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RESEARCH ARTICLE

CHARACTERISTICS OF BIOCHARS FROM PLANT BIOMASS WASTES AT LOW-TEMPERATURE PYROLYSIS

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ABSTRACT

The effects of biochar as soil ameliorants depend on their characteristics that are influenced by the variation in biomass origin and pyrolysis process. In this context, the objective of this study was to determine the chemical and physical characteristics of seven biochar derived from different biomass wastes - rice husk, corn cob, empty oil palm fruit bunch, bagasse, and sawdust of albazia (*Albizzia falcataria*), maesopsis (*Maesopsis eminii*), and mahogany (*Swietenia macrophylla*) at two low-pyrolysis temperatures (250 and 350 °C). The results showed that the percentage of biochar yield decreased at higher temperature level. However, the increased thermal decomposition of plant biomass wastes (at 350 °C) resulted in higher pH, as well as ash, C, N content of the biochar; but it did not significantly affect nutrient availability. Biochar from wood waste had more C and Ca content. Biochar from rice husk produced the highest ash content, while biochar from empty oil palm fruit bunch yielded the highest pH value, and possessed more nutrients than all the others. Increasing pyrolysis temperature from 250 to 350 °C resulted in greater biochar surface area and total pore volume but produced smaller average pore radius.

Keywords: ameliorant, pyrolysis process, thermal decomposition

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INTRODUCTION

The use of biomass wastes in the form of charcoal, which is also referred to as biochar, as a soil ameliorant has lately shown rapid developments. This is demonstrated by the growing number of biochar research by soil and environmental scientists worldwide. Global interest in biochar utilization started with the discovery of a black soil (or dark earth), later known as *terra preta*, in the Amazon valley in Brazil. This soil is believed as a product of prior human activity in the site, especially shifting cultivation and burning remains of forest wood practices (Glaser, Lehmann, & Zech, 2002). This black soil (dark earth) turned out to be much better, in terms of physical and chemical properties, than the virgin soil in the surrounding area. In their investigation, (Glaser, Haumaier, Guggenberger, & Zech, 2001) and (Neves, Petersen, Bartone, & Da Silva, 2003) wrote that *terra preta* typically contained at least twenty times more carbon, making it very dark in color, and three times more nitrogen and phosphorus, compared with the virgin soil.

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Biochar is derived from thermal decomposition process, or carbonization, of organic materials such as plant parts, wood, sawdust, animal dung, and the like at a certain temperature level and condition without oxygen. Carbon in biochar is generally more stable, chemically and biologically than carbon in organic materials and in the products of their natural decomposition processes. In fact, some researchers, like (Lehmann & Joseph, 2009; Liang et al., 2008; Schmidt, Skjemstad, & Jager, 2002), have reported that soils containing biochar could hold carbon for as long as hundreds, or even thousands, of years. It should be noted, however, that the role of biochar in conserving carbon, as well as in ameliorating soils, depends on its characteristics of biochar. Characteristics of biochar, on the other hand, depending on the source material and the biochar-making process involved. Thus, it is not surprising that there is a growing international research focus on knowing and understanding the characteristics of biochar towards its optimal utilization, as well as for environmental conservation.

The attributes of biochar rely primarily on the thermal decomposition process, or pyrolysis, which can occur in four conditions, namely: gasification, rapid pyrolysis, moderate pyrolysis, and slow pyrolysis. As implied, gasification (at a temperature level of >800 ^{o}C) produces mostly gas, while rapid (at 600–700 ^{o}C) and moderate (at 500–600 ^{o}C) pyrolysis yield mainly bio-oil. On the other hand, slow pyrolysis (at <400 ^{o}C) results in predominantly solid material, called biochar (Sohi, Lopez-Capel, Krull, & Bol, 2009).

