

RESEARCH PAPER

Comparative characterization of biochar derived from diverse biological waste sources

H. C. NAGAVENI¹*, N.S. HEBSUR¹, V.B. KULIGOD¹, S. RAJKUMARA² AND P. JONES NIRMALANATH³

¹Department of Soil Science and Agricultural Chemistry, ²Department of Agronomy

³Department of Agricultural Microbiology, College of Agriculture, Dharwad

University of Agricultural Sciences, Dharwad - 580 005, India

*E-mail: nagu.hcsn@gmail.com

(Received: August, 2024 ; Accepted: June, 2025)

DOI: 10.61475/JFS.2025.v38i2.07

Abstract: The use of biochar as a soil amendment has gained significant attention in recent years due to its potential to enhance the chemical, physical and biological properties of agricultural soils. This study aimed to evaluate the physical and chemical characteristics of biochar produced from three different feedstocks: maize cob rind, *Prosopis* wood and coconut shells. Regardless of the source material, all biochar samples contained essential nutrients required for crop growth. However, the concentration of these nutrients varied depending on the type of feedstock and the pyrolysis temperature used during production. The biochars were alkaline in nature, with pH values ranging from 8.15 to 9.05. Electrical conductivity (EC) values ranged from 1.72 to 2.72 dS m⁻¹. Among the tested materials, *Prosopis* biochar exhibited the highest concentrations of total carbon, C:N ratio, 124.17, Nitrogen (0.63%), phosphorus (0.37%), potassium (2.43%), magnesium (1.20%), sulphur (0.29%), iron (252 mg kg⁻¹), manganese (372.10 mg kg⁻¹), zinc (30.10 mg kg⁻¹) and copper (34.20 mg kg⁻¹). In contrast, the highest calcium (1.60%) content was observed in coconut shell biochar, followed by *Prosopis* biochar and maize cob rind biochar.

Key words: Carbon, Coconut shell, Maize cob rind, *Prosopis* spp

Introduction

Efficient use of biomass like crop residues and other farm wastes by converting them into a useful organic manure source of nutrients (*i.e.*, biochar) is one way of managing soil health for sustainable crop production. Different crop residues like coconut shell, wood, cob rind, stover of maize, cotton, tur, grasses, animal manure and areca husk *etc.*, could be used for biochar production. Biochar has a potential to emerge as an important amendment, a source of carbon and nutrients. The biochar has been found to have a significant positive impact on soil fertility, resulting in an increase in crop yields without deteriorating the soil health. (Lee *et al.*, 2013).

Biochar is a carbon rich organic solid material derived from biomass pyrolysis *i.e.*, thermal decomposition of biomass in the absence or limited amount of oxygen condition. During the pyrolysis process biomass is heated up to 250°C to 700°C temperature which results in the production of volatile compounds, which are condensed to give bio-oil. The other products produced from pyrolysis include a gaseous material called “Syngas” and carbon (C) rich charcoal material known as bio-char (Lehmann, 2003). The left over organic solid biochar in the reactor contains C, O, H, N and ash (Ca and K). Biochar produced at low temperatures (250 to 400°C) contains C=O and CH functional groups that can act as nutrient exchange sites after slow oxidation. These may be better substrates for bacteria and fungi, which play an important role in nutrient turn over processes and soil aggregation. On the other hand, biochar produced at high temperatures (400°C to 700°C) contain lesion-exchange functional groups due to dehydration and decarboxylation, potentially limiting its usefulness in retaining soil nutrients.

The importance of biochar for soil improvement is mainly due to its high surface area and a greater number of micro pores which help retain nutrients and also provide habitat for beneficial soil microorganisms. It promotes storage of organic carbon (OC) in soil and it has characteristic ability to endure in soil with very little biological decay (Lehmann *et al.*, 2015). It's incorporation in the soil is known to increase water holding capacity, soil fertility and enhance agricultural productivity (Hesu *et al.*, 2014).

It improves soil cation exchange capacity (Chintala *et al.*, 2014), physical properties (Chan *et al.*, 2007) and used as a soil additive along with organic and inorganic fertilizers. Biochar has been reported to improve nutrient availability to plants (Glaser *et al.*, 2002). In the past few years, biochar is being used as a source of an amendment to acid soils and has attracted widespread attention as a method to increase soil carbon sequestration besides reducing atmospheric CO₂ concentrations. The objective of this study is to Characterization of different sources of Biochar derived from biological wastes.

Material and methods

Characterization of Biochar: The Biochar samples were procured commercially, sieved and their important characteristics were analysed by using standard analytical procedures. The characterization of different sources of biochar with methodology has been mentioned in Table 1.

