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TRANSFORMING AGRICULTURAL WASTE INTO BIOCHAR: AN ECO-FRIENDLY SOLID WASTE MANAGEMENT STRATEGY

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ABSTRACT: Solid waste is considered to be a major threat to environmental sustainability. Increase in population and urbanization has elevated this issue to an alarming level. One of the best ways to manage waste is to convert it into valuable product. The main aim of this research was the production and determination of physicochemical characteristics of biochar and to determine its efficacy on plant growth attributes. The results indicated that in case of non-wood biomass derived biochar, biochar pyrolyzed at 500 C for 1 hour showed best results having moisture content, ash content, volatile matter and fixed carbon content of 1.3%, 15.1%, 28.8% and 82.8%, respectively. In wood biomass derived biochar, biochar pyrolyzed at 500 C for 1 hour showed best results having moisture content, ash content, volatile matter and fixed carbon content of 1%, 13.1%, 16.4%, and 74.8%, respectively. Elemental and morphological analyses were determined by modern progressive technique: SEM-EDX. Further, phytotoxicity test by seed germination method was performed to assess the potential of biochar as soil amendment. Three concentrations of biochar: 0%, 1% and 2% were evaluated on coriander plant growth and effects were analyzed considering root length, shoot length and germinated seeds. Treatment T2 showed maximum increment in growth attributes of coriander plant in both non-wood and wood biomass derived biochar. Therefore, it can be concluded that both wood and non-wood biomass derived biochar can be applied safely as soil amendment leading to reduction in solid waste.

Keywords: Biochar; Wood biomass; Non wood biomass; Pyrolysis; Residence time.

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INTRODUCTION

In recent years, the global population surge has led to a more than three-fold increase in agricultural activities, hence producing tons of agro-waste (Neito *et al*., 2016). India, China and Africa have recently experienced tremendous population and economic growth, which has increased the capacity for agricultural waste production (Koul *et al*., 2022a). Technical developments have expanded agriculture and also made it a profitable sector to meet the food demand of continuously expanding human population. Environmental issues such as pollution, climatic changes, global warming, waste disposal, and degradation of natural resources have also been increased in recent years due to uncontrolled human population on our planet (Hoornweg *et al*., 2013). The Sustainable Development Goals can never be achieved without resolving with the issues related to food security, and environmental issues presented by ever-growing population in the world (Hoornweg *et al*., 2013). Agricultural residue needs to be lessened, reused, and recycled to decouple environmental pressures with economic growth (resource decoupling and impact decoupling), decrease human reliance on the utilization of resources, and prevent the pressures on soil, water, biodiversity, and global food security (Nyazika *et al*., 2019).

Adopting circular economy concept is helpful to mitigate the negative environmental impacts of agricultural activities and to ensure the long-term sustainability of agriculture. One of them is by following the circular economy model, which strives to transform waste into useful products (Casarejos *et al*., 2018). This solution does not only comply with the effective use of agricultural waste but also reduces climate change and limit global warming (Koul *et al*., 2022b). Agricultural waste is the by-product produced during the production and processing of the different agricultural products, which include crops, fruits, vegetables, and dairy products (Babu *et al*., 2022). The situation of harvest and agricultural methods can influence the quantity of agricultural waste. Whereas certain albeit lingo-cellulosic biomass of agricultural waste consists of proteins, carbohydrates as well as nitrogen, others are predominantly a blend of cellulosic compounds with essential oils and fatty acids (Urbina *et al*., 2021). Koul *et al*. (2022b) concluded that agricultural wastes can be easily recycled, and the resulted products improve the porosity of the soil, which improves soil aeration and water retention and supplies the soil with necessary nutrients to plants.

The ratio of cellulose, hemicellulose, and lignin of various biomass types differ and, thus, lead to the thermal breakdown following various pathways and mechanisms and yielding various chemical products (Singh *et al*., 2017). Biomass has a huge content of cellulose, which is why it is the ideal substance to be digested by microorganisms (Koul *et al*., 2022b). Some of the most suitable methods of managing the agricultural waste include landfilling, anaerobic digestion, plasma gasification, pyrolysis, recycling, incineration and composting. The process of recycling gathers, classifies, and reuses the waste resources to create new valuable products, whereas the process of composting needs the assistance of a wide range of bacteria, fungus, and actinomycetes to break the organic waste of plants and animals down into a fertile matrix through exposure to oxygen (Waqas *et al*., 2023). Biochar, compost, bio-hydrogen, bio-coal, bio-bricks, bio-methane, bioethanol, bio-butanol, organic acids, and bioelectricity are among the few bio-products that are produced by the utilization of lingo-cellulosic biomass (Atinkut *et al*., 2020). The pyrolyzing of agricultural waste to make biochar, is a good long term waste management strategy. The advantages of producing biochar and applying it to fields are suitable for boosting the food production, enhancing the soil quality and environment (Li *et al*., 2019; Pal *et al*., 2021), waste management and treatment to prevent negative effects on the environment (Xia and Murphy, 2016).

The chemical and physical characteristics of the individual biomass feedstock may influence the reactivity and thermal characteristics of the samples and the byproducts that are produced during the pyrolysis. Nevertheless, in circumstances where different feedstock undergoes pyrolysis at the same time, there are synergistic reactions that may lead to the attainment of superior pyrolysis by-products (Fakayode *et al*., 2020). Co-pyrolysis is an innovative technology which involves pyrolyzing two or more biomass feedstock by exploiting the synergistic interactions. This is done by subjecting a mixture of biomass feedstock to thermal degradation, in this case, the interplay between the various constituents gives rise to a form of synergy which results in various advantages. The consequence of such a synergic effect can be a rise in density, increased pore volumes, specific surface area, and the existence of more functional groups being active on the biochar surface (Yin *et al*., 2019).

Biochar is a carbon-rich substance that has a thin matrix structure, which gives it the exceptional adsorption properties and high specific surface area (Hadiya *et al*., 2022a). The yield and quality with its mineral content, organic carbon content, pore structure, and surface functional groups (Dhyani and Bhaskar, 2018) of biochar, is dependent on the type of biomass feedstock and pyrolysis conditions such as the heating rate, temperature, pressure, and residence time (Bai *et al*., 2020). The previously used adsorbent i.e., activated carbon has been replaced by biochar as an excellent adsorbent and is economically feasible. The energy demand to produce biochar is lower than the energy demand to produce activated carbon and leads to lower net energy use and costs (Tan *et al*., 2017). In addition, biochar has a relatively high adsorptions potential, a well-developed pore structure, and environmental stability (Kwak *et al*., 2019). The biochar can be used to remove a variety of organic and inorganic pollutants in the environment (Lu *et al*., 2014).

