786 Egypt. J. Chem. Vol. 66, No.SI 13. pp. 2231 - 2236 (2023)

Egyptian Journal of Chemistry
http://ejchem.journals.ekb.eg/

Wheat Straw Pyrolysis for Biochar Production: Characterization and Application as Soil Conditioner

Adel S. El-Hassanin[1*]; Amira Sh. Soliman[1]; Magdy R. Samak[1]; Ghadir A. El-Chaghaby[2] and Abeer R. Radwan[2]

[1]*Faculty of African Postgraduate Studies, Cairo University, EGYPT*

[2]*Regional Center for Food and Feed, Agricultural Research Center, Giza, EGYPT*

Abstract

The re-use of plant biomasses by converting them into value added products is a major sustainability challenge. Large amounts of plant biomass are usually available especially during main crops harvest seasons. In the present work, biochar was produced by thermal decomposition of wheat straw biomass at 450^{o}C under limited oxygen condition. The resulting biochar (WSB) was subjected to different types of characterization. The biochar elemental compositions showed a high carbon content (41.43%), hydrogen (6.43%) and nitrogen (1.06%). The FTIR results revealed several functional groups such as O-H, C-H, C=N–, C=C, and C=O on the biochar's surface. The SEM results were obtained for wheat straw before and after pyrolysis and the results revealed that the surface morphology of wheat straw was converted from non-porous to porous surface upon pyrolysis. After characterization experiments, the biochar from wheat straw was tested as soil conditioner. In this part of the work, a sandy soil sample was collected from Al-Ismailia governorate. The soil was subjected to different tests to get its properties before beginning the experiment. Then biochar was applied to the soil (w/w) at two rates low (2.5%) and high (10%). Soil samples with no biochar served as control. All samples were incubated for 3 months with continuous moisturizing. At the end of the incubation, soil samples were collected and analyzed. The results indicated a significant effect for biochar application on the tested soil physical and chemical properties. The statistical analysis results revealed a significant ($P<0.05$) increase in organic matter, organic carbon, pH and electric conductivity values after biochar addition and this increase was proportional to the level of biochar used. As compared with the control treatment, it can be observed that the application of biochar into soil significantly ($P<0.05$) increased its nitrogen, phosphorus and potassium content. The concentrations of soluble anions and cations in soil were significantly ($P<0.05$) increased as a result of biochar addition. From the results obtained in this study, it can be concluded that by pyrolyzing wheat straw resulted in a well porous carbonaceous biochar which was successfully applied as a soil conditioner especially for sandy soil.

Keywords: biochar; sandy soil; wheat straw; soil conditioner; chemical properties; physical properties.

1. Introduction

Environmental studies especially those related to finding out solutions for mitigating global warming effects have received a lot of attention over the past years. The management of agricultural wastes/ by-products is an environmental concern. Converting these by-products into value added materials such as soil conditioners could be as a solution to reduce global warming and improve environmental management [1].

Biochar which is a product of pyrolysis reaction under anaerobic conditions, it has a granular-porous structure with a variety of benefits when applied as a soil conditioner. Biochar application improves soil quality, increases its pore size and water holding capacity and most important it reduces carbon dioxide emissions[2].

The nature of the starting material used for biochar preparation is an important factor as biochar

*Corresponding author e-mail: adelelhassanin@cu.edu.eg, (Adel S. El-Hassanin)
Received date 22 March 2023; revised date 24 May 2023; accepted date 14 June 2023
DOI: 10.21608/EJCHEM.2023.201693.7764

properties are influenced by properties of the starting material that determine its final applications in soil [3]. Several types of agricultural wastes were successfully converted to biochar e.g. Coconut husk [4], rice husk and rice straw[3, 5], sugar cane straw [6], soybeans and corn stalks [7], elephant grass [8], etc. According to Kapoor et al. [9], the yearly global production of wheat straw, a by-product collected after harvesting wheat grains, is 529 million tonnes.

Arid regions are mainly characterized by sandy soils which due to their poor quality, are considered insignificant for agriculture. Organic additives in sandy soils face constant turnover challenges due to their fast degradation rates. Thus, biochar could be a suitable choice for enhancing the properties of sandy soils [10].

The present work was performed aiming: 1- to investigate the effect of pyrolysis on biochar production from wheat straw and to characterize the produced biochar by different tools; and 2- to assess the chemical and physical changes in the properties of sandy soil when amended by this biochar at different rates.

