Biochar for sugarcane: 1. Simple Technology for Biochar Production from Sugarcane Trash

Budi Hariyono, Wani Hadi Utomo, Sri Rahayu Utami, Titiek Islami

***Abstract*— A simple techniques have been developed to make biochar from cane trash. The biochar result from hhree types of kiln (drum kiln, trench kiln and mound kiln) was compared with vacuum pyrolysis reactor. The study was conducted in Asembagus Experimental Station of Indonesian Sweetener and Fiber Crops Research Institute (ISFCRI), East Java (7o45'34.62" S, 114o15'8.15" E) and ISFCRI Laboratory, Malang, East Java (7o54'32.34" S, 112o37'22.45" E). Variables observed were the performance techniques of making biochar, its characteristics and production cost. The results showed that the simple techniques produced biochar of 33.7%, 25.1% and 26.6% respectively for drum, trench and mound kiln. Biochar produced by drum kiln have 35.20% of carbon and 15.08 cmolkg-1 of cation exchange capacity, lower than other techniques. Nutrient content of biochar produced from drum kiln higher than the trench and mound kiln. FTIR spectras showed sugarcane trash biochar have major functional groups potentially as a source of the charge. SEM analyses showed that biochar made with simple techniques have a microstructure that is almost the same withthat of produced by pyrolysis. Drum kiln was faster and easier to applied than trench and mound kiln.**

***Index Terms*— sugarcane trash, biochar, drum kiln, trench kiln, mound kiln, characteristics of biochar**

I. INTRODUCTION

Since the implementation of Presidential Instruction No. 9/1975, the production of cane (*Sacharum officinarum* L) decreased drastically, and to overcome the shortage of raw materials Indonesian government had developed sugar cane to upland area. The soils of these land are mostly very un-productive, either due to degradation or its natural conditions. With these conditions, the yield obtain is very low (around 30 – 50 t/ha) with low sugar content.

One of the main problems planting cane in upland area is the low of organic matter of the soil. Therefore, the key of increasing soil productivity in upland soil is increasing organic matter of the soil. However, due to the difficulty obtaining organic material source farmers hardly did this practice. On the hand, in sugarcane cultivation there are abundance of trash left after sugarcane harvesting. Some report said that this trash could be as high as 6-8 t/ha/year (Singh *et al*., 2008 and Chandel *et al*., 2012) or even 10-20 t/ha/year (Leal *et al*., 2013). Hassuani *et al*. (2005) reported that the amount of trash left behind in the fields after harvesting the cane was about 14% of the cane harvested. Thus if the yield of sugarcane is 85 t ha^{-1}, then there are about 11.9 t ha^{-1} $year^{-1}$ of cane trash left in the land. So far these trash are only viewed as rubbish that makes difficulty for farmers to ratoon their cane, so that the trash is burned, only a few farmers used it as a mulch, or processed into compost (Goenadi and Santi, 2006).

With the discovery of black Amazon terra preta, which then followed by extensive research in biochar application, it was thought that these trash would be a valuable materials as biochar feedstock. Biochar is known as carbon solid material results from combustion or pyrolysis process of biomass under limited oxygen conditions. The advantages of biochar for soil quality improvement and as a carbon sequestration have been shown by many researchers (Lehmann et al., 2006; Brown, 2009; Widowati et al., 2012). The advantages of biochar compared to other organic material sources is its resistance to decomposition so that once it applied to the soil its effect would last for a longer time (Islami et al., 2013; Sukartono et al., 2011a).

The problem of making biochar from sugarcane trash is the technology. The technology should not too complicate, but still efficient to produce biochar. It has been understood that the yield of biochar as well as the properties of biochar was influenced by the type of kiln, temperature of pyrolysis (Chan and Xu, 2009). Some study had shown that pit kiln yielded biochar of 2.5 to 30%, mound kiln yielded 2-42%, and brick kilns 12.5-33% (Brown, 2009). Sukartono et al. (2011b) developed a simple biochar kiln made from drum for making biochar from cattle dung.. This kiln is very efficient; it could produce biochar up to 70%.

