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Study on the Responses of Seed Germination and Vegetation Growth in Degraded Lands by the Application of Biochar Composites

Isha Medha[1], Subhash Chandra[2] and Bidus Kanti Das[3]

[1] *Indian Institute of Technology, Kharagpur - 721302, West Bengal, India; medhaisha@gmail.com*
[2] *GITAM University, Visakhapatnam - 530045, Andhra Pradesh, India; schandra3@gitam.edu*
[3] *Zelence Industries Private Limited, Kharagpur - 721302, West Bengal, India; bidus123@gmail.com*

Abstract

Approximately 25% of the Earth's land is classified as degraded. Degraded lands are distinguished by their very low production attributable to the lack of major and micronutrients, as well as inadequate water retention capacity. The present work has successfully synthesized biochar, a porous carbon substance, by subjecting raw wood biomass to pyrolysis at three distinct temperatures (400, 500, and 600 °C). The biochar was combined with several binders, including lime, vermicompost, and clay, and then transformed into pellets by moulding it and subjecting it to compressive pressure ranging from 20 to 200 MPa using a universal testing machine. The physicochemical characteristics of the biochar pellets were analyzed and afterward evaluated for their suitability as a soil ameliorant using a laboratory-scale seed germination test. The findings revealed that the biochar pellets exhibit an alkaline pH range and include a high concentration of nutrients. The results of the seed germination test showed that the addition of biochar pellets to the soil significantly enhanced both the seed germination index and seed growth, in comparison to the raw soil. Hence, this initial laboratory experiment unequivocally shown that biochar pellets can be employed for the restoration of deteriorated soil due to their straightforward methodology and cost-efficiency.

Keywords: *Biochar, Degraded Land, Seed Germination Test, and Pelletization*

1. Introduction

Soil contamination is a major problem worldwide caused by the deposition of organic and inorganic pollutants in soil[1]. Soil contamination may be defined as the presence of elements and compounds in the soil in a limited excess than desired through direct exposure or secondary exposure that may cause health or life risks to the biota or human beings[2-4]. Soil contamination is caused by the direct disposal of waste generated from industries (like the mining industry, metal industry etc.) as well as the dumping of municipal solid wastes into the landfills. These contaminated sites need to be reclaimed back to their initial condition as they were before any dumping of contaminated materials over them to remediate the soil and this improvement process of soil degraded by human activities is called land reclamation[5]. Thus, soil remediation is a process of removing, neutralizing or reducing the toxicity of certain compounds[5]. Each of the contaminated sites is either contaminated with a specific type of pollutant or with a combination of pollutants.

Further the local topography, climate and watershed dynamics enhance the impact of these pollutants on the population[6]. For these kinds of degraded lands, biochar can be proved to be an effective tool to remediate the pollutant load and reclaim the sites to their original condition. Biochar can promote revegetation over

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**Author for correspondence*

degraded soil and sorbs a variety of compounds in the soil[7]. These multiple potential benefits of biochar at a very low cost are an environmentally friendly tool for soil reclamation[8]. Biochar application is also very helpful over heavy metals contaminated soil, as biochar application over heavy metals contaminated soil has been found to sorb variety of heavy metals, including cadmium (Cd), arsenic (As) and lead (Pb)[6,7]. A study reported about the removal of heavy metals from aqueous solution by biochar made from pine and oak wood at 400-450°C[9]. reported about immobilization effect of broiler litter biochar which addition to the soil immobilizes a mixture of Pb, Cd and Ni in soil[12].

As far as organic contaminants are concerned, biochar addition to organic pollutants contaminated soil improves its sorption capacity 10 to 1000 times more for organic compounds in the soil as compared to bare soil[11]. Despite having such beneficial properties, biochar has some drawbacks which make its use a little bit problematic and uneconomical. This includes very low bulk density, low energy density, and high transportation and storage cost[12]. All these drawbacks of biochar can be overcome by the densification process. The densification process is a means to give biochar a consolidated shape and improve its bulk density and energy density, thus, reducing its handling and transportation cost. However, due to the hydrophobic nature of the biochar densification process, biochar needs some assistance from binders to form biochar pellets. These biochar pellets have slightly different properties as compared to biochar powders. The use of suitable binders with biochar for the densification process can lead to the concept of designer biochar whose properties are specifically designed to deal with specific types of pollutants[13]. In this paper, a review has been done for land reclamation using sustainable biochar technology that includes biochar production, pelletization, and characterization techniques.

2. Motivation

As biochar is a very well-known noble material for various applications such as soil reclamation, heavy metal adsorption etc., there are certain limitations of biochar which makes it unsuitable for its application in non-acidic soils, its storage and transportability. This can be mediated by biochar densification as well as the addition of useful binders which can add positive attributes to biochar itself.

3. Research Gaps

a) There are certain limitations in the physio-chemical properties of non-densified biochar which makes it unsuitable for application in non-acidic soils[14,15].
b) Non-densified is not easy to handle, transport or store due to its lightweight, low unit density and tends to easily get oxidized under open environmental conditions[16].
c) As we know from the reported studies, during reclamation of mine spoils, when seeds are supplied on the surface, a majority of the seeds are scattered by wind, consumed by seed-eating birds as well as cattle, damaged or degraded due to other reasons. So, biochar pellets with seeds integrated in it can provide dual benefits by supplying nutrients to the soil and protecting the seeds from the above-mentioned problems. Despite the benefits, not much research has been conducted on this material, i.e., biochar-integrated seeds[17].
d) Although clay-biochar composites have proved to be a noble material in the field of densification and plant growth, very few research has been conducted on this material and it has not been explored fully[18].

4. Objectives

(i) Production of biochar composite by pyrolysis and densification with an appropriate binder, followed by physico-chemical composition analysis.
(ii) Assessment of the performance and response of deliverable biochar composites on degraded soil and plant growth in terms of seed germination and growth at the lab-scale studies.

5 Concept of Biochar

Biochar is a fine-grained, carbon-rich and highly porous material that remains after plant biomass (agricultural wastes, organic wastes, plant wastes etc) is subjected to a thermochemical conversion process (pyrolysis) at a low-temperature range (350°C – 600°C) in an environment of very little or no oxygen (Lehmann and Joseph, 1995).

Biochar is not pure carbon, but rather a mix of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S) and ash in different proportions. Biochar is charcoal that has been produced under conditions that optimize certain characteristics deemed useful in soil amelioration, such as high surface area per unit of volume and low amounts of residual resins[19]. Owing to its unique properties as soil ameliorant as well as in carbon sequestration, currently, biochar is being in extensive among different countries all over the world. Biochar has emerged as a technology for waste management by converting agricultural, organic, municipal and plant wastes into biochar that could be used for different purposes for sustainable development and conserving the environment. The central properties of biochar that make it suitable for soil ameliorant are its highly porous surface, high water holding capacity, high organic matter content, and high surface area to provide an adsorption site for soil nutrients as well as a site for microbial growth[20].

5.1 Biochar Production Technologies

Preparing biochar is not very new to human civilization, it has been practised from the very past time through heating or carburizing the biomass. Although there are various methods of biochar production, all of them involve heating biomass in a little or very limited oxygen environment which is generally termed as pyrolysis[22]. Pyrolysis is the process of slow heating of organic materials that thermally decompose them under oxygen-free conditions in a temperature range of 300°C-900°C[23,24]. During the thermal decomposition process, all the cellulose, hemicellulose and lignin content of waste biomass undergo different chemical pathways by the process of cross-linking, depolymerization and fragmentation at their temperature, thus, producing solid, liquid and gaseous products that are called biochar, bio-oil and syngas respectively[25]. The yield and chemical properties of biochar are influenced by several parameters, of which the pyrolysis temperature and nature of biomass are the main factors[26].

