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Production of Paddy Straw Biochar for Amelioration of Coastal Saline Sandy Soil

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ABSTRACT

The pot-based experimental study was undertaken during the pre-*kharif* season (2022) at CSIR-Institute of Minerals and Materials Technology, Bhubaneswar, Odisha, India. Paddy straw waste pyrolyzed in drum kiln to produce alkaline biochar and utilized for amelioration of saline coastal sandy soil. The soil samples collected from Puri, Odisha was utilized for Mung bean (*Vigna radiata* var. NVL-516) plant growth experiments (in triplicate) following completely randomized design (CRD). Four levels of salinity (in PSU) i.e. 0 (control), 5 (moderate), 10 (severe) and 20 (extremely severe) were maintained in experimental pots using different volumes of seawater. The three treatment doses of biochar (% weight) i.e. 0.5, 1, and 2 % were applied to each pot. Within 14 days of study period, important soil characteristics (pH, EC, Na, K and Ca), seed germination (%), physiological and growth parameters such as total Chlorophyll, plant height, root length etc. were measured to evaluate the ameliorating influence of biochar on salt stress. The 1% biochar treatment dose resulted into positive influence on germination (enhanced up to 100%), growth and available nutrient concentration up to moderate salinity level (5 PSU). However, biochar treatment alleviating the effect of salt stress, with its increasing doses and salinity beyond 5 PSU showed unsupportive results. Therefore, compared to untreated soil, the lower dose of biochar could enhance the suitability of coastal saline sandy soil for plant growth.

KEYWORDS: Mung bean, straw, waste, kiln, biochar, coastal soil, salt stress

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1. INTRODUCTION

Paddy the third-largest cereal crop in the world (Binod et al., 2010) and in India it ranks second towards rice production leading to large quantities of straw waste generation. Each year In India, around 200 metric tons of paddy straw was generated (Sakhiya et al., 2021). The increased productivity of rice cultivated areas resulted in massive accumulation of paddy straw in farmers field and its disposal by burning in developing countries practiced as the most cost-effective method (Phuong et al., 2021). Burning of agricultural wastes like paddy straw lead to air pollution (Amal, 2020), health hazards (Phuong et al., 2021) and nutrient loss from the soil (Singh et al., 2021).

About twenty percent of paddy straw utilized (used as mulch, and integrated into soils) and the rest burned in situ (Choudhary et al., 2018). Paddy straw contained nutrients like phosphorous, nitrogen, and carbon; can boost soil organic matter, soil fertility and growth of microorganisms in the soil (Sommer et al., 2011; Turmel et al., 2014; Miura et al., 2016). The massive quantity of paddy stubble on farmers field could potentially be pyrolyzed to make biochar and it provides an alternative to the problem of stubble burning as an environmentally friendly waste management (Tokas et al., 2021). Pyrolysis, a viable method to transform biomass waste into biochar and potential to reduce issues associated with the gasification and combustion process (Durak, 2023). The thermochemical process regarded as a reliable climate change mitigation strategy with potential to trap carbon and reduce greenhouse gas emission and further targeted sustainable development goals related to emissions (Tiwari et al., 2024 and Shoudho et al., 2024). Several research investigations were conducted on biochar and its potential characteristics for soil amendment and soil productivity (Jeffery et al., 2011; Biswas et al., 2023; Alkharabsheh et al., 2021).

Salinity is one of the major environmental stresses which showed negative impacts on crop growth and productivity (El Sabagh et al., 2020). According to prior studies, salinity affected 33 percent of irrigated land cover worldwide (Shahbaz and Ashraf, 2013). In India, about 6.7 mha are affected by salt stress (Arora et al., 2016). Saline soils accounts about 44% of the total salt-affected areas, covering about 1.75 mha of inland plains with 1.2 mha being coastal plains (Kumar and Sharma, 2020). Higher concentrations of salts can cause ion toxicity, nutrient imbalance, and hyperosmolarity in plants by adversely affecting their growth and metabolism (Ehtaiwesh, 2022). In several research studies, it was documented, that materials which are rich in carbon source like compost, biochar, and lignite can help plants to avoid salt toxicity (Wu, et al., 2023; Bello et al., 2021). Biochar critically reduces the negative impacts of salinity in soils by improving water holding capacity, organic carbon content, aeration, availability of nutrients, enhance microbial activity, crop yield, and productivity (Muhammad et al., 2023).