Brown (2009) studied the effect of pyrolysis type on biochar yield and found that the value of 35% was 'obtained by slow pyrolysis, 20% by moderate pyrolysis, and 12% by fast pyrolysis. The temperature of pyrolysis effect has been studied by Lopez *et al*., (2013) and Melo *et al*. (2013). These researchers showed that the higher is the temperature the lower the biochar obtained.

The study described here was intended to develop biochar technology production which can be adopted and operated by sugarcane farmers. Therefore, the technology should be not complicated, easy to operated and maintained.

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II. Materials and Methods

The study was conducted in Asembagus Experimental farm of Indonesian Sweetener and Fiber Crops Research Institute (ISFCRI), East Java (7°45'34.62" S, 114°15'8.15" E) and ISFCRI Laboratory, Malang, East Java (7°54'32.34" S, 112°37'22.45" E) from October 2013 until February 2014. Four techniques of making biochar were developed. The first technique called the "drum kiln"; made from 60 cm diameter drum (Figure 1a). Forty nine (49) holes (ϕ 1 cm) were made at the bottom of the drum. These holes were for primary air entry. Wedge bricks were placed in the bottom of drum to provide air space. Drums filled with sugarcane trash until full and then burned on the top. Once lit closed with a half middle drum, next mounted chimney. Among the biomass kiln drum and center drum there slit holes to the entry of secondary air. This system is known as top lit updraft (TLUD) as done by Andreatta (2007), and Frogner (2013). Air flows from the bottom of the drum holes towards the top, aided by the inclusion of secondary air from the slits between the bottom and middle drum, continue to push the smoke upward to exit through the chimney. The fire burning the biomass from the top downwards simultaneously. The combustion process is stopped when the smoke coming out of the chimney has been thinned.

Figure 1. The techniques for making biochar: (a) drum kiln;(b) trench kiln; (c) mound kiln, (d) pyrolysis reactor

The second technique was called as the "trench kiln" (Figure 1b). This is the modification of the technique reported by Reddy (2011). The trench was made in between plant row with 40 cm width and 50 cm depth. Sugarcane trash dumped in the trench, then covered by soil, except at the end of a hole to the start of combustion and on the other end for the exhausted of smoke. When trash burned, then soil surface cover declined.

The third technique, i.e. "mound kiln" (Figure 1c) was similar to that of developed by Brown (2009). In This technique, biochar was made by stacking the sugarcane trash between plant rows without making a trench, and then covered with corrugated tin roof sheets. The conection between sheets were covered with soil. Mound of trash made in accordance elongated length segment (10 m). At the end of a mound a hole was made to the start the combustion, and at the other end for the exhaust smokes. When the trash has been burned the tin cover then declined.

In the fourth technique, biochar was made with "vacuum pyrolysis reactor", with the heating input used electric power. With these tools, trash is heated from the walls of the reactor. With increasing temperatures, raw material converted into biochar by evaporating water and organic gases. The water mixed with a compound of gases is condensed into bio-oil. An indicator that the process has been completed is if it is no longer bio-oil that drips.

Variables observed were the performance of techniques and production cost. Chemical characters (pH, C, N, P, K, Na, Ca, Mg, CEC) were analyzed in the Laboratory of the Indonesian Legumes and Tuber Crops Research Institute, Malang, Indonesia. Carbon content was determined by Walkley-Black method; N with the Kejldahl method; P, K, Ca and Mg were extracted with HNO_3 + $HClO_4$, and then P concentration was measured with spectrophotometer, K with flame photometer , Ca and Mg with AAS.

Analysis of Fourier Transform Infrared Spectroscopy (FTIR) was done with Shimadzu FTIR-8400S at the Chemistry Laboratory University of Brawijaya. To determine the surface morphology structure of biochar, the scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) was done with Hitachi TM3000 in Biosciences Laboratory, University of Brawijaya.