The nature of biomass used, the nature of the reactor, and the production conditions are among the factors that may influence the properties and composition of biochar. Various pyrolysis temperatures can have an effect on the surface area, and in many cases, an increase in pyrolysis temperature increases the surface area (Pendry and Salvatore, 2015). The increase in surface area is associated with the loss of aliphatic alkyl and ester groups and the exposed aromatic lignin component also increases surface area. The increase in the pore size distribution determines the development of the total surface area of biochar as the relationship between the volume of the micropores and their surface area is proportional (Biochar for Environmental Management, 2015). Carbon is the major element of the biochar structure, but the levels of each element differ based on the conditions of the process and the source material (Cha *et al*., 2016). The primary components of biochar are carbon, hydrogen, oxygen, and some level of nitrogen and sulphur (Liu *et al*., 2015). It also comprises of graphite agglomerates, which are layers overlaid by graphene and graphene oxide. The reactive edge carbons in these layers have functional groups such as -COOH, -OH, -O- and -OH, which are CO_2 binding sites (Chen *et al*., 2014).

Biochar has wide range of applications in industrial sector including fuel cells, super capacitors, carbon sequestration and amending soil. Biochar when incorporated in soil not only reduces pollutant concentration, but it also improves the properties of soil. It enhances chemical and physical qualities such as carbon sequestration, immobilization of pollutants and physiological characteristics such as oxygen concentration, moisture consumption and water retention. Biochar also enhances bio-quality of soil by promoting the growth and activity of microbes (Gul *et al*., 2015). Biochar has several advantages including carbon sequestration in the soil, reducing greenhouse gas emissions and improving soil physicochemical characteristics (Stewart *et al*., 2013). Biochar can adsorb polar molecules, therefore, immobilizing heavy metals and agrochemicals within the rhizosphere, inhibiting their distribution into the crops because of its charged surface functional groups (Ahmad *et al*., 2014; Spokas *et al*., 2009). This study will endeavor to meet the following objectives i) to analyze how the pyrolysis parameters including temperature and residence time affect the biochar production ii) use of proximate, ultimate and morphological analysis tools to characterize the biochar samples, comprehensively and iii) examine the effects of biochar on soil quality and any possible phytotoxicity on plant growth. Through these achievements this study will help in advancing existing knowledge on biochar production and use as soil amendment.

MATERIALS AND METHODS

Collection of raw material: Bamboo leaves, corncob, rice husk and java pulm wood were collected from University of the Punjab to prepare non-woody and woody biomass samples Figure 3.1. The collected samples were then sun-dried for a week and oven dried to remove moisture content (Biswas *et al*., 2017). Bamboo leaves were oven dried at 60℃-70℃ and corncob, rice husk and java pulm wood at 100℃-105℃ for 24 hours (He *et al*., 2021). Dried samples were then shredded, grounded and sieved to < 2mm to guarantee homogeneity (Biswas *et al*., 2017). Two biomass samples were prepared from dried and sieved biomass: (1) java plum wood for pyrolysis and (2) bamboo leaves, corncob and rice husk were mixed in ratio 1:1:1 for co-pyrolysis.

Preparation of biochar: Both the biomass samples were then subjected to muffle furnace (model 6X25-12) for slow pyrolysis equipped with digital temperature (Sahoo *et al*., 2021). The biomass samples were pyrolyzed under oxygen limited conditions (Wang *et al*., 2014), for the residence time of 1 and 2 hours at temperatures of 450℃ and 500℃ for non-woody biomass sample, and 550℃ and 600℃ for woody biomass sample. All the experiments were performed in triplicates.

Figure 1. Biomass sample collection

Biochar yield: The biochar yield is determined as the ratio of biochar mass to initial mass of biomass used in pyrolysis process (Qin *et al*., 2020) given as;

$$\text{Yield of biochar (\%)} = \frac{\text{mass of biochar}}{\text{initial mass of biomass sample}} \times 100$$

Characterization of biochar: Different analyses were performed to characterize both biomass as well as biochar samples and effect of pyrolysis temperature and residence time on structural, chemical and functional characteristics of both biomass and biochar samples were also determined.

Proximate analysis of biomass and biochar: The proximate analysis was conducted to determine moisture content, volatile matter, ash content and fixed carbon for both biomass and biochar samples, followed by ASTM standard. Moisture content of both biomass and biochar samples was determined by oven drying at 105℃ for 2 hours. For volatile matter determination, samples were combusted at 950℃ for 7 minutes and for ash content; samples were combusted at 750℃ for 6 hours, in the muffle furnace. The levels of moisture content, volatile matter, ash content and fixed carbon were determined by following formulas;

$$\text{Moisture level \%} = \frac{\text{mass of produced biochar} - \text{biochar mass after oven drying}}{\text{mass of biochar}} \times 100$$

$$\text{Volatile content \%} = \frac{\text{weight of oven dried biochar} - \text{weight of biochar at 950°C}}{\text{weight of oven dried biochar}}$$

$$\text{Ash content \%} = \frac{\text{weight of biochar at 950°C} - \text{weight of biochar at 750°C}}{\text{weight of biochar 950°C}} \times 100$$

$$\text{Fixed carbon (\%)} = 100 - (\text{Moisture level \%} + \text{Volatile Matter \%} + \text{Ash Content \%})$$

pH and electrical conductivity of biomass and biochar: The pH and electrical conductivity were recorded by portable digital pH and electrical conductivity meter for both biochar and biomass samples. A solution was prepared by adding 1g of sample in 60 ml of distilled water. The solution was then shaken in a shaker for 1 hour and was allowed to cool at room temperature (Bian *et al*., 2018).

Cation exchange capacity (CEC) of biochar: The CEC of the biomass as well as biochar samples were determined by using a modified ammonium acetate compulsory displacement method. Two of the best biochar samples were selected for further analysis based on proximate and CEC results in particular: non-wood biochar prepared at 500℃ for 1 hour and wood biochar prepared at 600℃ for 1 hour.