Aside from the process of pyrolysis, the characteristics of biochar depend on the biomass from where it is derived or the source material that is used. One promising source material for biochar production is wood residue, such as sawdust. In this regard, (Menlhk, 2016) reported that the total volume of processed wood in Indonesia in 2015 was 15.9 million m^3, out of which sawnwood volume amounted to 1.9 million m^3 (12.19%), and wooden furniture output was 0.1 million m^3 (0.75%), accounted for mostly by production in Java island. To illustrate, sawnwood and wooden furniture production in Java island reached 1,6 million m^3 (53.21%) and 0.1 million m^3 (94.69%), respectively out of the national total production volume. Albazia (*Albizzia falcataria)*, maesopsis (*Maesopsis eminii*) and mahogany (*Swietenia macrophylla)* are among the most common, or favored, tree species for such utilization purpose. Again, (Menlhk, 2016) reported that the combined production of albazia, maesopsis and mahogany wood in 2015 was 2.9 million m^3 (6.58%) out of total log production (43.9 million m^3) in the whole country. This log production volume came mostly from community forests, in which wood waste management remains a major concern.

Apart from wood residue utilization, there is huge potential for biochar production from agricultural wastes, such as rice husks, corn cobs, empty fruit bunches of oil palm, cane bagasse, among others. To illustrate, the gross national product of rice, corn, palm oil, and cane sugar in Indonesia in 2013 were 71; 18; 26; and 2 million tons year^{-1}, respectively (BPS, 2017). These can be correlated with the reported production wastes likewise generated, that is, 30-40% rice husk (Patabang, 2012), 40-50% corn cob (Richana et al., 2007), 40-45% empty oil palm fruit bunch (Gurning, Tetuko, & Sebayang, 2013), and 30% bagasse (Mirwan, 2005) out of the respective gross harvest yields of the said crops. Unless effectively and efficiently utilized, these agricultural wastes would potentially just go down the drain and even pose a serious environmental hazard.

As mentioned earlier, the characteristics of biochar produced from plant biomass wastes may vary with the source material. Such variation can be reflected by its chemical and physical composition. Hence, as biochar is produced mainly at a low-temperature level (<400 ^oC), there is a need to look into the characteristics of biochar relative to pyrolysis temperature within this range. In this light, this study aimed to determine the properties of biochar derived from various plant biomass wastes, and at different low-temperature pyrolysis.

MATERIALS AND METHODS

Materials and Equipment

In this study, the source biomass waste materials used to produce biochar included rice husk, corn cob, empty oil palm fruit bunch, bagasse, and plantation wood residue, as described earlier. Rice husk samples were gathered from a rice mill in Cikarawang, Bogor. Corn cobs came from available stock at the Agrochemical Material Residues Laboratory in Balingtan, Ciomas, Bogor; empty oil palm fruit bunch samples were obtained from PTPN VIII in Banten; while bagasse was collected from Rajawali Sugar Factory II in Subang. Sample amounts of sawdust of albazia and maesopsis were collected from a sawmill in Jasinga, Bogor, while mahogany sawdust was taken from a furniture-making shop in Ciampea, Bogor. Some chemicals like 2% citric acid, lantan, and Bray solution were used for chemical characterization of biochar in the laboratory.

Laboratory equipment used in this study included a pyrolysis reactor (Figure 1), pore surface area and size analyzer *e3200 type FD-3*, CN-elemental autoanalyzer in laboratory tekMIRA, Bandung, *Scanning Electron Microscope (SEM) jsm-6063La*, and some analytical and measurement devices commonly used in laboratory work. To produce the experimental biochar, a pyrolysis reactor at the Agrochemical Material Residues Laboratory in Balingtan, Ciomas, Bogor was used. The pyrolysis reactor consisted of a reactor box with an attached thermometer coupling, ceramic pottery containers into which the source materials were placed, and fire source. The stove was fueled by liquefied natural gas (LPG).

Figure 1. Pyrolysis reactor at the Agrochemical Material Residues Laboratory in Balingtan, Ciomas, Bogor

The process of Making Biochar

All source materials (biomass residues from rice husk, corn cob, empty oil palm fruit bunch, bagasse, and wood sawdust) were sun-dried for 24 hours in order to minimize their respective moisture content to dry air. Afterward, a 5 kg sample (Figure 2) of each source material was respectively placed inside (a ± 30 x 30 x 15) cm^3 ceramic pottery container, were arranged inside the pyrolysis box, and then, the fire was ignited. By regulating fire size over time, the desired pyrolysis temperature level to a range of 250 or 350 °C , was reached. These temperature levels were chosen because the process of carbonization of organic materials starts only at 220 °C (Yang et al., 2004). The desired temperature levels of 250 and 350 °C were reached after 30 and 45 minutes, respectively. The biochar-making process took 4 hours after the desired temperature was reached and stabilized by fire control. Then, the fire was turned off, and the resulting biochar was made to settle and cool down over the next 24 hours. The biochar was then taken out of the pyrolysis reactor, weighed, fined and sifted through a 2-mm sieve. In the end, biochar produced at 250 and 350 °C respectively, consisted of 7 kinds, each coming from the different source materials used thus, total yield for this step was 14 biochar.

