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Research article

Physico-chemical characterization of biochar prepared from rice stubble in India

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ABSTRACT

Rice stubble (RS) is one of the most challenging agricultural wastes in the world, with an estimated 731 million metric tonnes produced each year. Burning of rice stubble in an open field result in air pollution, greenhouse gas emissions (7300 kg CO_2-equivalent per hectare), losses of soil nutrients and biodiversity, and risks to human health. Transforming crop straws into biochar provides a potential answer to these concerns by delivering a value-added product while simultaneously sequestering carbon. Biochar systems in energy-constrained in developing countries may bring benefits at many levels of energy provision. There are various fields in which biochar systems might be particularly relevant in developing-country contexts. Land application of biochar for small farmers reduces the fertilizer costs, increased yield and enhanced soil quality. Improved cook stoves that produce biochar as well as heat for cooking is another advantage. In the present study, biochar from the rice stubble was produced by slow pyrolysis method in a muffle furnace at 350°C, 450°C and 550°C. Proximate and physico-chemical analysis of biochar were done to characterize the prepared biochar at three temperatures. The pH, electrical conductivity (EC), volatile matter, ash content, moisture content, fixed carbon etc. were analysed to characterize the biochar. Biochar found to get more alkaline with an increase in temperature while biochar yield (48 to 34%) and volatile matter content was decreased. Fixed carbon content and ash content also increased with an increase in pyrolysis temperature.

1. Introduction

On average 140 billion metric tons of waste is generated from agriculture every year across the globe (Phadtare and Kalbande, 2022). Crop burning is the conventional and most common method to get rid of these agricultural residues, mainly crop straws. Approximately 25% of these agricultural residues are burned in every harvesting season, which is a major environmental and health concern. (El-Hassanin et al., 2020) India is an agriculture driven economy.Agriculture is the source of employment for about 60% of the population. India also ranks third in the list of most greenhouse gas emitting countries (Choudhary et al., 2021). On an estimate India produces 750 million metric tons of agricultural waste per year (Phadtare and Kalbande, 2022). Reusability of agricultural residue is a major challenge faced by researchers currently in developing countries.

Rice straw is one of the most produced agricultural residues around the world with an annual production of 731 million tonnes per year (El-Hassanin et al., 2020). This number is only going to increase with the world population explosion as rice is the staple diet across the world. Rice stubble burning is one of

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the major concerns especially in northern India. For last few decades, Delhi and its neighbouring states are on the forefront of receiving the consequences of the stubble burning by the farmers of Punjab and Haryana. Every year in October-November the outburst of smog followed by the worst air quality index in Delhi has received criticism across the globe (Choudhary et al., 2021). This study presents the idea of converting the surplus rice stubble into biochar so that the burning is completely avoided. The characterization of biochar is carried out to identify its potential use.

Activated carbon, biochar, biofuels, mushroom farming, husbandry feeding, and other renewable energy sources are the few other applications of the abundant rice straw (Bhattacharyya et al., 2021). Among these, rice straw-derived biochar has drawn a lot of attention and has been the subject of numerous studies and applications in the agricultural sector.

Agricultural residue-based biochar is an efficient technique of waste management due to ease of use, reliability, and low cost. Biochar carbon rich product having fine structure and high porosity produced by thermal decomposition of biomass in limited supply or non -availability of oxygen (Phadtare and Kalbande, 2022). Two factors that makes agricultural residues such as crop straws an excellent substrate for biochar production is its high percentage of lignin-cellulose content and its availability in abundance (Stella et al., 2016). Biochar is most commonly produced by Pyrolysis. The three major categories of pyrolysis areslow, flash, and fast pyrolysis. Slow pyrolysis produces a significant quantity of char because of combustion of biomass takes place at lower temperature with a slower heating rate and a longer residence time. The flash pyrolysis process generally takes usually in seconds, and with a short residence time and a high heating intensity. The production of bio-oil products is typically favoured by fast pyrolysis, which takes place at a moderate temperature and short residence time (Adekanye et al., 2022). Biochar is a great tool towards sustainable future and has been gaining a lot of attention from past few years due to its wide agronomical applications (Choudhary et al., 2021). Biochar is also effective for reducing emission of harmful gases such as carbon dioxide, nitrous oxide and methane (Phadtare and Kalbande, 2022). It is known as excellent soil amendment, it enhances soil's fertility, improves crops yield and help in sequestering atmospheric carbon into soil. Biochar is also known to improve soil quality by increasing its cation exchange capacity, water holding capacity and nutrition uptake. Biochar is now also being used in wastewater treatments for the absorption of dyes and heavy metals found in industrial effluents. Application of Biochar is greatly influenced by its physio-chemical properties and are dependent on biomass type, residence time and temperature of pyrolysis (El-Hassanin et al., 2020).