Elemental and morphological analysis: The elemental and morphological characterization of samples was determined by SEM-EDX (American Brand: FEI, Model: Inspect S50), silicon drift detector (SDD) instrument for pore size and surface topography and elemental analysis. Analysis was performed on selected biochar samples with results being analyzed at magnification range of 500X-3000X at accelerating voltage of 20kV.

Phytotoxicity test: Two of the eight biochar sorted samples: non-wood biochar prepared at 500℃ for 1 hour and wood biochar prepared at 600℃ for 2 hours were analyzed by phytotoxicity test. Coriander plant not previously treated with fungicide was used for biochar phytotoxicity test. 250g of soil was sieved (2mm) and mixed thoroughly with biochar at three increasing w/w rates of 0% (Control), 1% (Treatment T1) and 2% (Treatment T2). 7 undamaged seeds were sown in each pot at 0.3-0.5 inches soil depth. The experiment was set for triplicates and was watered daily, keeping the soil moistened (Figure 2). Morphological characteristics of coriander plant were determined which include root length, shoot length, and number of seeds germinated. The relative seed germination (RSG), relative root growth (RRG) and germination index (GI) were calculated using the following formulas (Pampuro *et al*., 2017);

$$\text{RSG}\ (\%) = \frac{\text{Number of seeds germinated in eperimental group}}{\text{Number of seeds germinated in control}} \times 100$$

$$\text{RRG}\ (\%) = \frac{\text{Mean root length in eperimental group}}{\text{Mean root length in control}} \times 100$$

$$\text{GI}\ (\%) = \frac{\text{RSG} \times \text{RRG}}{100}$$

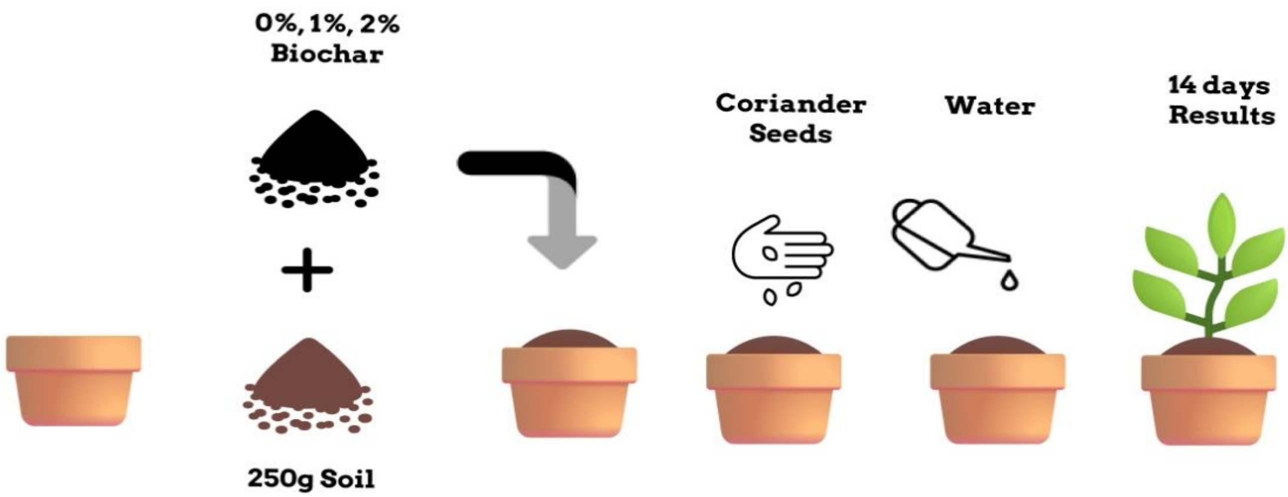

Figure 2. Process for phytotoxicity test of biochar on coriander plant

RESULTS

Yield of biochar: The yield of wood and non-wood biomass derived biochar was determined in this study. The yield results are presented in Figure 3. The yield of non-wood biochar ranged from 23.98% to 25.66%, whereas the highest yield of 25.66% was obtained from non-wood biochar pyrolyzed at 450°C for 1 hour. The lowest yield of 23.98% was observed for non-wood biochar pyrolyzed at 450°C for 2 hours. In case of wood biochar, the yield ranged from 27.35% to 28.7%. The highest yield of 28.7% was obtained from wood biochar pyrolyzed at 550°C for 2 hours, whereas the lowest yield of 27.35% was observed for wood biochar pyrolyzed at 600°C for 2 hours.

Proximate analysis: The proximate analysis of biomass (non-wood and wood) as well as produced biochar samples is given below. As per the previous studies, low values for moisture content and ash content whereas for volatile matter and fixed carbon content high values are preferred for the biomass utilization in biochar production.

