International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2025; 9(3): 134-139
www.biochemjournal.com
Received: 10-01-2025
Accepted: 16-02-2025

Naina Goswami
ICAR-Agricultural Technology Application Research Institute, Zone-VI, Guwahati, Assam, India

Priyanka Das
Department of Biochemistry and Agril. Chemistry, Assam Agril. University, Jorhat, Assam, India

Gautam Kr. Saikia
Department of Tea Husbandry and Technology, Assam Agril. University, Jorhat, Assam, India

Kritideepan Sarmah
Department of Biochemistry and Agril. Chemistry, Assam Agril. University, Jorhat, Assam, India

Tankeswar Nath
Department of Agricultural Biotechnology, Assam Agril. University, Jorhat, Assam, India

Corresponding Author:
Kritideepan Sarmah
Department of Biochemistry and Agril. Chemistry, Assam Agril. University, Jorhat, Assam, India

Prospect of managing factory tea waste as biochar

Naina Goswami, Priyanka Das, Gautam Kr. Saikia, Kritideepan Sarmah and Tankeswar Nath

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i3b.3904

Abstract
A comprehensive experiment was carried out in the year 2021 under the Department of Biochemistry and Agricultural Chemistry and Department of Agricultural Engineering, Assam Agricultural University, Jorhat, Assam to study the prospect of managing factory tea waste from a selected Tea Garden of Assam as Biochar. In this present study, factory tea waste was collected from Cinamara Tea Estate, Jorhat and biochar was produced from the waste material by two methods *i.e.*, by using charring device and by using muffle furnace. Other physical and chemical properties of tea waste and biochar prepared from above two methods were determined following standard procedure proposed by earlier workers. Each estimation was replicated thrice and the data obtained from laboratory analysis were examined statistically under Completely Randomized Design (CRD). The yield of biochar was recorded to be 71.07% (charring device) and 77.21%, (muffle furnace), respectively. Among the physical properties, moisture content of tea waste biochar and factory tea waste were 6.10% (method 1-charring device), 3.34% (method 2-muffle furnace) and 6.98%, respectively. The bulk density of biochar and factory tea waste were 0.19 g/cm^3 (method 1-charring device), 0.21 g/cm^3 (method 2-muffle furnace) and 0.09 g/cm^3, respectively. Whereas, carbon content (%) was found maximum in tea waste biomass (65.11%) followed by method 2 (60.24%) and method 1 (50.9%). Overall, higher bulk density and water holding capacity were observed in biochar produced by second method i.e., muffle furnace besides its higher values for ash content, carbon content, mineral content (nitrogen, potassium, phosphorus) and cation exchange capacity. Thus, factory tea waste can be profitably converted to biochar using charring device and muffle furnace and thereby contributing to carbon sequestration. Furthermore, the biochar produced from tea waste can be effectively used to improve soil health.

Keywords: Carbon sequestration, factory tea (*Camellia sinensis* var. *assamica*) waste, muffle furnace, pyrolysis

Introduction
Biochar is a fine-grained, carbon-rich, porous material left after thermochemical conversion process (pyrolysis) of plant biomass at temperatures about 350-600 °C in a condition with little or no oxygen (Amonette and Joseph, 2009) [2]. Biochar is not a pure carbon (C), but it is a mixture of ash, Hydrogen (H), Nitrogen (N), Sulphur (S), Phosphorus (P), Potassium (K), etc. (Masek, 2009) [26]. Now-a-days, biochar has gained popularity due to its potential to sequester carbon and enhance soil quality, as well as for land reclamation, water remediation, and soil amendment (Barrow, 2012; Meyer *et al*., 2011) [5, 28]. There are different methods to produce biochar, but all of them involve heating the biomass with little or no oxygen to run off volatile gasses and leave carbon behind. This simple method is called thermal decomposition, typically achieved from pyrolysis or gasification. Biochar's characteristics are variable depending upon the composition of biomass used for its preparation and on the conditions of pyrolysis (Chowdhury *et al*., 2016) [8]. Some workers have reported about many key properties for the evaluation of biochar *i.e.* pH, content of volatile compounds, ash content, water-holding capacity, bulk density, pore volume, and specific surface area. All these properties mainly depend upon the quality of the feed stock that is used for the biochar production. In addition, pyrolysis temperature and duration of pyrolysis are the other two most considerable factors that affect the physico-chemical quality of biochar (Okimori *et al.*, 2003; Sohi *et al*., 2010) [30, 35].
The wastes obtained during the processing of tea are regarded as tea waste which includes unwanted tea leaves, buds, stems and the factory waste (Chowdhury *et al*., 2016) [8]. The minimum volume of tea waste and made tea should be at the ratio of 2:100 (Tea Waste