III. Results and Discussion

Charing process

The performance process of the of making biochar with four techniques were shown in Table 1. Each of these techniques tested had a different capacity of trash raw material. Capacity of drum kiln sufficient to accommodate trash originates from one segment row of sugarcane harvest (10-12.5 kg). In the trench and mound kiln technique capacity is almost the same, reaching about 40 kg, which is derived from the felling 3 segments row. In the drum kiln techniques, trench kiln and mound kiln whole sugarcane trash directly used without cut / crushed. In the vacuum pyrolysis reactor the capacity was only about 500 grams, and trash diced / crushed first.

Table 1. Performance process of sugarcane trash charing by various techniques

Performance	Drum kiln	Trench kiln	Mound kiln	Vacuum pyrolysis
Capacity (kg)	12.5 ± 1.7	39.3 ± 3.7	42.2 ± 8.3	0.46 ± 0.44
Temperature (°C)	366.1 ± 32.9	361.9 ± 31.1	367.6 ± 56.4	499.7 ± 2,5
Time of process (minute)	110 ± 15	210 ± 33	150 ± 27	379 ± 42
Cooling process (minute)	20 ± 8	480 ± 180	480 ± 120	60 ± 11
Biochar yield (%)	33.7 ± 3.4	25.1 ± 0.8	26.6 ± 1.5	46.4 ± 7.1

Burning trash cane in the drum, trench and mound kiln techniques was done by self-combustion, without external energy input. The vacuum pyrolysis reactor used electrical power to charred the biomass.. Peak temperature of the heating/combustion of the drum, trench and mound kiln techniques was almost the same at around 360 °C. These three techniques can be categorized as slow pyrolysis (Brown, 2009). In the vacuum pyrolysis maximum temperature was set at 500^{o} C.

The time required for the combustion of biomass was influenced by the condition of the raw material, the drier is the trash the faster was combustion. In the drum kiln technique, it only took less than 2 hours combustion and less than half an hour of cooling time, after that biochar can be harvested. This result is slightly higher than sugarcane trash biochar obtained by Quirk *et al*. (2012) amounted to 33.6%, but lower than the results of Melo *et al*. (2013) which showed the figures of 38-45%. It was observed that wind conditions greatly affected the speed of this process with drum kiln. High wind speed made the process went faster. This was due to the higher amount of air supply through a hole in the bottom of the drum and drum slits between the bottom and the middle drum.

The trench and mound kiln techniques took a longer time than drum kiln. It is reasonable because in these two kilns, the biomass charred was 3- 4 times greater than the other kiln. Moreover, it seems that there was less air supply during combustion process. It was observed that wind conditions greatly affect the speed of the process in both these techniques. If there was a strong wind from the opposite direction of combustion, the process going faster. Cooling time at both techniques were also longer; it took about 8 hours. It was suggested that these both techniques burning is done in the afternoon, then cooling process happens throughout the night, so the biochar can harvested in the morning. Biochar obtained from both techniques are almost equal 25-26% of raw materials, less than that of Quirk *et al.* (2012) and Melo *et al*. (2013).

The process of making biochar with vacuum pyrolysis reactor took 6 hours for combustion and one hour for cooling time. Biochar produced was 46%, higher than the results of Quirk *et al*. (2012) and Melo *et al*. (2013). In this kiln in addition to solid product of biochar, the reactor also produced bio-oil that can be used for pesticides. The high results of biochar in this technique was due to no oxygen during combustion. Biochar yield decreases with increasing pyrolysis temperature.

Chemical characteristics

Chemical properties of the biochar obtained from the four techniques are presented in Table 2. Sugarcane trash biochar processed by drum kiln has a higher pH than biochar processed with other techniques. Carbon total above 30%, is good in order to carbon sequestration in the soil. The highest carbon content was owned by biochar from the trench kiln (40.23%). Total nitrogen is lower than the results of Quirk *et al*. (2012) and Melo *et al*. (2013), trench kiln produced biochar with total N content is higher than the three other techniques.

