RESEARCH ARTICLE

INVESTIGATION ON QUALITY OF COIR WASTES BIOCHAR FOR SOIL AMENDMENT AND SOIL CARBON SEQUESTRATION APPLICATIONS

Shalini Ramesh* and Pugalendhi Sundararaju[1]

Ph.D Scholar, Department of Bioenergy, AEC & RI, Tamil Nadu Agricultural University,
Coimbatore- 641 003, Tamil Nadu, India
[1]Professor, Department of Bioenergy, AEC & RI, Tamil Nadu Agricultural University,
Coimbatore- 641 003, Tamil Nadu, India

Received-12.03.2019, Revised-15.04.2019

Abstract: In this paper, coir wastes biochar was prepared from coirwaste biomass at low temperatures (400-450°C) and the quality of the biochar was tested with reference to the International Biochar Initiative (IBI) criteria for soil amendment and soil carbon sequestration applications. The coir wastes biochar had mass yield (20.02%), H/C_{org} (0.48), O/C (0.59), pH (7.28) and EC (0.09 dS cm^{-1}). Carbon (%) of the coir waste biochar was found to be increased from 34.52% to 44.98%. The nitrogen (%) and sulphur (%) was found to be low in the coirwastes biochar compared to the raw biomass, indicating that it would produce less NOx and SOx emissions during combustion. The total organic carbon (%) was notably increased from 18% to 52% and follows class 2 biochars (≥30<60%) based on the criteria given by IBI. It is observed from the results that the thermo-chemically converted coir wastes biochar had greater potential and stability to sequester organic carbon in the soil because H/C_{org} of the biochar was found to be <0.70 and all other characteristics were in the threshold criteria as declared by IBI.

Keywords: Coir wastes biomass, Biochar, Organic carbon, Stability, IBI criteria

INTRODUCTION

The world's environment is being severely polluted and global temperature level has been rising up due to the continuous burning of fossil fuels for energy generation, manmade activities inefficient method of wastes disposal and changes in land use pattern resulting in enormous release of harmful green house gas (GHG) emissions to the atmosphere. The concentration of CO_2 in the atmosphere has increased from 277 ppm in 1750 (Le Quere *et al.*, 2016) to 413.52 ppm in 2019 (CO_2 now.org). Due to the changes in land use pattern, global carbon emissions were accounted for about 9% i.e. 0.9 (Gt C) with the release of 3.303 Gt CO_2 in the year 2014 (Butler and Montzka, 2015). From 2005 to 2014, about 44% of CO_2 emissions accumulated in the atmosphere, 26% in the ocean and 30% on land. From 1870 to 2014, cumulative carbon emissions totalled about 545 Gt C. Emissions were partitioned among the atmosphere (230 Gt C or 42%), ocean (155 Gt C or 28%) and the land (160 Gt C or 29%). In 2013, the largest national contributions to the net growth in total global emissions were China (58%), USA (20%) followed by India (17%). Fossil fuel emissions were 0.6% (9.735 Gt C) and 60% more than the emissions in 2013 and 1990 respectively (www.CO_2.earth accessed on May 2019).

In order to reduce the consumption of fossil fuels, to lower the greenhouse emissions produced from fossil fuels and to balance the uneven distribution of energy resources in the energy portfolio, a shift to renewable energy sources is being made mandatory to ensure long term energy supplies (Unrean *et al.*, 2018).

Among all the different types of renewable energy sources, lignocellulosic biomass feedstocks are the most promising sources to produce carbon rich materials since they are the only carbon neutral sources which are abundantly available in nature, cheaper in costs and locally available for efficient fuel conversion (Iaquaniello et al., 2017). The majority of the wood wastes are produced from agricultural, forestry and energy-based industries (Burgert et al., 2015). In India, the annual biomass production is about 550 MT with a surplus of about 120-150 MT per annum covering agricultural and forestry residues with the energy potential of 18,000 MW (www.mnre.gov.in accessed on Jan 2019). When the biomass or biomass derived fuel is burnt, it gives net zero / lower carbon dioxide emission and promotes carbon dioxide emission reduction and also helps to minimize waste disposal (Nizami et al., 2017).

Recently, carbonization technology receives greater interest and it is considered as one of the most important processes since it converts the biomass into carbon rich solid product called biochar or pyrochar and releases the volatile matter in the form of gaseous product through slow pyrolysis process (Correa et al. 2019). This study mainly focuses on the synthesis of biochar derived from coir wastes biomass and to compare the effect of basic utility properties of coir waste biochar with reference to guidelines (Version 2.0) suggested by International Biochar Initiative (IBI, 2015) for soil amendment and soil carbon sequestration applications.