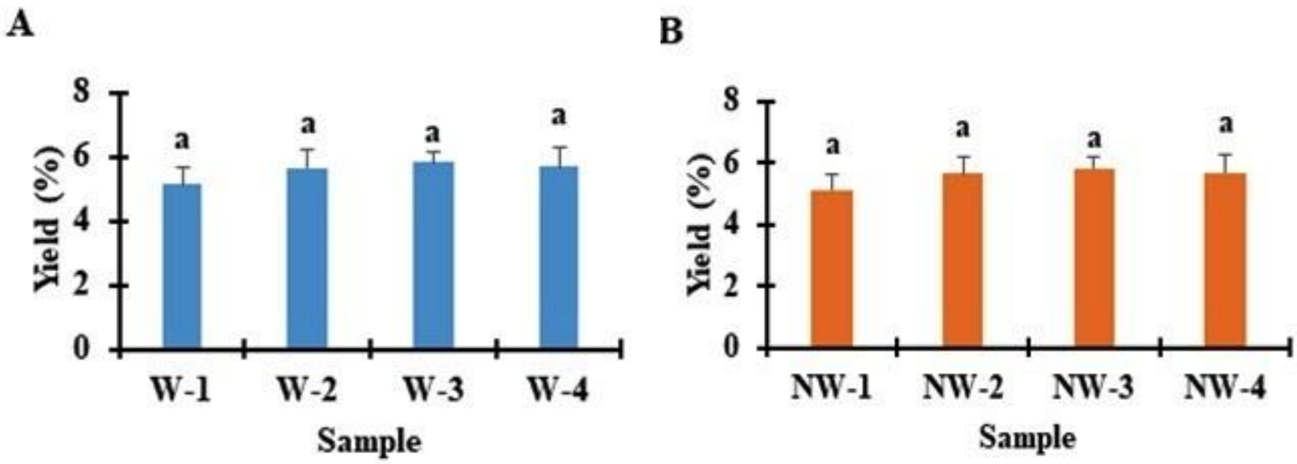

Figure 3. Yield of Non-wood and Wood biochar. NW-1: non-wood biochar prepared at 450℃ for 1hour, NW-2: non wood biochar prepared at 450℃ for 2 hours, NW-3: non-wood biochar prepared at 500℃ for 1 hour; NW-4: non-wood biochar prepared at 500℃ for 2 hours; W-1: wood biochar prepared at 550℃ for 1hour; W-2: wood biochar prepared at 550℃ for 2 hours; W-3: wood biochar prepared at 600℃ for 1hour; W-4: wood biochar prepared at 600℃ for 2 hours.

Moisture content: Moisture content of wood, non-wood biomass and of the produced biochar was investigated and results are given in Table 1. Moisture content of the non-wood and wood biomass was measured at 24% and 19.66%, respectively. Moisture contents for non-wood biochar samples were obtained as 1-2%. Highest moisture content (2%) was observed for non-wood biochar pyrolyzed at 450°C for 1 hour, whereas lowest moisture content (1%) was recorded for non-wood biochar pyrolyzed at 500°C for 1 hour. The wood biochar samples displayed moisture contents ranging from 1.33-1.67%. The highest moisture content of 1.67% was observed for wood biochar pyrolyzed at 550°C for 1 hour and lowest (1.33%) was recorded for wood biochar pyrolyzed at 600°C for 1 hour.

Volatile content: In this study, the volatile content of both wood and non-wood biomass, as well as the volatile content of the produced biochar was investigated. The volatile content results are presented in table 1. The non-wood biomass used in this study had a volatile content of 55.27% whereas 52.62% was observed for wood biomass. The non-wood biochar samples obtained from pyrolysis displayed volatile content values ranging from 16.49- 22.59%. The highest volatile content of 22.59% was observed for non-wood biochar pyrolyzed at 500°C for 1 hour, while the lowest volatile content of 16.49% was recorded for non-wood biochar pyrolyzed at 450°C for 1 hour. The wood biochar samples exhibited volatile content values ranging from 9.12-28.8%. The highest volatile content of 28.80% was observed for wood biochar pyrolyzed at 600°C for 1 hour, while the lowest volatile content of 9.12% was recorded for wood biochar pyrolyzed at 550°C for 1 hour.

Ash content: The ash content of both wood and non-wood biomass, as well as the ash content of the produced biochar was investigated. The ash content results are presented in table 1. The non-wood biomass used in this study had an ash content of 4.91%. The non-wood biochar samples obtained from pyrolysis displayed ash content values ranging from 7.69-13.05%. The highest ash content of 13.05% was observed for non-wood biochar pyrolyzed at 450°C for 1 hour, while the lowest ash content of 7.69% was recorded for non-wood biochar pyrolyzed at 500°C for 1 hour. When it comes to wood biomass, the 5.24% of ash mass was measured. The ash content value of the wood biochar samples was found between 6.7-15.09%. The maximum ash content of 15.09% was found in the wood biochar pyrolyzed at 550^{o}C for 1 hour and the minimum ash content of 6.70% was found at 600^{o}C in 1 hour.

Fixed carbon: The fixed carbon content of both wood and non-wood biomass, as well as the fixed carbon content of the produced biochar, was determined. The fixed carbon content results are presented in table 1. The non-wood biomass used in this study had a fixed carbon content of 15.81%. The non-wood biochar had fixed carbon contents of 63.01- 74.80%. The maximum fixed carbon content of 74.8% was found in non-wood biochar pyrolyzed at 500^{o}C for 1 hour and minimum fixed carbon content of 63.01% was found in non-wood biochar pyrolyzed at 450^{o}C for 1 hour. The fixed carbon in the case of the wood biomass was 22.46%. The wood biochar samples had fixed carbon values ranging between 59.11-82.84%. The wood biochar that had the highest fixed carbon content (82.84%) was found at 600^{o}C and 1 hour and the lowest fixed carbon content of 59.11% was found at 550^{o}C for1 hour.

Table 1. Proximate analysis of non-wood and wood biomass and biochar samples

	Sample	Moisture Content	Volatile Content	Ash Content	Fixed Carbon	Units
Wood biomass						
1.	**Wood biomass**	24±1.52	55.27±1.01	11.9±1.1	64.95±0.9	%
2.	**W-1**	2±0.57	21.01±1.7	13.1±1.0	15.8±1.1	%
3.	**W-2**	1.3 ±0.88	22.5±2.1	13.1±1.2	63±1.7	%
4.	**W-3**	1±0.1	16.4±1.2	4.91±1.2	74.8±1.3	%
5.	**W-4**	1.3±0.0	16.8±2.07	7.7±0.5	73.2±1.2	%
Non-wood biomass						
6.	**Non-wood biomass**	19.6±1.7	52.2±1.6	5.2±1.4	22.4±1.2	%
7.	**NW-1**	1.7±0.6	5.5±1.0	15.1±3.2	59.1±2.4	%
8.	**NW-2**	1.6±0.6	9.1±2.4	10.4±3.4	59.2±2.5	%
9.	**NW-3**	1.3±0.3	28.8±0.6	6.7±1.14	82.8±1.7	%
10.	**NW-4**	1.5±0.4	24.1±2.2	8.2±3.35	74.8±1.9	%

NW-1: non-wood biochar prepared at 450℃ for 1hr; NW-2: non-wood biochar prepared at 450℃ for 2hr; NW-3: non-wood biochar prepared at 500℃ for 1hr; NW-4: non-wood biochar prepared at 500℃ for 2hr; W-1: wood biochar prepared at 550℃ for 1hr; W-2: wood biochar prepared at 550℃ for 2hr; W-3: wood biochar prepared at 600℃ for 1hr; W-4: wood biochar prepared at 600℃ for 2hr.

