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Designing and Evaluating Biochar Pyrolysis Kiln

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ABSTRACT

Enhanced biochars pyrolysis Kiln was developed and used to produce biochars from rice straw and date palm fronds biomass. The pyrolysis kiln was an internal rectangular chamber with a total volume of 0.30 m^3. the pyrolysis temperature either to reach 250 °C, 450 °C or 650 °C with heating rate of 5 °C min^{-1}. Three residence times (2, 4, 5 h) were examined to study the impact of temperature on the quality of biochars. Study measurements included the chemical properties, elemental analysis, scanning electron microscopy (SEM) images and elemental compositions on the surfaces of produced biochars. Rice straw and date palm fronds biochars yield decreased with increasing pyrolysis temperature from 250 °c to 650 °c. Also volatile matter yield decreased with increasing pyrolysis temperatures. Ash content and fixed C in rice straw biochars increased with increasing pyrolysis temperatures. Where, minimum recorded ash content was 23.5 % at 250 °c temperature for 2 h residence time, and maximum recorded value was 32.5 % at temperature degree of 650 °c for 5 h residence time, with similar data trend for date palm fronds biochars but with lower ash content values. Both H and O decreased in rice straw biochars with increasing pyrolysis temperature, while C content increased. N content had no constant change behaviour as it increased until temperature of 450 °c, but decreased afterwards at 650 °c. In date palm fronds biochars pH increased with the applied pyrolysis temperatures and there was decrease in CEC with increasing temperature.

Keywords: rice straw, date palm fronds, biochar, pyrolysis, elemental compositions.
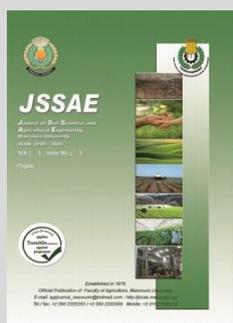
INTRODUCTION

When biomass is heated to temperatures typically between 300°C and 700°C under total or partial absence of oxygen, the remaining solid product is called Biochar and the process is known as pyrolysis. Biochar falls into the spectrum of materials called black carbon, and it contains substances of properties, including slightly charred biomass, charcoal, and soot (Masiello, 2004; Lehmann *et al.*, 2011). Many traditional practice using biochar are still being discovered worldwide. While there is increasing interest in researching new evidence for these ancient practices, for instance in the search for African dark earths (Fairhead and Leach, 2009), the currently best-known examples include the ancient practice of adding rice husk charcoal to agricultural soils in Asia (Ogawa and Okimori, 2010) and the development of the Amazonian soils known as dark earths that is rich in organic matter and highly fertile compared to the adjacent native soils. Biochar can be produced many types of feedstock including agricultural wastes, rice husks, bagasse, paper products, animal manures, and even urban green waste (Lehmann and Joseph, 2009). It is important to understand how different production conditions can result in different types of biochars, and how these chars interact with different types of soils. This understanding is an essential component to the design of any successful biochar system. Ongoing efforts are being led by the International Biochar Initiative (IBI) to develop a characterization standard for biochars (IBI, 2012).

Production of biochar can be conducted at a very wide range, from household levels in cookstoves to the industrial pyrolysis plant to generate both bioenergy and biochar, where system's size and the needs are major factors for determining the final impact of such systems (Whitman *et al.*, 2011; Hammond *et al.* 2011). Scholz *et al.* (2014) classified biochar-producing systems as gasifiers or pyrolyzers and produce in essence three different products that depend on the technology used, namely biochar (solid), syngas (gaseous), and bio-oil (liquid by-product). Pyrolysis systems use kilns or retorts, and exclude oxygen while allowing the pyrolysis gases to escape and be captured for combustion. Also, pyrolysis systems are classified as slow, fast, and flash pyrolysis, with fast pyrolysis producing more oils and liquids while slow pyrolysis tends to produce more syngas, and flash pyrolysis generating mostly biochar. Gasification systems are usually designed with gas production as the central focus rather than biochar or oil production, and generally produce less biochar than pyrolysis. The potential effects of biochar on soil fertility and agricultural productivity are widely reported (Sohi *et al.*, 2010; Verheijen *et al.*, 2010).Gaunt and Lehmann (2008) cleared that applying biochar to soil as instead of being burned as a fossil fuel will reduce greenhouses gas (GHG) emissions between two and five times. If climate change mitigation was the producer's objective, then biochar application to soil would be the clear choice for its end use. In addition, during the application of biochar to soil, two major aspects to consider are the appropriate selection of biochars for specific soil constraints and the actual biochar application methods. The global model developed by Woolf *et al.* (2010) to estimate the total contribution of sustainable biochar to climate