*Corresponding Author

MATERIALS AND METHODS

Coir wastes biomass was collected from a coirpith industry located at Pollachi, Coimbatore, Tamil Nadu, India (Latitude: 10.65°N and 77.01°E). The coir wastes was initially dried in the solar tunnel drier until it reaches the optimum moisture content (<10%). The dried coir wastes biomass was stored in the airtight zip lock covers for further characterization and biochar production.

The designed slow pyrolyzer consists of combustion zone in the lower part with grate system to collect the ash and pyrolysis zone in the upper part extended with chimney set up for the release of volatiles during pyrolysis process. According to the bulk density of the biomass and volume of the slow pyrolyzer, about 150 g of dried coirpith biomass was loaded in the pyrolytic zone. Likewise, in the combustion zone, charcoal was filled and used as a combustion fuel. The pyrolysis process was initiated by igniting the combustion fuel and the reactor was sealed immediately. After 30 min the biomass was completely converted to biochar emitting the volatile substances and enhancing the non-volatile carbon at the temperature of above 400-450°C (Prabha et al., 2015). The reactor was allowed to cool and the biochar was collected, sieved down to <2 mm and stored in the zip lock covers for further analysis.

Characterization of biochar

The coir waste biochars was tested for category A-Basic utility properties since the test is mandatory for all biochars with reference to the standard methods developed by International Biochar Initiative (IBI) (2015) (IBI STD. version 2.1), USA. The physical properties such as moisture content (%) were calculated by ASTM D1762-84 and particle size (nm) was determined by standard procedure. Total Carbon (%) and other elements such as Hydrogen (%), Nitrogen (%), S (Sulphur) and Oxygen (%) was determined by dry combustion method in the elemental analyzer and O is calculated by the difference of other elements from 100%. Total inorganic carbon (%) was determined by ASTM D4373. Total Organic Carbon (C_{org}) was calculated from the difference of Total Carbon and Inorganic Carbon. The molar ratios such as H: Corg (Carbon stability) and O: C is calculated from elemental composition of the biochars. The pH, EC and liming ability of the biochars were determined as per TMECC (2001) and Rayment and Higginston (1992). The total ash (%) present in the biochar sample was determined as per the ASTM D1762-84.

RESULTS AND DISCUSSION

The summary of the results including a comparison to the criteria set by the IBI for the coir wastes biochar are furnished in table 1. Coir wastes biochar was found to be in the threshold criterion set suggested by IBI. The moisture content (%) and particle size distribution (nm) of the coir wastes biochars were found to be 8.80% and <0.05mm.

Carbon (%) of the coir waste biochar was found to be increased from 34.52% to 44.98% with the decrease of hydrogen(%) from 3.92% to 2.12%, nitrogen(%) from 0.57% to 0.29%, sulphur(%) from 0.44% to 0% and oxygen(%) from 53.56% to 35.62% after pyrolysis.

Table 1. Basic utility properties for coir wastes biochar

S.No	Test Category A-Basic Utility Properties	Coir waste biomass	Coir waste biochar	IBI criteria
(a) Physical properties				
1.	Moisture content (% db)	8.97	8.80	Declaration
2.	Particle size distribution (mm)	0.0014	0.0016	Declaration if <0.5
(b) Elemental composition (% db)				
1.	Carbon (%)	34.52	44.98	NR
2.	Hydrogen (%)	3.92	2.12	NR
3.	Nitrogen (%)	0.57	0.29	Declaration
4.	Sulphur (%)	0.44	0.00**	NR
5.	Oxygen (%)	53.56	35.62	NR
	(c) Organic Carbon (C_{org}) (%)			
1.	Total Organic Carbon (%)	18.00	52.00	Class 2 : ≥ 30 < 60 biochars
2.	Total Inorganic Carbon (%)	0.30	1.80	Declaration
3.	Total ash (% db)	7.00	17.00	Declaration
(d) Molar ratio				
1.	$H:C_{org}$	2.61	0.48	Declaration if ≥0.7
2.	O:C	1.12	0.59	NR
(e) Electrochemical properties				
1.	pH	5.48	7.28	Declaration
2.	Electrical Conductivity (dS cm^{-1})	0.40	0.09	Declaration
3.	Liming ability (%$CaCO_3$ – eq)*	NA	0.30	Declaration if pH >7
	(f) Proximate composition (% db)			
1.	Volatile matter (%)	62.00	33.00	NR
2.	Fixed carbon (%)	31.00	50.00	NR

