spectral of Raw and Biochar Rice Husk

The SEM micrograph of raw rice husk and rice husk biochar was shown in Figure 16 and 17. The raw rice husk had porous rough surface arranged uniformly as stacked layers. Raw rice husk have a porous rough structure on the surface compared to the rice husk biochar with porous fine structure. Increasing pyrolysis temperature causes changes in biochar surface area and porosity (Bonelli et al., 2007). This most likely may due to decomposition of organic matter and the formation of micropores which enhance the adhesion of the materials during densification.

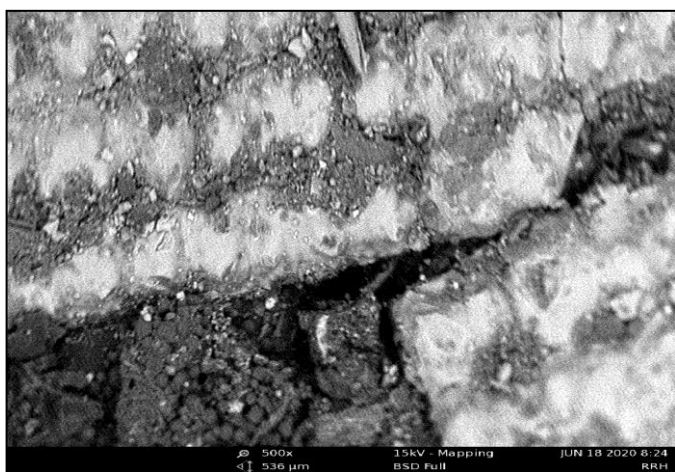


Figure 16: The SEM image of raw rice husk at 536µm

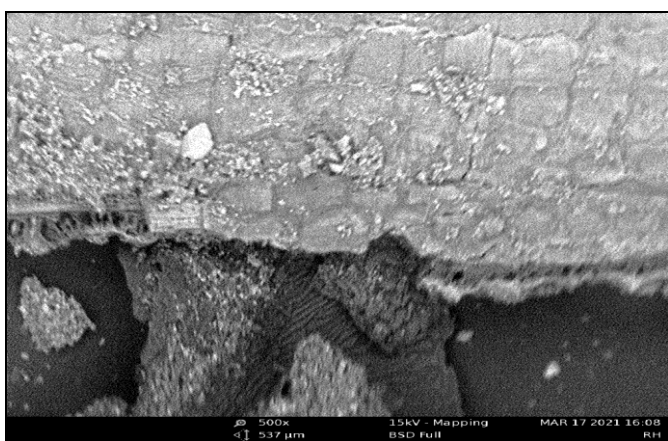


Figure 17: The SEM image of biochar rice husk at 537µm

#### 4. CONCLUSION

The study investigated the effects of pyrolysis on the physico-chemical and combustion properties of rice husk biochar briquette. The finding of the study for all the necessary parameters showed that the rice husk biochar briquette had an improved performance than the raw rice husk briquette examined. Furthermore, an observable decrease in the intensity of the hydroxyl peak (O-H) for the biochar sample indicates that the loss of hydrogen and oxygen atoms due to the breaking bond from hydroxyl group as a result of pyrolysis. This improved adhesion and compactness resulting to high energy release. Conclusively, pyrolyzing a biomass before briquetting improves the quality and combusting performance of the briquette.

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