2. Materials and methods

2.1. Biochar preparation

The precursor material used for biochar preparation was wheat straw which was collected from Agricultural Research Center, Giza, EGYPT after wheat harvest. The straw materials were cleaned and chopped into small pieces then allowed to dry in an electric oven set at 105°C until constant weight. The dried material was then pyrolyzed at 450°C for 4 hours in a muffle furnace. To ensure minimal oxygen during pyrolysis process, the dried straws were enclosed in a firmly closed steel box especially designed for this experiment. At the end of pyrolysis, the resulting biochar (WSB) was allowed to cool to room temperature, then collected and kept in plastic bags in a desiccator.

2.2. Characterization of WSB

Wheat straw before and after pyrolysis was subjected to analysis in order to get its main surface and compositional characteristics. An elemental analyzer, model: VARIO EL III GERMANY, an electronic microscope, model: JEOL-100S JAPAN and a Fourier Transform Infrared, Model: FT-IR SPECTROMETER 4100 JASCO JAPAN were used to obtain the different biochar characteristics.

2.3. Soil sampling and analysis

Soil samples were randomly collected from Al-Ismailia and thoroughly mixed into one representative sample for the study area before being sent and subjected to different analysis in SWERI (Soil, Water and Environmental Research Institute) at the Agricultural Research Center, Giza, Egypt. The soil was analyzed to determine its organic matter, total carbon, pH, electric conductivity, exchangeable anions and cations and macronutrients (N, P and K). Exchangeable cations and anions and macro-elements were determined by the procedures described in the work of [5]. The soil properties are shown in Table (1).

Table 1

Soil Properties

Chemical Properties									
		Soluble anions (meq/l)				Soluble cations (meq/l)			
pH	**EC dS/m**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**CO^{-}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{2-}**
8.10	3.93	2.27	1.56	0.44	0.42	n.d	2.42	1.31	0.76

Particle size distribution				
Fine Sand (%)	**Coarse Sand (%)**	**Silt (%)**	**Clay (%)**	**Soil texture**
45.4	40.7	12.1	1.8	Sandy soil

Physical properties		
Bulk density (g/cm^3)	**Wilting point (%)**	**Saturation (%)**
1.66	4.2	21.3

n.d. not detected

2.4. Soil/ biochar experiment

The biochar prepared from wheat straw was applied to the soil at two different rates (low rate 2.5% and high rate 10%). The procedure used was as described by Abdelhafez et al., [11] with some modifications. The soil was divided into three groups of three replicates. The 1st group was used as control without any biochar addition, 2nd group was soil ammended with 2.5% biochar (w/w) and 3rd group was soil ammended with 10% biochar (w/w). Soil samples after amendments were then incubated atroom temperature for 3 months during which they were systematically hydrated. At the end of incubation experiment, soil samples were collected, dried, sieved and analyzed to determine the changes in their chemical and physical analysis.

2.5. Statistical analysis

The experiment was laid out using completely randomized design. The results were analyzed using ANOVA test and the means were compared by Duncan's test at a significance level ($p<0.05$).

3. Results and discussion

3.1. Biochar characterization results

In order to check the differences in the properties of wheat straw and its biochar, several characterization tools were used. Figure 1 a and 1b show the scanning electron microscope photos for wheat straw and wheat straw biochar, respectively. It can be observed that wheat straw, before its transformation to biochar, did not have a porous structure as seen from figure 1a. On the other hand, wheat straw biochar has a porous structure as seen in figure 1b where asymmetrical pores appear on the surface of the biochar. Increasing temperature during the pyrolysis process forces volatile components out of the char, resulting in the formation of pores and an increased surface area[12].