3.	Higher Heating Value (MJ kg^{-1})	20.57	22.69	NR
4.	Biochar mass yield (%)	NA	20.02	NR

*Liming equivalence, NR – Not Required, (% db) - % on dry basis
** In trace amount not detected by the instrument

The nitrogen (%) and sulphur (%) was low in the biochar compared to the raw biomass, indicating that it would produce less NOx and SOx emissions during combustion (Neves et al., 2011). The total organic carbon (%) was notably increased 18% to 52% and which falls in the class 2 biochars (≥30<60%) based on the criteria given by IBI. The inorganic carbon (%) was increased from 0.30% to 1.80% since the ash content (%) increased from 7% to 17% when compared to parent initial biomass.

The H:Corg and O:C molar ratios was found to be decreased from 2.61 to 0.48 and 1.12 to 0.59 in coir wastes biochar. The molar ratios was significantly dropped from biomass state to coal state and confirms that the pyrolysis process effectively contributed in increasing the carbon (%) in the biochar, similar results were observed by Ahmad and Subawi (2013). The use of biochar as a soil amendment is often considered as a mechanism to sequester organic carbon (C_{org}) which remains in the soil for centuries depending on the degree of aromaticity, chemical complexity (O/C) and carbon stability (H/C_{org}) of the biochars (Spokas, 2010). The molar ratios of the thermo chemically converted coirwaste biochar was below 0.7 (H/C_{org} <0.7) and declared with the criteria given by IBI.

The pH of the coir wastes biomass was acidic (5.48) than the coir wastes biochar (7.28). Most of the biochars had alkaline pH. The EC (dS cm^{-1}) of the coirwaste biochar was found to be decreased. The pH and EC of the biochars were observed to increase at higher temperatures (600-800°C) and decrease at lower temperatures (400-500°C), and the results were aligned with Al-Wabel et al. (2013). The volatile matter(%) of the biochar was found to be decreased from 62% to 33% due to the release of volatiles into the atmosphere during pyrolysis process with increase in fixed carbon(%) from 31% to 50% with increased HHV(MJ kg^{-1}) from 20.57-22.69 MJ kg^{-1} compared to raw biomass. A reduction percentage of 53.22% volatile matter was observed before and after pyrolysis indicating that gaseous fuels present in the coir wastes biomass was released to the atmosphere. The average yield of the coir wastes biochar was varied from raw biomass and found to be 20.02%. When the temperature increased from 200-500°C, the biochar yield decreases from 99.3% to 26.8% in wheat straw biochar and 98% to 35.8% in pig manure biochar (Liu et al., 2015). Combination of biochars with high ash content and low volatile matter could give increased biochar mass yield (%) as per the results given by Djousse Kanouo et al., (2017) for eucalyptus tree bark biochar (68%) and corncob biochars (33%). The proximate composition results were consistent with the oak and green house woody biomass derived biochars which had fixed carbon (>50%), volatile matter (<30%) and ash content (<20%) (Weidemann et al., 2018).

CONCLUSION

The quality of the coir wastes biochar was tested and found that coir waste biomass is one of the potential lignocellulosic feedstocks for soil amendment and soil carbon sequestration applications. The coir wastes biochar prepared at low temperatures would be more reactive in soil and exhibits higher molar ratios that implies more diversified organic molecules with more O-containing functional groups which are easily bio-degradable and also has larger ion-exchange capacity than the biochars prepared at higher temperatures.

ACKNOWLEDGEMENT

The authors sincerely thank the Department of Bioenergy, TNAU, Coimbatore for providing advanced lab facilities and the DST-INSPIRE Scheme, New Delhi, India for financially supporting to conduct research by providing research grants.

REFERENCES

Ahmad, M. and Subawi, H. (2013). New Van Krevelen diagram and its relation with the heating value of biomass. Res.J.Agric.Environ. Manag, 2, 295-301.

Al-Wabel, M.I., Al-Omran, A., El-Naggar, A.H., Nadeem, M. and Usman, A.R.A (2013). Pyrolysis temperature induced changes in characteristics and chemical composition of biochar produced from conocarpus wastes. Bioresour. Technol., 131, 374-379.

ASTM D1762-84. 1990. Standard method for chemical analysis of wood charcoal.

Butler, J.H. and Montzka, S.A (2015). The NOAA Annual Greenhouse Gas Index (AGGI). Published online http://www.esrl.noaa.gov/gmd/aggi/aggi.html.