Determination of physical parameters of biochar

Electrical conductivity (EC): The EC values of biomass as well as biochar of both non-wood and wood was measured (Figure 4). The EC values of non-wood biochar ranged from 286.6 to 333.3 µS/cm. The EC values of non-wood biochar ranged from 286.6 to 333.3 µS/cm. The highest EC value of 333.3 µS/cm was observed for non-wood biochar pyrolyzed at 500°C for 1 hour and the lowest EC value of 286.6 µS/cm was obtained from non-wood biochar pyrolyzed at 450°C for 1 hour. For wood biochar, the EC values ranged from 156.6 to 233.3 µS/cm. The highest EC value of 233.33 µS/cm was obtained from wood biochar pyrolyzed at 600°C for 1 hour, while the lowest EC value of 156.6 µS/cm was observed for wood biochar pyrolyzed at 550°C for 1 hour.

pH: The pH values for both types of biomasses and biochar were determined and results are presented in Figure 4. The pH values of non-wood biochar ranged from 10.26 to 10.56 and the pH value of 8.5 was observed for non-wood biomass. The highest pH value of 10.56 was observed for non-wood biochar pyrolyzed at 500°C for 1 hour, whereas the lowest pH value of 10.26 was obtained from non-wood biochar pyrolyzed at 450°C for 1 hour. For wood biochar, the pH values ranged from 11.33 to 11.83 and the pH value of 7.6 was observed for wood biomass. The highest pH value of 11.83 was obtained from wood biochar pyrolyzed at 600°C for 1 hour, whereas the lowest pH value of 11.33 was observed for wood biochar pyrolyzed at 550°C for 1 hour.

Cation exchange capacity (CEC): The findings reveal the CEC of the various types of biomass and biochar samples (Figure 4). The CEC value of non-wood biomass (14.86 meq/100g) was higher than that of the wood biomass (8.23 meq/100g). The sample pyrolyzed at 500°C in 1 hour had the highest CEC value of 15.35 meq/100g and the lowest CEC value was 13.84 meq /100g in the sample pyrolyzed at 450°C in 1 hour. In case of wood biochar, the highest CEC value of 14.91 meq/100g was obtained from the sample pyrolyzed at 600°C for 1 hour, while the lowest CEC value of 11.79 meq/100g was recorded in the biochar pyrolyzed at 550°C for 1 hour.

Best sample selection: Out of all the biochar samples, the non-wood biochar prepared at 500°C for 1 hour and wood biochar prepared at 600°C for 1 hour was selected for further analysis, considering the preferred values resulted from proximate analysis and comparatively higher CEC values of biochar.

Elemental analysis: For morphological and elemental analysis of the selected samples, Scanning Electron Microscopy (SEM) with Energy Dispersive X-Ray Analysis (EDX) analysis were performed. SEM images of Non-wood biochar show rough porous appearance as shown in Figure 5. This could indicate the presence of a high porosity and complex pore structure within the biochar. But it may also be suggested that there are some impurities or agglomeration of particles leading to an uneven surface at the microscopic level. In case of wood biochar, SEM images show striped appearance and a rough porous structure can be seen in one end of the image. It is suggested that this may be due to impurities or remnants of vascular tissues or cell walls. Striped structure may also suggest that there is presence of aligned carbonaceous materials or the formation of crystalline or fibrous structures within the biochar.