Analysis of Biochar Characteristics

The biochar parameters that were analyzed in this study included biochar yield, along with chemical and physical properties. The chemical properties consisted of levels of ash yield, total carbon (C) and total nitrogen (N), pH, as well as available phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na). The physical properties included biochar surface area, total pore volume, average pore radius, and surface morphological features.

The ash yield rate of each biochar was obtained by burning (the biochar) up to 600 °C for 6 hours (BSN, 1995). Total C and total N were determined using a CN-elemental autoanalyzer. Biochar pH was measured with a pH meter as referenced from 1:25 biochar and distilled water. P_2O_5 was measured using Bray 1 method, while the levels of available Ca, Mg, K, and Na were analyzed through extraction method with 2% citric acid. Biochar surface area, total pore volume, and average pore radius were measured with Surface Area and Pore Size Analyzer using Brunaeur Emmet Teller (BET) method. Further, biochar surface morphology was obtained from the results of Scanning Electron Microscopy (SEM).

Figure 2. Replicate sample for Sawdust of mahogany wood

RESULTS AND DISCUSSION

Yield of Biochar

Biochar yield results at two pyrolysis temperatures (250 and 350 °C) are presented in Table 1. It can be seen that the yields of all biochars produced at 250 °C were higher than those produced at 350 °C. Biochar yield went down at the higher temperature (350 °C) apparently as a result of vaporization of moisture bringing about thermal decomposition of organic compounds. A similar observation was reported by (Khan, Yusup, & Ahmad, 2011; Sricharoenchaikul, Pechyen, Aht-Ong, & Atong, 2008; Yang et al., 2004) who found that maximum vaporization of organic matter moisture occurs at a temperature of 220 °C, and at higher temperatures, for instance, at 220–315 °C, hemicellulose decomposition takes place, cellulose decomposition happens at 315–400 °C and lignin decomposition occurs above 400 °C.

In general, source material from the wood residues (e.g. sawdust from albazia, maesopsis, and mahogany) exhibited comparable or uniform hemicellulose, cellulose and lignin content as compared to the other categories of source materials such that wood biochar yield was usually higher. According to (Sun & Cheng, 2002), wood residue from broad-leaved tree species contained 18–25% lignin, 40–55% cellulose and 24–40% hemicellulose. In comparison, wood waste from needle-leaved tree species possessed 25–35% lignin, 45–50% cellulose and 25–35% hemicellulose. As can be deduced from these relative percentages, biochar yield of wood waste source material are generally more variable.

As shown in Table 1, the comparative difference in biochar yield at 350 °C and at 250 °C ranged from 2.48% (biochar from sawdust of mahogany) to 10.20% (biochar from corn cob), with the latter showing the highest yield reduction. This can be attributed to the fact that the lignin content of corn cobs is much lower compared to that of the other source materials. In this regard, (Sun & Cheng, 2002) reported that corn cobs contain 15% lignin, 45% cellulose, 35% hemicellulose, and 5% extractive minerals. Thermal decomposition of hemicellulose and cellulose of corn cobs peaks at a pyrolysis temperature of 350 °C hence, biochar formed at this temperature level is lower than that formed at 250 °C.

Chemical Properties of Biochar

The chemical properties of biochar that were investigated included: ash yield rate, total C, total N, C/N ratio, available nutrients (Ca, Mg, K, Na, and P_2O_5), and pH. Ash yield rate, C, N, C/N ratio, available nutrients, and pH are depicted in Table 2 – 7.

Ash yield generally increased at higher pyrolysis temperature from 250 °C to 350 °C (Table 2). The rise in ash yield was expected as thermal decomposition (carbonization) of the biochar source material was greater at the higher temperature (350 °C).