(Control) order, 1959). In comparison to the huge amount of tea waste, there are very less management strategies are available due to lack of guidelines for tea waste management (Chowdhury *et al*., 2016) [8]. Though, Assam is the largest producer of tea in India, there is no report of proper management of factory tea waste. Currently, tea waste is disposed off through inefficient incineration, which leads to environment pollution. So, these wastes are suitable for assessment as biochar (Akgul *et al*., 2018) [1]. At present, tea waste is sometimes used for the extraction of caffeine. In Assam, tea wastes are sometimes used as poultry and piggery feed (Chowdhury *et al*., 2016) [8]. Thus, there is a scope to study the potential of tea waste for production of biochar which has a significant importance for opening a new area of research for alternative use of tea waste. Therefore, the present study was conducted to explore the prospect of managing factory tea waste from a selected Tea Garden of Assam as Biochar.

Materials and Methods

The factory tea waste was collected from Cinamara Tea Estate, Jorhat, Assam. The collected factory tea waste was sun dried till the moisture content came down to less than 10%, fresh basis. In this present study, Biochar was produced by two methods-(a) method 1-using charring device and (b) method 2-using muffle furnace. Under the Method-1, Biochar production unit (charring device) available at the Department of Agricultural Engineering, Assam Agricultural University, Jorhat was used for production of biochar. The kiln was filled with sun dried tea waste, covered with a lid and pyrolyzed at 300-350 °C under limited oxygen condition. After pyrolysis, the biochar was allowed to cool in the kiln overnight at room temperature. The next day, the biochar was collected, sundried and weighed. Under the Method-2, Muffle furnace, available at the Department of Biochemistry and Agricultural Chemistry, Assam Agricultural University, Jorhat was used to make biochar. The sundried biomass was taken in a pre-weighed silica crucible and pyrolyzed at 350 °C for 45 minutes. The crucible containing the biochar was cooled to room temperature by placing these in a desiccator and then weighed. The average of three replications was calculated.

Moisture, ash and nitrogen content were determined by using method of AOAC (1980) [1]. Total potassium in the mineral solution was determined by using a double beam atomic absorption spectrophotometer (Koeing and Johnson, 1942) [22]. Total P was determined by vanadomolybdate method (ISO, 2017) [17]. Bulk density of the sample was determined by core method or volumetric cylinder method (Baruah and Borthakur, 1997) [6]. The maximum water holding capacity of the sample (biochar and factory tea waste) was determined using Keen Rackzowski box following the method described by Baruah and Borthakur (1997) [6] and expressed in percentage. The pH of the dry biochar and factory tea waste were determined with a glass electrode pH meter, in a 1:2 sample water suspension as described by Jackson (1973) [18]. Cation exchange capacity of biochar was measured by leaching it with neutral normal ammonium acetate solution. The titrimetric determination, also known as the "wet-digestion method" involves a rapid titration procedure for the estimation of organic carbon content of dried sample (biochar and tea waste) (Walkley and Black 1934). Crude fibre was determined by the method given by Maynard (1970) [27]. Each estimation was replicated thrice. The data obtained from laboratory analysis were analyzed statistically by Completely Randomized Design (CRD). Average of 3 replications was taken for one-way analysis of variance (ANOVA).