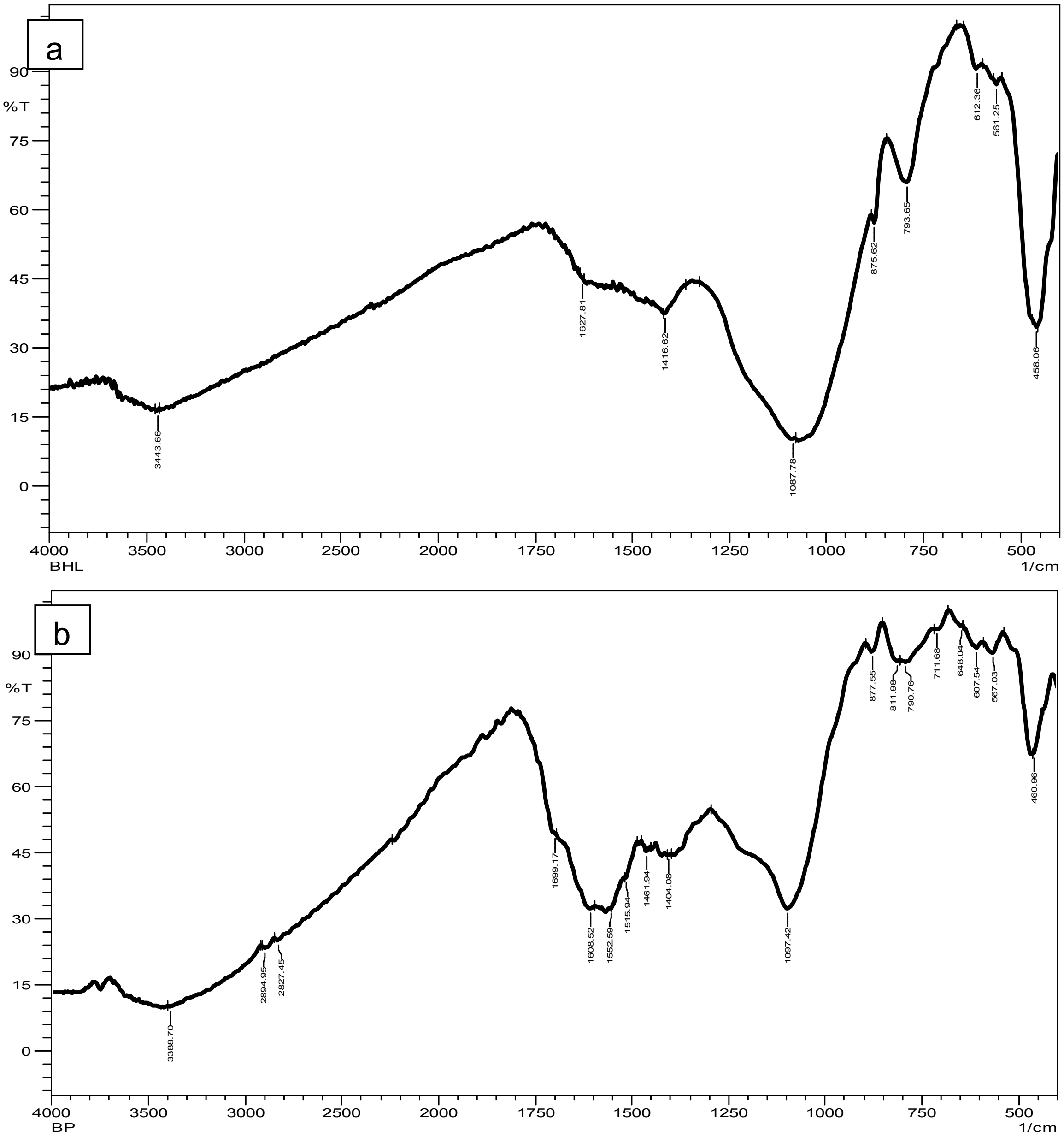
The result in Table 2 shows that the highest total P and K obtained from drum kiln technique (2.75% and 3.19%). Trench kiln produced biochar with low Na content. The content of Ca and Mg of the four techniques were almost the same. The CEC varied from 15.08 $cmol^{+}.kg^{-1}$ (drum kiln) to 33.31 $cmol^{+}.kg^{-1}$ (trench kiln). The differences of biochar properties of biochar are observed in these techniques was reasonable, because the properties of biochar is not only ifluenced by the feedstock, but also by the techniques of biochar production (Chan and Xu, 2009; Melo *et al*., 2013; Lawrinenko, 2014).