Correa, C. R., Hehr, T., Rauscher, Y., Alhnidi, M. J and Kruse, A. (2019). Biomass Carbonization - An experimental comparison between pyrolysis and hydrothermal carbonization. Journal of Analytical and Applied Pyrolysis. doi:10.1016/j.jaap.2019.03.007.

Djousse Kanouo, B. M., Allaire, S. E. and Munson, A. D (2017). Quality of biochars made from eucalyptus tree bark and corncob using a pilot-scale retort kiln. Waste and biomass valorization, 9(6), 899–909. doi:10.1007/s12649-017-9884-2

Iaquaniello, G., Centi, G., Salladini, A., Palo, E., Perathoner, S and Spadaccini, L. (2017).Waste-to-methanol: process and economics assessment. Bioresour. technol. 243, 611-619.

IBI. (2015). Standardized product definition and product testing guidelines for biochar that is used in soil. IBI biochar standards. (Version 2.1).

Le Quere, C., Andrew, R. M., Canadell, J. G., Sitch, S., Korsbakken, J. I., Peters, G. P., Manning, A. C., Boden, T. A., Tans, P. P., Houghton, R. A., Keeling, R. F., Alin, S., Andrews, O. D., Anthoni, P., Barbero, L., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Currie, K., Delire, C., Doney, S. C., Friedlingstein, P., Gkritzalis, T., Harris, I., Hauck, J., Haverd, V., Hoppema, M., Klein Goldewijk, K., Jain, A. K., Kato, E., Körtzinger, A., Landschützer, P., Lefèvre, N., Lenton, A., Lienert, S., Lombardozzi, D., Melton, J. R., Metzl, N., Millero, F., Monteiro, P. M. S., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., O'Brien, K., Olsen, A., Omar, A. M., Ono, T., Pierrot, D., Poulter, B., Rödenbeck, C., Salisbury, J., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Stocker, B. D., Sutton, A. J., Takahashi, T., Tian, H., Tilbrook, B., van der Laan-Luijkx, I. T., van der Werf, G. R., Viovy, N., Walker, A. P., Wiltshire, A. J. and Zaehle, S. (2016). Global Carbon Budget. Earth Syst. Sci. Data, 8, 605-649, https://doi.org/10.5194/essd-8-605-2016.

Liu, W.J, Jaing, H and Yu, H.Q (2015). Development of biochar based functional materials toward a sustainable platform carbon material. Chem.Rev.115(2), 12251-12285. American chemical society.

Neves, D., Thunman, H., Matos, A., Tarelho, L. and Gomez Barea, A. (2011). Characterization and prediction of biomass pyrolysis products. Prg. Energy Combust.Sci.37, 611-630.

Nizami, A. S., Rehan, M., Waqas, M., Naqvi, M., Ouda, O. K. M., Shahzad, K., Miandad, R., Khan, M.Z., Syamsiro, M., Ismail, I.M.I and Pant, D. (2017). Waste biorefineries: enabling circular economies in developing countries. Bioresour. technol. 241, 1101-1117.

Prabha, B., Pugalendhi, S. and Subramanian, P. (2015). Design and development of semi-indirect non-electric pyrolytic reactor for biochar production from farm waste (Vol. 85). Indian Journal of Agricultural Sciences 85(4):585-591.

Rayment, G.E. and Higginson, F.R. (1992). Australian Laboratory Handbook of Soil and Water Chemical Methods. Reed International Books, Australia/ Inkata Press, Port Melbourne.

Spokas, K.A. (2010). Review of the stability of biochar in soils: predictability of O:C molar ratios. Carbon Manag. 2010, 1, 289-303.

Unrean, P., Lai Fui, B.C., Rainawati, E. and Acda, M (2018). Comparitive techno-economic assessment and environmental impacts of rice husk-to-fuel conversion technologies. Energy. doi:10.1016/j.energy.2018.03.112.

US Composting Council and US Department of Agriculture (2001). Test methods for the examination of composting and compost. (TMECC) Thompson W.H. (ed.) http://compostingcouncil.org/tmecc/ (Accessed January 2012).

Weidemann, E., Buss, W., Edo, M., Masek, O and Jansson, S. (2017). Influence of pyrolysis temperature and production unit on formation of selected PAHs, oxy-PAHs, N-PACs, PCDDs, and PCDFs in biochar—a screening study. Environmental Science and Pollution Research, 25(4), 3933–3940. doi:10.1007/s11356-017-0612-z.