Results and Discussion

Yield of biochar

The yield of biochar was recorded to be 71.07% (charring device) and 77.21%, (muffle furnace), respectively (Table 1). Loss of more carbon in charring device than muffle furnace might attribute to the observed lower yield of biochar. The yield of biochar depends on various factors like technique chosen for production, type of biomass and also the process conditions such as heating rate, temperature, residence time, etc. In the slow pyrolysis, rate of heating is very low with a longer residence time. Hence, the slow pyrolysis has a better yield of char relative to different pyrolysis and carbonization strategies (Yaashika *et al*., 2020, Daful and Chandraratne 2018) [41, 9]. According to Akgul *et al*. (2018) [1] yield of biochar decreased as the pyrolysis temperature increased. Demirbas (2004) [11] stated that the high lignin composition of biomass resulted in higher char formation. The present findings were found to be comparable with Akgul *et al*. (2017) [43]. They prepared biochar from industrial tea waste using muffle furnace at temperatures 300 °C and 400 °C and yield was reported to be 60-64%.

Table 1: Percent yield of biochar from factory tea waste (sun dried, 8% moisture content, fresh basis)

Biochar made using Charring device (Method 1)	Biochar made using Muffle furnace (Method 2)
71.07%	77.21%

Physical properties

The moisture content of tea waste biochar and factory tea waste were 6.10% (method 1-charring device), 3.34% (method 2-muffle furnace) and 6.98%, respectively (Table 2). The moisture content of tea waste biomass were found to be comparable with those of Nagaraja *et al*. (2013) [29], Rajapaksha *et al*. (2014) [33], Akgul *et al*. (2018) [1], who reported that moisture content (FW basis) of tea waste were 7.26%, 10.86% and 7.20%, respectively. However, in the present study, the moisture content of biochar from tea waste biomass was found to be higher than those reported by Rajapaksha *et al*. (2014) [33], Akgul *et al*. (2018) [1], Peiris *et al*. (2019) [31], who reported that moisture content of biochar was 2.80% (at temperature 300 °C), 1.5% (at 500 °C) and 6.33% (at 300 °C), respectively. The differences in moisture content of biochar might be due to differences in bulk density of the biochar. Biochar with low bulk density, an indication of highly porous structure, has the potential to hold moisture (Hernandez-Mena *et al*., 2014) [16].

The bulk density of biochar and factory tea waste (Table 2) were 0.19 g/cm^3 (method 1-charring device), 0.21 g/cm^3 (method 2-muffle furnace) and 0.09 g/cm^3, respectively (Table 2). Deka *et al*. (2018) [10] reported that bulk density of biochar produced from rice husk, rice straw, toria stover and bamboo were 0.629 g/cm^3, 0.729 g/cm^3, 0.641 g/cm^3 and 0.178 g/cm^3, respectively. Ghorbani *et al*. (2019) [14] reported about bulk density of biochar from rice husk at 500 °C to be 0.84 g/cm^3. However, there is no report of bulk density of biochar produced from factory tea waste. Studies have shown that the properties of biochar were greatly

dependent on the production procedure and type of raw material used (Lehmann and Joseph, 2009; Liu and Balasubramanian, 2013) [29, 25].

In the present study, the water holding capacity for biochar and factory tea waste (Table 2) were 80.17% (method 1-charring device,), 84.67% (method 2-muffle furnace) and 63.33%, respectively (Table 2). Though, there are reports of changes in water holding capacity of soil after application of biochar, there were hardly any report on water holding capacity of biochar. Liao and Thomas, 2019, reported that water retention capacity of biochar was influenced by processing method of biochar. They observed water retention capacity of biochar to be increased with reduction in particle size; from 47% to 360% in comparison to sand (37%). Sieved biochar and conventional biochar had higher water retention capacity than ground biochar and pelletized biochar of similar particle sizes, respectively.

