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Evaluating the effect of pyrolysis temperature on the physio-chemical properties of banana (*Musa spp.*) peduncle biochar derived from three different cultivars

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Abstract

The aim of this study is to evaluate the effect of pyrolysis temperature on the physio-chemical properties of banana peduncle biochar derived from three different cultivars. Biochar was produced from the peduncles of three different cultivars which belongs to three different genomes namely Red Banana (AAA), Nendran (AAB) and Monthan (ABB) pyrolyzed at 400, 600 and 800 °C for 2 hours. Physical properties viz., bulk density (g cm^{-3}), particle density (g cm^{-3}), porosity (%), moisture content (%) and biochar yield (%), and chemical properties viz., pH, electrical conductivity (dS m^{-1}), cation exchange capacity [cmol (+) Kg^{-1}], ash content (%) and total organic carbon (%) were calculated. The results showed that the highest bulk density (0.241 g cm^{-3}), particle density (0.753 g cm^{-3}), porosity (68.28%), pH (12.58), electrical conductivity (2.38 dS m^{-1}), ash content (65.53%) and total organic carbon (36.64%) were found in C_2T_3 (Nendran peduncle biochar obtained at 800 °C during pyrolysis). The highest biochar yield (45.27%) was recorded in C_2T_1 (Nendran peduncle biochar obtained at 400 °C during pyrolysis). Overall, Biochar derived from Nendran peduncle at 800 °C during pyrolysis (C_2T_3) consistently performed better than other treatments.

Keywords: Banana peduncle biochar, pyrolysis temperature, physical properties, chemical properties

1. Introduction

Banana (*Musa spp.*) is a large, perennial herb cultivated as an annual crop, globally in the tropical and subtropical regions, and belongs to the Musaceae family. The plant is characterized by a succulent pseudostem, broad leaves and a corm with fibrous root system that collectively generate substantial biomass residues during the crop cycle. After the harvest, almost 60% of banana biomass is remains as waste including pseudostem, leaves, peduncle and peels (Acevedo *et al.*, 2021) [3]. Banana cultivation of one hectare generates about 220 tons of biomass residue. India is the leading producers of banana which produces about 190 million MT of biomass residue from banana cultivation (Priyadarshana *et al.*, 2022) [13]. It is a novel approach of valorisation of banana peduncle into biochar.

A carbon-rich solid that is produced when organic material is thermally broken down in the absence or with little oxygen is known as biochar. Biochar is mostly used as a soil additive to improve soil functioning (Abdullah *et al.*, 2023) [1]. It has various positive impacts on agriculture such as raising water retention capacity, reduction of nutrient leaching, enhancement of nutrient availability, enhancing soil microbial activity, improve soil quality and plant growth (Islam *et al.*, 2019) [7]. Also, biochar is an affordable, sustainable, and eco-friendly agriculture material. Due to its special ability to both improve soil quality and prevent climate change, it has recently become an important aspect of research. In this study, we selected three different cultivars namely Red Banana, Nendran and Monthan from three different genomes AAA, AAB and ABB respectively (Simmonds and Shepherd, 1955) [16], to explore the effect of cultivars on biochar properties.

2. Materials and Methods

The current experiment was conducted at Division of Horticulture, School of Agricultural Sciences, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India

located at 10.9362° N, 76.7441° E during 2025-2026. This study used a Factorial Randomized Block Design (FRBD) with nine treatment combinations and three replications.

2.1 Feedstock and biochar preparation

Peduncle of three different cultivars namely Red Banana (AAA), Nendran (AAB) and Monthan (ABB) were collected from local fruit market, Coimbatore. The damaged peduncles were discarded and the fresh peduncles were used for further process. The physio-chemical properties of biochar were mostly influenced by process condition. The characteristics of the biochar are significantly impacted by the temperature during pyrolysis (Zhang *et al.*, 2020) [18]. Temperature fixed for pyrolysis were 400, 600 and 800 °C to evaluate its effect on biochar properties. The peduncle was chopped into 2-3inch small pieces. After that, the chopped samples were cleaned of dust and soil particles that had remained to them using distilled water. Following the washing procedure, samples were dried for 48 hours at 60 °C in a hot air oven. The dried samples were collected and converted into biochar using Muffle Furnace (Hasthas Scientific Instruments) at three different pyrolysis temperature of 400, 600 and 800 °C for 2 hours. Biochar was cooled at room temperature within the muffle furnace.

