

Characterization of Sago-based Biochar as Potential Feedstock for Solid Fuel

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Abstract

Due to decreasing supply of fossil fuels and growing environmental concerns, the application of biomass-derived energy is gaining in importance nowadays. In this study, batch pyrolysis was used to derive biochar from Sago (*Metroxylon Spp*) in an electrical furnace reactor. Raw biomass was selected from different sources of Sago palm including barks, fronds and cortex and the characterization was conducted for each source individually. The range between 350 °C and 550 °C temperature, the materials were pyrolyzed and with constant nitrogen flow rate of 50 mL min⁻¹. Each sample of biochar produced are evaluated through proximate analysis, ultimate analysis and scanning electron microscopy (SEM) to study its potential as solid fuel for energy production. The pH value of biochar was also calculated experimentally. The total yield following by the amount of ash, volatile matter, fixed carbon content and high heating value (calorific value) were obtained in the results of all three biochar samples. Various pyrolysis temperatures resulted in different char production yield and therefore the carbon content of the produced biochars were varied within the range of 40 to 53 wt. % which is corresponded to 35 to 40 wt. % of the carbon content in biomass samples. The pH of biochar was observed to increase from 7 to 8.3 with temperature risen from 350 °C to 550 °C. The results from this study can be used to establish the ideal utilization routes of biomass in production of biochar as well as the source of energy.

Keywords: Sago (*Metroxylon Spp*); pyrolysis; calorific value; energy; pyrolysis

1.0 INTRODUCTION

Rural population according to the databank of Department of Statistics Malaysia (DOSM, 2017) [1] accommodate about 25% of the total living population in Malaysia. The biomass residue is usually produced in rural area. Biomass pose a challenge in its use in their original form as fuel, as they have characteristics of low bulk density, with low heating value and smoke they emit with low volume. Organic material such as lignocellulosic has great numbers and used as fuel and it is can be upgraded to generate biochar [2]. When pyrolysis of forestry or agricultural biomass is done on a solid product, the term for it is called Biochar [3, 4, 5]. The pyrolysis process involves a heated substrate without the presence of oxygen [5]. This way of processing gives a new way of adding value to the biomass residues [2, 6, 7]. Yields of biochar are affected by the factors from the way of processing and pyrolysis temperature. However, the physiochemical attributes of the feedstock should not be neglected [5, 8, 9, 10]. The outcome of the biochar that is derived from biomass can be broken more into fuel briquettes as a result of carbonization. Hence, different types of biomass generate biochars of the thermal characterization are vital to be investigated. The most fitting to biochar production are then identified. Until now, research is scarce in the area of assessing the thermal characteristics of these biomass sources that generates biochars.

The current research aims to study the potential of Sago palm in production of biochar as solid fuel through characterization analysis. The biochar is produced as a result of pyrolysis with different temperature values and the final product is aimed to be analyzed for its capability of use in thermal processing application. To put it simply, the final result of the study will rule the substrates that will be relevant as fuel biochar material. In addition, the results would help in providing in giving a technical guide for agricultural and forestry residues that are used for biochar.

2.0 METHODOLOGY

2.1 Biomass and Samples

Three types of sago sources namely Sago barks, fronds and cortex obtained from Oya district in Mukah, Sarawak, Malaysia. The sago was dried, minced by a pulverizer and grinded to obtained the particles size below 40-mesh.

2.2 Biochar Yield Production

By using the electrical furnace, carbonization is done between 350°C to 550°C temperature, heating rate of 10°C min⁻¹ at 10 minutes of operation and under an inert flow rate of 50 mL min⁻¹ nitrogen. Three biomass samples were prepared according to each source and five values of temperatures (350 °C, 400 °C, 450 °C, 500 °C and 550 °C) were selected for the design of experiment. Each experiment was repeated twice to gain more accurate outputs. The produced samples were then collected, crushed and filtered using a 50µm 80-mesh sieve for the further analyses.

2.3 Analysis of Biomass and Biochar

Thermogravimetric analysis (TGA) and ASTM methods were utilized to compare and examine the properties of Sago biomass and biochar through proximate analysis. The ultimate analysis of the contents of C, H and N contents were performed by the elemental analyser (CE Instruments, EA 1108). The determination of O content can be done by computing the difference (100 = %C - %H - %N), respectively.

To investigate the weight loss, thermogravimetric analysis (TGA) (Shinco, TGA N-1000) was performed. The high heating value was determined using the 1341 Standard (Method, 2015) with a Bomb Calorimeter.

