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Biochar production potential of pearl millet (*Pennisetum glaucum* L.) crop residues and its physico-chemical characterization

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Abstract
Carbon rich biochar is created by pyrolyzing plant wastes under controlled conditions. Biochar applied to soil improves soil health and enhance plant growth. Research found that biochar offers a promising solution for removing CO_2 from the atmosphere. When biochar is added to soils, carbon can be stored in the soil for centuries and possibly millennia. In 2022–23, research was carried out at the ICAR-IIMR in Hyderabad to assess the pearl millet stover's biochar-making potential and characterise physical and chemical properties of biochar produced in this manner. The pearl millet stover was pyrolyzed after it had been at 400 °C for an hour. Later the biochar was analysed for various physical and chemical properties. The research indicates that the pearl millet stover has a 40.01% biochar conversion ratio. The bulk density and particle density of pearl millet biochar are 0.19 and 0.55 g/cc, respectively, while its porosity and water holding capacity are 65.46% and 596%. Pearl millet biochar was found to have a considerably alkaline nature (pH: 10.07) with an EC value of 2.06 dS/m. Hence, owing to its reliable properties biochar can significantly improves soil physical and chemical properties which enhances soil health and good plant establishment.

Keywords: Pearl millet, pyrolysis, conversion efficiency, soil health and porosity

Introduction

The accelerating pace of urbanisation and industrialization brought about by population growth is the cause of the rise in pollution. Pesticides, food additives, untreated industrial effluents, dangerous industrial chemicals, and artificial nanomaterials are some of the pollutants that influence atmospheric gases and contribute to climate change. Another method that greenhouse gases (GHGs) are getting into the atmosphere is by burning agricultural waste. A large amount of biomass is present in agricultural farm wastes, which are either burned in fields to release carbon dioxide into the atmosphere and cause severe air pollution, or they are left on open fields as cover after harvests, where they gradually decompose and release carbon dioxide into the atmosphere. The Indian Ministry of New and Renewable Energy estimates that there are now 511 million tonnes (MT) of agricultural leftovers available annually [1]. Two kilogrammes of SO_2, 3 kg of particulate matter, 60 kg of CO, 1460 kg of CO_2, and 199 kg of ash are released for every tonne of biomass burned [2]. Thus, turning agricultural waste into inexpensive, carbon-enriched biochar is a sustainable way to reduce global warming. By effectively converting organic biomass into biochar by pyrolysis, the amount of carbon released into the atmosphere during burning and decomposition may be decreased.

Thermal breakdown, or slow pyrolysis, of biomass at low temperature, low-oxic, or anoxic conditions produces biochar, a flexible and inexpensive carbonaceous solid product [3]. It is an end product that has been carbonised and is produced by pyrolyzing biomass, such as wood, straw, or other waste materials and agricultural leftovers. Typically, slow pyrolysis is carried out at temperatures between 300 and 600 ºC. Then, by using this biochar concurrently, crop growth, carbon sequestration, and soil fertility may all be improved. Because it may enhance the chemical, physical, and/or biological qualities of soil, biochar can be a highly helpful organic supplement for agriculture [4]. Increases in pH, nutrient availability, cation exchange capacity, water-holding capacity, soil structure, and soil microbial diversity have all been shown to occur when biochar is added to soils; meanwhile, nutrient leaching, nitrous oxide emissions, and soil tensile strength have all decreased [5, 6, 7]. Depending on the climate, soil, crop, and type of biochar, the effects on agricultural output have been observed to range from somewhat negative to extremely favourable [8].

Pearl millet is cultivated all over the world because of its rapid growth, high field productivity, and potential as a grass for the generation of bioenergy. The residue to production ratio (RPR), is used to calculate the total amount of millet residue that is accessible. The weight of residues generated per unit of crop is indicated by the RPR. According to [9], an RPR of 1.0 means that there will be one tonne of residues for every tonne of crop. Pearl millet's RPR varies, according to the writers. It is between 1.10 and 1.95 [10]; 1.80 and 2.00 [11]; it would be equal to 1.75 [12]. The slow pyrolysis is the most effective for biochar production with a typical biochar yield of 35.0% from dry biomass weight. The fast pyrolysis is the most efficient method for producing biofuels [13].

Bera *et al.*, (2017) investigated the physicochemical, nutritional, and spectral characteristics of biochar made from India's four major agricultural leftovers, including pearl millet [14]. According to the International Union of Pure and Applied Chemistry, the pores present in biochar may be micro (<2 nm), meso (2−50 nm) and macro (>50 nm). The biochar with less pore size cannot adsorb the pesticide molecules despite their polarity or charges. The surface area is the keynote for determining biochar sorption capacity while temperature plays a major role in biochar formation [15].

Biochar is characterized by a high specific surface area, high content of surface functional groups, pH and biochar exhibits high porosity, with longitudinal pores of sizes ranging from micro- to macropores [16] (Hernandez-Mena *et al*. 2014). Large pores, originating from the vascular bundles of the raw biomass, are important for improving soil quality because they can provide habitats for symbiotic microorganisms [17] (Thies and Rillig 2009). Porous structures can also act as release routes for pyrolytic vapours [18] (Lee *et al*. 2013).