The main objective of this study is to prepare biochar using agricultural residue (rice stubble) at different temperatures (350°C, 450°C and 550°C) using slow pyrolysis method. Physical and chemical characterization of the prepared biochars with respect to pH, Bulk density, organic carbon, proximate analysis, and yield percentage is also done. The study also aims to analyse the effect of temperature on the yield and physio-chemical properties of Biochar.

2. Materials and methods

2.1 Biomass collection and processing

Rice stubble was used as a feedstock to produce biochar. The feedstock was collected from an agricultural field at Bahadurgarh in Haryana. The collected rice stubble was sun-dried and stored at room temperature before further processing. The air-dried sample was cut into small pieces then grinded using grinding mill. The sample was again grinded in a household mixer for further reducing the particle size. The grinded feedstock was sieved through a 420-micron (mesh size -36) brass sieve and was stored in airtight zip lock bags, labelled as RS, for further analysis.

2.3 Biochar Production

Biochar was prepared by slow pyrolysis method in a muffle furnace under partial presence of oxygen. 30 grams of the sieved biomass was weighed and placed in ceramic crucible with a lid. The biochar was prepared by carrying out pyrolysis of biomass in muffle furnace at three different temperatures i.e., 350°C, 450°C and 550°C with residence time of 1 hour and heating rate of 10°C/min. After the process of pyrolysis, the biochar was allowed to cool for 2-3 hours in a muffle furnace and was kept in a desiccator overnight. Obtained biochar was weighed and stored in an airtight zip lock bag. The obtained samples were labelled as BC 350, BC 450, and BC 550. The Biochar yield was determined using the formula (Eq. 1):

$$Y\ (\%) = (W_B/W_F) \times 100 \qquad (1)$$

Where; W_B =Weight of biochar produced (in grams)
W_F =Weight of Biomass used (in grams)

2.4 Biochar Characterization

2.4.1 Proximate Analysis

Proximate analysis was performed following the American Society for Testing and Materials (ASTM - D1762-84) to determine volatile matter, ash content, moisture content and fixed carbon.

2.4.2 Physico-chemical characteristics

The pH and EC of the samples were analysed using the method described by Rajkovich et al. (2011), with modified dilution ratio 1:100 (w/v). The samples were kept on the orbital shaker for 90 mins to equilibrate the biochar with distilled water and pH, EC were measured using Hanna digital pH and EC meter. To determine the bulk density procedure outlined by Stella et al. (2016) was adopted. Organic carbon content of biochar was measured by following the Walkley and black method (Lehmann and Joseph, 2015).

3. Results and discussion

Biochar was characterized in terms of physico-chemical characteristics such as pH, bulk density, ash content, moisture content, volatile matter and ash content and organic carbon content. Fig. 1 depicts the biochar produced at 350°C, 450°C and 550°C and presence of ash can be clearly seen in biochar produced at 550°C. The characterization parameters of the prepared biochar at three different temperatures are summarized in Table 1.