The scanning electron microscopy (SEM, Model HITACHI): S-3400 N with potential of 1-25kV was used to study the morphology the biochar.

3.0 RESULTS AND DISCUSSION

The results from characterization of biomass as well as biochar are indicated and discussed accordingly in following sections.

3.1 Biomass Characterization

Characterization of the analysis is a measure of total biomass components in terms of moisture content, Ash content, volatile matter and fixed carbon content of solid fuel (proximate analysis) [14,19,23]. The advantages of biomass characterization are cheap, relatively simple and robust that is commonly used to explain the biomass fuels properties. The composition of compounds including carbon, nitrogen, hydrogen and sulfur can be obtain through ultimate analysis. The present study shows that for the biochars and raw biomass, their ash and volatile contents differed immensely. The pyrolysis components such as heating rate, peak temperature and residence time will affected the structural components from the raw biomass [3, 5,8,9,10].

The comparative results of Sago used in this study and others biomass for biomass characterization are summarized in Table 1. The results are indicated in comparison of Sago to other types of commonly used biomass in biochar production taken from the literature. From the results of proximate analysis, it observed that the volatile matter of sago are in the range of between 73.59 and 74.58% hence it considers relatively high as compared to other biomass. The fixed carbon contents are in the range of between 7.80 and 7.93% which is apparently in acceptable range when compared to other common biomass such as empty fruit bunch (8.35%) and Napier grass (8.35%). The change interval of the ash contents are obtained between 4.13 and 4.60% which seem to be low enough to be considered suitable in biochar production as compared to Napier grass (9.68%), EFB (4.50%) and Macroalgal (41.66%). Carbon content of Sago samples as regard to the results of ultimate analysis are observed between the ranges of 35.73% to 40.46% that is comparable to other common biomass.

Table 1. Characterization of biomass samples (Proximate and ultimate analysis)

Biomass	Sago Bark's (this study)	Sago Fronds (this study)	Sago Cortex (this study)	Napier Grass [11]	Empty Fruit bunch [12]	Macroalgal <i>Ulva prolifera</i> [13]
Moisture	13.88	13.32	13.49	9.43	7.80	6.05
Volatile matter ^a	73.59	74.52	74.58	72.58	79.34	47.74
Ash ^a	4.6	4.32	4.13	9.68	4.50	41.66
Fixed Carbon ^{ac}	7.93	7.84	7.8	8.35	8.36	3.26
Carbon ^b	35.73	40.46	37.6	42.40	43.52	33.45
Hydrogen ^b	6.67	6.38	6.64	5.96	5.72	5.14
Nitrogen ^b	0.2	0.3	0.2	1.71	1.20	5.51
Sulfur ^b	0.19	0.1	0.12	0.09	0.66	0.85
Oxygen ^c	57.21	52.76	55.44	45.32	48.90	55.05
HHV (MJ/kg)	21.63	23.23	22.33	18.05	15.22	8.89

^aResults expressed as a percentage of dry matter

^bResults expressed as a percentage of dry matter free of ashes

^cCalculated by difference

3.2 Yield Analyses

According to the results from Figure 1 all biochar yields from Sago barks, fronds and cortex decrease constantly with higher pyrolysis temperatures. For Sago barks, it decreased from 43.15% at 350 °C to 33.75% at 550 °C, whereby for fronds and cortex it dropped from 25.3% and 43.7% at 350 °C to 21.41% and 33.20 % at 550 °C respectively. The same results was previously reported in the literature [14,15]. The results of greater decomposition of organic material happened at higher temperature with lower biochar yields compared to at higher temperatures will promoting the release of volatile materials. Because of the contrast that is present in the produce of the different biomass of its relative abundance of lignin, hemicellulose and cellulose; there is a known variety of produce. These yields also have different degradation kinetics. The differences between the resultant biochars were most likely attributable to the thermal resilience of lignin, as opposed to hemicellulose and cellulose that decompose at temperatures lower than 400°C and at higher carbonization temperatures biochar yields are decreased [7,9,16,17,18,19].

Products of pyrolysis yields more solid of biochar than bio-oil and noncondensable gases with the conversion of raw material as appointed by (McKendry, 2002) [20]. Slow pyrolysis is used in this study since there is a general favor to the production of biochar. Char is primarily produced when slow pyrolysis is done at slow heating rates at lower temperatures. On the other hand, high temperatures of slow pyrolysis primarily give out product that are gaseous [21,22]. As an example, the yield rice straw biochars were significantly higher via slow pyrolysis (45-48%) as opposed to fast pyrolysis (27%)[21,22]. Adversely, there is a general favor in the production of bio-oil for fast pyrolysis. It is based on fast heating rates, short resident times and moderate temperature [23,24]. The highest yield of biochar was related to the pyrolysis of Sago barks which is aimed to be taken into further analysis to study its potential as solid fuel in following sections.