Table 2: Physical properties of tea waste and biochar

Treatment	Moisture (%)	Bulk density (g/cm3)	Water holding capacity (%)
Tea waste (TW)	6.98	0.09	63.33
Biochar (BC1)	6.10	0.19	80.17
Biochar (BC2)	3.34	0.21	84.67
Mean	9.24	0.16	76.06
CD(0.05)	0.75	0.008	2.88

* Where, TW-Tea waste; BC1-Biochar prepared by using Charring device and BC2-Biochar prepared by using Muffle furnace

Chemical properties

pH

In the present study, the pH observed for biochar and the factory tea waste were 7.88 (method 1-charring device), 7.90 (method 2-muffle furnace) and 5.2 (tea waste), respectively (Table 3). Rajapaksha *et al*. (2014) [33] and Yasar *et al*. (2017) [43], stated that the pH of tea waste biomass was 5.14 and 5.09, respectively. Rajapaksha *et al*. 2014 [33], stated that pH of tea waste biochar produced at 300 °C and 700 °C were 7.93 and 11.05, respectively. Yasar *et al*. (2017) [43] reported that the pH of biochar produced from tea waste biomass at temperatures 300 °C and 400 °C were 9.15 and 9.28, respectively. Pyrolysis temperature had a strong influence on pH of biochar, higher temperature resulted in an increase of pH of biochar (Tomczyk *et al*., 2020) [38]. Higher pH with increasing temperature has been associated with the increase in ash content and oxygen functional group that occur during pyrolysis (Ghorbani *et al*., 2019) [14].

Ash content (%, DW basis)

The ash content of biochar was 6.20% (method 1-charring device), 6.37 % (method 2-muffle furnace) and 4.23 % (tea waste biomass), respectively. The present findings for ash content (%) of tea waste was found to be comparable with Rajapaksha *et al*. (2014) [33] and Akgul *et al*. (2018) [1] which were 3.22% and 3.74%, respectively (Table 3). However, Rajapaksha *et al*. (2014) [33] stated that the ash content (%) of tea waste biochar produced at 300 °C and 700 °C were 5.69% and 10.87%, respectively. Peiris *et al*. (2019) [31], reported that ash content (%) of biochar produced from tea waste at temperatures 300 °C, 500 °C, 700 °C were 6.15%, 11.40% and 9.26%, respectively. Biochar pyrolyzed at low temperature contains low ash content (Rafiq *et al*., 2016) [32]. Types of feedstocks also affect the ash content of biochar (Tomczyk *et al*., 2020) [38]. Studies have also shown that there was an increase in the ash content increase in pyrolysis temperature from 250 to 500 °C for 3 h (Borgohain *et al*., 2020) [7]. However, the significant differences in ash content of biochar prepared by two methods, as observed in the present study might involve the differences in device used for pyrolysis leading to differences in pyrolysis temperature, retention time and availability of oxygen during pyrolysis.

Table 3: The chemical properties of tea waste and biochar

Samples	pH	Ash (%)	C (%)	N (%)	P (%)	K (%)	CEC (cmole/kg)	CF (%)
Tea waste (TW)	5.20	4.23	65.11	2.57	0.0210	0.067	5.58	22.00
Biochar (BC1)	7.88	6.20	50.90	3.94	0.0377	0.071	11.87	1.63
Biochar (BC2)	7.90	6.37	60.24	4.54	0.0441	0.073	15.77	1.13
Mean	6.99	5.60	58.75	3.68	0.0342	0.070	11.07	8.26
CD (0.05)	0.016	0.0285	1.586	0.272	0.0031	0.0014	0.405	0.747

* The data are based on dry weight basis.