The percentages of ash yielded by the 7 kinds of biochar, at both temperature levels (250 °C and 350 °C), ranged from 2.96% to 50.41%, with rice husk biochar producing the highest rate values (41.99–50.41%). Ash yield is influenced by the mineral content of the material being burned, and according to (Fengel & Wegener, 1989), the principal mineral components of ash are Ca, K, Mg, and silica (Si). (Amonette & Joseph, 2012) presented their finding that rice husk contains the highest level of Si (22%), followed by bagasse (1.70%), and corn cob (0.99%). The levels of the other key mineral contents (Ca, K, and Mg) of rice husk, corn cob, and bagasse correspondingly reach 0.18, 0.91, and 0.16%; 0.02, 0.94 and 0.17%; and 0.15, 0.27, and 0.63%, respectively. (Law, Daud, & Ghazali, 2007) also reported that empty oil palm fruit bunch contains 1.8% Si, while (Idris et al., 2014) found that its Ca, K and Mg content is 0.13, 0.12, and 0.09%, respectively. On the other hand, ash yield level from wood residues varied from 2.96 to 6.13%. These rates are much lower than those of the other biochar source materials, except corn cob. This is also consistent with the finding of (Fengel & Wegener, 1989) that wood from trees in tropical regions contain 0.1–6.0% ash, consisting of main components Ca (25–50%), K, and Mg, followed by Mn, Na, P, and Cl as well as other elements that did not exceed 50 ppm.

Table 1. Biochar yield of various plant biomass waste materials at a pyrolysis temperature of 250 and 350 °C

No.	Biochar Source Material	Biochar Yield (%)		
		250 °C	350 °C	-Δ
1	Sawdust of albazia wood	37.83	33.47	4.36
2	Sawdust of maesopsis wood	37.69	34.27	3.42
3	Sawdust of mahogany wood	29.70	27.22	2.48
4	Rice Husk	36.33	30.83	5.50
5	Corn Cob	31.72	21.52	10.20
6	Empty Oil Palm Bunch	26.44	23.14	3.30
7	Bagasse	22.51	19.13	3.38

Table 2. Rates of biochar ash yield from various plant biomass residues at pyrolysis temperatures of 250 and 350 °C

No.	Biochar Source Material	Ash Yield (%)	
		250 °C	350 °C
1	Sawdust of albazia wood	6.13	4.57
2	Sawdust of maesopsis wood	2.96	3.64
3	Sawdust of mahogany wood	5.50	4.33
4	Rice Husk	41.99	50.41
5	Corn Cob	3.33	5.72
6	Empty Oil Palm Bunch	20.41	20.36
7	Bagasse	15.47	18.53

Table 3. Rates of Carbon (C) – total from various biochar source material at a pyrolysis temperature of 250 and 350 °C

No.	Biochar Source Material	(%) Carbon (C)	
		250 °C	350 °C
1	Sawdust of albazia wood	59.04	57.43
2	Sawdust of maesopsis wood	58.46	61.44
3	Sawdust of mahogany wood	55.39	61.14
4	Rice Husk	33.66	24.72
5	Corn Cob	57.26	58.48
6	Empty Oil Palm Bunch	49.36	38.86
7	Bagasse	50.93	53.18

Table 3 also shows that the rates of biochar C ranged from 24.72 (in rice husk) to 61.44% (in the sawdust of maesopsis wood). The highest C rates came from wood residue and corn cob, while lowest C values were yielded by rice husk. This variation in C rates inversely affects ash yield of the biochars, as depicted in Table 2. In other words, as (Enders, Hanley, Whitman, Joseph, & Lehmann, 2012) found, the higher the biochar C rate, the lower would be its ash yield.

