Original Research Article

Physico-chemical characterization of biochar from different biomass materials

ABSTRACT

Aim: To conduct the physico-chemical analysis of biochar derived from various organic residues, an examination of the physical characteristics including bulk density, water retention capacity, and the chemical properties such as pH, electrical conductivity, cation exchange capacity, total organic carbon, as well as the concentration of macro and micro nutrients were evaluated.

Study Design: Experiment was conducted in completely randomized design with 7 treatments and 3 replications.

Place and Duration of Study: The investigation was conducted at Integrated Farming System Research, Karamana, Kerala Agricultural University during 2022-2023.

Methods: Organic residues from different sources were converted into biochar utilizing a double barrel *Biochar Kiln*, and subsequently, the biochars were analyzed in a Soil and Plant Analysis laboratory to determine their physical and chemical properties.

Result: Physio-chemical properties of biochar vary significantly with the choice of feedstock material. Banana pseudostem biochar reported the lowest bulk density (0.21 Mg m^{-3}) and highest water holding capacity (327.74%). All the biochar produced were alkaline in nature, and they contained high cation exchange capacity ranging between 9.34 to 14.10cmol (+) kg^{-1}. Macro and micro nutrient contents were comparatively higher in *Limnocharis flava* biochar and Banana pseudostem biochar.

Conclusion: Organic residues can be successfully converted to biochar and results obtained show the suitability of application of produced biochar as a soil amendment.

Key words: biochar, pyrolysis, organic residue, physico-chemical properties

1.INTRODUCTION

The plethora of farming methods has led to a notable escalation in the quantity of agricultural goods produced, consequently contributing to a general surge in the generation of organic waste and the ensuing contamination of the ecosystem. The indiscriminateincineration of these remnants has led to numerous ecological hazards, including substantial dispersal of particles in the air and the release of gases that contribute to the greenhouse effect [1]. It has been reported that the combustion of 116.3 Teragrams (Tg) of agricultural remains resulted in the emission of approximately 176.1 Tg of carbon dioxide, 10 Tg of carbon monoxide, 313.9 Gigagrams (Gg) of methane, 8.14 Gg of nitrous oxide, and 151.14 Gg of ammonia [2]. The potential ramifications of these consequences hold the capacity to impact the overall composition of the Earth's atmosphere as well as the chemical makeup of the environment. An imperative requirement of the present moment is the implementation of an efficacious and proficient management plan for the handling of organic waste. The significance of biochar applications in agricultural production systems is increasingly being recognized due to the economic and environmental advantages it offers [3]and it has been demonstrated to serve as a viable alternative approach for managing agricultural waste [4].

Biochar is a substance that contains a high level of carbon and is formed through the process of burning organic materials in the presence of restricted supply of oxygen. It exhibits a strong resistance to microbial decay and possesses remarkable capacity to sequester carbon in the soil for extended periods of time, often spanning centuries to millennia. Notably, the discharge of greenhouse gases, such as carbon dioxide and methane, from the atmosphere can be notably diminished [5]. The recalcitrance of the substance arises from its aromatic composition and the presence of a crystalline graphing sheet within its structure. In comparison to organic matter, the substance exhibits a significantly prolonged period of recalcitrance within the soil, spanning 10-1000 times longer [6]. Biochar application has benefits such as soil carbon sequestration [7], an amendment to improve soil fertility [8] and for remediation of contaminated soils [9]. Biochar characteristics, such as nutrient composition, are ascertained by the initial source material, while the stability of biochar are primarily affected by the conditions under which it is produced. In general, biochar prepared from manure are nutrient rich followed by grasses and then wood [10]. Pyrolysis temperature for biochar production generally ranges between 300 to 1000 ^{0}C [11]. But slow pyrolysis carried out at temperature range between 300 to 700 ^{0}C yields more biochar [12] and have desirable properties such as high porosity, carbon rich product, and aromatic surfaces [13].

Biochar serves as a soil conditioner, enhancing various physical and chemical properties of soil, including its ability to retain water, its specific surface area, porosity, aggregation [14], cation exchange capacity (CEC), soil reaction, electrical conductivity (EC), soil organic matter (SOM) content, and nutrient retention [15].

In this study organic residues generated within the homestead based integrated farming system were converted into biochar and physical and chemical properties of the produced biochar were assessed.

2. MATERIALS AND METHODS

2.1 Collection of organic residue

Organic residue produced within the premises of the Integrated Farming System Research, located in Karamana, Trivandrum, including coconut leaves, banana pseudostem, okra crop residues, teak leaves, and aquatic weeds namely *Eichhornia crassipes*, *Limnocharis flava*, and *Colocasia esculenta*, which were found in the irrigation channels, were collected for the purpose of biochar production. The gathered materials were subjected to sun drying in an open environment for a period ranging from 3 to 5 days in order to eliminate the moisture present on the surface.