Mung bean (*Vigna radiata* L.) is a popular pulse crop that provide high-quality supply of protein, vital fibers, fatty acids, amino acids, vitamins and minerals (Mohan et al., 2020). Under salt stress, mung growth was reported to be stunted due to imbalance of nutrient (Podder et al., 2020). It was documented that potassium rich biochar having a superior ability to reduce sandy soil salinity and support mung growth (Islam et al., 2024). Based on the availability of paddy straw waste and the prevalent problem of saline sandy soil particularly in coastal areas; the present work was focused on the scope of drum kiln-based biochar production from paddy straw waste and its evaluation for improving the edaphic condition of coastal saline sandy soil with mung bean as test plant.

2. MATERIALS AND METHODS

2.1. *Feedstock collection and preparation*

Paddy straw (*Oryza sativa*) was chosen as feedstock material for the production of biochar. Straw waste was collected from nearby villages of Hanspal area, Bhubaneswar, Odisha, India. The paddy straw was cleaned with tap water to remove dust and soil particles. Thereafter it was threshed in a chipper cum shredder machine (FREDS Engineering, 7.5 HP); and subsequently sun-dried for 6 to 8 days. Later, the dried samples were stored in an airtight container for making biochar.

2.2. *RoCC Kiln for biochar production*

A rotatable covered cavity (RoCC) kiln (developed by Paul S. Anderson) inspired horizontal drum kiln was used for low-cost biochar production and its schematic representation dipicted in Figure 1. Dried paddy straw biomass (10 kg) was fed inside the RoCC kiln and ignited with fire using a

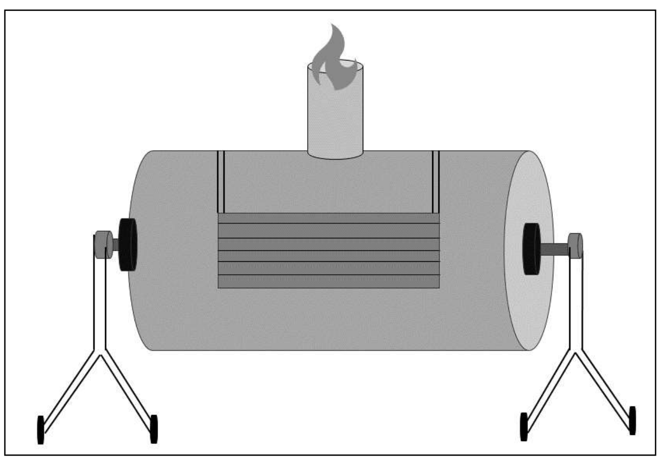

Figure 1: Schematic representation of RoCC kiln

candle. After a few minutes, kiln was covered with a lid to limit the influx of air (providing oxygen-limited conditions) for better pyrolysis conditions. Biomass was allowed to undergo charring for approx. 20 minutes, mid while the kiln was rotated clockwise and anti-clockwise to facilitate proper mixing of charring materials during pyrolysis. The maximum heating temperature during the charring of straw waste was around 450°C (measured with gun type Infrared thermometer, Fluke). To prevent ash formation and retaining carbon in biochar, the charred materials were removed from the kiln and quenched with distilled water. Biochar was properly sun-dried, ground (below 500 microns) and stored in an airtight polythene bag.

2.3. Characterization of biochar and feedstock

Biochar yield was calculated according to (Gaskin et al., 2008) the mass ratio of biochar product to oven-dried/sun-dried feedstock. The pH and EC of biochar and biomass were analyzed by taking the biochar sample and distilled water in a 1:20 ratio and equilibration at 90 minutes on the shaker then measured in Multi 340i/SET, (WTF), (McLean, 1982). The proximate (moisture, ash, and fixed carbon) and elemental [carbon (C), hydrogen (H), nitrogen (N)] content of biochar samples were determined on an air-dried basis by thermogravimetric (TGA601, LECO, St. Joseph, MI) and by elemental analyzer (Leco, TruSpec, CHNS analyzer) respectively (Oginni and Singh, 2020). The ash content was estimated by heating biochar and biomass samples in a muffle furnace and calculating the difference between initial weight and final weight (i-therm AI-7981) using the ASTM method of (Aller et al., 2017). The wet digestion method was followed (Zhang et al., 2015) for the extraction of nutrients from biochar and its feedstock. The filtered sample solutions were analyzed using a flame photometer. The presence of mineral phase in biochar was identified by X-ray diffractometer (PANalytical, Xpert Pro). The analysis was performed with Cu target (Kα - 1.5406 Å), 2θ values (angle of diffraction) from 5 to 80 degrees, and at a scanning rate of 5° min-1 (Yoo et al., 2018). A database maintained by the International Centre for Diffraction Data (ICDD) was mainly referred for identification. The morphology of biochar was detected through a scanning electron microscope (JSM-6510, JEOL). Surface morphology and semi-quantitative elemental analysis of biochar were done through FESEM-EDS analysis (EVO 18 SEM, Carl Zeiss, Germany).