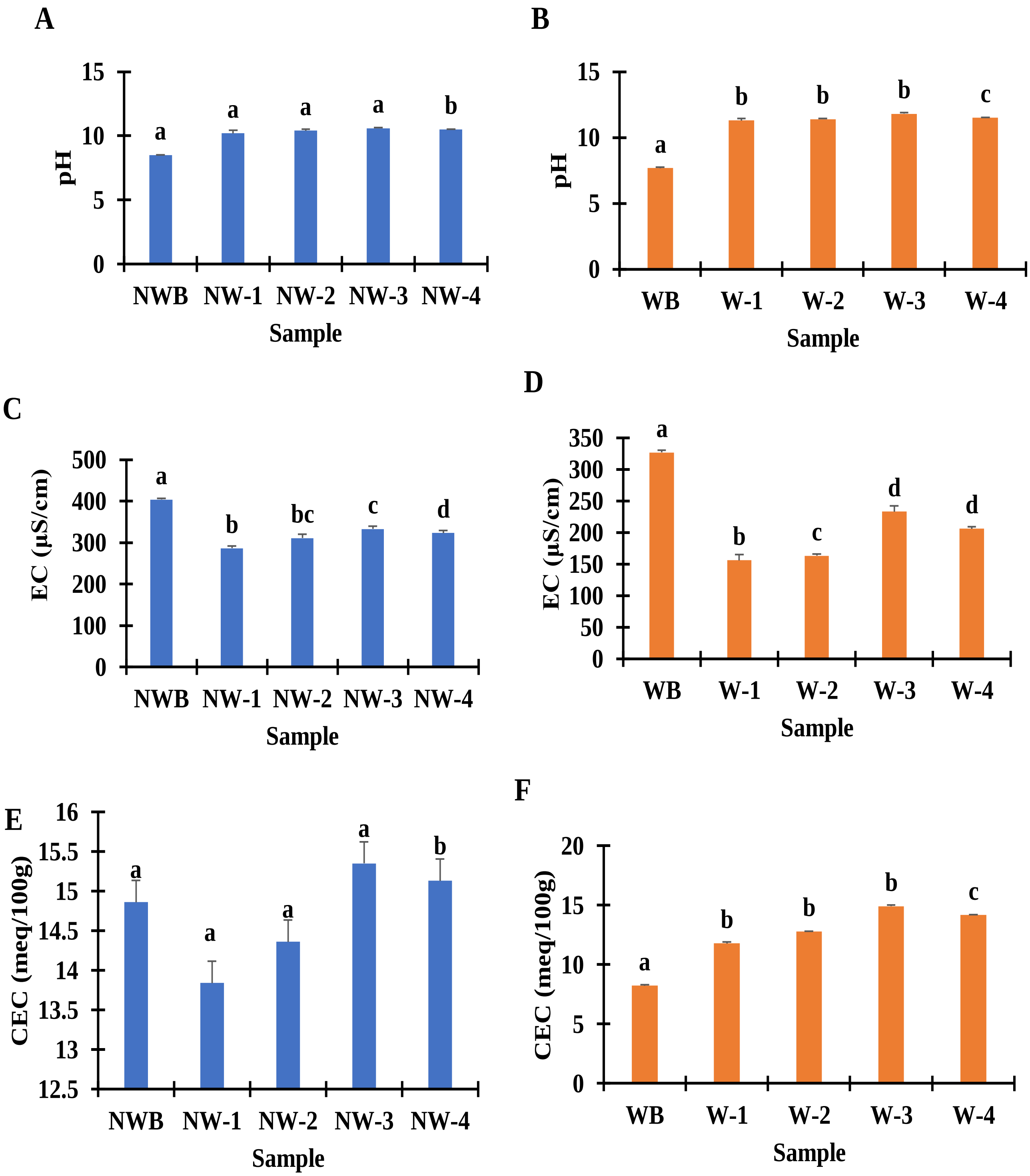

Figure 4: Physical analysis of non-wood and wood biomass and biochar samples (a) Electrical conductivity (EC), (b) pH and (c) Cation exchange capacity (CEC) of Non-wood and Wood biomass and biochar. NW-B: non-wood biomass; NW-1: non-wood biochar prepared at 450℃ for 1hr; NW-2: non-wood biochar prepared at 450℃ for 2hr; NW-3: non-wood biochar prepared at 500℃ for 1hr; NW-4: non-wood biochar prepared at 500℃ for 2hr; W-B: wood biomass; W-1: wood biochar prepared at 550℃ for 1hr; W-2: wood biochar prepared at 550℃ for 2hr; W-3: wood biochar prepared at 600℃ for 1hr; W-4: wood biochar prepared at 600℃ for 2hr.

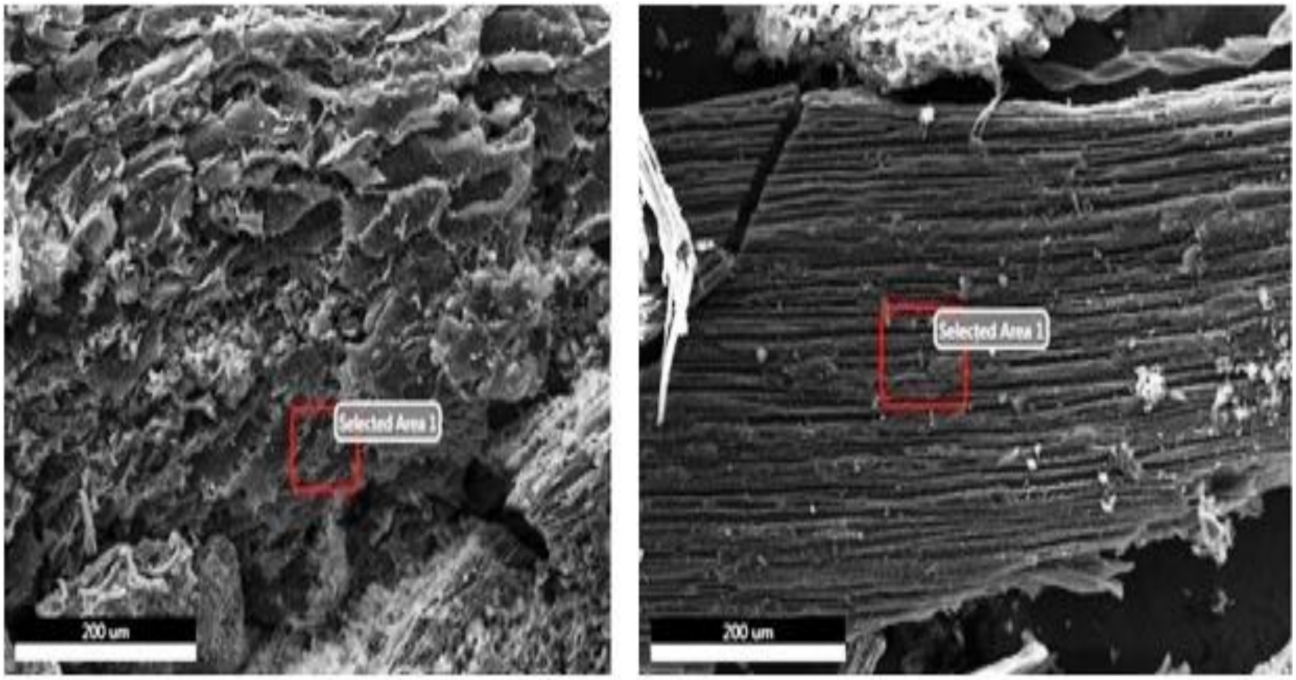

Figure 5. Elemental analysis of non-wood and wood biochar

Phytotoxicity Test

Root length: Both wood and non-wood biomass derived biochar was analyzed for phyto-toxicity test by determining the growth attributes of coriander plant (Figure 6). In soil amended with non-wood biochar, the maximum root length of 4.3cm was shown by treatment T2 in comparison to the control, followed by treatment T1 where root length of 3.7 cm was recorded. Similar trend was observed in treatments comprising of wood biomass derived biochar, where maximum root length of 4.76 cm was recorded in treatment T2 in comparison to the control, followed by treatment T1 where root length of 3.6 cm was recorded.

Shoot length: Shoot length of coriander plant grown in soils amended with two different levels of non-wood and wood biomass derived biochar was determined and presented in Figure 6. In soil amended with non-wood biochar, the maximum shoot length of 4.56 cm was exhibited by treatment T2 in comparison to the control, followed by treatment T1 where root length of 4.16 cm was observed. Similar trend was observed in treatments comprising of wood biomass derived biochar, where maximum root length of 4.46 cm was recorded in treatment T2 having 2% biochar concentration in comparison to the control, followed by treatment T1 where root length of 4.1 cm was recorded.

Relative seed germination (RSG): Relative seed germination of coriander plant grown utilizing different concentrations of non-wood and wood biomass derived biochar was analyzed. In soil amended with non-wood biomass derived biochar, the maximum RSG of 115.47% was shown by treatment T2 in comparison to the control, followed by treatment T1 where RSG of 105.2% was recorded. Similar trend was observed in treatments comprising of wood biomass derived biochar, where RSG of 133.2% was recorded in treatment T2 in comparison to the control, followed by treatment T1 where 120% of RSG of coriander plants was recorded (Figure 6).