5.2 Mechanism of Biochar Formation in the Biomass Pyrolysis Process

Understanding the whole mechanism involved in the formation of biochar from biomass is essential. Biomass is mostly composed of hemicellulose, cellulose and lignin,

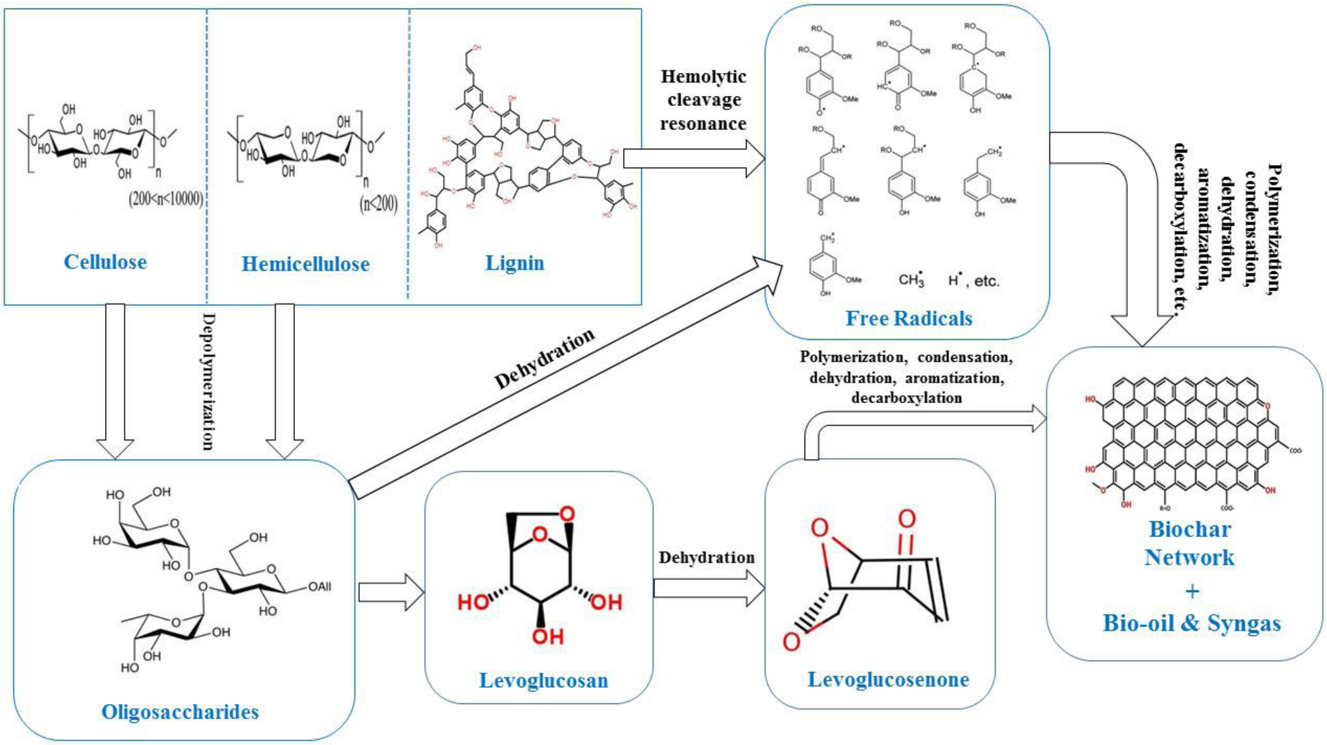


Figure 1. Biochar formation mechanism from cellulose pyrolysis (Reprinted (Adapted) from Liu *et al.*[21] © 2015 American Chemical Society).

and each component is pyrolyzed at different temperatures and follows different decomposition pathways[21]. The rate and degree of decomposition mostly depend on the process parameters, like reaction chamber type, temperature, particle size and heating rates[26,27]. Like for example, during pyrolysis, the hemicellulose decomposes in the temperature range of 200-260 °C, cellulose breaks down in the temperature range of 240-350 °C and lignin decomposition begins at the temperature range from 280-500 °C. The biochar formation mechanism from cellulose pyrolysis is shown in Figure 1.

5.3 Background of Biomass Densification

Behind only coal and oil, biomass stands as the third largest energy resource in the world. One of the major limitations of using biomass as a feedstock for bioenergy products is its low bulk density (wet basis), which typically ranges from 80–100 kg/m^3 for agricultural straws and grasses and 150–200 kg/m^3 for woody resources like wood chips and sawdust. The low densities of biomass often make the material difficult to store, transport, and interface with biorefinery infeed systems. For example, when low-density biomass is co-fired with coal, the difference in density causes difficulties in feeding the fuel into the boiler and reduces burning efficiencies. One way to overcome this limitation is to increase biomass density, which has the added benefit of increasing the material's unit density as much as tenfold. The densification process is critical for producing a feedstock material suitable as a commodity product. The densification and deformation mechanisms of powder particles under compression are shown in Figure 2.

Densification enables several advantages, including (i) improved handling and conveyance efficiencies throughout the supply system and biorefinery in feed, (ii) controlled particle size distribution for improved feedstock uniformity and density, (iii) fractionated structural components for improved compositional quality, and (iv) conformance to pre-determined conversion technology and supply system specifications. Common biomass densification systems have been adapted from other highly efficient processing industries like feed, food, and pharmacy, and include (i) pellet mill, (ii) cuber, (iii) briquette press, (iv) screw extruder, (v) palletizer, and (vi) agglomerator. Among these, the pellet mill, briquette press, and screw extruder are the most common ones used for bioenergy production. The quality of densified biomass produced using these systems is evaluated with the existing international standards developed for pellet mill and briquette press systems; there are no system-specific standards developed for the others. Several studies have been performed on densification of herbaceous and woody biomass using pellet mills and screw/piston presses. The different stages of the densification process are shown in Figure 3.

5.4 Biochar Pellets and Pelletization Process

Biochar pellets are formed from biochar powders derived by pyrolysis of biomass after crushing of pyrolyzed

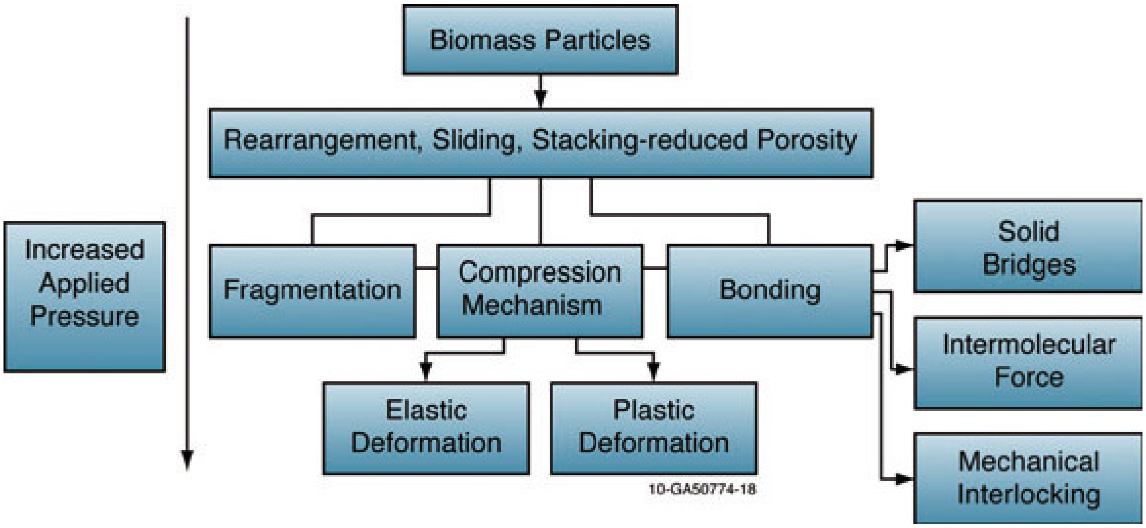


Figure 2. Deformation mechanisms of powder particles under compression (Adapted from[28]).

products in a crusher and then pelletized in a pelletizer. The pelletization process is a well-proved densification technology[29] that converts biomass or biochar into pellets by application of desired compressive pressure in a die or another pelletizing machine. Densification of biomass or biochar to regular shape products like pellets, briquettes or cubes is a way to increase their bulk density and thus, remove their handling problems and reduce their transportation cost[30]. It was reported that the densification process or pelletization of biochar depends upon its material properties (like particle size, shape, moisture content, composition and pyrolyzing condition) and processing conditions like compressing speed, temperature, pressure, and die size and shape etc[28]. The complete conversion of non-densified biomass to densified biomass is shown in Figure 4.