2.4. Experimental design for plant growth pot experiments

Coastal sandy soil samples were collected from five locations along the beach of Puri, Odisha, India. The locations are;

1. Satsang Thakur Badi (19°48’48” N 85°49’53” E)
2. Golden beach (19°48’06” N 85°49’07” E)
3. Swargdwar Sea Beach (19°47’29” N 85°48’56” E)
4. Lighthouse (19°47’19”N 85°48’15” E)
5. Sunset point (19°46’54”N 85°47’07” E)

The collected samples were air-dried for 48 hrs and mixed to make a representative sample for triplicate analysis. Table 1. presents the characteristics of coastal sandy soil. It was found to be slightly alkaline in pH, with low EC and water holding capacity. The bulk density of soil was higher, reflecting poor micro porosity, which may affect plant growth. The texture of majority of the samples were sandy with Sand (99.7%), Silt (0.1%), and clay (0.2%). The salinity was 1 PSU. While the content was found to be more in calcium (0.033%) this soil followed by sodium (0.028%) and potassium (0.019%) content.

Mung bean seeds (*Vigna radiata*) of its summer variety green gram NVL-516 (Nirmal Seeds Pvt. Ltd. (NSPL) was utilized for pot experiments. Mung bean roots and rhizobia combines a symbiotic relationship that lowers the cost of nitrogen fertilizers (Limpens et al., 2003). For the kharif crop experiment, pot trials were conducted based on the completely randomized design (CRD) with triplicates during June-July 2022, for 14 days in a polycarbonate greenhouse environment at Environment & Sustainability Department, CSIR-IMMT campus. Experimental details are presented in Table 2. The average daily temperature during the pot experiment was 27°C. In total, twenty-one (7×3 replicates) pots with 500 g of coastal sandy soil were utilized for the experiment. The different treatments were untreated soil as control, saline seawater treatment and three different treatment doses of pyrolysis biochar.

Four levels of salt stress were introduced by using seawater into 0 (control), 5 (moderate), 10 (severe), and 20 (extremely severe) PSU. 100 ml of each salt level was added in 500 g of soil according to its water-holding capacity. Treatment

Table 1: Relevant characteristics of coastal sandy soil

pH	EC (μs cm^{-1})	WHC (%)	Bulk density (g cm^{-1})	Salinity (PSU)	Na (%)	K (%)	Ca (%)
7.43 (0.04)	121 (3.51)	33.33 (2.31)	1.53	1.000 (0.624)	0.028 (0.002)	0.019 (0.004)	0.033 (0.005)

Note: Mean values with standard deviation (in parenthesis) based on triplicate analysis

Table 2: Experimental details of paddy straw biochar treatment plan for mung bean pot growth experiments

Treat-ments		Biochar (%)	Biochar dose (g)	Salinity level (PSU)
T_0	Control	0	0	0
T_1	CSD+PSB 1	1	5	0
T_2	CSD+PSB 1+S_1	1	5	5
T_3	CSD+PSB 1+S_2	1	5	10
T_4	CSD+PSB 1+S_3	1	5	20
T_5	CSD+PSB 2+S_2	0.5	2.5	10
T_6	CSD+PSB 3+S_2	2	10	10

CSD: Coastal sand dune; PSB: Paddy straw biochar; S_1: Salinity level 1 moderate i.e., 5PSU; S_2: Salinity level 2 severe i.e., 10PSU; S_3: Salinity level 3 extremely severe i.e., 20 PSU; T_0: Control; T_1: CSD+ PSB1; T_2: CSD+PSB1+S_1; T_3: CSD+PSB1+S_2; T_4: CSD+PSB1+S_3; T_5: CSD+PSB2+S_2; T_6: CSD+PSB3+S_2

doses (on wt wt^{-1} basis) for biochar were 0.5, 1 and 2 % i.e., 2.5, 5 and 10 g respectively. Salinity levels were selected on the basis of the salt threshold of mung beans and biochar samples selected based on earlier studies (Norolahi and Farasati, 2022). Salinity and biochar samples were mixed thoroughly with coastal sandy soil. Then, five mung bean seeds were sown in each pot at a specified uniform depth (approx. half an inch) and 3 cm distance between seeds. Throughout the growth period, pots were moistened with 40 ml of tap water to uphold the soil water holding capacity near field capacity. Emergence and germination % of mung bean seeds for each treatment were periodically recorded and plants were carefully uprooted after 14 days of sowing and plant samples were taken out of each pot for analysis.