Relative root growth (RRG): Relative root growth of coriander plant grown utilizing different concentrations of non-wood and wood biomass derived biochar was analyzed. In case of non-wood biomass derived biochar, the RRG rate of coriander plant was 124.06% when treatment T2 was applied followed by treatment T1 where RRG rate of 106.75% was recorded. On the other hand, when wood biomass derived biochar was applied, the RRG rate of 118.17% was recorded in treatment T2 in comparison to the control, followed by treatment T1, where RRG rate of 89.26% was recorded (Figure 6).

Germination index (GI): After the application of selected non-wood and wood biomass derived biochar, the GI of coriander plant was measured. In case of non-wood biomass derived biochar, the GI rate of coriander plant was 143.25S% when treatment T2 was applied, followed by treatment T1 where GI rate of 123.26% was recorded. In treatments comprising of soil amended with wood biomass derived biochar, the GI rate of 157.4% was recorded in treatment T2 in comparison to the control treatment, followed by treatment T1, where GI rate of 107.1% was recorded (Figure 6).

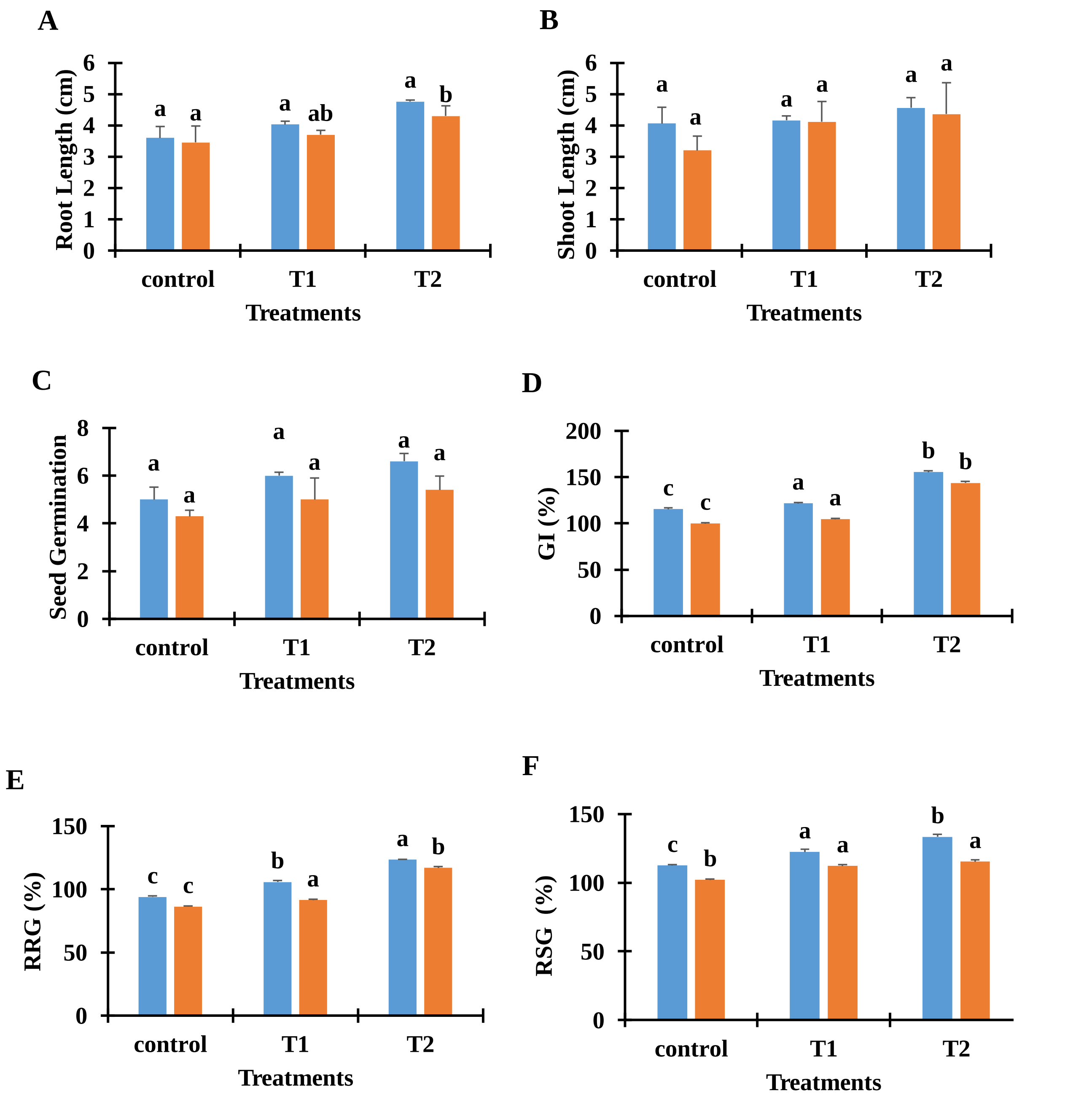

Figure 7. Growth attributes of coriander plant. (A) Root length (B) Shoot length (C) Seed germination (D) Relative seed germination (RSG) (E) Relative root growth (RRG) (F) Germination Index (GI).

DISCUSSION

Yield of biochar is considered as one of the crucial parameters since it defines the effectiveness of biochar production and amount of biochar that can be utilized for further applications. Comparing the yield of non-wood biochar with wood biochar, the yield of the wood biomass derived biochar was higher than the non-wood biomass derived biochar. The higher yield of wood biochar might be due to its unique chemical composition comprising of lignin, cellulose and hemicellulose in varying concentrations. It is anticipated that the declining trend of yield of biochar as the temperature rises is due to the degradation of lignin-cellulose structure of the biomass and the combustion of organic substances with the rising temperature (Han, 2020). Our findings are in agreement with the findings reported by Al Arni (2018) who examined the conditions needed to carry out the pyrolysis of biomass.