Different types of binders used by different authors for the densification process have been listed in the table below.

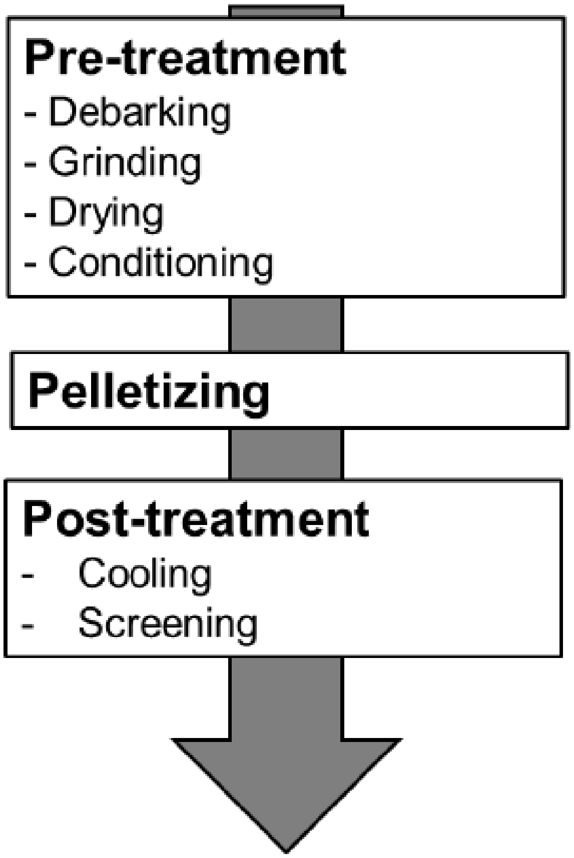


Figure 3. Different stages of the densification process, i.e., pre-, post and pelletizing stages.

5.5 Biochar Composite Pellets for Application in Degraded Mine Soil

As compared to other amendments that have been conventionally used by different scientists and authors for soil reclamation all over the world like compost, sewage sludge, fly ash etc., biochar pellets could prove to be an efficient material owing to their physical, chemical, biological and surface properties. Compared to this, biochar does not possess any health risks associated with it, further, it's operational and production cost is less as compared to compost production. Biochar helps in microbial growth on its surface as compared to compost which depends upon microbes for production. Biochar has a high nutrient retention capacity and reduces the leaching losses from the soil as it is not in the case of compost use.

During the last decades, the use of sewage sludge as a soil ameliorant has gained much momentum due to its abundance from wastewater treatment plants and rich in nutrients required for plant growth. The sludge resulting from the treatment process is commonly used as fertilizer or as a soil amendment in agricultural soils[31]. Sewage sludge availability at a cheap rate and the additional benefits of having a high level of soil organic matter and microbial activity suggest that the benefits of their use are much higher than the hazards to the environment. However, the abundance of heavy metals and the persistent environmental organic pollutants usually present in the sludge may have a deleterious effect on soil biota[32]. High heavy metals content and ecotoxicological effects due to the presence of organic contaminants like phenols, polynuclear aromatic hydrocarbons PAHs, organic acids, aliphatic etc. (Dai *et al.,* 2006) in sludge make it unsuitable for use as soil ameliorant in mine soil which already contain higher level of heavy metals or other contaminants in it. Land application of sewage sludge imparts risk to human health and other organisms in the food chain by exposing a large range of organisms to organic contaminants, either directly or indirectly[33].

The soil fauna, soil microflora, and plants growing on sludge-amended soil are directly exposed. By consumption of plants or predating soil biota from sludge-amended soil, domestic and wildlife animals can be affected, which in turn, affects the health of human beings through the introduction of contaminants in the food chain[33]. Thus, the use of sewage sludge as soil ameliorant proves to be

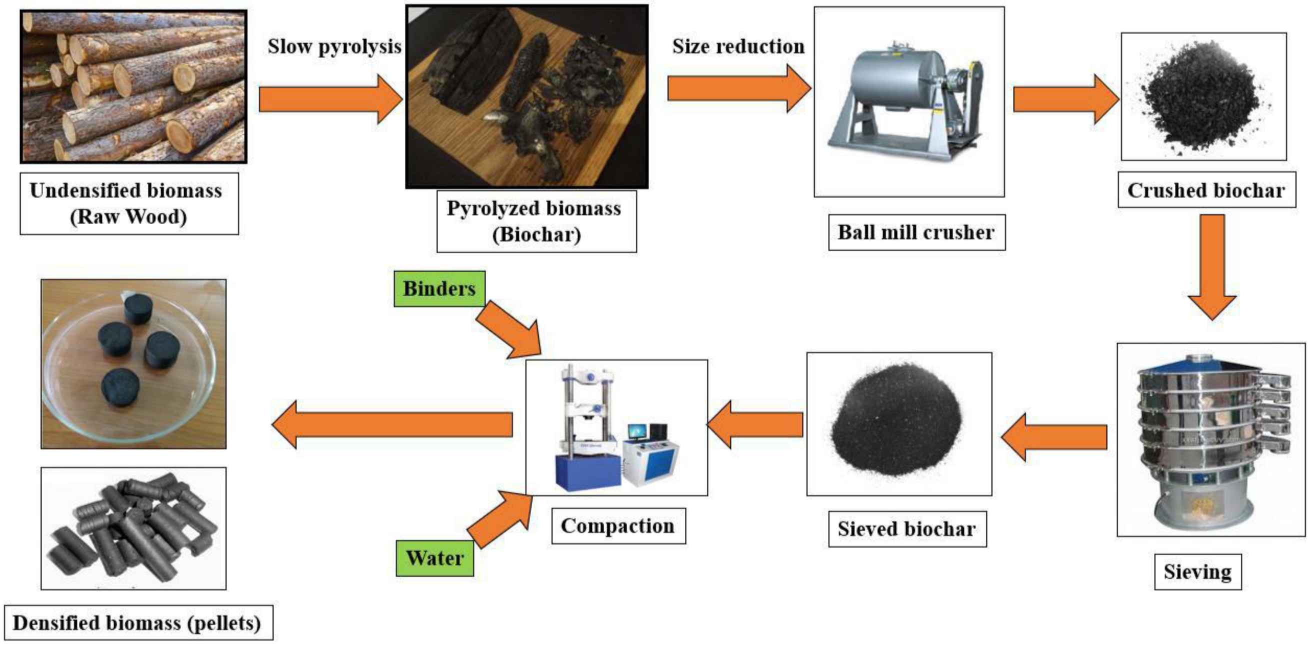


Figure 4. Biomass densification process.