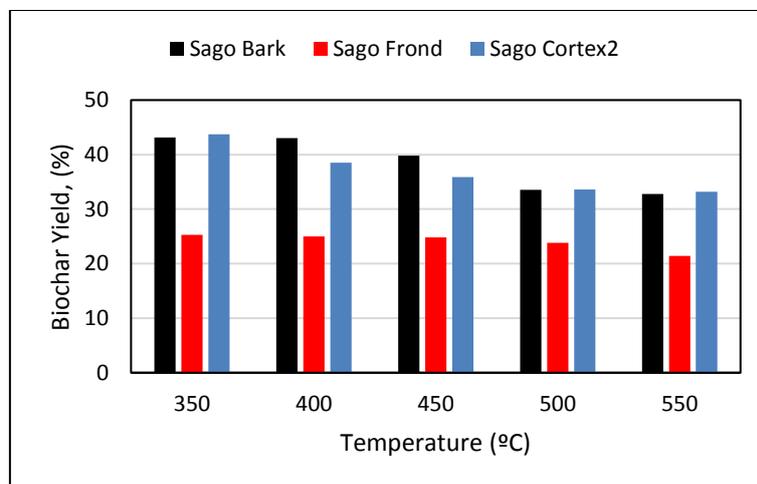


Figure 1. The effect of temperature on biochar yield from pyrolysis of Sago barks, fronds and cortex

3.3 Characterization of Biochar produced from Sago barks

Characterization analyses and calorific value (HHV) of the sago barks biochar is summarized in Table 2. A comparison of results to some biochar samples from literature are also indicated in the table. According to results of characterization, the volatile matter content is 61.51%, which as compared to the results from table 1 shows that around 12% of volatiles has been reduced during the pyrolysis. Fixed carbon content of biochar from Sago barks was 10.37% which is comparable to the one from EFB (10.80%). The sago barks were relatively high of ash content. The results are in agreement with Obernberger et al. (1997)[21], in his research found that ash content was higher in the bark. Silicates potassium, calcium carbonate, iron and other metals with different form the ash concentration have correlation to differences in content of ash. Ash is not combustible and effect of calorific value in a way that negative [26]. To add, the combustible waste with the best process is needed for this purpose. Also, since there is an increase in emissions of dust, there will be an increase in maintenance of boilers [26, 27, 28, 29, 30]. As a result of this unnecessary and lowers the efficiency of the process; down time and reduce the efficiency of the process. Therefore, the reason for the selected fuel sources is chosen among the biomass with a low ash content.

Table 2. Characterization and higher heating value (HHV) of biochars from Sago barks and other sources

	Sago Bark's (this study)	Napier Grass [21]	EFB [13]	Microalgal [30]
Moisture	3.97	1.30	6.90	1.45
Volatile matter ^a	61.51	27.00	79.4	28.00
Ash ^a	24.15	12.30	2.90	29.50
Fixed Carbon ^{ac}	10.37	60.70	10.80	42.00
Carbon ^b	53.53	77.40	43.06	51.00
Hydrogen ^b	5.06	5.01	5.98	2.50
Nitrogen ^b	0.23	1.21	0.55	7.70
Sulfur ^b	0.06	0.29	0.00	0.00
Oxygen ^c	41.12	16.10	50.42	18.00
HHV (MJ/kg)	25.44	29.70	21.34	NA

3.4 Higher Heating Value (HHV)

Biomass have high heating value are the best select to generate energy source. For this purpose, the HHV is one of the most important parameters related to energy analyses. It is interpreted as the energy that is let out per unit mass or volume of the fuel after the completion of the process of combustion. This includes the energy that is present in the water vapour in the exhaust gases [12,23,31,32]. Since HHV illustrates the energy content, it is an indicator for best use of biomass fuel [2,24,27,32,33]. The calorific values are represented by HHV for this study given in Table 2. Sago samples were approximately 25.44 MJ/kg of the HHVs. However, the high heating values of different biochar samples (Napier Grass and EFB) in the literature are 29.70 and 21.34 (MJ/kg) respectively. [13,17,21,23,30,32] The same study was reported that biochars derived from bark had higher HHVs in general.