Results

Characterization of different sources of biochar and FYM

The data regarding physico-chemical characteristics and nutrient composition of different sources of biochar were presented in Table 2.

Table 1. Characterization of different sources of biochar

Parameter	Method	Reference
Physical parameters		
Maximum water holding capacity(%)	Keen's cup method	Klute (1986)
Bulk density (Mgm ⁻³)	Keen's cup method	Klute (1986)
Chemical parameters		
pH _(1:5)	Potentiometric method	Jackson (1973)
EC _(1:5) (dS m ⁻¹)	Conductivity bridge method	Jackson (1973)
CEC (cmol (p ⁺)kg ⁻¹)	Neutral NNH ₄ OAc	Jackson (1973)
Total Nitrogen (%)	Micro Kjeldahl's distillation method after digestion with Conc. H ₂ SO ₄ plus digestion mixture	Tandon (1998)
Total Phosphorus (%)	Yellow colour Phospho vando molybdate complex method after diacid digestion	Tandon (1998)
Total Potassium (%)	Flame photometer method after diacid digestion	Tandon (1998)
Total Ca and Mg (%)	Complexo metric titration method after diacid digestion	Tandon (1998)
Total Sulphur (%)	Turbidimetric method after diacid digestion	Tandon (1998)
Total Fe, Cu, Zn, Mn (mg kg ⁻¹)	Atomic absorption spectroscopy after digestion with diacid	Tandon (1998)
Total carbon (%)	CHNS analyzer method	Bird <i>et al.</i> (2017)

Physico-chemical properties of biochar

The data revealed that the biochar sources had lower bulk density and higher moisture holding capacity than FYM *i.e.*, 0.43, 0.45 and 0.40 Mg m⁻³, 65, 63 and 61 per cent for maize cob rind biochar, *Prosopis sps* biochar and coconut shell biochar, respectively.

The pH values of maize cob rind biochar (8.50), *Prosopis sps* biochar (8.15) and coconut shell biochar (9.05) were alkaline in reaction. Similarly, electrical conductivity values were also slightly higher (2.72, 2.41 and 1.72 dS m⁻¹) for maize cob rind

biochar, *Prosopis sps* and biochar coconut shell biochar, respectively.

Nutrient composition of biochar

Among the different sources, *Prosopis sps* biochar had a higher amount of total carbon (78.23 g kg⁻¹) followed by the coconut shell biochar (76.07 g kg⁻¹) and maize cob rind biochar (78.23 g kg⁻¹). Correspondingly, the C:N ratio values were 124.17 (*Prosopis sps* biochar), 134.84 (coconut shell biochar) and 166.83 (maize cob rind biochar).

Prosopis sps biochar recorded higher amounts of nutrients, N (0.63%), P (0.37%), K (2.43 %) and S (0.29%) than coconut shell biochar (N- 0.56%, P- 0.29%, K- 1.80%, Mg- 0.89% and S- 0.23%) and maize cob rind biochar (N- 0.42%, P- 0.23%, K- 1.25%, Mg- 0.70% and S- 0.18%). But, higher amount of Ca was recorded by coconut shell biochar (1.60%), followed by *Prosopis sps* biochar (1.44%) and maize cob rind biochar (1.07%). Micronutrients like Fe, Mn, Zn and Cu varied from 148.10 to 252.00, 82 to 372.10, 10.40 to 30.10 and 15.20 to 34.20 mg kg⁻¹, respectively. Among the biochar sources, *Prosopis sps* biochar had relatively higher amounts of micro nutrients, whereas maize cob rind biochar registered lower values.

Results and discussion

The analytical results of biochar for various physico-chemical properties (Table 3) revealed that, the biochar sources *viz.*, maize cob rind biochar, *Prosopis sps* biochar and coconut shell biochar had comparable bulk density and maximum water holding capacity. The variations in BD among biochar sources arise due to loss of volatile matter and increased volume during pyrolysis process. Depending on feedstock, higher ash content leads to denser biochar and lower bulk density. According to Elangovan (2014), the biochar produced from wood and stalk biomass registered higher bulk density. The higher water holding capacity of biochar sources might be a result of varying pores and void sizes, which can hold and retain water

Table 2. Physico-chemical properties and nutrient composition of different sources of biochar and FYM