Table 1. Different types of binders are used for the densification process[16]

S. No.	Binders used	Different binder and biochar ratio used	Pressure applied	Biochar Pellets size	Reference
1	Lignin	1: 20 (binder + biochar ratio) with different water content %	32 – 224 MPa	20 mm Dia. and 12 – 20 mm height	–
2	Ca $(OH)_2$	5 to 20 % w/w (binder + biochar ratio) with different content	30 kN	20 mm Dia.	(Hu *et al.*, 2015)
3	NaOH	5 to 20 % w/w (binder + biochar ratio) with different content	30 kN	20 mm Dia.	(Hu *et al.*, 2015)
4	Starch	5 to 20 % w/w (binder + biochar ratio) with different content	30 kN	20 mm Dia.	(Hu *et al.*, 2015)

beneficial for nutrient-less soil, however, their overdoses in soil may lead to the introduction of contaminants in the cycle of the food chain and may affect the health of human beings or other organisms. So, there is a need for a framework and policies in every country to specify and control the dose of sludge in soil and to conduct regular assessments of the ecotoxicological effect of sludge in soil.

6. Materials and Methods

6.1 Methodology for Research

The methodology for research is shown in the form of a flowchart in Figure 5. In this flowchart, the different processes such as biochar production, biochar palletization to produce biochar composite pellets, characterization of biochar composite pellets and application of these pellets in degraded mine soil.

6.2 Derivation of Biochar from Biomass

Rice straw and Eucalyptus wood-based biochar were produced using a slow pyrolysis process in a biochar pilot plant established near the premises of J C Bose Laboratory Complex, IIT Kharagpur. Rice Straw and Eucalyptus wood biochar were prepared at three different pyrolysis temperatures 400°C, 500°C, and 600°C. The scheme of biochar production is presented in Table 5 and biochar derived from rice straw and eucalyptus wood is shown in Figure 6.

6.3 Pyrolysis Setup

Biochar was produced using a semi-industrial scale slow pyrolysis setup designed and fabricated indigenously at the School of Environmental Science and Engineering, Indian Institute of Technology, Kharagpur. This setup consists of a pyrolysis chamber, a connecting pipe, and a gas-absorbing cum exhaust chamber. The details of the pyrolysis setup are shown in Figure 7. The main pyrolysis chamber consists of a firewood loading chamber to feed firewood for heating purposes, and a biochar box loading chamber in which a closed biochar cylinder is loaded over the main fire pipe with inclination upside down having holes on the top lid to allow a limited supply of oxygen inside the cylinder. The temperature in the pyrolysis chamber can rise to 900°C, which was measured using a thermocouple. The gases after leaving the pyrolysis chamber go to a gas-absorbing chamber filled with chilled water under continuous stirring to trap the maximum amount of gas within its volume. The residue amount of gas passes through the exhaust chimney with the help of an induced draft fan. The air and gas flow within the pyrolysis chamber is maintained using induced draft fan suction pressure and a damper to control the gas flow rate.

6.4 Design and Fabrication of Die

The mould is designed and fabricated for making biochar pellets of size 20 mm diameter where the height of the pellet can be changed according to the requirement. The mould comprises 8 components which are the base, the spacers (2 nos.), the middle component (2 nos.), the upper and the bottom components (2 nos.) and the press. The mould is purely made of stainless steel and weighs about kg. The mould is designed to be tested under the following conditions:

a) Compression speed = 5 mm/min
b) Compressive load (max) = 30 kN
c) Storing temperature = 55°C
d) Particle size (avg.) = 0.1 mm

Table 2. Scheme of biochar production using slow pyrolysis

Feedstock material	Production condition
Rice Straw/ Eucalyptus wood	400°C
	500°C
	600°C

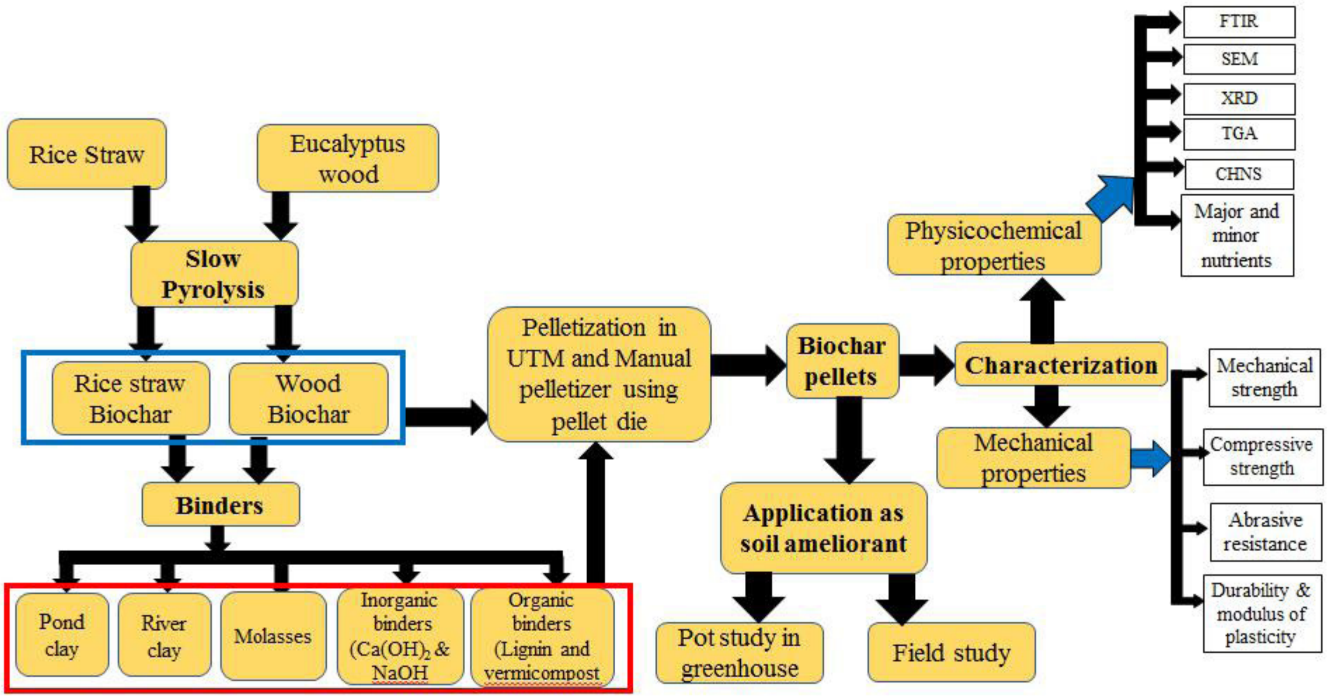


Figure 5. Flowchart of biochar production, palletization, characterization, and application.

6.4.1 Components of the Mould

Base (1 NOS.)

Used for providing support to the whole mould assembly as well as safely retrieving the pellets after the press.

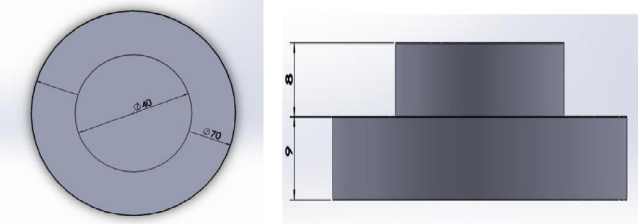


Figure 8. Top and front view of the base of the mould.

Design Parameters: Outer diameter=70 mm
Inner diameter=40 mm
First height, H1=9 mm
Second height, h1=8 mm

Spacer (2 NOS.)

Used for providing a proper base as well as determining the height of the pellet. It helps the powder material to get pressed from the bottom as well as the top to form pellets of desired diameter, height and strength.