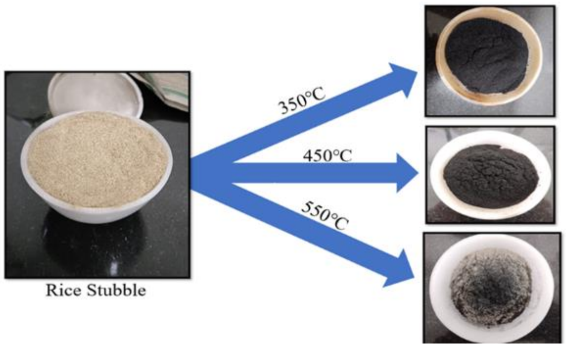

Fig. 1 Biochar produced at different temperatures

3.1 Biomass characteristics

Rice stubble was found to be slightly acidic in nature with a pH of 6.41. Electrical conductivity of Rice stubble was low i.e., 0.73 mS/cm. Rice stubble also had a low moisture and ash content i.e. 3.5%, and 13%, respectively; while a significantly higher organic carbon content 40.5%. The literature suggests that an optimal feedstock to produce biochar should possess a higher carbon content, as well as lower levels of moisture and ash. This is necessary to ensure that the resulting biochar is of high quality, exhibits strong stability, and possesses the ability to sequester carbon over an extended period (Lehmann et al., 2015). Rice Stubble exhibits a high organic carbon content, making it a promising feedstock for biochar production. This characteristic can enhance its utility as a sustainable tool for carbon sequestration and soil enhancement.

Table 1 Characterization of biomass and biochar prepared at different temperatures

	Characteristics	Rice stubble	BC350	BC450	BC550
Proximate analysis	Yield (%)	-	48%	41%	34%
	pH	6.41	8.4	10.4	11.3
	EC (mS/cm)	0.73	1.27	1.25	1.58
	Moisture content (%)	3.5%	2%	1.5%	1.5%
	Ash content (%)	13%	30.61%	35.35%	40%
	Volatile matter (%)	-	40.61%	31.6%	26.53%
	Fixed carbon (%)	-	28.58%	33.05%	33.47%
	Bulk Density(g/mL)	-	0.1995	0.1935	0.211
	Organic carbon (%)	40.5%	11.06%	10.25%	5.55%

3.2 Biochar yield

Highest yield of biochar was found at 350 ℃ i.e., 48%. However, as the pyrolysis temperature increased, the yield of biochar decreased. Biochar yields at 450℃ and 550℃ were found to be 41 % and 34%. Fig. 2 shows that with every increase in temperature by 100℃, there is a decrease of 7 % in biochar's yield. The reduction in the biochar yield can be due to the degradation of organic content present in the biomass into bio-oil, gas and other by- products. (Phuong, Uddin and Kato, 2015).