2.2 Production of biochar

Biochar was generated through the utilization of the slow pyrolysis technique within a dual-barrel biochar kiln, equipped with a chimney for the expulsion of syngas. The internal barrel was responsible for holding the substrate, and in order to facilitate partial aeration, perforations were present at both the bottom and lid sections. Below the barrel, there was a designated fuel slot for the purpose of incineration. To monitor the temperature developed throughout the process, a digital infrared thermometer was employed [16].

2.3 Characterization of biochar

The biochar derived from coconut leaves (CLB), banana pseudostem (BPB), crop residues (CRB), teak leaves (TLB), *Eichhornia crassipes* (EB), *Limnocharis flava* (LB), and *Colocasia esculenta* (CB) were pulverized and filtered through a 2mm sieve. The resulting samples were subjected to characterization using standard procedures. pH, electrical conductivity (EC) (1:20 (w/v)), cation exchange capacity (CEC), and the concentrations of nitrogen (N), phosphorus (P), and potassium (K) in the samples were determined using the protocols established by [17]. The estimation of N was carried out using the Kjeldahl steam distillation method, while the concentrations of P, K, and S in the biochars were analyzed after digestion with nitric-perchloric acid. The physical parameters viz., bulk density and water holding capacity and total organic carbon (TOC) content were determined using the procedure outlined by Piper [18].

2.4 Statistical analysis

Data generated was analyzed using completely randomized design (CRD). The f values for the treatments were compared to the values in the table. If the effects were found to be significant, critical differences (CD) at a significance level of 5% were calculated to compare the means. For data analysis, the R-package grapesAgri1 was utilized [19].

3. RESULT AND DISCUSSION

3.1 Production of biochar

The temperature of pyrolysis of bioresidues ranged 300 to 500 ^{0}C (Table 1). Higher temperature range of 450-500 ^{0}C was recorded for coconut leaves biochar and lowers 250-350^{0}C for *Eichhornia crassipes* biochar. Banana pseudostem biochar required higher retention time of 90-120 minutes, while lower 30-50 minutes in *Eichhornia crassipes* biochar. A temperature range of 350-450^{0}C was also recorded by [20] for the production of biochar from coconut palm residues. [21] have reported that the pyrolysis temperature for biochar production generally ranges 300 to 1000 ^{0}C. But pyrolysis carried out at temperature range 300 to 700 ^{0}C yields more biochar [22]. Coconut leaf biochar recorded the higher recovery percentage of 46.53 per cent.

Table 1. Production parameters and recovery percentage of biochar

Biochar	Temperature of pyrolysis (^0C)	Residence time (min)	Recovery percentage (%)
TLB	400-500	45-60	34.57
CLB	450-500	60-90	46.53
BPB	350-400	90-120	26.10
CRB	350-450	60-90	32.70
EB	250-350	30-50	24.93
LB	300-400	30-60	27.46
CB	350-400	45-60	30.40

3.2 Physical properties of biochar

The range of bulk density observed for biochar was from 0.21 (Banana pseudostem biochar) to 0.52 (Teak leaves biochar) Mg m^{-3} as shown in Table 2. According to [23], biochar generally exhibits a lower bulk density, typically falling within the range of 0.2-0.5 g cm^{-3}. It is important to acknowledge that the density may vary depending on the type of raw material used and the specific processes utilized in biochar production. The decrease in bulk density of biochar may be ascribed to the desiccation and carbonization of biomass, leading to an increase in pore volume and specific surface area [24].

The findings showcased the remarkable ability of biochar to retain water. The biochar derived from banana pseudostem exhibited the highest water retention rate, measuring at 327.74%, followed by the biochar produced from *Limnocharis flava*, which recorded a water retention rate of 274.56% (Table 2). This disparity may be attributed to the significantly lower bulk density observed in the banana pseudostem biochar in comparison to the other samples. Water holding capacity depends on porosity of biochar's bulk volume [25].

3.2 Chemical properties of biochar

The chemical properties of produced biochar is given in Table 3.Thebiochars that were generated exhibited an alkaline characteristic, with their pH values ranging from 8.19 (*Limnocharis flava* biochar) to 10.4 (Banana pseudostem biochar). During the pyrolysis process, the cations, namely potassium (K), calcium (Ca), silicon (Si), and magnesium (Mg), undergo a conversion into metal oxides, which are commonly referred to as ash. Subsequently, these metal oxides are blended with the biochar, resulting in the alkaline nature of the latter [26]. Additionally, the hydrolysis of salts containing alkaline metals has the capacity to render the biochar alkaline [27].