Figure 7. Slow pyrolysis setup for biochar production designed and fabricated at the School of Environmental Science and Engineering, Indian Institute of Technology Kharagpur. (Reproduced from Chandra *et al.*[26] with permission under the license agreement: 5861810142943)

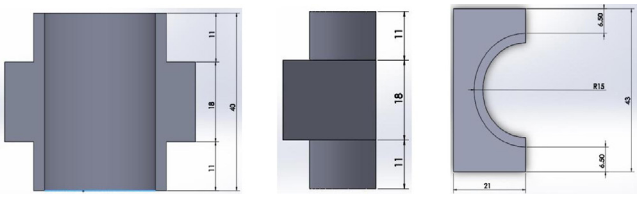


Figure 9. The top and front view of the spacer of the mould.

Design Parameters: Diameter=20 mm
Height=3 mm

Middle Component (2 NOS.)

It is the most important component of the whole mould assembly where the pellet-making is done. It is used to provide the desired shape and size to the pellet. This component comprises 2 identical parts which are put together to form a tunnel-like structure where the powder material is filled. Also, after the powder is put into it, the press is pushed on the top spacer.

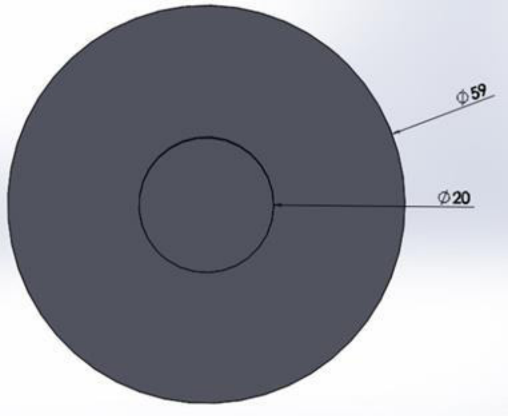


Figure 10. Front and front view of the middle component of the mould.

Design Parameters: Outer diameter r = 30 mm
Inner diameter = 20 mm
Height upper = Height lower = 11 mm
Height middle = 28 mm

Upper and Bottom components (2 NOS.)

Used for providing support from the top as well as bottom to the middle component of the mould. The upper and the bottom components are identical in shape of size irrespective of their position in the mould.

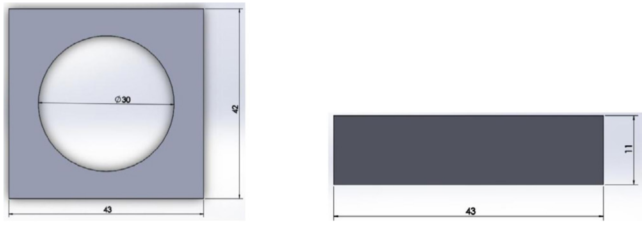


Figure 11. Top view and front view of upper and bottom components of mould.

Design Parameters: Length, a = 43 mm
Width, b = 42 mm
Outer diameter = 30 mm
Inner diameter = 20 mm
Height = 11 mm

Press (1 NOS.)

Used for pressing the top spacer on the bottom spacer along with the powder material. It is also used for retrieving the pellet safely without breaking by pressing the top spacer.

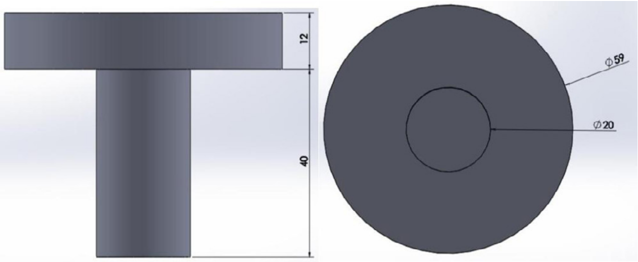


Figure 12. The top and front view of the press of the mould.

Design Parameters: Outer diameter = 59 mm
Inner diameter = 20 mm
First height, H1 = 40 mm
Second height, h1 = 12 mm

6.5 Palletization Process of Biochar Using UTM and Manual Pelletizer

Biochar pellets were produced using biochar as base material and mixed with different organic and inorganic binders. After mixing the biochar and binders in different ratios, the mixture was mixed with a fixed volume of water. The resulting mixture was then poured into the mould and compressed using a UTM or screw-type manual pelletizer. After allowing the biochar-binder mixer to pellets, the compressive pressure was released, and biochar pellets were taken out and stored for further characterization. The scheme of the biochar pelletization process using different binders is shown in Table 6.

6.6 Characterization of Biochar Pellets

6.6.1 pH and Electrical Conductivity (EC)

The pH of biochar was measured by mixing biochar samples with deionized (DI) water or 0.01M of $Cacl_2$ in a 1:20 (w/v) ratio[34]. Briefly, 2g of biochar sample was mixed with 40 cm^3 of DI water and 0.01M $Cacl_2$, and the solution mixture was shaken for 30 min followed by filtration and measurement of pH using a thermo scientific (VERSA STAR) multi-parameter meter.

The EC of the biochar samples were measured by mixing biochar samples with DI water in a 1:10 (w/v) ratio[34]. Briefly, 2g of biochar samples were mixed with 20 cm^3 of DI water, and the solution was shaken for 30 min followed by filtration and measurement of EC using a thermo-scientific (VERSA STAR) multiparameter meter.

6.6.2 Exchangeable Nutrients

Exchangeable nutrients in biochar mostly consist of sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg). These are vital nutrients required for plant growth. The presence of these nutrients in biochar assures its ability to support plant growth when added to the soil. The concentration of these essential nutrients was accessed through extraction using 1 N ammonium acetate (NH_4OAc) with pH 7 followed by detection using ion chromatography (IC) (Thermo Scientific, Model: Dionex ICS 2100)[35].

6.6.3 Cation Exchange Capacity (CEC)

The cation exchange capacity of biochar is determined using the modified ammonium acetate displacement method[36]. Briefly, 0.4g of biochar was washed with 20 ml of DI water to remove excess salt. Further, samples were washed with 1M sodium acetate solution having pH 8.2 in a centrifuge, which was followed by five times washing with 20 ml ethanol in the centrifuge to remove excess Na+ ions. After that, samples were washed with 20 ml 1M ammonium acetate solution in a centrifuge to extract Na+ ions from the exchangeable sites of the biochar. This procedure was repeated four times to collect sufficient leachate for the analysis of Na+ ions using the flame photometer. The CEC of biochar is expressed as the cmol/kg, which is the amount of Na+ ions adsorbed in the porous structure of the biochar.

6.6.4 Bulk Density

The bulk density of biochar is an important parameter which reflects the presence of pores and the size of biochar as well as its ability to regulate water solute movement. For determination of the bulk density of biochar, 2.5 g of 40 mesh powdered biochar was placed in a 25 ml glass cylinder. The cylinder was dried overnight at 80°C and tapped for 1-2 min to compact the char. The bulk density of the chart was calculated and presented in g/ml using the formula given by equation 2[37].

Bulk density (g/ml) = Weight of dry biochar (g)/ Volume of dry packed biochar (ml) ....(2)

6.6.5 Elemental Analysis

Elemental analysis of biochar samples was carried out using Euro– EA, CHNS analyzer. Briefly, 5 mg of oven-dried biochar samples were used to determine C, H, and H content in them. Oxygen (O) content in the samples was determined by subtracting the percentage mass fractions of C, H, N and ash from the total as given in equation 3[38].

Oxygen (O) % = [100 – (C + H + N + S + ash)]....(3)

6.6.6 Proximate Analysis

The proximate analysis gives important information about the volatile matter, ash content, and fixed carbon content in biochar. Proximate analysis of the biochar samples was performed using Thermogravimetric Analyzer (TGA) NETZSCH technology, USA. Briefly, 2 – 5 mg of biochar samples were placed in a pre-weighed platinum crucible of volume 5 cm3. Before placing the samples into the TGA, the crucibles were pre-conditioned in the TGA furnace to remove moisture and other impurities. After placing the samples into the TGA, samples were heated from room temperature to 105°C under an inert (N_2) gas atmosphere and kept at this temperature for 1 hour to determine the moisture content in the samples. After this, samples were heated to 900°C under an inert atmosphere and kept at this temperature for 15 minutes to determine the Volatile Matter (VM) loss. Further, samples were kept at this temperature under an oxygen environment to determine the ash content until the sample weight became constant. Fixed carbon content was obtained after subtracting the mass fractions of VM, moisture, and ash content from the total 100 per cent mass moss of the samples.