2.5. *Characterization of biochar treated soil*

The pH, EC, and salinity of pot soil were calculated on the basis of deionized water and soil sample ratio at 1: 2.5 (weight $volume^{-1}$) and equilibration at 90 minutes on shaker then measured in Multi 340i/SET, (WTF), (McLean, 1982). WHC of control and biochar-treated soils were determined through the gravimetric method (Huang et al., 2019). Wet digestion method was followed for extraction of nutrients from biochar-treated soil sample by taking 1 g of soil sample (Zhang et al., 2015). After acid digestion, the suspension was filtered into a 100ml volumetric flask using Whatman 41 filter paper, which was diluted and properly stored for analysis using a flame photometer.

2.6. *Plant growth and productivity*

Growth and development parameters of mung bean plants like germination, number of leaves, area of leaf, plant height, root length, fresh weight and dry weight, chlorophyll content, and nutrient analysis were estimated. Germination % was calculated after observing seed germination on a daily basis. Plant length was measured from the top of the soil to the top of the tassels in centimetres using measuring tape. Leaf area was calculated by taking the leaf width at three places converting them into average width multiplying by the length of the leaf and multiplying by a constant factor 0.75. In this way, the leaf area of all leaves in the plant was measured and then through summation converted into leaf area. Shoot, root length, and number of leaves were counted after 14 days of sowing. Root samples were well cleaned with distilled water and oven dried weights at 70°C were recorded. Wet digestion method (Zhang et al., 2015) was followed for the extraction of nutrients from biomass samples. The chlorophyll content was estimated by taking 100mg of fresh leaf cut into pieces and kept in 10 ml of 80% acetone overnight. The absorbency was taken at 645 nm, 652 nm, and 663 nm in a visible spectrophotometer. The formula is demonstrated by (Arnon et al., 1949). The formula used to calculate the different chlorophyll molecules are as follows:

$$\text{Chl a (mg ml}^{-1}\text{)}=12.7\times A663-2.69\times A645 \quad (1)$$

$$\text{Chl b (mg ml}^{-1}\text{)}=22.9\times A645-4.68\times A663 \quad (2)$$

$$\text{Total chlorophyll}=\text{Chl a}+\text{Chl b} \quad (3)$$

2.7. *Statistical analysis*

Experimental data were analyzed by one-way ANOVA and means were compared with the Tukey test at $p<0.05$ level of significance and 95% confidence level. All statistical tests were performed by using MINITAB Version 17.

3. RESULTS AND DISCUSSION

3.1. *Characterization of biochar*

Table 3. showed the mean values of pH, electrical conductivity (EC), % of yield, % of TC-Total Carbon, TH-Total Hydrogen, TN-Total Nitrogen, TS-Total Sulphur, TK-Total Potassium, TCa-Total Calcium in feedstock and biochar of paddy straw. As per earlier yield % of produced biochar may get affected due to osmotic and toxic impact of NaCl (Wahid, 2004). The pH of paddy straw biomass was neutral (7.03) while the biochar was alkaline (9.67) as compared to feedstock; it may be due to the rich mineral content of biochar (Zhang et al., 2015). With increasing temperature, feedstock having materials with high thermal resistance gets volatilized resulting in an increase in inorganic mineral component that ultimately increases the pH. (Novak et al., 2009). Acid functional groups and concentrates ash contents release volatile matter under high temperatures leading to an increase in the pH of pyrolyzed material (Zhang et al., 2022; Puri et al., 2024).