Wide variation in the electrical conductivity (EC) was observed among the different types of biochars. The EC of biochar is primarily dependent on the material used as feedstock. Notably, the teak leaves biochar exhibited a high EC value of 5.5 dS m^{-1}. The high electrical conductivity observed in the biochar can possibly be attributed to several factors. These factors include the presence of phosphates, silica, heavy metals, and sesquioxides, dominance of carbonates of alkali and alkaline earth metals, as well as the reduced amount of organic and inorganic nitrogen [28].

Table 2. Physical properties of biochar

Biochar	Bulk density (Mg m^{-3})	Water holding capacity (%)
TLB	0.52	169.62
CLB	0.43	236.54
BPB	0.21	327.74
CRB	0.28	274.56
EB	0.37	252.65
LB	0.32	266.61
CB	0.41	228.09
SEm±	0.022	3.552
CD (0.05)	0.066	10.774

Table 3: Chemical properties of biochars

Biochar	pH	EC (dS m^{-1})	TOC (%)	CEC (cmol(+) kg^{-1})
TLB	9.95	5.50	42.30	13.42
CLB	8.46	1.98	47.49	11.90
BPB	9.53	2.57	59.61	12.70
CRB	8.83	3.60	53.78	14.10
EB	9.16	4.70	64.80	11.37
LB	8.19	4.30	67.52	12.00
CB	10.40	3.86	50.87	10.13
SEm±	0.193	0.271	1.091	0.238
CD (0.05)	0.585	0.823	3.249	0.722

The biochar derived from banana pseudostem exhibited the highest CEC value, measuring 13.68 cmol (+) kg^{-1}. This can be attributed to the incomplete decomposition of cellulose during the carbonization process, which leads to the retention of oxygen-containing functional groups in the biochar [29]. Additionally, the amorphous structure of the graphene sheets within the biochar contributes to a larger surface area available for chemical reactions, thereby influencing the CEC of the biochar [30].

Biochar is known for its elevated carbon composition, predominantly consisting of carbon in an aromatic configuration. The presence of a condensed aromatic framework within biochar is responsible for its stability [31].Thetotal carbon content (TOC) of produced biochars exhibits variability, ranging from 42.3% (Teak leaves biochar) to 67.52% (Banana pseudostem biochar), which aligns with the outcomes obtained by [32]. In comparison to combustion, the conversion of biomass to biochar effectively sequesters approximately 50% of the initial carbon [33].

The nutrient composition in biochar is subject to variation based on the selection of feedstock material. Primary and secondary nutrient content of produced biochar is given in Table 4. Banana pseudostem biochar has been found to possess high levels of nitrogen (1.34%), potassium (2.24%) and sulfur (0.33%) content, whereas biochar derived from *Limnocharis flava* exhibits elevated phosphorus content (0.77%). Biochar derived from the crop residue of okra exhibits notable calcium (0.54%) and magnesium (0.43%). Furthermore, biochar contains a significant quantity of trace elements (Table 5) and is capable of enriching the soil nutrient pool by acting as a source of both macro and micronutrient.

Table 4. Macro nutrient content of biochar

Biochar	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
TLB	0.58	0.41	0.64	0.23	0.19	0.03
CLB	0.86	0.53	1.97	0.33	0.23	0.31
BPB	1.34	0.45	2.24	0.52	0.32	0.33
CRB	0.75	0.62	1.12	0.57	0.43	0.24
EB	0.67	0.31	0.79	0.25	0.18	0.11
LB	0.94	0.77	0.92	0.43	0.20	0.18
CB	0.37	0.28	1.04	0.27	0.24	0.16
SEm±	0.027	0.006	0.048	0.024	0.010	0.007
CD (0.05)	0.585	0.823	0.722	0.074	0.029	0.025

Table 5. Micro nutrient content of biochar

Biochar	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})
TLB	2992.50	101.93	24.26	14.01	22.13
CLB	1876.11	192.86	41.69	7.10	6.26
BPB	1494.26	338.06	48.00	25.00	42.47
CRB	997.83	212.23	37.93	10.04	14.50
EB	1665.93	174.46	52.13	25.12	36.60
LB	1893.67	323.76	84.00	37.12	51.60
CB	3314.15	289.47	76.44	29.13	47.06
SEm±	4.302	6.231	1.731	0.585	0.766
CD (0.05)	13.129	18.915	5.416	1.773	2.323

4. CONCLUSION

There exists an excess in the production of organic waste due to the escalation of farming practices. The challenge of managing organic waste can be addressed by converting it into biochar, which transforms biomass into a carbonaceous substance that is abundant in nutrients. The physio-chemical characteristics of biochar are predominantly influenced by the original feedstock material. Previous studies have demonstrated the positive impact of applying biochar on soil properties and crop growth. The utilization of biochar within agricultural systems presents a potential alternative for augmenting the natural rates of carbon sequestration in soil, diminishing farm waste, and enhancing soil quality.

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