Factor details

Factor A (Varieties)	Notation	Factor B (Pyrolysis temperature)	Notation
Red Banana	C ₁	400 °C	T ₁
Nendran	C ₂	600 °C	T ₂
Monthan	C ₃	800 °C	T ₃

Treatment details

Notations	Treatment details
C ₁ T ₁	Red Banana peduncle @ 400 °C
C ₁ T ₂	Red Banana peduncle @ 600 °C
C ₁ T ₃	Red Banana peduncle @ 800 °C
C ₂ T ₁	Nendran peduncle @ 400 °C
C ₂ T ₂	Nendran peduncle @ 600 °C
C ₂ T ₃	Nendran peduncle @ 800 °C
C ₃ T ₁	Monthan peduncle @ 400 °C
C ₃ T ₂	Monthan peduncle @ 600 °C
C ₃ T ₃	Monthan peduncle @ 800 °C

2.2 Evaluation of physical and chemical properties

Bulk density (BD), particle density (PD), and porosity were determined by the below equations outlined by Aller *et al.* (2017) [2].

$$\text{Bulk density (g cm}^{-3}\text{)} = \frac{M}{V}$$

$$\text{Particle density (g cm}^{-3}\text{)} = \frac{M}{V - P}$$

$$\text{Porosity (\%)} = \left[1 - \left(\frac{BD}{PD} \right) \right] \times 100$$

Where, M is the mass of the biochar (g), V is the volume of biochar (ml) and P is the pore volume (ml).

Biochar yield, moisture content and ash content were calculated by the following formulas quoted by Nanganoa *et al.* (2019) [11].

$$\text{Biochar yield (\%)} = \frac{M_b}{M_d} \times 100$$

$$\text{Moisture content (\%)} = \frac{A - B}{A} \times 100$$

$$\text{Ash content (\%)} = \frac{B - C}{B} \times 100$$

Where, M_b is the mass of the biochar (g), M_d is the mass of the raw dried sample before pyrolysis (g), A is the mass of the sample before drying at 105 °C (g), B is the mass of the sample after drying at 105 °C (g) and C is the mass of the ash (g).

The pH and EC (Electrical Conductivity) of biochar were determined by a digital pH meter and an EC meter (Labtronics ISO 9001-2008 certified), respectively. The total organic carbon of biochar was calculated using the Chromic Acid Wet Digestion Method as described by Walkley and Black (1934) [17]. CEC (Cation Exchange Capacity) was assessed using the ammonium acetate method as described by Piper (1942) [12]. The factorial and interaction effects of biochar on chemical and physical properties were evaluated using analysis of variance (ANOVA). The differences between treatment means have been analysed by using the least significant difference (CD @ 5%) test.

3. Results and Discussion

3.1 Bulk density and Particle density

The data present in table 1. depicted that the cultivars and pyrolysis temperature had significantly affected BD and PD of the banana peduncle biochar. The highest (0.241 g cm⁻³) and the lowest (0.107 g cm⁻³) BD were recorded in C₂T₃ and C₃T₁ respectively. As the temperature during pyrolysis raised from 400 °C to 800 °C, both bulk density and particle density increased. As pyrolysis temperature increased (400 °C to 800 °C), BD increased from 0.161 g cm⁻³ to 0.193 g cm⁻³, and PD also increased from 0.377 g cm⁻³ to 0.546 g cm⁻³, respectively. These findings match with those of Khater *et al.* (2024) [8]. Their results revealed that the BD raised with increase in temperature during pyrolysis for biochar derived from sawdust (195.0 to 211.9 kg m⁻³), tree leaves (188.0 to 199.4 kg m⁻³), and rice straw (161.5 to 187.1 kg m⁻³), respectively.

3.2 Porosity and moisture content

According to the data in Table 1, there is a significant effect of cultivars and pyrolysis temperature on porosity and moisture content of banana peduncle biochar. The highest (68.28%) and the lowest porosity (40.65%) were found in C₂T₃ and C₃T₁, respectively. The highest (14.49%) and the lowest (8.20%) moisture content were found in C₃T₃ and C₂T₁, respectively. Pore size and porosity are inversely proportional to each other; as pore size decreases, micropore volume increases while total porosity declines (Gray *et al.*, 2014) [6]. Porosity is inversely proportional to water permeability (Rizwan *et al.*, 2023) [14]. These results agreed with those obtained by Sathyabama and Firdous (2025) [15]. They found that when the temperature elevated from 250 °C to 350 °C during pyrolysis, the moisture content in rice husk, sugarcane bagasse, and groundnut shells decreased from 7 to 9.5%, 10.2 to 13.6%, and 11.2 to 13%, respectively.