Table 3: Relevant characteristics of paddy straw feedstock and its biochar

	Yield (%)	pH	EC (mS m^{-1})	Ash (%)	TC (%)	TH (%)	TN (%)	TS (%)	K (%)	Ca (%)
PSF	NA	7.03 (0.21)	0.72	11.37	38.42 (0.02)	5.40 (0.13)	0.78 (0.05)	0.22 (0.00)	1.58 (0.02)	1.70 (0.01)
PSB	42.50 (1.48)	9.67 (0.20)	3.23	25.83	25.83 (0.41)	1.49 (0.24)	0.58 (0.12)	0.10 (0.04)	2.10 (0.04)	2.07 (0.14)

Mean values with standard deviation (in parenthesis) based on triplicate analysis; PSB: Paddy straw biochar; PS: Paddy straw feedstock; TC: Total carbon; TH: Total hydrogen; TN: Total nitrogen; TS: Total sulphur; TK: Total potassium; TCa: Total calcium

The electrical conductivity (3.23 μs cm^{-1}) of biochar tends to be higher than its feedstock material (0.72 μs cm^{-1}). The reason could be with rise in pyrolysis temperature resulted into increases in exchangeable and highly soluble cations, manifested as elevated EC level of biochar (Rehrah et al., 2014). The pyrolysis temperature induces labile components to release by enhancing mineral phase proportion leading to higher ash content (25.83%) in pyrolyzed product than feedstock (11.37%)

Total carbon content was minimally higher in paddy straw feedstock (38.42%) as compared to its biochar form (25.83%). During kiln pyrolysis, the temperature mostly remains below 500°C, where carbon retention was lower due to the prominence of dehydration and depolymerization reactions for which the carbon content decreases after pyrolysis (Speight, 2020). Whereas, under high temperatures above 500°C, polymerization and aromatization reactions dominate, which results in high carbon content in condensed aromatic form (Lehmann and Joseph, 2009; Domingues et al., 2017). Pyrolysis temperature was above 400°C, which led to intensive volatilization of hydrogen, nitrogen and sulfur resulting in lower content of these elements in biochar than feedstock (Babu et al., 2024). At temperatures above 400°C, intensive volatilization of nitrogen into amino sugars, amino acids, and amines occurs. The remaining nitrogen (0.58%) and hydrogen (1.49%) are retained in biochar in the form of recalcitrant heterocyclic compounds (Castejon-del et al., 2023). The hydrogen, nitrogen and sulfur present in the aliphatic form volatilized easily and become part of bio-oil or syngas (Putun et al., 2004), while due to polymerization reactions carbon gets retained in biochar (Yaashikaa et al., 2020). Likewise, biomass pyrolysis at extensive temperature which intensified the dehydration and deoxygenation reactions, which led to more volatilization of H, O, N and S and retention of more C (Cantrell et al., 2012; Zhang et al., 2015; Leng and Huang, 2018). The potassium and calcium content of biochar increased to 2.10% and 2.07% respectively. From the evidence of ash content, it was marked Ca oxides, hydroxides, and carbonates of biochar mineral phases precipitate and resulted into increase in total Ca concentration up to 2.07% in biochar. The high Ca content of paddy straw feedstock also explains the elevated pH in biochar. The enrichment of potassium and calcium in biochar with an increase in pyrolysis temperature was also reported in earlier studies (Hossain et al., 2011; Roberts and de Nys, 2016).

SEM images of paddy straw biochar illustrated in Figure 2. showed variations in the surface morphology and porosity. The sample of paddy straw biochar was found amorphous with distinct scratch, nonuniform structures with large macropores. It was observed that number of widening pores that occurred due to pyrolysis process as the particles from inside release instantaneous volatile compounds by creating pores in the pyrolysis product. The surface morphology of paddy straw biochar showed a smooth and platy surface with distributed macropore structures and distribution patterns (Tan et al., 2018). The presence of macropore structure holds crucial nutrients and represents higher water adsorption and water-holding potential. It also indicated deposition of some elements like carbon, silica, magnesium, and calcium on the surface (Mane et al., 2024).

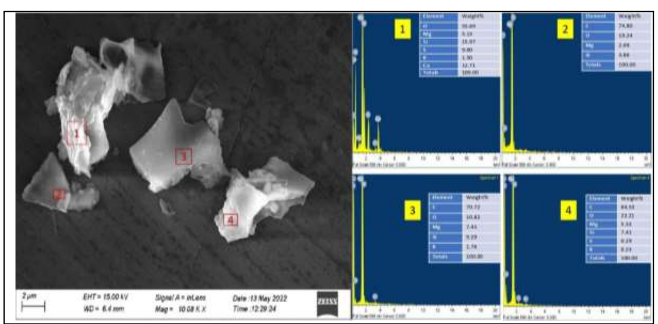

Figure 2: SEM-EDS of paddy straw biochar

The prominent peaks in PSB showed the presence of inorganic components like calcite ($CaCO_3$), quartz (SiO_2), and sylvite (KCl). Peaks correspond to calcite at 2θ values of 23.09, 29.44, 31.44, 36.01, 43.22, 47.52 and 48.52 degrees at 3.03, 2.84, 2.49, 1.91 and 1.87 Å respectively. Along with higher calcite content another peaks of graphite content was reflected at 20.9 diffraction peak. The high content of SiO_2 having 2θ values of 20.9, 26,67 and 50.15 degrees (at 4.25,