change mitigation expands this finding. It concludes that biochar has greater mitigation potential applied to soil than as an energy source only if it generates soil productivity benefits or reduces emissions of non-carbon dioxide GHGs from soil. Rasul *et al* (2017) stated that there is likely to be two types of biochar production systems: a simple kiln or retort type of pyrolysis unit for producing biochar only and more sophisticated, and considerably more expensive, pyrolysis reactors for producing biochar, bio-oils and syngas for further energy conversion. In the shorter-term, the quickest way to produce large biochar quantities is likely to be by using simple kiln and or retort type pyrolyzers. On a dry yield basis, fast pyrolysis can yield 75 % liquid, 12 % char and 13 % gas (Bridgwater, 2003). It is important to have a relatively dry feedstock (~10 % moisture content) to prevent excess water in the bio-oil product. The heating rate for fast pyrolysis varies between 10-200 K/s, however only small particles can be used because of mass and heat transfer limitations (Mohan, *et al.*, 2006). So, the main goal of this present study is to make affordable enhanced flash biochars pyrolyser for small scale production and agronomic systems.

MATERIALS AND METHODS

Pyrolysis kiln specification

The pyrolysis kiln is an internal rectangular chamber (0.75 x 0.8 x 0.5 m) length, width and height respectively with a total volume of 0.30 m^3. The reactor is designed to limit and to reduce mass and heat transfer to the minimum. The used gas moves naturally towards the combustion chamber with 0.025 m in diameter and 1.2 m in length LPG tube. The pyrolysis gases exit the cylinder into the where they are ignited to also assist with heating. Internal chamber is made of 4 mm stainless steel to withstand the operating temperature up to 900 °C. The Internal chamber is surrounded by the combustion chamber with 40 mm clearance between them. The overall dimensions of designed pyrolysis kiln with frame are 0.85 x 1 X 1 m as length, width and height respectively, and it was made from 4 mm stainless steel sheet too. A 0.025 m exit port tube was fixed through and top of internal rectangular chamber. Pyrolyser was kept for natural cool down after completing each pyrolysis cycle of the feed materials and biochar was collected. Pyrolysis set-up (Fig. 1) was designed and adapted to perform the required process based on Aladin *et al.* (2017) and Tahir *et al.* (2020). Dimensions and engineering drawing of developed pyrolysis set-up unit are presented in Fig. 2.
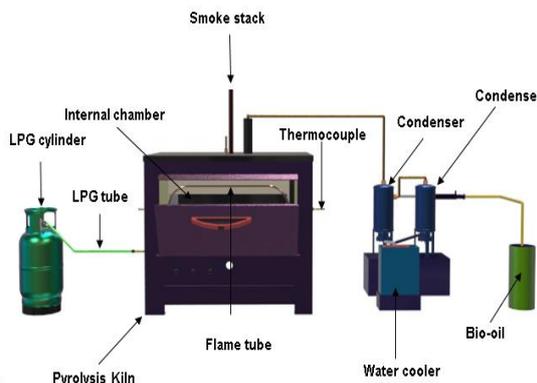

Fig. 1. Pyrolysis set-up unit for biochar production.
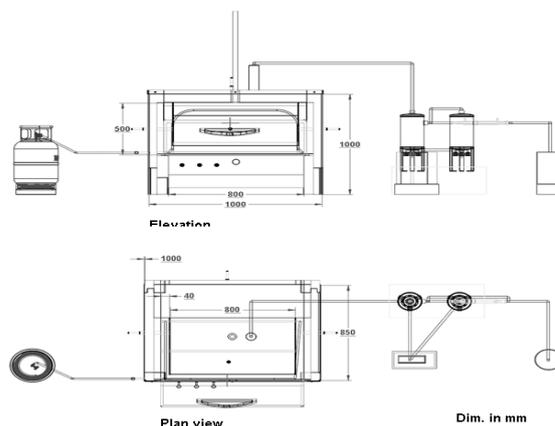
Fig. 2. Dimensions and engineering drawing of developed pyrolyser kiln.