Particulars	Maize cob rind Biochar	<i>Prosopis sps</i> Biochar	Coconut shell Biochar	FYM
Physico-chemical properties				
Bulk density (Mg m ⁻³)	0.43	0.45	0.40	0.55
MWHC (%)	65.00	62.00	61.00	42.00
pH (1: 5)	8.50	8.15	9.05	7.60
EC (1: 5)(dS m ⁻¹)	2.72	2.41	1.72	0.42
Nutrient composition				
Carbon (%)	70.07	78.23	76.07	11.47
Nitrogen (%)	0.42	0.63	0.56	0.55
C : N (ratio)	166.83	124.17	135.84	20.85
Phosphorus (%)	0.23	0.37	0.29	0.23
Potassium (%)	1.25	2.43	1.80	0.52
Calcium (%)	1.07	1.44	1.60	0.27
Magnesium (%)	0.70	1.20	0.89	0.18
Sulphur (%)	0.18	0.29	0.23	0.04
Iron (mg kg ⁻¹)	148.10	252.00	225.20	54.23
Manganese (mg kg ⁻¹)	82.00	372.10	308.20	60.12
Zinc (mg kg ⁻¹)	10.40	30.10	18.10	34.67
Copper (mg kg ⁻¹)	15.20	34.20	25.40	15.84

effectively, and larger surface area of the particles Purakayastha *et al.* (2015) reported that the BD and water holding capacity of rice and wheat straw biochar was lower than that of maize stover and pearl millet stalk biochar. According to Vivek (2022) the superior BD and maximum water holding capacity of pigeon pea straw biochar compared to cotton stalk and maize cob rind biochar highlights the significant influence of biomass type on the quality of biochar.

The pH and EC of the biochar varied with the sources and comparatively higher pH was recorded with coconut shell biochar and higher EC was recorded with maize cob rind biochar. Increased pH and EC of biochar sources resulted from pyrolysis-induced alkaline ash. Contributing factors include alkaline earth metals, alkali carbonates, silica, heavy metals, sesquioxides, phosphates and minor organic or inorganic nitrogen. Yu *et al.* (2014) reported that the pH and EC of the biochar increased with increasing pyrolysis temperature. This was also confirmed by the study conducted by Karthik (2019) who reported that higher pH and EC could be the result of more processing time during pyrolysis due to woody nature of the material compared to crop residues.

The study indicated that the carbon content was found relatively higher in *Prosopis sps* biochar than coconut shell biochar and maize cob rind biochar. This carbon-rich composition is a key feature of biochar, contributing to its unique properties. The major constituents (C, H and O) of biomass volatilize during dehydration and pyrolysis with H and O being lost in proportionally greater amounts than C. The pyrolytic process transforms biomass into a stable form of carbon, preventing the release of carbon dioxide into the atmosphere and effectively sequestering carbon in the biochar matrix. According to Lee *et al.* (2013), dry biomass with high carbon content would result in greater carbon content in the biochar after pyrolysis.

The major nutrients contained in biochar in the order of $S < P < N < Mg < Ca < K$ with appreciable amounts of micronutrient cations. The variation can be attributed to different feed stocks and conditions under which the various biochar was manufactured. Schmidt and Noack (2000) revealed that the exact chemical composition of biochar was a function of the conditions during combustion, such as temperature and moisture content of the source. The temperature and

heating time, heating rate during pyrolysis greatly influence the chemical constituents of biochar particularly recalcitrant forms. During the pyrolysis process, heating can cause some nutrients to volatilize (N and S), especially at the surface of the material, while other nutrients become concentrated in the remaining biochar. Nitrogen and sulphur are the most volatile of all macronutrients to heating, thus the N and S content were low (Shenbagavalli *et al.*, 2023). Biochar is high in plant available potassium, because potassium is not volatile at temperatures up to 700, consequently all the potassium is retained in biochar on the other hand concentrations of NH_4^+ and PO_4^{3-} generally decrease with increasing pyrolysis temperature, with a portion of NH_4^+ being oxidized to NO_3^- pool at higher temperatures (Gundale and Deluca, 2006). Egamberdieva *et al.* (2021) observed variation in nutrient composition in biochar prepared using maize two different pyrolysis techniques *i.e.*, heating at 600°C for 30 minutes and batch wise hydrothermal carbonization at 210°C for 8 hours. In the present investigations it was observed that the major and minor nutrient contents were more in *Prosopis sps* biochar followed by coconut shell biochar and maize cob rind biochar. The superiority in nutrient composition of *Prosopis sps* biochar over other biochar was confirmed by Shenbagavalli and Mahimairaja (2012) and Karthik *et al.* (2019).