3.3 Biochar yield

Biochar yield was significantly affected by cultivars and pyrolysis temperature as described in Figure 1. Biochar yield decreased from 42.52 to 37.46%, with raise in pyrolysis temperature from 400 °C to 800 °C, respectively. When compared to other cultivars, Nendran showed the highest biochar yield (43.23%). The highest (45.27%) and the lowest (33.95%) biochar yield were obtained from C₂T₁ and C₃T₃, respectively. This finding was similar to Babu *et al.* (2024) [5] in coconut husk waste biochar. They reported that the highest (41.28%) and the lowest (28.92%) biochar yield were recorded in the highest (800 °C) and the lowest (400 °C) pyrolysis temperatures, respectively.

3.4 pH and Electrical Conductivity (EC)

According to the data in Table 2, there is a significant effect of cultivars and pyrolysis temperature on pH and EC of banana peduncle biochar. Both EC and pH were raised with increase in temperature during pyrolysis. The highest (pH-12.580, EC-2.380 dS m⁻¹) and lowest (pH-10.437, EC-1.340 dS m⁻¹) were recorded in C₂T₃ and C₃T₁. These results related with those reported by An *et al.* (2025) [4]. They revealed that the highest pH (9.23), EC (2278 µS cm⁻¹) were obtained in the highest pyrolysis temperature of 700 °C from hemp stalk-derived biochar.

3.5 Cation Exchange Capacity (CEC)

Cultivars and pyrolysis temperature had a significant effect on CEC of banana peduncle biochar as presented in Table 2. The CEC decreased from 34.95 cmol (+) Kg⁻¹ to 25.73 cmol (+) Kg⁻¹, when pyrolysis temperature climbed (400 °C to 800 °C), respectively. The highest (36.75 cmol (+) Kg⁻¹) and the lowest (24.65 cmol (+) Kg⁻¹) CEC were found in C₂T₁ and C₃T₃, respectively. This result agreed with those obtained by Melo *et al.* (2013) [10], who reported that the CEC was lowest (18 mmol (+) kg⁻¹) in their highest pyrolysis temperature of 600 °C from sugar cane straw derived-biochar.

3.6 Ash content and total organic carbon

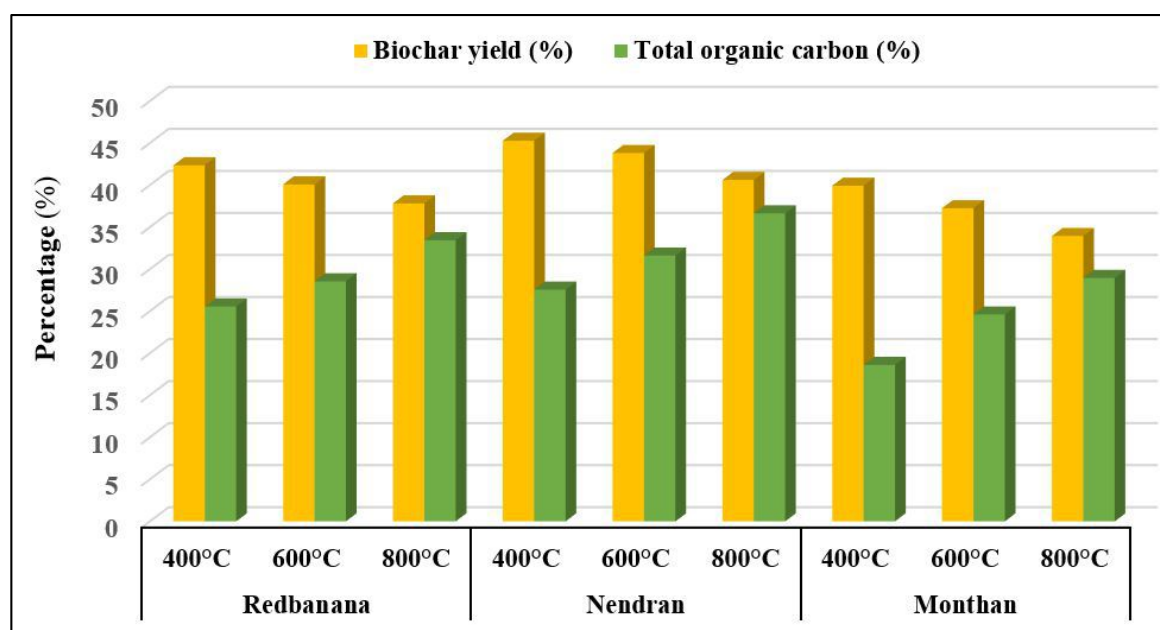
The data in Table 2. illustrated that the ash content of banana peduncle biochar was significantly affected by the cultivars and pyrolysis temperature. Figure 1. shows the effect of cultivars and pyrolysis temperature on the total organic carbon. The highest (ash content-65.53%, total organic carbon-36.64%) and the lowest (ash content-45.81%, total organic carbon-18.61%) were recorded in C₂T₃ and C₃T₁, respectively. These results agree with those obtained by Li *et al.* (2022) [9], who reported that the highest ash content (8.01%) and biochar carbon (79.32%) were found in the highest pyrolysis temperature of more than 500 °C, in wood biochar.