Process description

The process of pyrolysis begins with heat supplied from an external LPG cylinder as a heating source. LPG is widely used in Egypt and it has a calorific value of 43.1 MJ kg^{-1} with producing lower emissions. There are three sets of holes in combustion chamber connected to gas cylinder. One set of holes is located just down the internal chamber, the other two are located right and left side of the internal chamber flame directed across the chamber. There are air inlets open holes in combustion chamber for creating create a flammable mixture with LPG and is ignited by external burner. There are 3 thermocouples are located at three different points in the internal chamber. Only biochars were considered in this study with no investigation of produced bio-oil.

Study variables, methods and technique

For setting the study' variables, the gas rate was calibrated to control the temperature needed based on the releasing gas valve, the temperature either to reach 250 °C, 450 °C or 650 °C with heating rate of 5 °C min^{-1} . Second study variable was two biomass material used to generate biochar (rice straw and date palm fronds). Holding time was third variable, three residence/holding times (2, 4. 5 h) were examined to study the impact of temperature on the quality of biochar. Study measurements were composition and analysis of O (oxygen), C (carbon), H (hydrogen), N (nitrogen), total N, P, K, Ca, Mg, the cation exchange capacity (CEC), moisture, volatile matter, fixed carbon and char yield with measuring pH and EC as recommended by Bridges (2013). Rice straw and date palm fronds were dried at 60 °C for 24 h and cut to different needed particles sizes and they was kept in a stainless steel container inside the inner chamber of the pyrolyser, and was burnt under absence of oxygen for the defined times. Characteristics and analysis of used biomass materials are presented in Table 1.

Table 1. Characteristics and analysis of used biomass materials.

Analysis *	Rice straw	Date palm fronds
MC, %	11.9	7.9
Total N, g/kg	0.71	1.30
Total P, g/kg	0.48	0.04
Total K, g/kg	8.74	1.6
Total Ca, g/kg	16.58	0.75
Total Mg, g/kg	2.21	0.08
Cellulose, %	48.16	32.7
Hemicellulose, %	24.33	29.1
Lignin , %	3.09	28.3

∗ Percentages are on a dry weight basis

Fixed C and volatile matter (VM) analyses were conducted according to the American Society for Testing

and Materials (ASTM, 2007).The biochar yield was calculated as described by Lynch and Joseph (2010), on air-dry weight basis of the raw material, as follows:

Biochar yield (%) = (W_1/W_0) x 100……………. (1)
Where:
W_0 is the weight of the raw feedstock on an air-dried basis (g), and W_1 is the weight of the produced biochar (g).

Ash content was determined by the dry combustion for 1.00 g of the different feedstock or biochar samples at 700 °C for 12 hrs in an open porcelain crucible (Samsuri *et al.*, 2014). The crucible was cooled in a desiccator until reaching the room temperature, the ash weight was determined. The percentage of the ash content was calculated according to Lynch and Joseph (2010) as follows.

Ash content (%) = (W_{ash} / W_{sample}) X 100…………. (2)
Where:
W_{ash} is the weight of ash (g) and W_{sample} is the weight of biochar (g). The char yield was recorded and the biochar samples were milled to pass a 0.25 mm sieve (60 mesh) prior to further analyses. Moisture content: five grams of biochar were put in a porcelain crucible and dried in an oven at 80°C for 24 hours. After cooling in a desiccator, the sample was reweighed and the moisture content of the biochars was calculated. This process was repeated several times until a constant weight of biochar sample was obtained (Samsuri *et al.*, 2014) as follows:

Moisture content (MC), % = (W_2 - W_3/ W_2 - W_1) x 100… (3)
Where:
W_1 is the weight of crucible (g), W_2 is the initial weight of crucible plus biochar sample (g), W_3 is the final weight of crucible with biochar sample (g).