Table 2. Selected chemical characteristics of sugarcane trash biochar produced from various techniques.

Character	biochar produced by				cane trash feedstock
	Drum kiln	Trench kiln	Mound kiln	Pyrolysis	
pH (H_2O)	9.0	6.2	6.8	6.1	6.9
Total C (%)	35.20	40.23	35.54	30.52	55.83
Total N (%)	0.92	1.07	0.61	0.54	0.86
C/N	38.26	37.60	58.26	56.52	31.86
Total P (%)	2.75	0.22	0.17	0.22	2.20
Total K (%)	3.19	0.46	0.28	0.21	1.09
Total Na (%)	1.28	0.37	1.13	1.05	0.33
Total Ca (%)	1.60	1.59	1.18	1.43	5.52
Total Mg (%)	0.39	0.39	0.51	0.03	0.30
CEC ($cmol^{+}.kg^{-1}$)	15.08	33.31	22.37	20.12	26.64

FTIR analysis

FTIR spectra of the four biochar made by the techniques had a little variation (Figure 1). The main functional groups in biochar are shown in Table 3.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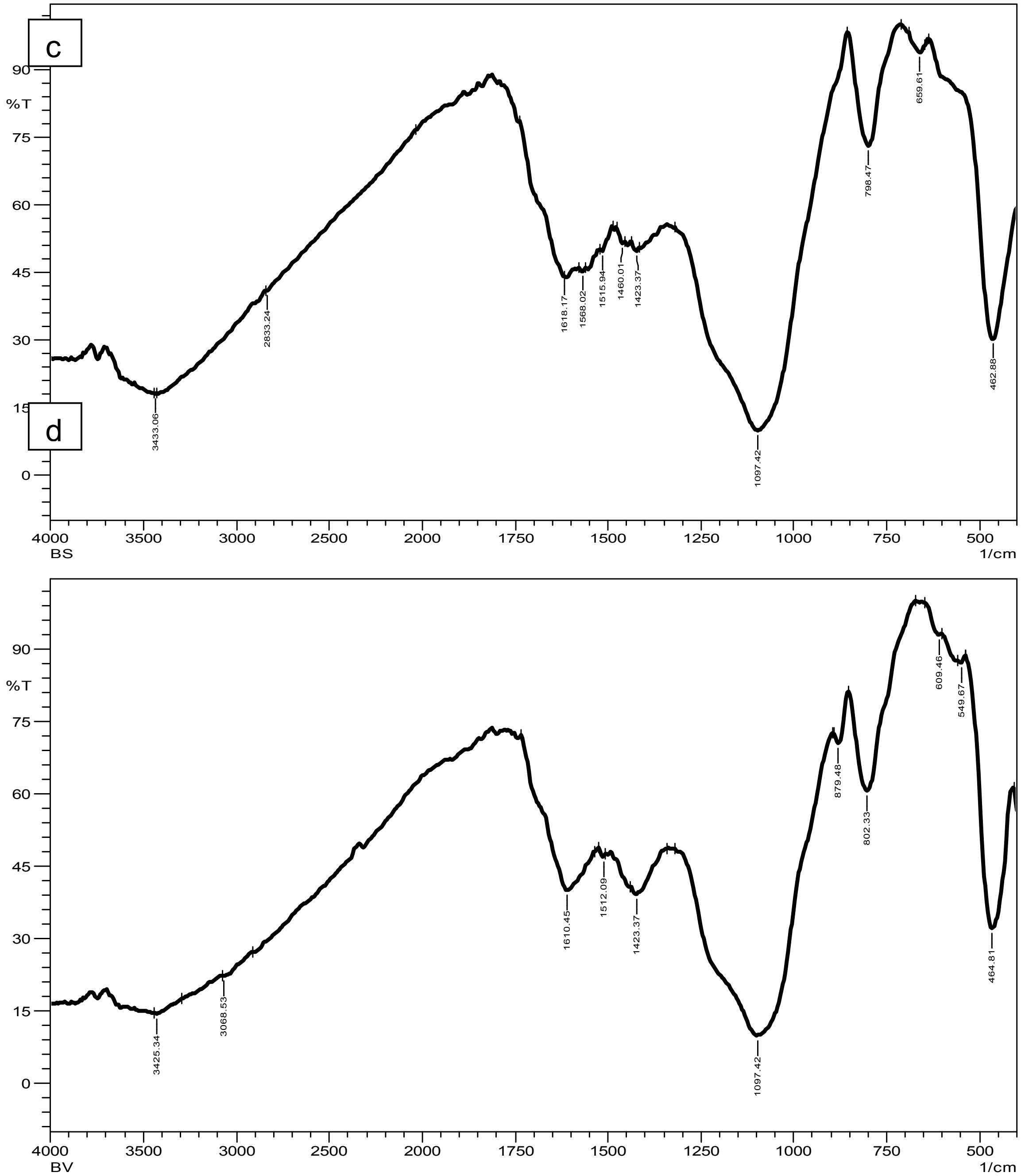