** Where, TW-Tea waste; BC1-Biochar prepared by using Charring device and BC2-Biochar prepared by using Muffle furnace.

Carbon content (%, DW basis)

In the present study, the carbon content (%) of biochar and tea waste biomass were 50.9% (method 1-charring device), 60.24% (method 2-muffle furnace) and 65.11% (tea waste biomass), respectively (Table 3). Yasar *et al*. (2017) [43] reported that carbon content of biochar produced from tea waste at 300 °C and 400 °C were 60.5% and 66.4%, respectively. Peiris *et al*. (2019) [31], stated that carbon content of tea waste biochar produced at 300 °C, 500 °C and 700 °C were 57.80%, 69.66% and 71.03%, respectively. Increased carbon content with an increase temperature occurs due to high degree of polymerization (Domingues *et al*., 2017) [12] leading to a more condensed carbon structure in the biochar (Lehmann and Joseph, 2009) [29]. The observed lower values of carbon content of biochar than the biomass (tea waste) might indicate loss of carbon during pyrolysis in both the methods, being higher in charring device than that in muffle furnace.

Total Nitrogen content (%, DW basis)

In the present study**,** the nitrogen content of biochar and tea waste were 3.94% (method 1-charring device), 4.58% (method 2-muffle furnace) and 2.57% (tea waste), respectively (Table 3). The present findings for nitrogen content of tea waste found to be comparable with Rajapaksha *et al*. (2014) [33], Peiris *et al*. (2019) [31] and Yasar *et al*. (2017) [43]. Akgul *et al*. (2017) [43] reported that nitrogen content of biochar produced from tea waste biomass at 300 °C and 400 °C were 3.4% and 3.6%, respectively. And Peiris *et al*. (2019) [31] which also stated that nitrogen content of tea waste biochar produced at 300

°C, 500 °C and 700 °C were 3.66%, 2.55% and 3.12%, respectively. The higher nitrogen content in biochar produced by using muffle furnace might indicate higher retention of nitrogen

Total Phosphorus content (%, DW basis)

In the present study**,** the data of the phosphorus content of both the biochar and tea waste were 0.0377% (method 1-charring device), 0.0441% (method 2-muffle furnace) and 0.021% (tea waste), respectively (Table 3). The present study of phosphorus content of biochar found to be comparable with Deka *et al*. (2018) [10], who reported that phosphorus content of biochar produced from rice husk, rice straw, toria stover and bamboo were 0.0237%, 0.0185%, 0.0324% and 0.0173%, respectively. However, Gondim *et al*. (2018) [15] and Severo *et al*. (2020) [34] also reported that phosphorus content of biochar prepared from cashew and rice husk were 1.10g/kg (0.11%) and 1.2 g/kg (0.12%), respectively. The nature of biomass and pyrolysis temperature influenced the variation in phosphorus content in biochar (Kamara *et al*., 2015) [20].

Total Potassium content (%, DW basis)

In the present study**,** the potassium content of biochar and tea waste were 0.071% (method 1-charring kiln), 0.073% (method 2-muffle furnace) and 0.067% (tea waste), respectively (Table 3) which were lower than those reported by Deka *et al*. (2018) [10], Gondim *et al*. (2018) [15] and Severo *et al*. (2020) [34]. The observed variation in potassium content of biochar might be due to differences in potassium content of raw biomass. The total mineral content in biochar were found to be higher than the biomass (Judd, 2016) [19], which might be due to the process of making biochar. Biochar production reduced the product weight and thus the mineral element proportion became higher (Evans *et al*., 2017) [13]. Kloss *et al*. (2012) [21], reported that the level of K increase with greater carbonization. As reported by Borgohain *et al*. (2020) [7] total P and K, increased consistently with increasing pyrolysis temperature

Cation exchange capacity (cmole/kg, DW basis)