Conclusion

The study reveals that different biochar sources, namely maize cob rind biochar, *Prosopis sps* biochar, and coconut shell biochar, exhibit distinct physico-chemical properties and nutrient compositions. All biochar types demonstrated lower bulk density and higher moisture holding capacity compared to farmyard manure (FYM), attributable to the unique pore structure and surface area developed during pyrolysis. The alkaline pH and variable electrical conductivity of the biochar were influenced by the pyrolysis process, particularly temperature and duration, with coconut shell biochar showing the highest pH and maize cob rind biochar the highest EC. *Prosopis sps* biochar emerged as superior in nutrient content, particularly in total carbon and essential nutrients like N, P, K, Mg and S, making it a potentially valuable soil amendment. The variations in nutrient content among the biochar can be linked to differences in feedstock and pyrolysis conditions, highlighting the importance of these factors in determining biochar quality.

References

- Bird M, Keitel C and Meredith W, 2017, Analysis of biochars for C, H, N, O and S by elemental analyser. Biochar: A guide to analytical methods, 39.
- Chan K, Y, and Xu Z, 2009, Biochar: Nutrient properties and their enhancement. In: Biochar for environmental management. Earthscan, 67 - 84.
- Chintala R, Mollinedoa J, Schumachera T E, Maloa D D and Julsonb J L, 2014, Effect of biochar on chemical properties of acidic soil. Archives of Agronomy and Soil Science, 60: 393-404.
- Egamberdieva D, Ma H, Reckling M, Omari R A, Wirth S and Bellingrath-Kimura S D, 2021, Interactive effects of biochar, nitrogen and phosphorous on the symbiotic performance, growth and nutrient uptake of soybean (*Glycine max* L.). Agronomy, 12(1): 27.
- Elangovan R, 2014, Effect of biochar on soil properties, yield and quality of cotton-maize-cowpea cropping sequence. M. Sc. (Agri.) Thesis, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

- Glaser B, Lehmann J and Zech J, 2002, Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal. *Biology and Fertility of Soils*, 35: 219-230.
- Gundale M J and Deluca T H, 2006, Temperature and source material influence ecological attributes of ponderosa pine and Douglas fir charcoal. *Forest Ecological and Management*, 231: 86-93.
- Jackson M L, 1973, Soil Chemical Analysis. Prentice Hall of India, New Delhi, India.
- Karthik A, 2019, Influence of biochar on the productivity of cotton-maize cropping system. *M. Sc. (Agri.) Thesis*, Tamil nadu Agricultural University, Coimbatore, India.
- Klute A, 1986, Water retention: laboratory methods. *Methods of soil analysis: part 1 Physical and Mineralogical Methods*, 5: 635-662.
- Lee Y, Park J, Ryu C, Gang K S, Yang W, Park Y K, Jung J and Hyun S, 2013, Comparison of biochar properties from biomass residues produced by slow pyrolysis at 500 C. *Bioresource Technology*, 148: 196-201.
- Lehmann J and Joseph S, 2015, Biochar for Environmental Management: Science, Technology and Implementation. Routledge.
- Lehmann J, D Kern, D German, L McCann, J Martins and Moreira, G, 2003, Soil fertility and production potential. In: Amazonian Dark Earths: Origin, Properties, Management.
- Purakayastha T J, Kumari S and Pathak H, 2015, Characterisation, stability and microbial effects of four biochars produced from crop residues. *Geoderma*, 239: 293-303.
- Schmidt M W I and Noack A G, 2000, Black carbon in soils and sediments: Analysis, distribution, implications, and current challenges. *Global Biogeochemical Cycles*, 14: 777-794
- Shenbagavalli S and Mahimairaja S, 2012, Production and characterization of biochar from different biological wastes. *International Journal of Plant, Animal and Environmental Sciences*, 2(1): 197-201.
- Shenbagavalli S, Satya J, Prabhu T and Dhanushkodi V, 2023, Application of prosopis wood biochar on soil and its effect on soil nutrient and carbon content. *Biological Forum – An International Journal*, 15(6): 685-689.
- Tandon H L S, 1998, *Methods of Analysis of Soils, Plants, Waters Fertilizers and Manures*. Fertilizer development and consultation organization, New Delhi, India.
- Vivek M S, 2022, Biochar production, characterization and its impact on nutrient use efficiency and crop yield under dry direct seeded rice-mustard cropping system. *Ph. D. Thesis*, University of Agricultural Sciences, Raichur, Karnataka, India.
- Yu L U O, Jiao Y J, Zhao X R, Li G T, Zhao L X and Meng H B, 2014, Improvement to maize growth caused by biochars derived from six feedstocks prepared at three different temperatures. *Journal of Integrative Agriculture*, 13(3): 533-540.