Figure 1. FTIR spectra of sugarcane trash biochar produced from (a) drum kiln, (b) trench kiln, (c) mound kiln and (d) vacuum pyrolysis.

The variation of the FTIR spectra of the biochar obtained by the four techniques may occur due to temperature differences in the process. The increase of the temperature and the time the pyrolysis will decrease the functional groups of CO, OH and aliphatic CH bond, but increase aromatic, and the alkalinity (Singh *et al*., 2010; Peng *et al*., 2011; Deng *et al*., 2014).

Table 3. Functional groups of sugarcane trash biochar produced from various techniques.

Sugarcane trash biochar	Wavenumber (cm^{-1})	Functional group (chemical bond) *)
Biochar produces from drum kiln	3443.66	O-H, N-H
	1627.81	C=C aromatic, or C-O carboxylate, or C=O ketone
	1416.62	C-H aliphatic
	1087.78	Ester, phenol C-O-C, C-OH
	875.62 - 793.65	C-H aromatic
Biochar produced from trench kiln	3388.70	O-H, N-H
	2894.95 - 2827.45	C-H aliphatic

	1699.17	C=O carboxylate
	1608.52	C=C aromatic, or C-O carboxylate, or C=O ketone
	1552.59	N-H amide, C=N
	1515.94	N-H amide, C=N, C=C aromatic
	1461.94	C-H aliphatic
	1404.08	C-O phenolic
	1097.42	Ester, phenol C-O-C, C-OH
	877.55 – 711.68	C-H aromatic
Biochar produced from mound kiln	3433.06	O-H, N-H
	2833.24	C-H aliphatic
	1618.17	C=C aromatic, or C-O carboxylate, or C=O ketone
	1568.02	N-H amide, C=N
	1515.94	N-H amide, C=N, C=C aromatic
	1460.01 - 1423.37	C-H aliphatic
	1097.42	Ester, phenol C-O-C, C-OH
	798.47	C-H aromatic
Biochar produced from vacuum pyrolysis	3425.34	O-H, N-H
	3068.53	C-H aromatic
	1610.45	C=C aromatic, or C-O carboxylate, or C=O ketone
	1512.09	N-H amide, C=N, C=C aromatic
	1423.37	C-H aliphatic
	1097.42	Ester, phenol C-O-C, C-OH
	879.48 - 802.33	C-H aromatic

*) Derrick *et al.* (1999); Parikh *et al*. (2014).