The cation exchange capacity of biochar and factory tea waste were 11.87 cmole/kg (method 1-charring kiln), 15.77 cmole/kg (method 2-muffle furnace) and 5.58 cmole/kg (tea waste), respectively (Table 3). In the present study, the cation exchange capacity of biochar was found to be comparable with Ghorbani *et al*. (2019) [14], Venegas *et al*. (2015) [39] and Zama *et al*. (2017) [44] who analysed tree bark biochar, buckwheat husk biochar and rice husk biochar, respectively. Deka *et al*. (2018) [10] also reported that cation exchange capacity of biochar produced from rice husk, rice straw, toria stover and bamboo to be 12.74 cmole (p+)/kg,15.67 cmole (p+)/kg, 14.72 cmole (p+)/kg and 16.68 cmole (p+)/kg, respectively. Biomass with a high content of ash can produce biochar with a higher cation exchange capacity. It might be due to alkali and alkali metals in biomass which promote the formation of oxygen-containing surface functional groups (Yang *et al*., 2015; Tag *et al*., 2016) [42, 36].

Crude fibre (%, DW basis)

The crude fibre content of biochar and factory tea waste were 1.13% (method 1-charring kiln), 1.63% (method 2-muffle furnace) and 22% (tea waste), respectively (Table 3). In the present study, crude fibre content was found to be comparable with Angga *et al*. (2018) [3], who reported the same in tea waste to be 17.405% (dry basis). However, presence of crude fibre in biochar might indicate need for increasing pyrolysis time to complete the combustion.

Conclusion

The yield of biochar, for method 1(using charring device) and method 2 (using muffle furnace) were recorded to be 71.07% and 77.21%, respectively. Considering the physical and chemical properties of biochar, the biochar produced by muffle furnace was found to be better as higher bulk density and water holding capacity were observed in addition to higher values for ash content, carbon content, mineral content (nitrogen, potassium, phosphorus) and cation exchange capacity. Thus, factory tea waste can be profitably converted to biochar using furnace and thereby contributing to carbon sequestration. Furthermore, the biochar produced from tea waste can be effectively used to improve soil health.

Add-on information

Authorship contribution: N. Goswami conducted the field as well as laboratory experiment and based on the final results had drafted the research manuscript. Dr. P. Das and Dr. G. K. Saikia outlined the overall research theme and standardized the methodology for successfully performing the experiment. Dr. T. Nath and Dr. K. Sarmah was actively involved in designing the final version of the said manuscript.

Conflict of interest: The authors declare that there is no conflict of interest.

Funding: No funding has been received to conduct the study

Ethical Approval: Not applicable

Data availability: Data is available with the corresponding author and can be collected whenever required.

Consent to publish: All authors have given their consent for the publication of this manuscript.

References

1. Akgul G, Maden TB, Diaz E, Jimenez EM. Modification of tea biochar with Mg, Fe, Mn and Al salts for efficient sorption of PO_4^{3-} and Cd^{2+} from aqueous solutions. Journal of Water Reuse and Desalination. 2018;9(1):57-66.
2. Amonette JE, Joseph S. Characteristics of biochar: Microchemical properties. In: Biochar for Environment Management Science and Technology Lehmann J, Joseph S, editors. Earthscan, London. 2009:33-52.
3. Angga WA, Rizal Y, Mahata ME, Yuniza A, Mayerni R. Potential of waste tea leaves (*Camellia sinensis*) in West Sumatra to be processed into poultry feed. Pakistan Journal of Nutrition. 2018;17(6):287-293.
4. AOAC. Washington D.C. 11th Edition, 1980.
5. Barrow CJ. Biochar: potential for countering land degradation and for improving agriculture. Applied Geography. 2012;34:21-28.