The components hemicellulose, cellulosa, and lignin from source material biochar is Sawdust of albazia wood 26.80, 49.40 and 24.59% (Martawijaya, Kartasudjana, Mandang, Prawira, & Kadir, 1989); Sawdust of maesopsis wood 24.24, 49.90 and 31.46 (Karlinasari, Rahmawati, & Mardikanto, 2010); Sawdust of mahogany wood 25.82, 47.26, and 27.37% (Karlinasari et al., 2010); Rice Husk 32.69, 43.46, and 23.16% (Maftu'ah & Nursyamsi, 2015); Corn Cob 15.00, 45.00, and 35.00% (Sun & Cheng, 2002); Empty Oil Palm Bunch 25.60, 49.63, and 20.69% (Maftu'ah & Nursyamsi, 2015); and bagasse 25.00, 50.00, and 25.00 % (Sun & Cheng, 2002). The main components of biochar source material it (hemicellulose, cellulose, and lignin), that are quite different in nature, and go through variable thermal decomposition hence, the resulting C-total rates likewise vary. This variability is clearly illustrated in Table 3, in which biochar coming from sawdust of albazia wood, rice husk and empty oil palm fruit bunch yielded decreasing C-total rates as pyrolysis temperature was raised (from 250°C to 350°C level). In contrast, biochar that came from sawdust of maesopsis, and mahogany wood, corn cob, and bagasse produced increasing C-total rates. This variation can be explained by the finding that the rates of hemicellulose decomposition from sawdust of albazia wood, rice husk, and empty oil palm bunch proceed faster than that of cellulose, because cellulose starts to decompose at a temperature of 315°C (Yang et al., 2004); however, by the time the pyrolysis temperature has reached 350°C, the hemicellulose would have been broken down totally into ash, and consequently, C-total rates would go down. In contrast, hemicellulose and cellulose decomposition in the sawdust of maesopsis and mahogany wood, corn cob and bagasse would reach a maximum level at a pyrolysis temperature of 350°C, rather than at 250°C. Thus, the resulting C-total rates would be higher at 350 °C.

Table 3 also shows that the rates of biochar C ranged from 24.72 (in rice husk) to 61.44% (in the sawdust of maesopsis wood). The highest C rates came from wood residue and corn cob, while lowest C values were yielded by rice husk. This variation in C rates inversely affects ash yield of the biochars, as depicted in Table 2. In other words, as (Enders et al., 2012) found, the higher the biochar C rate, the lower would be its ash yield.

Biochar that was produced at a pyrolysis temperature of 350 °C yielded higher N-total rates, compared to the biochar at 250 °C, except bagasse biochar (Table 4). The higher N-total rates were brought about by the greater thermal decomposition process, or carbonization, of the source material. In other words, the higher the decomposition rate, the higher the N-total percentage thus produced. (J. W. Gaskin, C. Steiner, K. Harris, K. C. Das, & B. Bibens, 2008) explained that the increase in N-total rate is due to the entry of more elemental N rendering the structure more complex and more resistant to heat before it is readily volatilized. However, an opposite result was yielded by bagasse biochar, in which N was volatilized, even before the pyrolysis temperature reached 350 °C hence, its N-total rate declined.

The rates of biochar N-total varied from 0.48 to 2.75%, with the highest value yielded by corn cob biochar that is, 1.10–2.75% (Table 4).

This can be explained by the fact that the corn cob came directly from harvested farm crop, in contrast to the other biochar biomass source materials. Besides, corn cob, by nature, contains heterocyclic compounds that contain N derived from hydrolysis of monosaccharide pentose (Hidajati, 2006). As a result, N-total rate from corn cob biochar came out much higher than of the other biochars.

Biochar at 350 °C pyrolysis temperature has a higher C/N ratio than at 250 °C. The C/N ratios of biochars vary widely between 21.27 to 115.40 (Table 5). This ratio is often used as an indicator of the ability of organic substrates to mineralize and release inorganic N when applied to soil. Generally, a C/N ratio of 20 of organic substrates is used as a critical limit above which immobilization of N by microorganisms occurs; therefore, the N applied with the substrate is not available to plants (Leeper & Uren, 1993). (Sullivan & Miller, 2001) suggested that composts with C/N ratios above 25 to 30 immobilize inorganic N. Based on these values, given their very high C/N ratios, most of the biochar are expected to cause N immobilization and possibly induce N deficiency of plant when applied to soils alone. However, there is a degree of uncertainty if the same criterion is directly applicable to biochar. C/N ratios of terra preta soils are usually higher than the adjacent ferralsol, but they tend to have higher available N (Lehmann et al., 2003).