The major functional groups found in the all biochar are: OH, NH, C=C aromatic, C-O carboxylate, C=O ketone, aliphatic C-H, esters, C-O-C phenol, C-OH, and C-H aromatic. The biochar surfaces containing O, H, and OH, hence, when the biochar is oxidized or hydrolyzed will produce negative or positive charges, and therefore biochar has a cation exchange capacity as well as the anion exchange capacity (Amonette and Joseph, 2009; Berek, 2014).

Scanning Electron Microscopy (SEM) analysis

The result of scanning electron microscopy (SEM) of biochar is shown in Figure 2. Biochar made from sugarcane trash shows the number of micropores with irregular surface shape. Pores occurs in biochar are partly genuine pores of trash tissue, which partially destroyed during the process of heating / pyrolysis. Increasing pyrolysis temperature will increase the pores, and hence, increase the specific surface of biochar (Deng *et al*., 2014) These micro pores has a potential as a store of water or air, so when applied to the soil can increase water holding capacity (Baronti *et al.*, 2014 and Bruun *et al*., 2014). These pores can also has a function as a habitat for soil microorganisms such as mycorrhizal (Lehmann *et al*., 2011; Berek, 2014).

The result in Table 4 shows the distribution of element detected by energy dispersive X-ray (EDX). The carbon content in biochar varied from 47 to 85% by weight. Elements of C, Si and K were detected in all of biochar by the 4 techniques. Magnesium and Chlorine was only detected in a the biochar made by mound kiln. Phosphorus was only detected in biochar made by drum kiln, whereas calcium was detected in biochar made by trench kiln and mound kiln.