6.6.7 Trace Elements Analysis

A total of 10 trace elements (Fe, Mn, Ni, Cu, Zn, Co, As, Pb, Cd, and Si) present in the biochar samples were analyzed using an Inductively Coupled Plasma–Optical Emission Spectrometer (ICP-OES) (Model: iCAP 6000 series, Thermo Fisher Scientific, USA). Before the sample analysis, pre-dried biochar samples were extracted using an acid mixture of nitric acid (HNO_3), hydrogen peroxide (H_2O_2, 30%), and Hydrofluoric Acid (HF) in the ratio 6:2:2 (EBC, Analysis of Biochar). Briefly, 5 mg of biochar samples were placed in the microwave digestion tubes and an acid mixture containing 6 ml HNO_3, 2 ml of H_2O_2 (30%), and 2 ml of HF was added to the digestion tubes. The digestion tubes were air-locked and placed inside the microwave digestion chamber. All the samples inside the digestion chamber were heated to 200˚C with a ramping time of 20 min and kept at this temperature for 40 min. Further, samples were cooled down and collected in the vials for further analysis using the ICP-OES.

6.7 Seed Germination Test of Biochar Pellets

To evaluate the effect of biochar pellets in soils, a laboratory-based experiment was carried out. In this experiment, assuming a biochar application rate of 15 tons per hectare in the top 30 cm of the soil, 1g of biochar pellet was added per 200 ml of aqueous solution. The aqueous solutions were shaken for 24 hours in a rotatory shaker. For practical reasons, the mixture was equilibrated for 48 hours respectively to mimic the field conditions after the application of biochar (i.e. the state of soil aqueous solution), to observe the effect of biochar on the chemical properties of the solutions. After the leachate extraction, a seed germination test was performed using the collected leachates to see the effect of biochar after attenuating the pH of control solutions as well as leachate

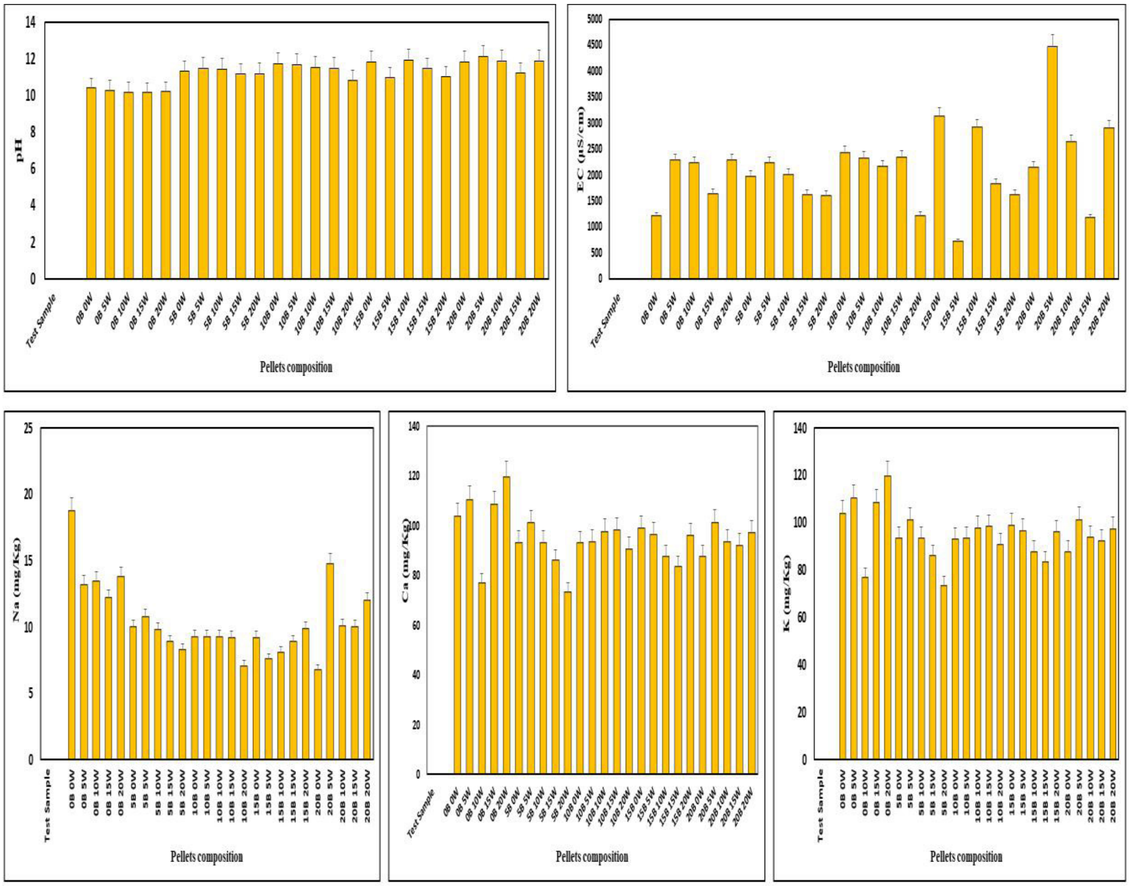


Figure 13. Chemical properties and nutrient concentration in lime-based biochar pellets.

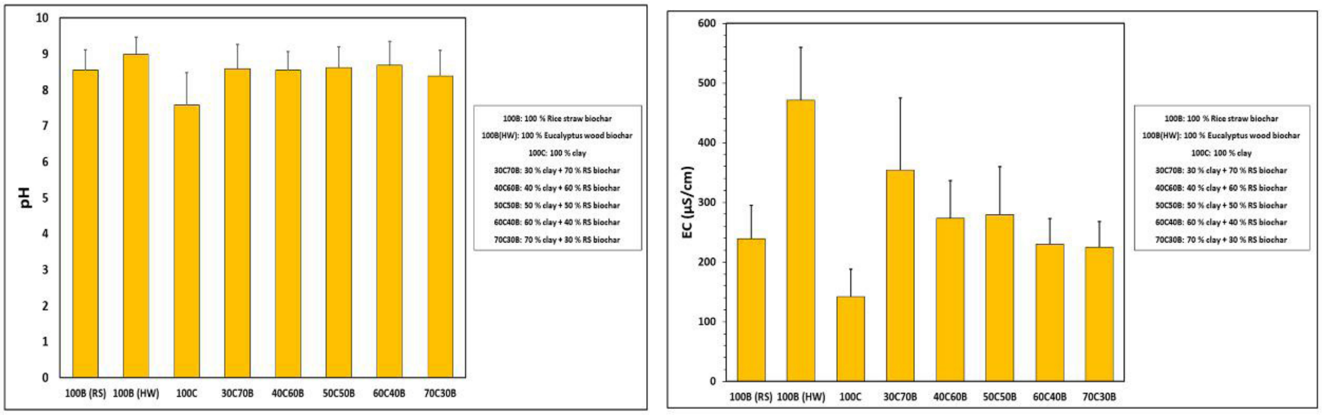


Figure 14. Chemical properties and nutrient concentration in lime-based biochar pellets.