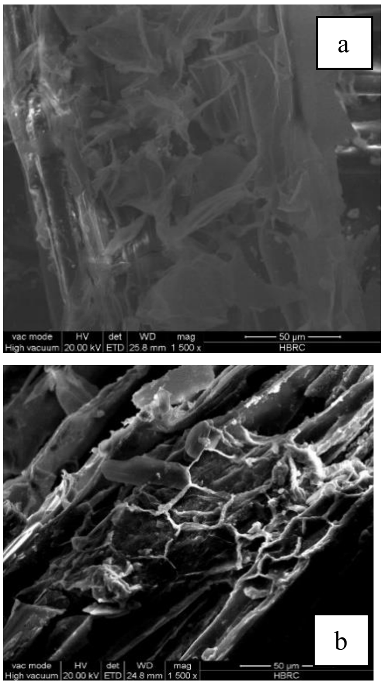

Fig. 1. SEM Photos of (a) Wheat Straw and (b) Wheat Straw Biochar

The biochar prepared from wheat straw was also shown to contain many functional groups as shown from its FTIR spectrum (Figure 2). The spectrum revealed a band at 3400 cm^{-1} demonstrating the occurrence of (-OH) hydroxyl groups in lignin and cellulose [13] [14]. Another band at 2913 cm^{-1} that may be ascribed to stretching vibration of the C-H [15]. Two other bands at 1706 and 1631 cm^{-1} representative for aliphatic acid C=O stretching[16] and C=N–, C=C, and C=O of protein [13], respectively. A sharp band at 1174 cm^{-1} that could be due to =C-N [17] and the bands at 800-900 cm^{-1} could be ascribed for the δNH bending vibration of amines and meta distribution of the aromatic protons [18].

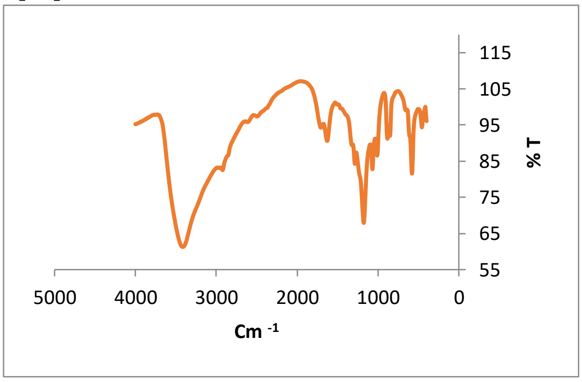

Fig. 2. FTIR spectrum of Wheat Straw Biochar

As seen from Table 2, the elemental analysis of biochar prepared from wheat straw exhibited that it was composed of 41.43% carbon, 6.43% hydrogen and 1.06% nitrogen. It can be observed that the biochar possessed a high carbon content while the contents of hydrogen and nitrogen were relatively low. The H/C ratio of wheat straw biochar was 0.15 which implies that the prepared biochar has an aromatic structure which was formed by carbonization [14].

Table 2

Elemental Analysis of wheat straw biochar

Carbon %	Hydrogen %	Nitrogen %	H/C
41.43	6.43	1.06	0.15

3.2. Effect of biochar on soil properties

The effect of biochar application on organic matter, organic carbon, pH and EC of the sandy soil is presented in Table (3). The statistical analysis demonstrated a substantial ($P<0.05$) rise in OM, OC, pH, and EC values following biochar addition, which was proportionate to the amount of biochar applied. The soil amended with 10% biochar had the greatest mean values for the four evaluated metrics, whereas the control had the lowest values.

Table (3) shows that after applying biochar, soil organic matter gone up significantly (P <0.05). The results indicated that as biochar transformation levels increased, so did total organic matter. This implies that organic matter is stored more efficiently, and the activity of microorganisms engaged in organic matter biodegradation in the soil is preserved [11].

The addition of biochar to sandy soil increased its amount of carbon significantly (p<0.05). It has been previously observed that following biochar, the minerals in soil can react with biochar in manners that boost the resistance to oxidation of biochar particles, improve biochar stabilization, and contribute to interfacial interactions that promote C sequestration [19].

The biochar addition had a significant (P<0.05) effect on soil pH and EC, and their values rose as the biochar application rate increased. This pH rise may be due to the dissolution of alkaline cations in ashy biochar [20]. The presence of salts in biochar may explain the rise in soil EC with biochar amendment rate [21]. Numerous prior investigations support the idea that biochar enhances soil electrical conductivity (EC) and pH [22, 23].

Table 3

Effect of Biochar on OM, OC, pH and EC in soil

Treatments	OM (%)	OC (%)	pH	EC dS/m
Control	0.897^{c}	0.507^{c}	8.1000^{c}	3.937^{c}
Biochar 2.5%	1.004^{b}	0.584^{b}	9.103^{b}	5.000^{b}
Biochar 10%	1.148^{a}	0.667^{a}	9.467^{a}	6.453^{a}

a,b,….: Means in the same row with different superscripts are significantly different (P<0.05)

Table 4

Effect of Biochar on NPK in soil

Treatments	N (%)	P (%)	K (%)
Control	0.009^{c}	0.0040^{c}	0.334^{c}
Biochar 2.5%	0.015^{b}	0.0047^{b}	0.371^{b}
Biochar 10%	0.025^{a}	0.0128^{a}	0.506^{a}

a,b,….: Means in the same row with different superscripts are significantly different (P<0.05)

Table 4 shows the effects of biochar application on three macronutrients N, P, and K in soil. When compared with the untreated treatment, the incorporation of biochar into soil raised its nitrogen, phosphorus, and potassium content considerably (P<0.05). It is well acknowledged that adding biochar to soil can change the status of organic matter (due to the release of nutrients such as nitrogen) [24]. As reported by El-Hassanin et al., [5], the higher nutrient preservation in biochar-improved soils may be ascribed to the biochar surface, which allows nutrients to engage with the biochar surface functional groups more easily.