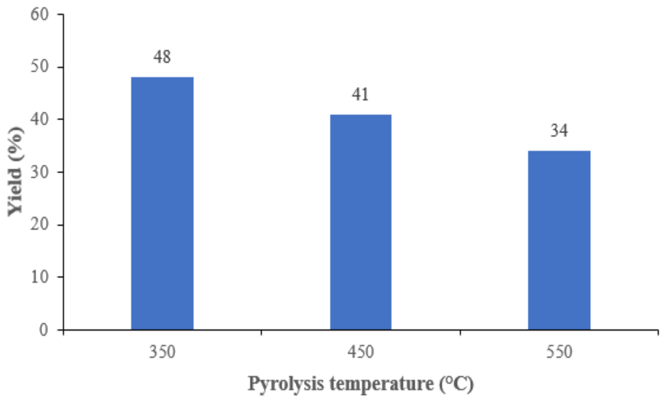

Fig. 2 Effect of pyrolysis temperature on biochar yield

3.3 Physio-chemical Characterization

Biochars produced from rice stubble were found to be alkaline in nature as their pH varied form 8.4-11.3. The highest mean value of pH of 11.3 was recorded at 550°C. The pH measurements obtained correspond with the findings reported in the literature (El-Hassanin et al, 2020), indicating a positive correlation between the reaction temperature and the pH value of biochar (Fig. 3). The variations in pH levels of biochar may be explained by the generation of compounds such as organic acids and phenolic compounds resulting from the degradation of cellulose and hemicellulose at lower temperatures, and the resulting release of volatile substances containing acidic functional groups and a rise in ash content (consists of alkaline mineral compounds) at higher temperatures (El-Hassanin et al 2020 and Phoung et al, 2015). Electrical conductivity of biochar samples were found within the range of (1.25 - 1.58mS/cm) and no significant effect of pyrolysis temperature was found. A lower EC value is generally preferred for soil amendment applications as it prevents the risks of accumulation of salts in high concentration in soil (Kammann et al., 2015). Bulk Density of biochar was found to be quite low in the range of (0.1935-0.2110 g/mL) and no noticeable effect was observed with an increase of pyrolysis temperature. Bulk density is an important factor in application of biochar as soil amendments. Biochar with a low bulk density has the potential to improve soil porosity and aeration, which may have a favorable impact on microbial respiration (Askeland et al., 2019). Organic carbon content was found to be low and decreasing with an increase in pyrolysis temperature.

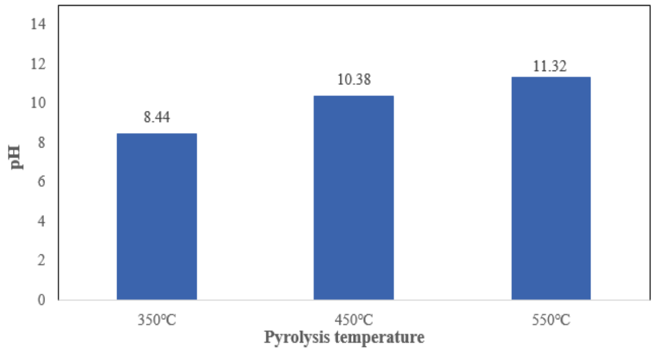

Fig. 3 Effect of pyrolysis temperature on pH of prepared biochar

3.4 Proximate analysis

The results of ash content determination indicated a significant effect of pyrolysis temperature on the ash content of biochar. The highest ash content of biochar was recorded at 550°C i.e. 40 %, which can be clearly observed in the crucible itself (Fig. 3) followed by 35 % and 30% at 450°C and 350°C, respectively. According to a number of studies on ash content of rice straw biochar were found to be on a higher side when compared to other feedstocks due to presence of high Si and alkali metal content (Phuong et al., 2022; Wu et al., 2012). Moisture contents of biochar were found within the range of (1.5-2%) with the highest moisture content at 350°C i.e. 2 %. Volatile matter (VM) and fixed carbon (FC) analysis provide a relative comparison of the unstable and stable constituents of biochar, respectively. As the temperature of pyrolysis was increased from 350°C to 550°C, there was a decrease in the VM content of the biochar observed from 40.61% to 26.53%. This may be due to the thermal degradation of volatile constituents, including organic compounds, moisture and gases. The elimination of unstable constituents in the form of gases leads to a reduction in the percentage of volatile matter present in the biochar (Phuong et al., 2022). On the contrary, the fixed carbon content of the biochar increased from 28.58% to 33.47% with the increase in temperature. Increased pyrolysis temperature aid in the carbonization process, resulting in the generation of carbonaceous structures that show enhanced stability. As a result, the fixed carbon content of the biochar also increases. A higher fixed carbon content implies a longer residence time of biochar in soil (Askeland et al., 2019). Fig. 4 depicts the influence of pyrolysis temperature on different parameters of proximate analysis of biochar.

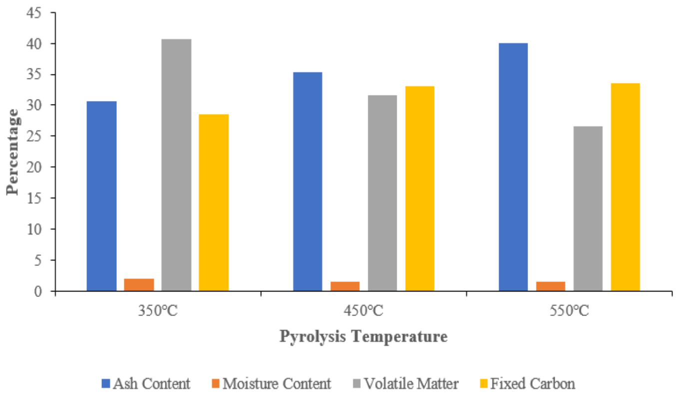

Fig. 4 Effect of pyrolysis temperature on proximate analysis parameters of biochar