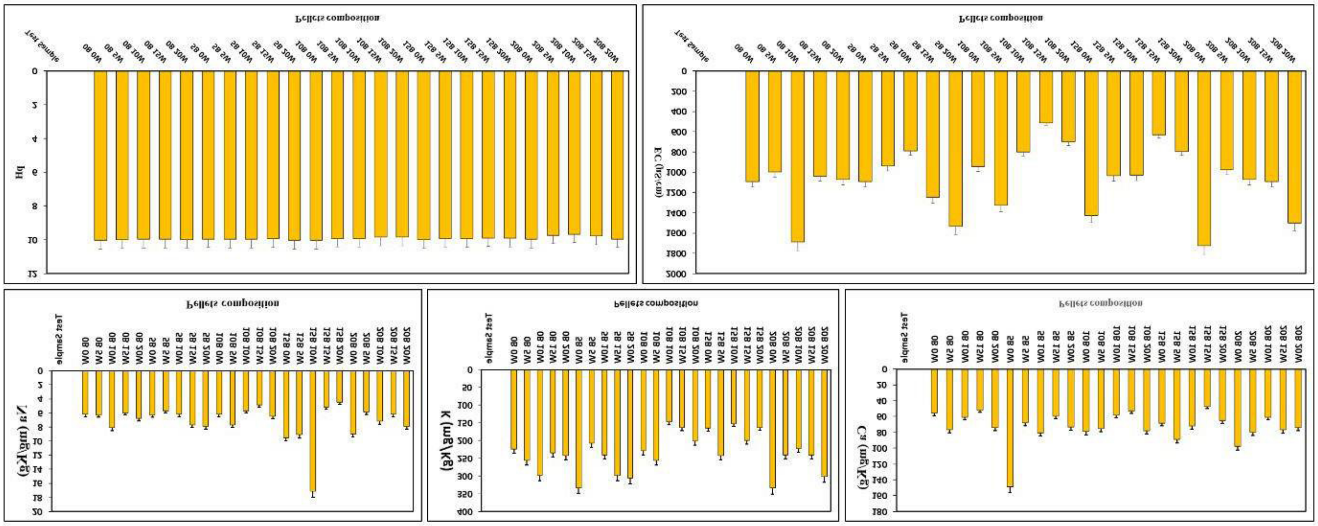


Figure 15. pH, EC, and available nutrients in clay-based biochar pellets.

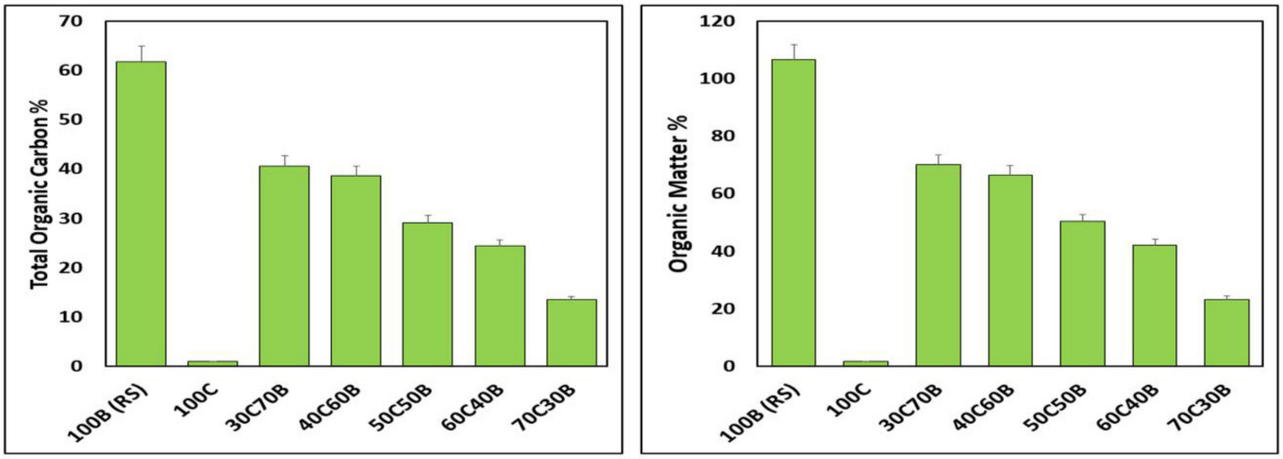


Figure 16. Total organic carbon and organic matter content in the clay-biochar-based composite pellets.

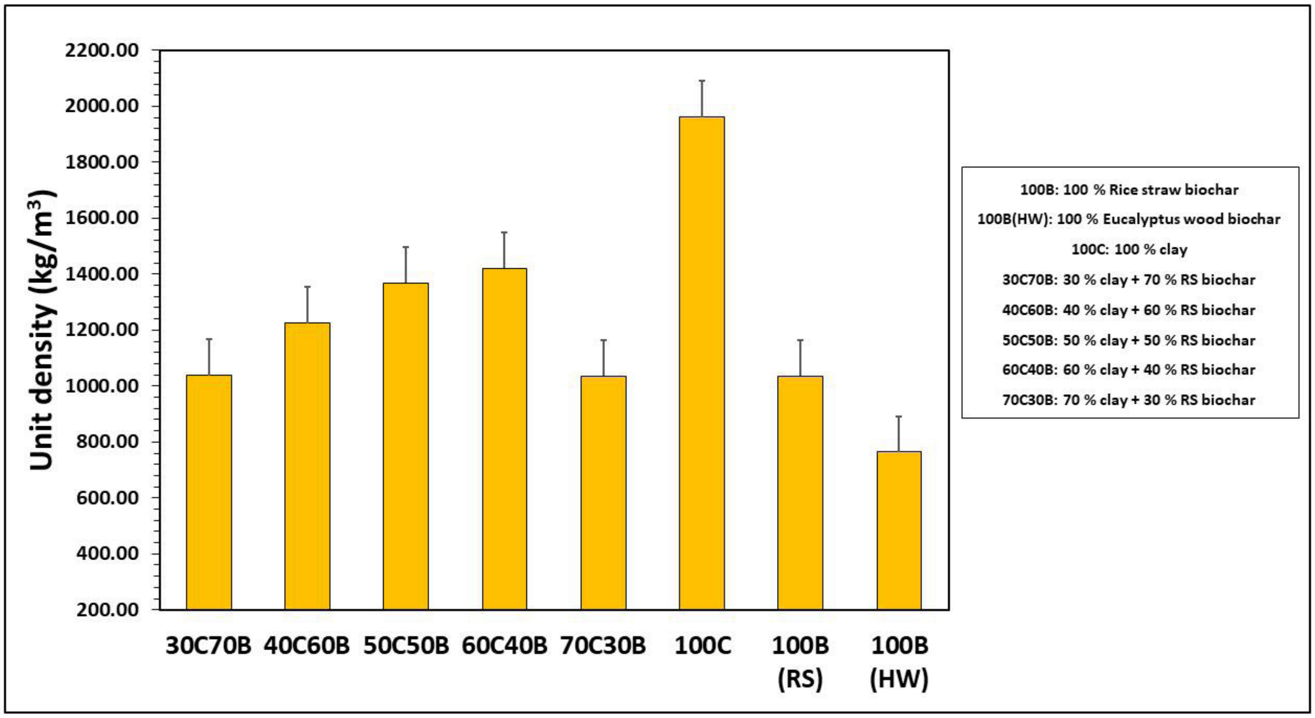


Figure 17. The unit density of clay-biochar composite pellets.