6. Baruah TC, Borthakur HP. A Textbook of Soil Analysis. Vikas Publishing House Pvt. Ltd. New Delhi. 1997.
7. Borgohain A, Konwar K, Buragohain D, Varghese S, Dutta KA, Paul RK, *et al*. Temperature effect on biochar produced from tea (*Camellia sinensis* L.) pruning litters: A comprehensive treatise on physico-chemical and statistical approaches. Bioresource Technology. 2020;318:124023.
8. Chowdhury A, Sarkar S, Chowdhury A, Bardhan S, Mandal P, Chowdhury M. Tea waste management: A case study from West Bengal, India. Indian Journal of Science and Technology. 2016;9(42):1-6.
9. Daful AG, Chandraratne MR. Biochar production from biomass waste-derived material. Reference module in materials science and materials engineering. Elsevier. 2018:11249-11258.
10. Deka K, Medhi BK, Kandali GG, Pathak K, Das R, Nath DC, *et al*. Physicochemical characteristics of activated biochar derived from different sources. International Journal of Biochemistry Research and Review. 2018;22(2):1-9.
11. Demirbas A. Effects of temperature and particle size on biochar yield from pyrolysis of agricultural residues. Journal of Analytical and Applied Pyrolysis. 2004;72:243-248.
12. Domingues RR, Trugilho PF, Silva CA, Melo ICNA, Melo LCA, Magriotis ZM, *et al*. Properties of biochar derived from wood and high-nutrient biomasses with the aim of agronomic and environmental benefits. PLoS ONE. 2017;12:e0176884.
13. Evans MR, Jackson BE, Michael P, Sadaka S. Chemical properties of biochar materials manufactured from agricultural products common to the Southeast United States. HortTechnology. 2017;27(1):16-23.
14. Ghorbani M, Asadi H, Abrishamkesh S. Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil. International Soil and Water Conservation Research. 2019;7:258-265.
15. Gondim RS, Muniz CR, Pacheco CE, Levi C. Explaining the water holding capacity of biochar by scanning electron microscope images. Revista Caatinga. 2018;31(4):972-979.
16. Hernandez-Mena LE, Pecora AAB, Beraldo AL. Slow pyrolysis of bamboo biomass: Analysis of biochar properties. Chemical Engineering Transactions. 2014;37:115-120.
17. International Organization for Standardization (ISO). Soil Quality—Determination of Dry Bulk Density. Available at: https://www.iso.org/standard/68255.html (2017).
18. Jackson ML. Soil Chemical Analysis. Hall of India Pvt. Ltd, New Delhi. 1973.
19. Judd LA. Physical and chemical analyses of two biochars produced from pine wood chips and rice hull and their effects on container substrates. North Carolina State University, Raleigh, PhD Diss. 2016.
20. Kamara A, Kamara HS, Kamara MS. Effect of rice straw biochar on soil quality and the early growth and biomass yield of two rice varieties. Agricultural Sciences. 2015;6:798.
21. Kloss S, Zehetner F, Dellantonio A, Hamid R, Ottner F, Liedtke V, *et al*. Characterization of slow pyrolysis biochars: effects of feedstocks and pyrolysis temperature on biochar properties. Journal of Environmental Quality. 2012;41(4):990-1000.
22. Koeing RA, Johnson CR. Colorimetric determination of biological materials. Industrial and Engineering Chemistry Analytical Edition. 1942;14(2):155-156.
23. Lehmann J, Joseph S. Biochar for environmental management: an introduction. In: Biochar for Environmental Management: Science and Technology. Lehmann J, Joseph S, editors. Earthscan, London. 2009:1-12.
24. Liao W, Thomas SC. Biochar particle size and post-pyrolysis mechanical processing affects soil pH, water retention capacity and plant performance. Soil Systems. 2019;3(1):14.
25. Liu Z, Balasubramanian R. Comparison of thermal behaviors of raw biomass, pyrolytic biochar, and their blends with lignite. Bioresource Technology. 2013;146:371-378.
26. Masek O. Biochar production technologies. In: Biochar for Environmental Management: Science, Technology and Implementation, Routledge. 2009:63-87.
27. Maynard AJ. Methods in Food Analysis. Academic Press, New York. 1970:176.
28. Meyer S, Glaser B, Quicker P. Technical, economical and climate-related aspects of biochar production technologies: a literature review. Environmental Science & Technology. 2011;45(22):9473-9483.
29. Nagaraja M, Charles I, Sundaresan R, Natarajan R, Srinivas T. Energy and by-product recovery from tea waste. International Journal of Electrical Energy. 2013;1(1):49-54.
30. Okimori Y, Ogawa M, Takahashi F. Potential of CO_2 emission reductions by carbonizing biomass waste from industrial tree plantations in Sumatra, Indonesia. Mitigation and Adaptation Strategies for Global Change. 2003:261-280.
31. Peiris C, Nayanathara O, Navarathna CM, Jayawardhana Y, Nawalage S, Burk G, *et al*. The influence of three acid modifications on the physicochemical characteristics of tea waste biochar pyrolyzed at different temperatures: a comparative study. Royal Society of Chemistry Advances. 2019;9(31):17612-17622.
32. Rafiq MK, Bachmann RT, Rafiq MT, Shang Z, Joseph S, Long R. Influence of pyrolysis temperature on physicochemical properties of corn stover (*Zea mays* L.) biochar and feasibility for carbon capture and energy balance. PLoS ONE. 2016;11:e0156894.
33. Rajapaksha AU, Vithanage M, Zhang M, Ahmad M, Mohan D, Chang SX, *et al*. Pyrolysis condition affected sulfamethazine sorption by tea waste biochars. Bioresource Technology. 2014;166:303-308.
34. Severo FF, Silva LSD, Moscoso JSC, Sarfaraz Q, Rodrigues LF, Lopes AF, *et al*. Chemical and physical characterization of rice husk biochar and ashes and their iron adsorption capacity. SN Applied Sciences. 2020;2:1286.
35. Sohi SP, Krull E, Lopez-Capel E, Bol R. A review of biochar and its use and function in soil. Advances in Agronomy. 2010;105:47-82.
36. Tag AT, Duman G, Ucar S, Yanik J. Effects of feedstock type and pyrolysis temperature on potential applications of biochar. Journal of Analytical and Applied Pyrolysis. 2016;120:200-206.