4. Conclusion

The production of biochar from agricultural residues, particularly rice stubble, has huge potential to be a sustainable and environmentally friendly solution. This study successfully produced biochar from rice stubble using a muffle furnace at various temperatures (350°C, 450°C and 550°C). The biochar produced was successfully characterized on its physical and chemical characteristics and the impact of reaction temperature on the characteristics of biochar was also investigated. The results indicate that reaction temperature has a substantial effect on biochar yield, proximate analysis, and other characteristics. The result of this study indicates that rice stubble could be an ideal feedstock for biochar production due to its low moisture, ash content and higher carbon content. Results of physico-chemical characterization, such as pH, bulk density revealed that this biochar had the potential to be applied to soil as it has good water holding capacity and porosity. Its application in soil has the potential to improve soil porosity, aeration, water holding capacity, nutrient availability, decrease soil acidity and boost crop yields. Although the lack of long-term field research raises concerns about the global impact, capability, and sustainability of biochar in the long run.

Authors' contributions: All authors have read and approved the manuscript. Priyanka Saxena originated the idea, contributed in writing, Himani Bhargav and Nidhi carried out the experiments and contributed in writing, Sanjeev Kumar Goyal contributed in manuscript critical review

Conflict of interest: There is no conflict of interest to declare.

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References

Adekanye, T., Dada, O., Jegede, K., Aderinto, M. 2022. Pyrolysis of maize cob at different temperatures for biochar production: Proximate, ultimate and spectroscopic characterisation. Res. Agric. Eng. 68(1), 27-34.

Askeland, M., Clarke, B., Paz-Ferreiro, J., 2019. Comparative characterization of biochars produced at three selected pyrolysis temperatures from common woody and herbaceous waste streams. Peer J. 7, e678.

Choudhary, M.P., Charan, H.D., Acharya, B., 2019. Converting agricultural waste into biochar for improving physical properties of soil. In Proceedings of the Indian Geotechnical Conference 2019: IGC-2019, 2. 107-116.

El-Hassanin, A.S., Samak, M.R., Radwan, S.R., El-Chaghaby, G.A., 2020. Preparation and characterization of biochar from rice straw and its application in soil remediation. Environ. Nat. Resour. J. 18(3), 283-289.

Kammann, C.I., Linsel, S., Gößling, J.W., Koyro, H.W., 2011. Influence of biochar on drought tolerance of Chenopodium quinoa Willd and on soil–plant relations. Plant Soil 345, 195-210.

Lehmann, J., Joseph, S., 2015. Biochar for environmental management: science, technology and implementation. Routledge (London) Imprint.

Phadtare, P.D., Kalbande, S.R., 2022. Biochar Production Technologies from Agricultural waste, Its Utilization in Agriculture and Current Global Biochar Market: A Comprehensive Review. Int. J. Environ. Clim. Chang. 12(11), 1010-1031. DOI:10.9734/IJECC/2022/v12i1131078

Phuong, H.T., Uddin, M. Kato, Y., 2015. Characterization of biochar from pyrolysis of rice husk and rice straw. J. Biobased Mater. Bioenergy 9(4), 439-446.

Rajkovich, S., Enders, A., Hanle,y K., Hyland, C., Zimmerman, A.R. Lehmann, J. 2012. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. Biol. Fertilit. Soils, 48, 271-284.

Stella, M.G., Sugumaran, P., Niveditha, S., Ramalakshmi, B., Ravichandran, P., Seshadri, S., 2016. Production, characterization and evaluation of biochar from pod (Pisum sativum), leaf (Brassica oleracea) and peel (Citrus sinensis) wastes. Int. J. Recycl. Org. Waste Agric. 5, 43-53.

Wu, W., Yang, M., Feng, Q., McGrouther, K., Wang, H., Lu, H., Chen, Y., 2012. Chemical Characterization of Rice Straw-Derived Biochar for Soil Amendment. Biomass Bioenergy 47, 268-276.

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