In terms of the effect of biochar amendment on the exchangeable cations and anions in soil, the data in Table 5 demonstrated that applying biochar to the soil considerably (P<0.05) enhanced exchangeable nutrient cations (Ca, Mg, and K) as well as exchangeable Na as compared to the control soil. The anions followed a similar pattern (HCO3, Cl and SO4). These findings are consistent with prior research [26].

Table 5

Effect of Biochar on soluble cations and anions in soil

Treatments	Cations				Anions			
	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
Control	2.16^{c}	1.56^{c}	0.44^{c}	0.42^{b}	N.D	2.42^{c}	1.31^{c}	0.76^{c}
Biochar 2.5%	2.20^{b}	1.60^{b}	0.47^{b}	1.07^{a}	N.D	3.36^{b}	2.20^{b}	1.13^{b}
Biochar 10%	4.20^{a}	1.83^{a}	0.69^{a}	1.07^{a}	N.D	4.10^{a}	3.14^{a}	1.87^{a}

a,b,….: Means in the same row with different superscripts are significantly different (P<0.05)

Conclusion

Wheat straw by the mean of pyrolysis was successfully converted into biochar with distinct physiochemical characteristics. When added to sandy soil, biochar was able to improve its properties. Based on the findings of this study, it can be stated that wheat straw-derived biochar may be recommended as an efficient soil conditioner, particularly for sandy soil. Future research might compare the effect of the recommended biochar on different soil types.

3. References

1. Takolpuckdee P (2014) Transformation of Agricultural Market Waste Disposal to Biochar Soil Amendments. Procedia Environ Sci 20:64–70. https://doi.org/10.1016/j.proenv.2014.03.010

2. Hussain F, Khan AHA, Hussain I, et al. (2022) Soil conditioners improve rhizodegradation of aged petroleum hydrocarbons and enhance the growth of Loliummultiflorum. Environ SciPollut Res 29:9097–9109. https://doi.org/10.1007/s11356-021-16149-7

3. Jindo K, Mizumoto H, Sawada Y, et al. (2014) Physical and chemical characterization of biochars derived from different agricultural residues. Biogeosciences 11:6613–6621. https://doi.org/10.5194/bg-11-6613-2014

4. Plaimart J, Acharya K, Mrozik W, et al. (2021) Coconut husk biochar amendment enhances nutrient retention by suppressing nitrification in agricultural soil following anaerobic digestate application. Environ Pollut 268:115684. https://doi.org/10.1016/j.envpol.2020.115684

5. El-Hassanin AS, Samak MR, Radwan SR, El-chaghaby GA (2020) Preparation and Characterization of Biochar from Rice Straw and Its Application in Soil Remediation. Environ Nat Resour J 18:xx–xx

6. Puga AP, Abreu CA, Melo LCA, Beesley L (2015) Biochar application to a contaminated soil reduces the availability and plant uptake of zinc, lead and cadmium. J Environ Manage 159:86–93. https://doi.org/10.1016/j.jenvman.2015.05.036

7. Liu N, Charrua AB, Weng CH, et al. (2015) Characterization of biochars derived from agriculture wastes and their adsorptive removal of atrazine from aqueous solution: A comparative study. BioresourTechnol 198:55–62. https://doi.org/10.1016/j.biortech.2015.08.129

8. Adesemuyi MF, Adebayo MA, Akinola AO, et al. (2020) Preparation and characterisation of biochars from elephant grass and their utilisation for aqueous nitrate removal: Effect of pyrolysis temperature. J Environ ChemEng 8:104507. https://doi.org/10.1016/j.jece.2020.104507

9. Kapoor M, Panwar D, Kaira GS (2016) Bioprocesses for Enzyme Production Using Agro-Industrial Wastes: Technical Challenges and Commercialization Potential. In: Agro-Industrial Wastes as Feedstock for Enzyme Production: Apply and Exploit the Emerging and Valuable Use Options of Waste Biomass. Elsevier Inc., pp 61–93