Table 1: Effect of cultivars and pyrolysis temperatures on physical properties of banana peduncle biochar.

Treatments	Bulk density (g cm ⁻³)	Particle density (g cm ⁻³)	Porosity (%)	Moisture content (%)
Factor A (Cultivars)				
C ₁	0.183	0.473	60.91	11.29
C ₂	0.222	0.657	66.01	9.66
C ₃	0.127	0.268	51.88	12.38
SE (d)	0.001	0.001	0.40	0.10
CD (5%)	0.002	0.003	0.84	0.21
Factor B (Pyrolysis temperatures)				
T ₁	0.161	0.377	53.52	9.66
T ₂	0.179	0.474	60.82	11.04
T ₃	0.193	0.546	64.46	12.63
SE (d)	0.001	0.001	0.40	0.10
CD (5%)	0.003	0.003	0.84	0.21
Treatment combinations (A x B)				
C ₁ T ₁	0.171	0.389	56.37	10.28
C ₁ T ₂	0.183	0.476	61.58	11.44
C ₁ T ₃	0.196	0.553	64.79	12.15
C ₂ T ₁	0.204	0.565	63.54	8.20
C ₂ T ₂	0.221	0.653	66.20	9.54
C ₂ T ₃	0.241	0.753	68.28	11.25
C ₃ T ₁	0.107	0.178	40.65	10.49
C ₃ T ₂	0.133	0.294	54.68	12.14
C ₃ T ₃	0.143	0.333	60.31	14.49
SE (d)	0.001	0.002	0.69	0.17
CD (5%)	0.002	0.005	1.46	0.36

Table 2: Effect of cultivars and pyrolysis temperature on chemical properties of banana peduncle biochar.

Treatments	pH	EC (dS m ⁻¹)	CEC [cmol (+) Kg ⁻¹]	Ash content (%)
Factor A (Cultivars)				
C ₁	11.277	1.658	29.79	56.28
C ₂	12.130	2.168	31.99	63.02
C ₃	10.722	1.607	28.45	47.41
SE (d)	0.085	0.039	0.20	0.27
CD (5%)	0.181	0.083	0.42	0.58
Factor B (Pyrolysis temperatures)				
T ₁	10.928	1.578	34.95	53.64
T ₂	11.388	1.791	29.55	55.56
T ₃	11.813	2.063	25.73	57.51
SE (d)	0.085	0.039	0.20	0.27
CD (5%)	0.181	0.083	0.42	0.58
Treatment combinations (A x B)				
C ₁ T ₁	10.757	1.513	34.52	54.09
C ₁ T ₂	11.483	1.603	29.61	56.92
C ₁ T ₃	11.590	1.857	25.23	57.83
C ₂ T ₁	11.590	1.880	36.75	61.02
C ₂ T ₂	12.220	2.243	31.92	62.50
C ₂ T ₃	12.580	2.380	27.31	65.53
C ₃ T ₁	10.437	1.340	33.58	45.81
C ₃ T ₂	10.460	1.527	27.13	47.25
C ₃ T ₃	11.270	1.953	24.65	49.16
SE (d)	0.148	0.068	0.34	0.47
CD (5%)	0.313	0.143	0.73	1.00

**Fig 1:** Effect of cultivars and pyrolysis temperature on biochar yield and total organic carbon.

4. Conclusion

Under various temperatures during pyrolysis of 400 °C, 600 °C, and 800 °C, the chemical and physical characteristics of the biochar derived from the peduncles of three different banana cultivars, viz., Red Banana (AAA), Nendran (AAB), and Monthan (ABB), that correspond to three different genomes, were assessed. The results revealed that the highest bulk density (0.241 g cm⁻³), particle density (0.753 g cm⁻³), porosity (68.28%), pH (12.58), electrical conductivity (2.38 dS m⁻¹), ash content (65.53%) and total organic carbon (36.64%) were found in C₂T₃ (Nendran peduncle biochar obtained at 800 °C). Further soil application and adsorption studies are recommended to evaluate the efficiency of biochar produced from different feedstocks and pyrolysis temperatures.

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6. Conflict of interest

The authors declare no conflicts of interest regarding the content of this publication.

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