Elemental analysis of O (oxygen), C (carbon), H (hydrogen), and N (nitrogen) contents of the biochars were determined by the CNHOS element analyzer [X-ray fluorescence spectrometry (XRF), Malvern Panalytical Almelo, the Netherlands)]. The available P was measured using the Bray II method (Bray and Kurtz, 1945).The total N was determined using the Micro-Kjeldahl method (Bremner, 1965).The exchangeable K, Ca, Mg and the cation exchange capacity (CEC) were analyzed following Sumner and Miller (1996). Both pH and EC were measured by soaking the biochar in distilled water boiling for 5 min; thereafter, the pH and EC values were measured in the suspension and supernatant after cooling (Shinogi *et al.*, 2003). Elemental compositions on the surfaces and microstructural textures of produced biochars measured by using a scanning electron microscopy (Model No.: S-3000N; Hitachi Co., Tokyo, Japan) with an energy dispersive X-ray spectroscopy (Swift ED3000, Oxford Instruments, Abingdon, UK).

RESULTS AND DISCUSSION

The chemical properties and characterization of produced rice straw biochars.

The chemical properties of produced rice straw biochars are shown in Table 2. Biochar yield decreased from 48.5 % to 41.7 % with increasing pyrolysis temperature from 250 °c to 450 °c with 2 h residence time. Also, biochar yield decreased from 41.7 % to 34.8 % with increasing pyrolysis temperature from 450 °c to 650 °c with 2 h residence time. While, the decreases in biochar yield were from 51.2 % to 35.1 % and from 49.3 % to 35.4 % when temperature increased from 250 °c to 650 °c for 4 and 5 h residence times respectively. Volatile matter in rice straw biochars decreased from 42.4% to 24.2% with increasing pyrolysis temperature from 250 °c to 450 °c with 2 h residence time. Also, volatile matter decreased from 24.2 % to 15.2% with increasing pyrolysis temperature from 450 °c to 650 °c with 2 h residence time. While, the decreases in biochar yield were from 38.5 % to 14.7 % and from 36.3 % to 13.9 % when temperature increased from 250 °c to 650 °c for 4 and 5 h residence times respectively. Ash content and fixed C in rice straw biochars increased with increasing pyrolysis temperature. Where, minimum recorded ash content was 23.5 % at 250 °c temperature for 2 h residence time, and maximum recorded value was 32.5 % at temperature degree of 650 °c for 5 h residence time. Minimum fixed C recorded value was 35.4 % at 250 °c temperature for 2 h residence time, and maximum recorded value was 56.7 % at 650 °c temperature for 4 h residence time. From results, it was clear that most significant changes in biochar yield, volatile matter, ash content and fixed C occurred when pyrolysis temperature changed from 250 °c to 450 °c, while, the rate of changes was slower when temperature changed from 450 °c to 650 °c.

Table 2. Chemical properties and elemental composition of produced rice straw biochar.

Biochar characteristics*	Rice Straw Biochar								
	Temperature								
	250°c			450°c			650°c		
	Residence time								
Chemical properties	2h	4h	5h	2h	4h	5h	2h	4h	5h
Biochar yield, %	48.5	51.2	49.3	41.7	42.4	44.5	34.8	35.1	35.4
Volatile matter (VM), %	42.4	38.5	36.3	24.2	21.1	19.1	15.2	14.7	13.9
Ash content, %	23.5	24.1	24.3	29.4	31.2	32.0	28.3	29.7	32.5
Fixed C	35.4	36.0	37.2	42.8	44.1	48.7	56.2	56.7	56.0
Elemental composition									
pH	8.98	9.11	9.27	10.33	10.45	1.54	11.10	11.23	11.28
CEC, cmol/kg	32.45	33.14	31.47	28.16	27.08	26.7	24.50	24.15	22.71
C, %	71.3	72.5	73.1	82.1	83.6	84.0	87.4	88.8	89.4
H, %	4.92	5.2	5.9	3.36	3.18	3.01	2.15	2.01	1.98
N, %	1.65	1.74	1.85	1.77	1.68	1.71	1.56	1.51	1.47
O, %	22.11	20.53	19.12	12.75	11.53	11.25	8.7	7.65	7.12
Total N, g/kg	0.34	0.35	0.37	0.41	0.40	0.44	0.50	0.51	0.53
Total P, g/kg	0.18	0.18	0.19	0.19	0.19	0.20	0.21	0.22	0.23
Total K, g/kg	4.8	4.6	4.5	5.7	5.5	5.5	72	7.3	7.4
Total Ca, g/kg	14.3	14.5	14.5	18.7	18.6	18.9	15.3	21.4	22.0
Total Mg, g/kg	1.02	1.04	1.11	1.32	1.24	1.50	1.71	1.72	1.84