10. Baiamonte G, Crescimanno G, Parrino F, De Pasquale C (2019) Effect of biochar on the physical and structural properties of a desert sandy soil. Catena 175:294–303. https://doi.org/10.1016/j.catena.2018.12.019

11. Abdelhafez A a, Li J, Abbas MHH (2014) Feasibility of biochar manufactured from organic wastes on the stabilization of heavy metals in a metal smelter contaminated soil. Chemosphere 117:66–71. https://doi.org/10.1016/j.chemosphere.2014.05.086

12. Pandey D, Daverey A, Arunachalam K (2020) Biochar: Production, properties and emerging role as a support for enzyme immobilization. J Clean Prod 255:120267. https://doi.org/10.1016/j.jclepro.2020.120267

13. Al-Ghouti MA, Razavi MM (2020) Water reuse: Brackish water desalination using Prosopisjuliflora. Environ TechnolInnov 17:100614. https://doi.org/10.1016/j.eti.2020.100614

14. Yang X, Liu J, McGrouther K, et al. (2016) Effect of biochar on the extractability of heavy metals (Cd, Cu, Pb, and Zn) and enzyme activity in soil. Environ SciPollut Res 23:974–984. https://doi.org/10.1007/s11356-015-4233-0

15. Imran M, Latif M (2013) International Journal of Biological Macromolecules Biosorption potentials of a novel green biosorbentSaccharumbengalense containing cellulose as carbohydrate polymer for removal of Ni (II) ions from aqueous solutions. Int J BiolMacromol 54:99–108. https://doi.org/10.1016/j.ijbiomac.2012.11.010

16. Singha B, Das SK (2013) Adsorptive removal of Cu(II) from aqueous solution and industrial effluent using natural/agricultural wastes. Colloids Surf B Biointerfaces 107:97–106. https://doi.org/10.1016/j.colsurfb.2013.01.060

17. Gupta VK, Rastogi A, Nayak A (2010) Journal of Colloid and Interface Science Biosorption of nickel onto treated alga (Oedogoniumhatei): Application of isotherm and kinetic models. J Colloid Interface Sci 342:533–539. https://doi.org/10.1016/j.jcis.2009.10.074

18. Klongklaew N, Praiboon J, Tamtin M, Srisapoome P (2020) Antibacterial and antiviral activities of local Thai green macroalgae crude extracts in pacific white shrimp

(litopenaeusvannamei). Mar Drugs 18:1–23. https://doi.org/10.3390/md18030140

19. Gao S, Hoffman-Krull K, Bidwell AL, DeLuca TH (2016) Locally produced wood biochar increases nutrient retention and availability in agricultural soils of the San Juan Islands, USA. AgricEcosyst Environ 233:43–54. https://doi.org/10.1016/j.agee.2016.08.028

20. Khadem A, Raiesi F, Besharati H, Khalaj MA (2021) The effects of biochar on soil nutrients status, microbial activity and carbon sequestration potential in two calcareous soils. Biochar 3:105–116. https://doi.org/10.1007/s42773-020-00076-w

21. Shah T, Sara, Shah Z (2017) Soil respiration, pH and EC as influenced by biochar. Soil Environ 36:77–83. https://doi.org/10.25252/se/17/51184

22. Karim MR, Halim MA, Gale N V., Thomas SC (2020) Biochar effects on soil physiochemical properties in degraded managed ecosystems in northeastern Bangladesh. Soil Syst 4:1–17. https://doi.org/10.3390/soilsystems4040069

23. Joner EJ (2020) Applied sciences Biochar A ffects Heavy Metal Uptake in Plants through Interactions in the Rhizosphere

24. Agegnehu G, Srivastava AK, Bird MI (2017) The role of biochar and biochar-compost in improving soil quality and crop performance: A review. Appl Soil Ecol 119:156–170. https://doi.org/10.1016/j.apsoil.2017.06.008

25. El-Hassanin AS, Samak MR, Radwan SR, El-Chaghaby GA (2020) Preparation and characterization of biochar from rice straw and its application in soil remediation. Environ Nat Resour J 18:283–289. https://doi.org/10.32526/ennrj.18.3.2020.27

26. Hossain MZ, Bahar MM, Sarkar B, et al. (2020) Biochar and its importance on nutrient dynamics in soil and plant. Springer Singapore