3.5 Scanning Electron Microscopy (SEM)

Micrographs of sago barks sample cells are seen from the Scanning Electron Microscopy (SEM) under 300 and 1,000 times magnification. Figures shows the results of increased porosity from volatiles escaping during thermochemical degradation. Rapid devolatilization creating very porous (macroporous) and fragmented chars when the pyrolysis char happened and the particle size will decrease.

The morphological properties of sago barks were studied over different pyrolysis temperatures of 350°C and 400°C. Figure 2 (a-d) shows, both prepared sago biochar possessed broken cell walls structures. It can be attributed to the low mechanical properties due to having low density [30, 31]. In order to mitigate this problem, the density of the sago biochar should be increased. Besides that, mechanically broken down the cell resulting in higher extraction yields when the drying process of biomass happened [18, 26, 31, 33, 34, and 35]. The development of pores in biochars can be explored using the SEM and pore volume distribution. The sago barks biochar have the pore sizes of about 50-500 µm. The raw biomass vascular structure is the source of these large pores. The larger lignin usually in the cell wall and it is observed that the

thermal decomposition of cellulose and hemicellulose has abandoned these cell walls.

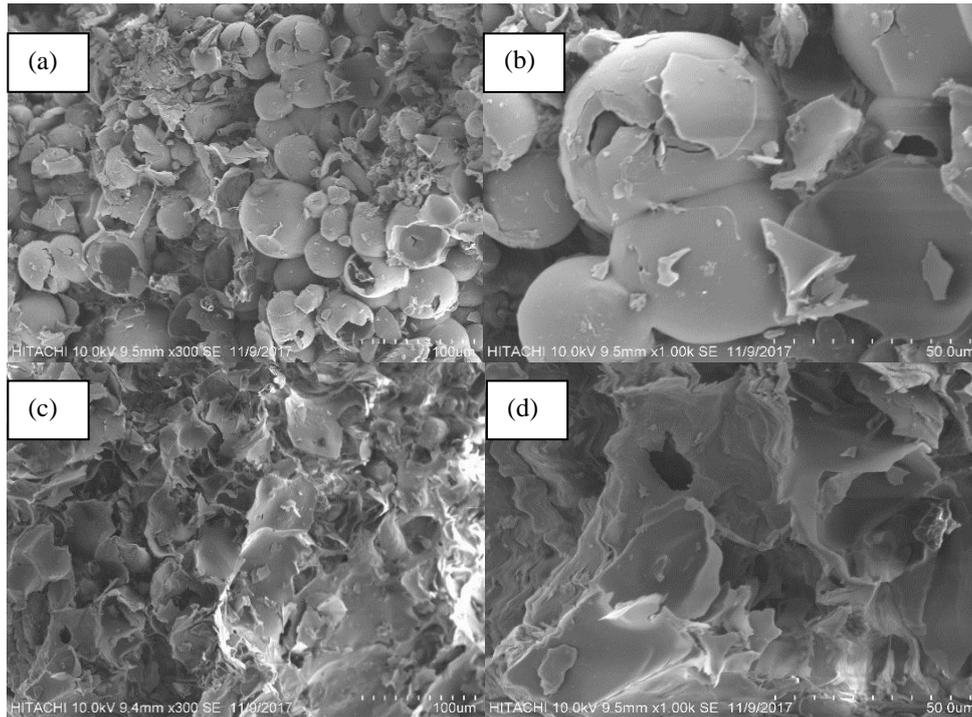


Figure 2. Micrographs of Sago barks biochar pyrolyzed at 350°C and 400°C.

4.0 CONCLUSION

The study was aimed to study the properties of Sago-based biomass in production of biochar through pyrolysis. Three types of biomass were selected from different source of the plant including Sago barks, fronds and cortex. Further in the study, the potential of biochar was analyzed and compared with other biomass with the purpose of use as solid fuel. It was observed from the results that, sago barks with relatively high fixed carbon of 7.93% and low ash content of 4.60% as well as the carbon content 53.53% can be considered suitable for biochar production. It was also observed that lower pyrolysis temperature effected the biochar yield and led to reduce the amount of production hence the lowest temperature of 350 °C was selected as the most suitable temperature. The biochar from sago barks since found with highest yield, was selected for further analysis. Although the ash content of the produced biochar is relatively high and considered an undesired feature as a solid fuel, the high HHV and high carbon content on the other hand are indicating a biochar with high combustibility and consistency. It was observed that both prepared sago biochar possessed broken cells wall structure and seen using scanning electron microscopy. It can be attributed to the low mechanical properties due to having low density and the density of the sago biochar should be increased in order to rectify the issue.

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