37. Tea Waste (Control) Order (1959) Tea Board of India, Kolkata.
38. Tomczyk A, Sokolowska Z, Boguta P. Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects. Reviews in Environmental Science and Biotechnology. 2020;19:191-215.
39. Venegas A, Rigol A, Vidal M. Viability of organic wastes and biochars as amendments for the remediation of heavy metal-contaminated soils. Chemosphere. 2015;119:190-198.
40. Walkley AJ, Black IA. Estimation of soil organic carbon by the chromic acid titration method. Soil Science. 1934;37:29-38.
41. Yaashikaa PR, Kumar PS, Saravanan A, Varjani S, Ramamurthy R. Bioconversion of municipal solid waste into bio-based products: A review on valorization and sustainable approach for circular bioeconomy. Science of the Total Environment. 2020;748:1413.
42. Yang F, Lee X, Wang B. Characterization of biochars produced from seven biomasses grown in three different climate zones. Chinese Journal of Geochemistry. 2015;34:592-600.
43. Yasar G, Akgul G, Ates A, Hatipoglu H. Production characterization of biochar from tea waste and its nickel removal capacity from aqueous solutions. Progress in Industrial Ecology. 2017;11(2):105-117.
44. Zama EF, Zhu YG, Reid BJ, Sun GX. The role of biochar properties in influencing the sorption and desorption of Pb(II), Cd(II) and As(III) in aqueous solution. Journal of Cleaner Production. 2017;148:127-136.
45. Zhao SX, Na T, Wang XD. Effect of temperature on the structural and physicochemical properties of biochar with apple tree branches as feedstock material. Energies. 2017;10(9):1293.