* **Percentages are on a dry weight basis.**

This trend in biochar yield, volatile matter, ash content and fixed C behaviour under different pyrolysis temperatures was being consistent with (Antal and Gronli, 2003; Bridges, 2013; Thammasom *et al.*, 2016; Weixiang, *et al.*, 2012 and Bridgwater, 2012).Volatile matter decreased with increasing pyrolysis temperature might show effect of higher temperature on the stability of the process. The ash content of rice straw biochar was high which make it a potential additional source of fertilizers. In order to see the porous textures, the scanning electron microscopy (SEM) observations were performed on the surface of rice straw biochar. Fig. 3 shows SEM micrographs images (×400, 600, 1500 and 2000) of produced rice straw biochar at 650 °c for 5 h residence time. The surface of rice straw biochar seems to be almost smooth and of a porous structure. Fig. 4 shows the elemental compositions on the surfaces of produced rice straw biochar at 650 °c for 5 h residence time by the energy dispersive X-ray spectroscopy (EDS). The contents of inorganic elements were consistent with the data in Table 2.

Elemental analysis of produced rice straw biochars

Results in Table 2 showed that both H and O decreased with increasing temperature, while C content increased. N content had no constant change behaviour as it increased until temperature of 450 °c, but decreased afterwards at 650 °c. the obtained data was in same trend as data generated by Thammasom *et al.* (2016) and Weixiang *et al.* (2012), which clearly showed highly condensed components formed at higher temperatures. However, similar production conditions of biochar from rice straw under same temperature and residence time gave higher values as cleared by Peng *et al.* (2011). The variation in results may be due to the differences in pyrolysis technology. pH increased with the applied temperature with some inconstant changes with residence times as it followed ash content change behaviour. There was decrease in CEC with increasing temperature, this might be due to reduction of the availability of P and cations as clarified by previous investigations by Thammasom *et al.* (2016) and Gaskin *et al.* (2008). N, P, K, Ca, and Mg concentrations in the biochar were significantly different under the three different pyrolysis temperatures with the trend of increasing with increasing the temperature.
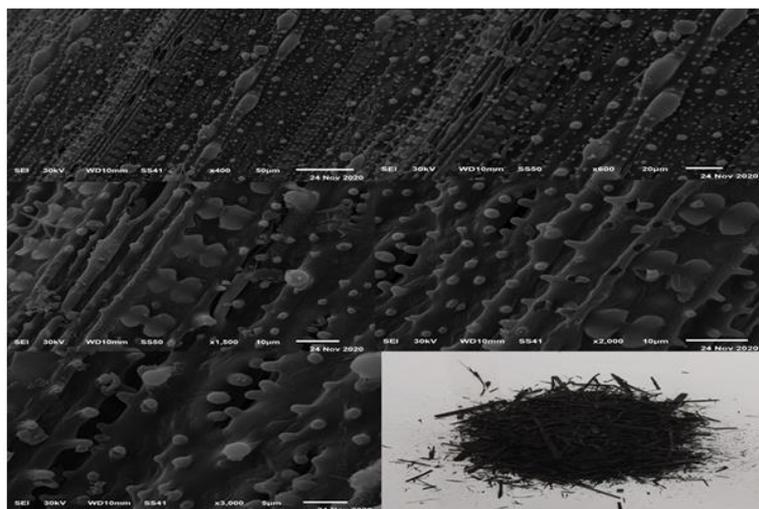
Fig. 3. Actual and scanning electron microscopy (SEM) images (×400, 600, 1500, 2000 and 3000) of rice straw biochar (at 650 °c for 5 h residence time).