Table 4. Rates of Nitrogen (N) – total from various biochar source materials at a pyrolysis temperature of 250 and 350 °C

No.	Biochar Source Material	(%) Nitrogen (N)	
		250 °C	350 °C
1	Sawdust of albazia wood	0.81	0.95
2	Sawdust of maesopsis wood	0.72	0.80
3	Sawdust of mahogany wood	0.48	0.53
4	Rice Husk	0.86	0.92
5	Corn Cob	1.10	2.75
6	Empty Oil Palm Bunch	0.80	0.98
7	Bagasse	1.81	1.68

Table 5. Rates of C/N ratio of biochars from various biomass waste materials at pyrolysis temperatures of 250 and 350 °C

No.	Biochar Source Material	C/N Ratio	
		250 °C	350 °C
1	Sawdust of albazia wood	72.89	60.45
2	Sawdust of maesopsis wood	81.19	76.80
3	Sawdust of mahogany wood	115.40	115.36
4	Rice Husk	39.14	26.87
5	Corn Cob	52.05	21.27
6	Empty Oil Palm Bunch	61.70	39.65
7	Bagasse	30.32	29.38

As the bulk of biochars is made up of biologically very recalcitrant organic C, which is not easily mineralized, it is expected that N immobilization is negligible or transient despite the high C/N ratios. Application of biochar may indeed lead to lower N uptake, as shown in several studies (Lehmann et al., 2003; Rondon, Lehmann, Ramirez, & Hurtado, 2007). It is likely that this is due to the presence of only a small portion of the freshly produced biochar that is relatively easily mineralizable but may cause N immobilization because of its high C/N ratio. However, the bulk of the remaining organic C (with even higher C/N) does not cause mineralization-immobilization reactions because of its high degree of biological recalcitrance.

The rates of available nutrient substances (P_2O_5, Ca, Mg, K and Na) in the biochar varied with the biomass waste material used (Table 6). As shown in this study, generally, biochar produced at a higher pyrolysis temperature (350 ^oC) contain higher nutrient levels than at lower temperature (250 ^oC). Like in the case of C and N described earlier, the variation in nutrient content or yield depends on pyrolysis temperature; at a higher temperature level nutrient yield rates are higher due to the correspondingly increased rates of carbonization and volatilization from the given biochar source material. This is consistent with the finding of (Novak et al., 2009) that the rise in nutrient element rates was caused by the concentration of elements inside the biochar as the temperature was raised rendering them more resistant to vaporization.

Available P_2O_5, Ca, Mg, K, and Na from the 7 kinds of biochar amounted to 0.03–0.12, 0.03–0.84, 0.03–0.24, 0.05–1.65, and 0.07–0.14%, respectively. The yield rate of P_2O_5 fell under the low category because all biochar source materials came from plant biomass residues, whereas animal waste biomass is typically richer in P content. Further, ash from wood residue contained 25–50% Ca hence, biochar from wood residues contained the highest rate of Ca-available (> 0.4%). On the other hand, the rates of available Mg, K, and Na in the empty oil palm fruit bunch biochar were greater, resulting in its correspondingly higher biochar ash rate (Table 3) than that of the other biochar after rice husk biochar, which is rich with mineral Si.

Biochar produced at a pyrolysis temperature of 350 ^oC had a higher pH value compared to biochar at 250 ^oC (Table 7). The rise in pH was due to the greater alkaline salt separation from the organic matter at 350 ^oC. This is consistent with the study result of (Yuan, Xu, & Zhang, 2011) that biochar alkalinity rises with pyrolysis temperature.

This study demonstrated that pH of biochar from different plant biomass waste materials varied from 4.72 to 6.58. Biochar from empty oil palm fruit bunch exhibited the highest pH value, i.e. most alkaline. This result was due to the higher rates of nutrient elements in the empty oil palm fruit bunch biochar than in the other kinds of biochar, except Ca rate. At the same time, the empty oil palm fruit bunch biochar had a higher ash yield rate than the others, except rice husk (Table 2). This observation was consistent with the results reported by (Enders et al., 2012). That biochar derived from certain wood residues, annual farm crop wastes, and animal dung have a positive correlative relationship between biochar pH and ash rate.

Physical Characteristics of Biochar

The physical attributes of biochar that were investigated in this study included surface area, total pore volume, and average pore radius, as presented in Table 8. Biochar surface area and pore total volume increased with higher pyrolysis temperature. This was caused by the opening up of particles thereby exposing more surface area; likewise increasing total pore volume. (Cetin, Moghtaderi, Gupta, & Wall, 2004) noted that higher temperature accompanied by a longer duration of biochar activation process results in more ester and polyester bonds in organic matter to be broken hence more and more new pores are formed from the biochar micropores.