Moisture content of produced biochar samples and their feedstock was analyzed. The moisture content of non-wood biochar was noted to be higher than the wood biochar. It might be possible that there was a difference in the natural moisture content of the biomass. The pyrolysis conditions including the temperature and the residence time affected the moisture content of the resulting biochar of both non-wood and the wood biomass. The reason was possibly the hygroscopic property; the potential to re-absorb the moisture of the surrounding of biochar pyrolyzed at a higher temperature (Palniandy *et al*., 2019). Our results coincide with the findings reported by Alkharabsheh *et al*. (2021).

Another parameter that is very important in determining the energy content, stability and combustion properties of the material is the volatile content of the biomass and biochar. It has been observed that volatile contents have been on the downward trends with the rise in temperature of 450 **°C** to 500 **°C** in non-wood and 550 **°C** to 650 **°C** in wood. Volatile content in wood biochar was found higher than the non-wood biochar. Chemical composition, structure and lignocellulosic nature of the wood are the major factors contributing to higher volatile content. Various authors reported similar trend of volatile content in proximate analysis (Lee *et al*., 2013; Vieira *et al*., 2020; Yu *et al*., 2019). The quality and characteristics of biomass and biochar depend on the ash content. On comparing the ash contents of non-wood and wood biochar, it was observed that ash content in wood biochar was higher than the ash content of non-wood biochar. Increases in pyrolysis temperatures and residence times typically increased the ash content of the resulting biochar though it should be pointed out that the ash content is also dependent on the mineral content of the feedstock biomass used. Conversely, the high content of ash shows the presence of competing ions of biochar sample that is utilized in the elimination of metal contaminants (Abdel-Fattah *et al*., 2015). The same results were found by (Amen *et al*., 2020) and (Amenaghawon *et al*., 2021).

The fixed carbon alteration of biomass and biochar implies the carbon rich part that is left behind after the volatile constituents escape during pyrolysis. When the fixed carbon contents of non-wood and wood biochar are compared, wood biochar showed higher fixed carbon content. The increased fixed carbon content in wood biochar might be due to higher concentration of carbon containing compounds persisting in the biochar after pyrolysis. Increased pyrolysis temperature and residence resulted in high fixed carbon levels in biochar. As the results have shown, high fixed carbon values are obtained as the values decrease in ash content. Such findings align with the work of the past (Yargicoglu *et al*., 2015) and (Armynah *et al*., 2018).

The pH value of biochar indicates the acidity or alkalinity of the biochar product. The pH values for both types of biomasses and biochar, pyrolyzed at different temperatures and residence times, were determined. Previous studies suggested that pH of biochar generally range from slightly acidic values of nearly 6.5 to highly alkaline values of 11.5 depending upon the type of biomass and pyrolysis conditions (Xie *et al*., 2015). It has been observed that the high pH is beneficial element of biochar for the neutralization of soil acidity (Chan *et al*., 2007). Comparing the pH values between non-wood and wood biochar, it can be observed that wood biochar generally showed slightly higher pH values compared to non-wood biochar. This difference in pH could be accredited to the inherent composition and structure of the respective biomass feedstock. Our results are in line with the studies reported by Cantrell *et al*. (2012) and Yuan *et al*. (2011).

The EC of biochar is associated with the capacity of the biochar to conduct electric current showing the existence of ions and dissolved salts. The non-wood biochar tend to have a little higher values of EC than the wood biochar. This difference in electrical conductivity could be because of variations in the chemical composition and structure of the respective biomass feedstock. Our results are in line with the studies reported by Cantrell *et al.* (2012) and Yuan *et al.* (2011). The morphology of non-wood and wood biochar was studied using SEM images. The SEM images of non-wood biochar indicated the rough and porous structure. The roughness of surface indicates the presence of a high porosity and complex pore structure within the biochar. It can also be suggested that there are some impurities or agglomeration of particles leading to an uneven surface at the microscopic level. In case of wood biochar, SEM images show striped appearance and a rough porous structure can be seen in one end of the image. Similar findings are described by (Beesley *et al*., 2011) who worked on the removal of heavy metals using biochar.

The influence of different concentrations of non-wood and wood biochar on different growth attributes of coriander plant was determined. The findings of conducted study indicate that the effect of wood biochar on root and shoot growth may be concentration-dependent. It was observed that 1% biochar concentration was lead to the substantial increase in root and shoot length. This may also be because of higher pH value of wood biochar effecting plant's root and shoot length when added to soil at higher concentration. However, the recommended level of biochar for soil application is 2% as reported by Li *et al*. (2022). Biochar input generally improves the whole plant growth, including root length, root volume and biomass, uptake capability and shoot length as reported by Ali *et al*. (2022); Li *et al*. (2022) and Maccarthy *et al*. (2020). The germination index is a trustworthy indicator of phytotoxicity. Comparing the results for both non-wood and wood biochar, indicated that non-wood biochar had a relatively lesser impact on seed germination compared to wood biochar. Both non-wood and wood biomass derived biochar showed higher germination rate when 2% biochar was applied, suggesting its potential as a soil amendment with minimum phytotoxicity. Similar findings were reported by Li *et al*. (2019).

Conclusion: Achieving the aim to manage and utilize waste by converting it into valuable product; biochar was prepared using agriculture and garden waste. Throughout our study, wood biochar showed ranging values at greater deviation, suggesting that wood biochar was more temperature and residence time sensitive as compared to non-wood biochar. Volatile content ranged from 16.49% - 22.59% for non-wood biochar whereas the range of 9.12% - 28.80% was observed for wood biochar. Ash content was observed to be ranging from 7.69% - 13.05% for non-wood biochar whereas values for wood biochar ranged from 6.70% - 15.09%. Values of fixed carbon content for non-wood and wood biochar was observed to be 63.01% - 74.80% and 59.11% - 82.84%, respectively. Cation exchange capacity values were observed to be ranging from 13.84 meq/100 g - 15.35 meq/100 g and 11.79 meq/100 g - 14.91 meq/100 g for non-wood and wood biochar, respectively. Phyto-toxicity studies demonstrated that both types of biochar had the potential to enhance root and shoot growth in coriander plants. Both non-wood and wood biomass derived biochar showed significant improvements in growth attributes of coriander in treatment T2 comprising of 2% biochar concentration. Non wood biomass derived biochar showed more improvement in growth attributes of coriander in comparison to the wood biomass derived biochar. Therefore, it can be concluded that both non wood and wood biochar can be utilized as an effective and ecofriendly approach for future implications.

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