Element	Weight%	Atomic%
C K	42.28	56.41
O K	29.18	29.22
Mg K	0.74	0.49
Si K	16.71	9.53
Cl K	2.82	1.27
K K	5.55	2.28
Ca K	0.80	0.32
Cu K	1.32	0.33
Zn K	0.60	0.15
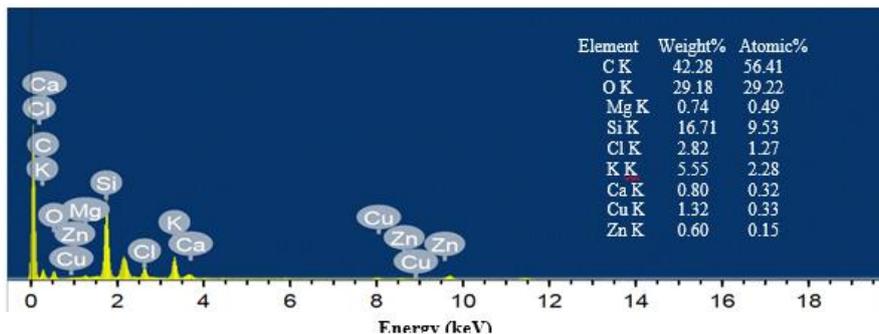
Fig. 4. Elemental compositions on the surfaces of produced rice straw biochar at 650 °c for 5 h residence time by the energy dispersive X-ray spectroscopy (EDS).

The chemical properties and characteristics of produced date palm fronds biochars.

The chemical properties of produced date palm fronds biochars are shown in Table 3. Biochar yield was significantly affected by temperature increase, where, the yield decreased from 50.1 % to 27.9 % when pyrolysis temperature increased from 250 °c to 650 °c for 2 h residence time. The reduction in biochar yield percentages maybe due to thermal degradation of cellulose and hemicellulose. Volatile matter also showed same trend in decrease under higher pyrolysis temperature. Where, volatile matter decreased from 43.5 % to 6.50 % when pyrolysis temperature increased from 250 °c to 650 °c for 2

h residence time. There were no significant effects with residence times under each pyrolysis temperature. Minimum value of ash content and Fixed C was 15.4 % and 45 % and reached 21.5 % and 73.15 as the maximum values respectively when pyrolysis temperature increased to 650 °c. The results are consistent with many studies as formation and condensation of mineral compounds happen during pyrolytic process (Usman *et al.*, 2015; Ahmad *et al.*, 2019). Scanning electron microscopy (SEM) observations were performed on the surface of palm fronds biochar. Fig. 5 shows SEM micrographs images (×300, 600, 1200 and 2000) of palm fronds biochars at 650 °c for

5 h residence time. The surface of palm fronds biochars seems to be almost smooth and of a porous structure. The porous structure leads to high surface area of palm fronds biochars. Fig. 6 shows the elemental compositions on the surfaces of produced of palm fronds biochars at 650 °c for 5 h residence time by the energy dispersive X-ray spectroscopy (EDS). The contents of inorganic elements were consistent with the data in Table 3.

Elemental analysis of produced date palm fronds biochars

pH increased with the applied temperature with some inconstant changes with residence times (Table 3).

Table 3. Chemical properties and elemental composition of produced palm fronds biochars.

| Biochar characteristics*	Rice Straw Biochar								
	Temperature								
	250 °c			450 °c			650 °c		
	Residence time								
Chemical properties	2 h	4 h	5 h	2 h	4 h	5 h	2 h	4 h	5 h
Biochar yield, %	50.1	49.2	48.7	34.8	34.5	34.0	27.9	26.5	27.2
Volatile matter (VM), %	43.5	42.1	430	16.5	14.22	14.10	6.50	6.23	5.95
Ash content, %	15.6	15.4	16.0	20.07	20.71	20.80	21.30	21.5	21.3
Fixed C	44.20	45.10	45.00	68.45	68.4	70.5	72.10	72.00	73.15
Elemental composition									
pH	7.94	7.92	7.91	8.14	5.95	8.74	10.20	10.24	10.98
CEC, cmol/kg	31.50	32.14	30.47	29.51	28.74	28.53	26.04	25.43	24.84
C, %	74.80	74.09	74.05	85.15	85.2	86.10	88.30	88.1	89.1
H, %	5.16	4.98	4.92	2.36	2.11	2.05	1.17	1.04	0.98
N, %	0.65	0.54	0.17	0.51	0.25	0.20	0.09	0.95	0.85
O, %	19.37	20.35	20.80	11.97	12.43	11.62	10.41	9.88	7.05
Total N, g/kg	0.37	0..29	0.28	0.34	0.33	0.33	0.32	0.34	0.37
Total P, g/kg	0.08	0.09	0.09	0.04	0.11	0.13	0.14	0.41	0.45
Total K, g/kg	2.00	2.20	2.15	2.47	2.58	2.64	2.71	2.87	2.81
Total Ca, g/kg	5.30	5.44	5.38	6.40	5.98	6.74	7.98	8.02	8.54
Total Mg, g/kg	1.3	1.4	1.1.42	1.61	1.71	1.85	2.1	1.22	2.23