Table 8 shows that average pore radius of biochar became smaller at a pyrolysis temperature of 350 °C. According to (Downie, Crosky, & Munroe, 2009). Biochar formed from biomass waste materials retain the original porosity and structure of its source material. However, as the temperature is raised to a certain level, there ensues more interaction between heat and carbon leading to more new pores formed. This follows the breakdown of existing macropores into mesopores and micropores, and consequently the pore radius become smaller, hence the mean pore radius declines.

Table 6. Nutrient yield rates of biochar from various biomass waste materials at pyrolysis temperatures of 250 and 350 °C

No.	Kind of Biochar	Temperature	P_2O_5	Ca	Mg	K	Na
			(%)				
1	Sawdust of albazia wood	250 °C	0.05	0.75	0.07	0.13	0.10
		350 °C	0.07	0.79	0.07	0.15	0.10
2	Sawdust of maesopsis wood	250 °C	0.06	0.40	0.07	0.09	0.08
		350 °C	0.07	0.54	0.08	0.12	0.09
3	Sawdust of mahogany wood	250 °C	0.03	0.80	0.05	0.05	0.07
		350 °C	0.04	0.84	0.07	0.06	0.07
4	Rice husk	250 °C	0.05	0.10	0.04	0.10	0.07
		350 °C	0.07	0.11	0.06	0.12	0.08
5	Corn cob	250 °C	0.05	0.03	0.03	0.13	0.09
		350 °C	0.07	0.04	0.03	0.18	0.11
6	Empty oil palm fruit bunch	250 °C	0.11	0.33	0.23	1.24	0.14
		350 °C	0.12	0.39	0.24	1.65	0.14
7	Bagasse	250 °C	0.06	0.26	0.06	0.10	0.07
		350 °C	0.08	0.28	0.10	0.12	0.08

Table 7. Condition pH of biochar from various biomass source materials at a pyrolysis temperature of 250 and 350 °C

No.	**Biochar Source Material**	**pH Biochar**	
		250 °C	**350 °C**
1	Sawdust of albazia wood	5.57	5.98
2	Sawdust of maesopsis wood	4.95	5.04
3	Sawdust of mahogany wood	4.72	5.02
4	Rice Husk	4.93	5.53
5	Corn Cob	5.19	5.77
6	Empty Oil Palm Bunch	6.44	6.58
7	Bagasse	4.89	4.97

Table 8. Surface area, total pore, volume pore and average pore radius of biochar from various plant biomass source materials at a pyrolysis temperature of 250 and 350 °C

No.	Kind of Biochar	Temperature	Surface Area (m^2/g)	Total Pore Volume (%)	Average Pore Radius (Å)
1	Sawdust of albazia wood	250 °C	10.40	2.39	15.06
		350 °C	142.35	0.45	11.79
2	Sawdust of maesopsis wood	250 °C	24.93	16.97	34.89
		350 °C	113.01	32.30	15.93
3	Sawdust of mahogany wood	250 °C	125.35	62.49	25.56
		350 °C	277.15	73.88	13.67
4	Rice husk	250 °C	21.85	0.22	21.58
		350 °C	109.67	1.15	16.09
5	Corn cob	250 °C	100.35	0.07	23.31
		350 °C	142.93	2.53	0.91
6	Empty oil palm bunch	250 °C	7.98	6.74	100.89
		350 °C	49.07	14.02	35.61
7	Baggase	250 °C	1.24	16.95	279.76
		350 °C	4.62	15.69	155.58