The pyrolysis environment and the quality of the original residue determine the chemical and physical characteristics of biochar, which determine its use in agriculture [19]. As a result, characterisation is necessary before biochar is used in the field in order to improve management and maximise potential benefits.

Materials and Methods

Feed Stock and Biochar Preparation

The pearl millet stalk used in this investigation was collected on 20 September 2022, from the arboretum field of the ICAR-Indian Institute of Millets Research in Hyderabad, India. The pearl millet stalk was dried until its moisture level was less than 9%, and then it was sliced into 15–20 cm pieces. Acquired from the CIAE, the electrical metal bin has a capacity of 20 kg of biomass and a temperature control range of 350 °C to 700 °C (Fig.1). After the feedstock is placed inside the bin, the lid is screwed on firmly. The pyrolysis temperature of the display unit is then manually set to 400 °C for an hour. Let the reactor cool. Then the biochar was taken out of the bin the next day, and the cooled product was then preserved in airtight plastic containers for further examination.

Biochar Characterization

Conversion efficiency

The amount of feedstock undergone pyrolysis and converted to the carbon rich biochar and measured in conversion efficiency. If more is the conversion efficiency, more is the carbon content and vice-versa.

The following formula is used to determine the conversion efficiency:

$= \text{Carbon (kg)}/\text{Biomass (kg)} \times 100$

pH

A pH meter (Systronics pH system 362) was used to test the pH of the biochar after it had been agitated for 10 minutes while 1 g of biochar was soaked in 20 mL of deionized water (1:20 w/v).

EC

An EC meter (Elico CM 180) was used to test the electrical conductivity (EC) of the biochar after 24 hours at room temperature in a 1:10 w/v suspension (biochar: deionized water) [20].

Biochar physical properties characterization

The Keen Rackzowski box technique was utilised to evaluate the bulk density (BD), particle density (PD), porosity (PO), and water holding capacity (WHC) of biochar [21].

Fig 1: Electrical bin used for making biochar and biochar obtained from pearlmillet straw

Results and Discussion
Biochar Characterization
Biochar Yield
At a 400 °C temperature range and an hour of residence, the pearl millet biochar conversion efficiency was 40.01% (Table 1) [22]. We computed the biochar yield using a weighted method. It diminishes when the pyrolysis temperature rises and is dependent on the two limiting factors, temperature and residence time [23]. Since slow pyrolysis usually promotes the generation of biochar, it was utilised in this investigation. According to [24] the primary product of slow pyrolysis, which involves extended residence times at slow heating rates at lower temperatures, is charcoal. At higher temperatures, gaseous products predominate. The heat impact causes moisture to be lost, which in turn causes the hemicellulose, cellulose, and lignin that make up the pearl millet secondary cell wall to depolymerize [25]. This is the reason for the mass yield decline.

Physico-chemical Characterization
Pearl millet biochar had an alkaline pH (10.07) and an electrical conductivity (EC) of 2.06 dS/m. Since EC is a measure of salt loading, it may be inferred that the biochar had relatively little salt in it. With a porosity of 65.46%, the pearl millet biochar generated at 400 °C had a bulk density of 0.19 g/cc and a particle density of 0.55 g/cc. Its ability to store water was quite great (596%) (Table 1).

The pH of biochar's is generally alkaline (from 7.1 to 10.5) [26, 27]. The basicity of the non-wood-derived biochar arises from the presence of salts (carbonates and chlorides of potassium and calcium in the ash) [28]. Our results are similar to [13] instance, in comparison to biochar's generated at higher temperatures, the EC is consistently lower in biochar's produced at a pyrolysis temperature of 400 °C [29]. Biochar has macro and micropores that may store either water or air, significantly reducing its bulk density [30, 31]. According to [32-35], bulk densities typically range from 0.09 to 0.5 g /cm^3. Ash content and particle density showed a positive correlation, suggesting that ash plays a significant role in influencing particle density (PD) [13]. Measuring the PO of the biochar verified the lower BD of the biochar's, which suggested a highly porous nature [13]. The gradual extraction of volatiles from pores and the chemical and physical condensation of the residual skeletal structure at the pyrolysis temperature might be the cause of increased PO [36]. Our results concur with those of [13]. Biochar's' hydrophobicity is linked to their residual aliphatic functional groups and are destroyed at 400 °C to 500 °C temperatures [37-40]. This explains why hydrophilic biomass is transformed into a hydrophobic char by torrefaction, which usually occurs up to 300 °C. However, if the temperature is raised over 500 °C, the hydrophobicity may be lost.

Table 1: Physicochemical properties of biochar derived from pearl millet residues at 400 °C

Parameters	Biochar
Conversion efficiency (%)	40.01
pH	10.07
EC (dS/m)	2.06
BD g/cc	0.19
PD g/cc	0.55
PO (%)	65.46
WHC (%)	596

Conclusion
We may infer that bulk pearl millet stover's can be used to make dense biochar. The resulting biochar's chemical and physical properties were significantly influenced by the temperatures of the feedstock and the pyrolysis process. Because pearl millet biochar is alkaline, it may be used to remediate acidic soils. Soils supplemented with biochar have a higher capacity to hold water, which can aid in drought management strategies.

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