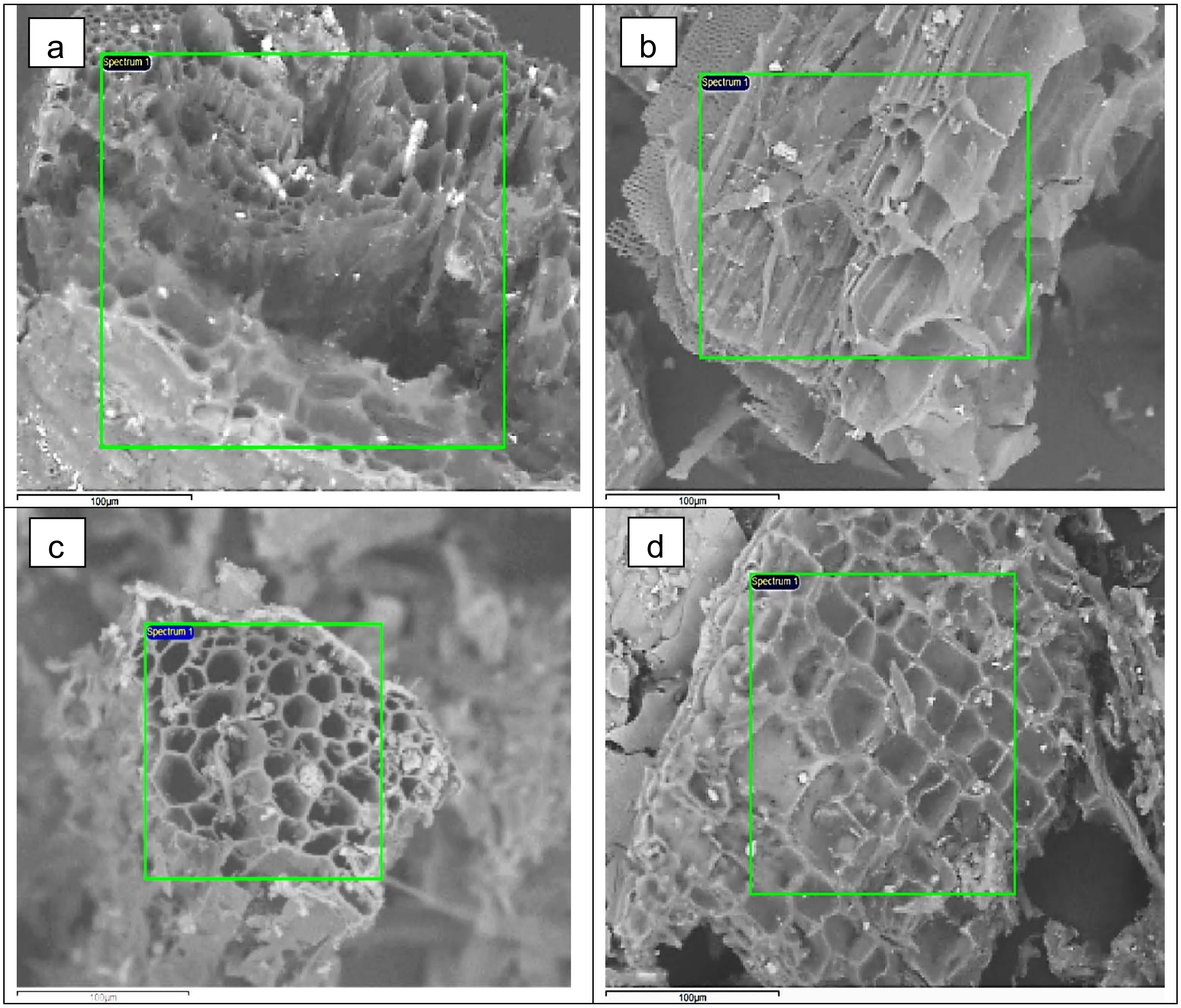

Figure 2. Scanning electron micrograph of sugarcane trash biochar produced by (a) drum kiln, (b) trench kiln, (c) mound kiln and (d) vacuum pyrolysis, in 500x magnification.

Table 4. Element detected by Energy Dispersive X-Ray (EDX) analysis from SEM blocked area of sugarcane trash biochar produced from various techniques.

	Biochar produced from various techniques			
Element	Drum kiln	Trench kiln	Mound kiln	Vacuum Pyrolysis
	.... % weight			
Carbon	85.212	47.665	54.848	53.916
Oxygen		24.895	34.503	32.242
Magnesium			0.361	
Silicon	9.620	4.185	6.132	12.419
Chlorine			0.338	
Phosphorus	0.175			
Potassium	4.994	2.512	1.032	1.423
Calcium		20.744	1.079	

Advantages and disadvantages

Drum kiln. The advantages of the technique is that the process faster and easier to implement, the result is quite good biochar. Drum kiln unit is relatively light weight, easily portable to move closer to the source of raw materials. It can be used in exfoliation of dried leaves stage of sugarcane cultivation. After completion of use drum kiln can be stored, even for a several seasons. Prices are relatively cheap because we can use the second-used drums for the kiln. The disadvantages are that the process emits smoke, capacity is relatively small, so it will require a lot of units to process the trash.

Trench kiln. The advantages of trench kiln is that is made directly on the land, so close to the source of raw materials and biochar produced can be directly applied to the soil. Capacity per unit process was 3-4 times larger than the drum kiln. The disadvantages are the need to dig a trench, as well as a long process and cooling time, during the process emits smoke.

Mound kiln. Similar to trench kiln, mound kiln can be done directly on the land near the source of raw materials, but do not need to dig a trench. It is easy to operate by accumulating the trash and covered with sheets of corrugated tin roofs were easily prepared and disasembled. Burning time is faster than the trench kiln. But the disadvantages are equal to the trench kiln during the process of removing smoke, long cooling time, as well as the necessary cost of purchasing tin sheets.

Vacuum pyrolysis. The vacuum pyrolysis reactor did not emit the smoke. In addition making biochar in pyrolysis reactor produced high biochar yield and produces bio-oil. However, the cost to build the reactor is high.

CONCLUSSIONS

Based on the discussion above, it can be concluded that biochar from sugar vcane trash can be made by a simple technique and can be done directly in the field. The technique of drum kiln, trench kiln and mound kiln can be used in the sugarcane fields after harvesting the cane. Biochar properties produced the 4 techniques have a relatively similar characteristics. The drum kiln technique is the most easily implemented and inexpensive.

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