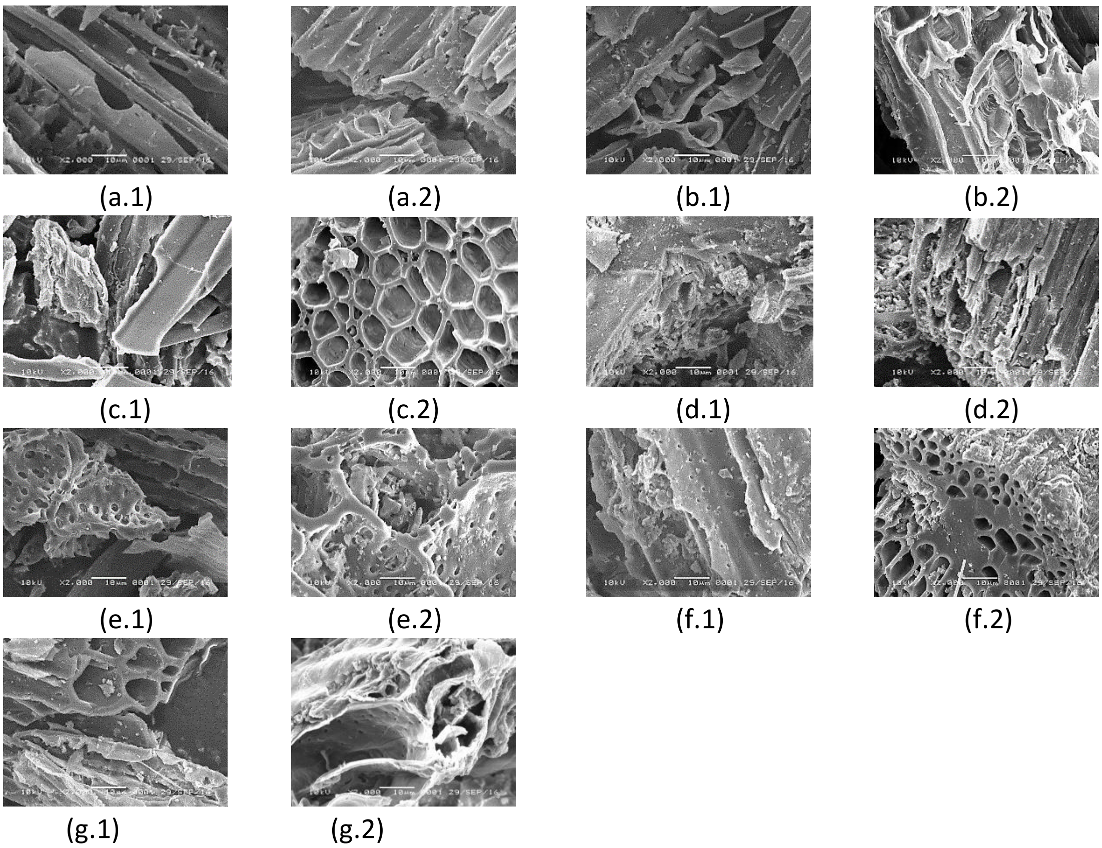

Figure 3. Surface morphology of biochar using *Scaning Electron Microscopy* (SEM) - biochar from wood waste [Sawdust of albazia wood (a) Sawdust of maesopsis wood (b) and Sawdust of mahogany wood (c)]; biochar from rice husk (d); corn cob (e); bagasse (f); and empty oil palm fruit bunch (g) at pyrolysis temperature of 250 °C (1) and 350 °C (2) – at 2000× magnification

The highest surface area and total pore volume were obtained from the biochar derived from mahoni wood sawdust at a pyrolysis temperature of 350 °C. This could be attributed to the lignocellulose composition from the sawdust of mahogany wood. (González, Molina-Sabio, & Rodríguez-Reinoso, 1994) stated that lignocellulose composition of the biomass waste materials is the determining factor in thermal decomposition, that influences the formation of biochar porosity. Aside from this, the vascular structure of the biochar source materials contributes to biochar macropore formation whereas, the formation of micropores occurs during biochar production process (Martínez, Torres, Guzmán, & Maestri, 2006).

Finally, another parameter that describes to biochar characteristics is its surface morphology (Figure 3). It provides a close-up view of biochar with the use of a *Scanning Electron Microscopy* (SEM) at 2000x magnification. Figure 3 illustrates that at a pyrolysis temperature of 350 °C, the biochar pores that have been formed can be seen in a highly clearer and larger scale, in contrast to the results at 250 °C (Table 3). Relatedly, (Cetin et al., 2004) reported that biochar source material particle size is much bigger as a result of raised pyrolysis temperature and pressure.

CONCLUSION

This study has established that: (1) Biochar yield decreased at higher temperature level; (2) The increased thermal decomposition of plant biomass wastes resulted in higher pH as well as ash C/N content, surface area and total pore volume of the biochars; (3) Biochar from wood waste had more C and Ca content; (4) Biochar from rice husk produced the highest ash content. (5) Biochar from empty oil palm fruit bunch yielded the highest pH value and possessed more nutrients than all the others.

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