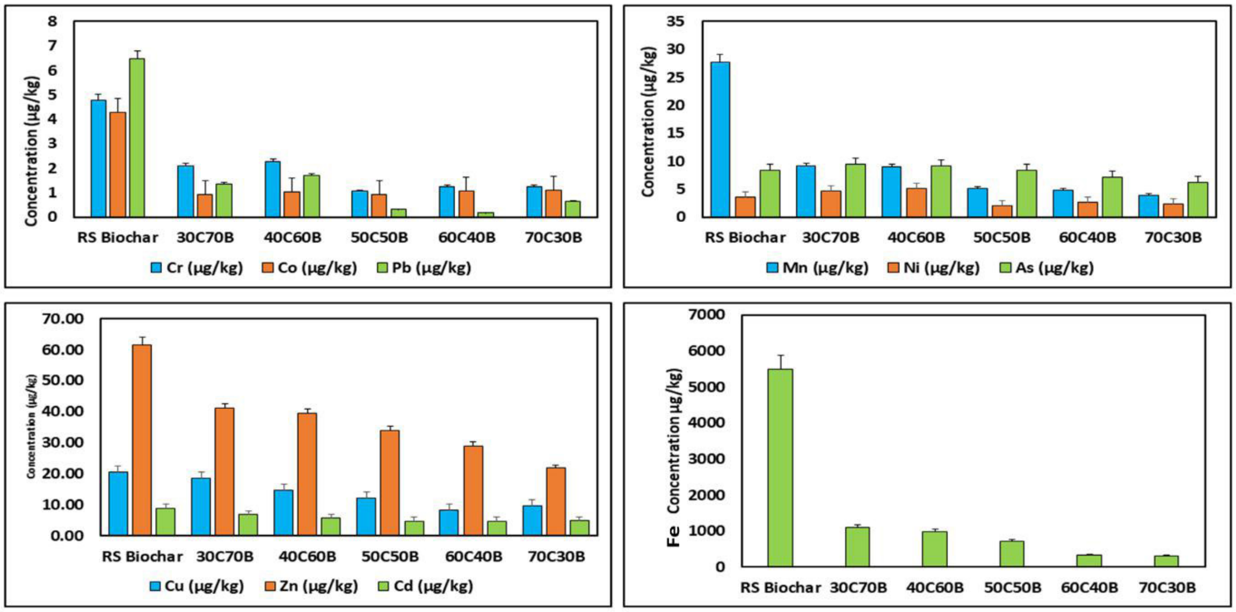
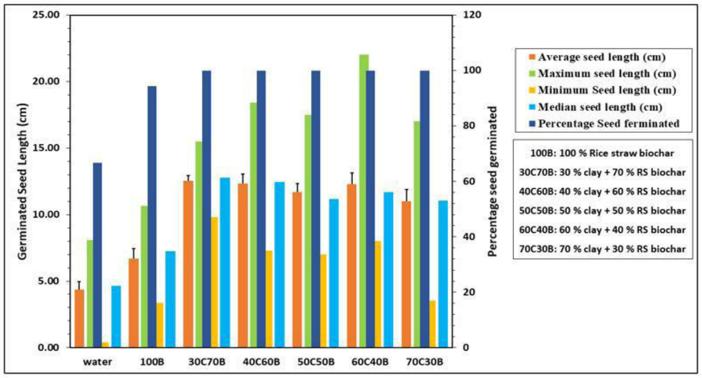


Figure 18. Micronutrient concentration in clay-based biochar pellets.

extraction time on the germination rate of seeds. To perform this test, eighteen mung bean seeds were placed on a germination paper, which was covered by another sheet of germination paper and rolled into a cylinder. The cylinders were placed in trays, which were covered by a clear plastic sheet to minimize moisture loss. The tray was then placed in the incubator at 25°C for 10 days. Every second day the cylindrical sheets were sprayed with the respective biochar extracts to replenish the moisture loss that occurs due to evaporation or seedling uptake.



Results of Seed germination test using extract of clay-biochar pellets

Results after 2 days

Results after 7 days

Figure 19. Seed germination test results of biochar and clay-biochar composite pellets.

After the incubation period, seeds were evaluated for the percentage of germination and early seedling growth by measuring the shoot length.

7. Results and Discussions

7.7.1 Biochar Pellets Produced Using a Lime as Binder

The chemical properties and macronutrient concentrations of lime-based biochar pellets are shown in Figure 11. It can be seen from the figure that as the concentration of lime as a binder in biochar pellets increased, the pH and EC of biochar also increased. However, the concentration of lime in pellets affects differently to the concentration of Na, K, and Ca. With an increase in the concentration of lime in pellets from 0 to 5 %, the concentration of plant extractable Na and Ca decreased. However, with further increase in the concentration of lime up to 10% did not show any variations in their concentration, but beyond this, the concentration of Na and K in biochar pellets also increased. On the other hand, the concentration of lime didn't significantly affect the concentration of plant extractable potassium in the pellets.

7.7.2 Biochar Pellets Produced Using Vermicompost as Binder

The chemical properties and nutrient concentration of Vermi-compost-based biochar pellets are shown in Figure 14. It can be inferred from the data presented in Figure 14 that concerning the doze of Vermicompost as a binder in the biochar pellets, the EC of the resulting pellets increased. However, there is a non-significant effect of Vermicompost as a binder on the pH of the biochar. As far as nutrient concentration is concerned, the average concentration of water-extractable Na, K, and Ca increased with an increase in the mass fraction of Vermicompost as a binder in the pellets.

7.7.3 Properties of Biochar Pellets Produced Using Pond-Clay as Binder

7.7.3.1 pH and EC of clay-based biochar pellets

The pH and EC result of clay-based biochar pellets is shown in Figure 15. From the figure, as compared to the pure non-densified biochar both from rice straw and eucalyptus wood the clay-based biochar pellets have lower pH and EC values. Further, with an increase in the mass fraction of clay in biochar pellets, its pH and EC conductivity values decreased respectively. Thus, biochar-clay composite helps to regulate the pH and EC of the biochar.

The results of TOC and OM of clay-based biochar pellets are shown in Figure 16. From the figure, it can be observed that as the mass fraction of clay in clay-biochar composite pellets increased, the concentration of TOC and OM in the respective samples decreased. Further, clay-biochar composites have lower concentrations of TOC and OM when compared to pure non-densified biochar.

7.7.3.2 Unit Density

The result of the unit density of clay-biochar composite pellets is shown in Figure 17. The unit density of clay-biochar composite pellets is lower as compared to pure clay. However, the unit density of clay-biochar composites is higher than pure non-densified biochar.

7.7.3.3 Micronutrients in Clay-Biochar Pellets

The availability of micronutrients in biochar decreased when mixed with clay to form composites. Further, as the mass fraction of clay in biochar pellets increased, the concentration of micronutrients decreased progressively. The results of micronutrients in clay-biochar composite pellets are shown in Figure 18.

7.8 Seed Germination Test Results

The seed germination test was performed using distilled water (control-1), biochar (control-2) and clay-based biochar pellets (case). The comparison was made for several seeds germinated, average seed length, maximum seed length, minimum seed length, and median length of germinated seeds. From Figure 19, it can be observed that the percentage of seeds germinated using clay-based biochar pellets was higher when compared with seeds germinated using non-densified biochar extract and DI water. Further, it can be observed that as the mass fraction of clay in biochar pellets increased, the average, maximum, and median length of seeds were also increased. As far as the minimum length of germinated seeds is concerned, this parameter length was also the maximum for clay-based biochar pellets as compared to both controls. Hence, it can be concluded that clay-biochar composite pellets enhance the performance of biochar in the soil to promote the maximum growth of plants and seeds.

8. Conclusions

- Densification of biochar pellets improves biochar's physicochemical properties like increase in bulk density, energy density, CEC, regulate pH and other properties as per the requirement of the soil.
- Biochar pellets are also easy to handle for transportation and application.
- Due to the above properties' biochar pellets can potentially be used as an amending material for remediation of contaminated mine spoils and waste materials, which are openly dumped in open areas.
- Remediation of such spoils using biochar pellets can reduce the environmental problems that are likely to arise due to their open dumping.

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