* Percentages are on a dry weight basis
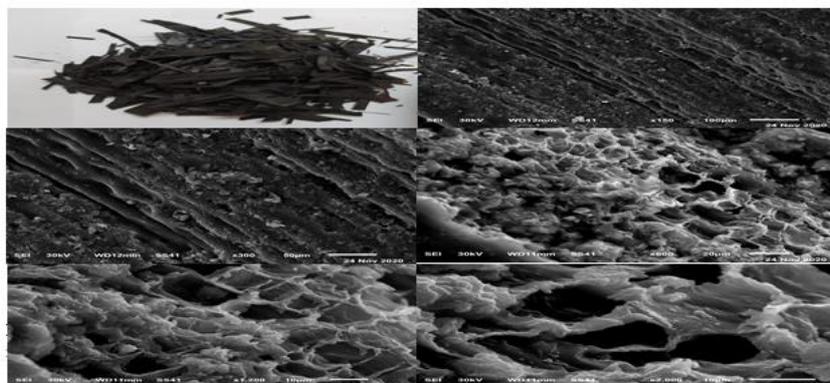
Fig. 5. Actual and scanning electron microscopy (SEM) images (×150, 300, 600, 1200 and 2000) of date palm fronds biochar (at 650 °c for 5 h residence time).

Element	Weight%	Atomic%
C K	68.58	75.87
O K	26.58	22.08
Mg K	0.61	0.33
Al	0.42	0.21
Si K	1.91	0.90
Cl K	0.15	0.06
K K	0.65	0.22
Ca K	0.79	0.26
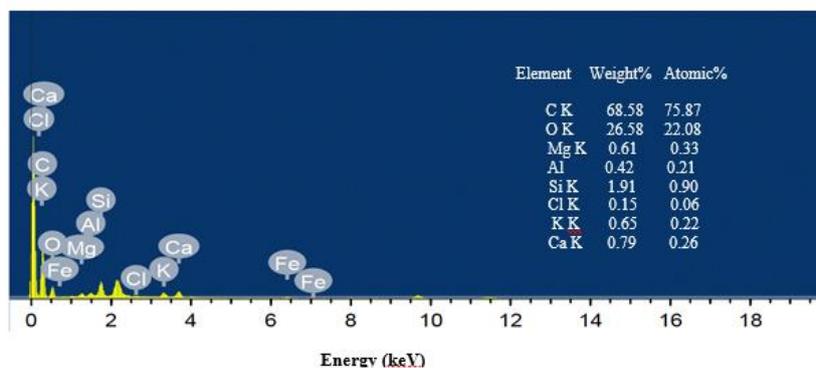
Fig. 6. Elemental compositions on the surfaces of produced of palm fronds biochars at 650 °c for 5 h residence time by the energy dispersive X-ray spectroscopy (EDS).

There was decrease in CEC with increasing temperature, this might be due to reduction of the availability of P and cations as clarified by previous investigations by Thammasom *et al*. (2016) and Gaskin *et al*. (2008). As expected due to the increase in pyrolysis temperature, H, O, N percentage decreased. These decreases are due to the loss of O and H containing surface functional groups by dehydration during the pyrolysis process. There were clear significant effect of pyrolysis temperature on N, P, K, Ca, and Mg, where, the maximum values were observed at 650 °c.

CONCLUSION

Rice straw and date palm fronds successfully processed to produce biochars with the new developed biochars pyrolysis. The analysis of produced biochars came consistent with the previous investigations. Most significant changes in biochar yield, volatile matter, ash content and fixed C occurred when pyrolysis temperature changed from 250 °c to 450 °c, while, the rate of changes was slower when temperature changed from 450 °c to 650 °c. Volatile matter decreased with increasing pyrolysis temperature might show effect of higher temperature on the stability of the process. The ash content of rice straw biochar was high which make it a potential additional source of fertilizers. N, P, K, Ca, and Mg concentrations in the biochar were significantly different under the three different pyrolysis temperatures with the trend of increasing with increasing the temperature.

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تصميم وتقييم فرن تحلل حراري لانتاج الفحم الحيوي
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تم تطوير واختبار فرن تحلل الحراري للفحم الحيوي لأنظمه الانتاج صغيرة الحجم واستخدامه لإنتاج فحم حيوي من اثنين من المخلفات الزراعية اللجينية السليلوزية (قش الأرز وسعف النخيل). الأبعاد الكلية لفرن التحلل الحراري المصمم مع الإطار هو 0.85 × 1 × 1 م من حيث الطول والعرض والارتفاع على التوالي ، وهو مصنوع من الفولاذ المقاوم للصدأ بسمك 4 مم. يحتوي الفرن الحراري علي حجرة مستطيلة داخلية (0.75 × 0.8 × 0.5 م) طول وعرض وارتفاع على التوالي بحجم إجمالي يبلغ 0.30 م 3. الحجرة الداخلية مصنوعة من الفولاذ المقاوم للصدأ 4 مم لتحمل درجة حرارة التشغيل حتى 900 درجة مئوية. الغرفة الداخلية محاطة بغرفة الاحتراق بمسافة 40 مم بينهما. درجة حرارة الانحلال الحراري إما تصل إلى 250 درجة مئوية أو 450 درجة مئوية أو 650 درجة مئوية بمعدل تسخين 5 درجات مئوية دقيقة -1. تم العمل علي ثلاث فترات لتوقيت الحرق (2 ، 4، 5 ساعات) لدراسة تأثير درجة الحرارة على جودة الفحم الحيوي. كانت قياسات الدراسة عبارة عن تكوين وتحليل O (الأكسجين) ، C (الكربون)، H (الهيدروجين) ، N (النيتروجين) ، إجمالي N، ‏P، ‏K، ‏Ca، ‏Mg ، قدرة التبادل الكاتيوني (CEC) ، الرطوبة ، المادة المتطايرة ، إنتاج الكربون والفحم الثابت مع قياس الأس الهيدروجيني والتوصيل. أثبت فرن التحلل الحراري للفحم الحيوي المطور قدرته على العمل بفاعلية لإنتاج الفحم الحيوي. لكل من قش الأرز و سعف التمر انخفض إنتاجية الفحم الحيوي مع زيادة درجة حرارة التحلل الحراري من 250 درجة مئوية إلى 650 درجة مئوية. كما انخفض إنتاج المواد المتطايرة مع زيادة درجة حرارة الانحلال الحراري. زاد محتوى الرماد و C ثابت في الفحم الحيوي لقش الأرز مع زيادة درجة حرارة التحلل الحراري. حيث كان الحد الأدنى من محتوى الرماد المسجل 23.5٪ عند درجة حرارة 250 درجة مئوية لمدة ساعتين من الحرق، وكانت القيمة القصوى المسجلة 32.5٪ عند درجة حرارة 650 درجة مئوية لمدة 5 ساعات من الحرق ، مع وجود اتجاه مماثل مع سعف النخيل ولكن مع انخفاض قيم محتوى الرماد. انخفض كل من H و O في الفحم الحيوي لقش الأرز مع زيادة درجة حرارة التحلل الحراري ، بينما زاد محتوى C. لم يكن لمحتوى النيتروجين سلوك ثابت حيث زاد حتى درجة حرارة 450 درجة مئوية ، ولكنه انخفض بعد ذلك عند 650 درجة مئوية. زاد الأس الهيدروجيني للفحم الحيوي في سعف النخيل مع درجة حرارة الانحلال الحراري المطبقة مع بعض التغييرات غير المتسقة مع أوقات الحرق. كان هناك انخفاض في قدرة التبادل الكاتيونيCEC مع زيادة درجة الحرارة ، وقد يكون هذا بسبب انخفاض الفسفور P