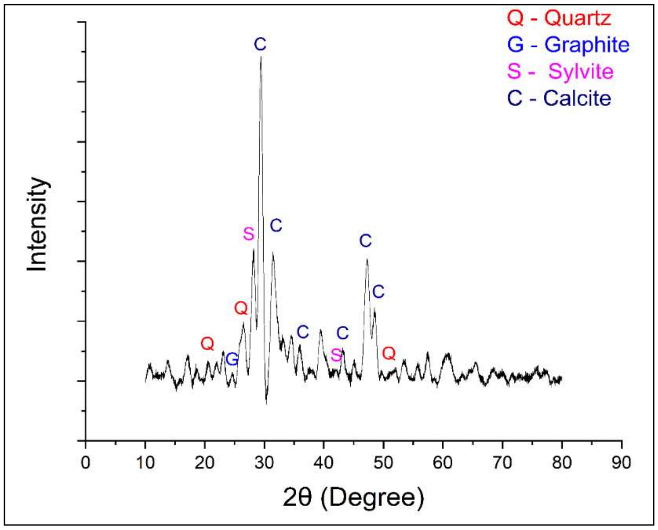

Figure 3: XRD pattern of paddy straw biochar

3.34, 1.81 Å) and KCl minor peaks are present at 2θ values of 28.29, 40.53 at 3.15, 2.22 Å was found in paddy straw biochar. Previous studies (Wu et al., 2012) also evident that calcite, quartz, and sylvite mineral phases in paddy straw biochar. However, the XRD pattern indicate paddy straw biochar as an amorphous material with a poor crystalline mineral structure along with carbon-rich phase.

3.2. *Effect of biochar on coastal saline sandy soil characteristics*

Table 4. showed the mean values of pH, electrical conductivity (EC), Salinity and water holding capacity (WHC) of control and coastal sandy soil treated with different levels of salinity and biochar doses. Biochar treatments significantly (p<0.001) increased the pH and WHC of the soil. The control sample showed pH–7.43 while biochar treated soil showed higher alkalinity because biochar produced at a higher pyrolysis temperature tends to poses alkaline pH due to reduction in carboxyl groups, deprotonation of acidic groups to conjugate bases and simultaneous enrichment of alkali metals (Murtaza et al., 2024). With the increase in biochar treatment dose up to 2 %, the soil pH increased from 7.43 to 8.80. The control (7.43) showed favourable soil pH i.e., 6.4–7.7 for efficient growth of mung bean plant. 0.5% dose of biochar showed a slight increase in pH i.e., 7.83, while 1% to 2% dose showed an alkaline pH 8.04 to 8.80. Earlier research studies also reported the liming effect of different feedstock's biochar to increase the pH of soils (Glaser et al., 2002). The electrical conductivity of sandy soils in control is found to be 121 µs cm^{-1}, while biochar treated soils mimics high EC (198 to 2579.33 µs cm^{-1}) as compared to control. T_1, with a lower EC of 198 µs cm^{-1} due to improved soil hydraulic conductivity that facilitates salt leaching in these soils (Chaganti et al., 2015). T_3 having coastal sandy soil treated with salinity 10 PSU and 1% biochar was higher EC (2597 µs cm^{-1}), which indicates dissolved salt concentrations retained from biochar. Biochar releases weakly bound mineral nutrients into soil thereby increasing its EC. Water holding capacity (WHC) of in the control (33.33%) sample increased up to 40–44% due to biochar treatment. The increase in WHC of soil after biochar treatment indicates the potential for improvement in moisture, water-soluble nutrient retention capacity, and drought resistance properties of sandy soil. Biochar treatment was previously reported to increase water-holding capacity in soils mainly due to its high surface area, porosity, and water sorption capacity (Karhu et al., 2011; Ippolito et al., 2016). The salinity of control (1 PSU) tends to decrease with increasing doses of biochar in coastal saline sandy soils. In many studies, it was observed that biochar reduces the salinity effect due to its ability to adsorb sodium ions by adsorption and ion exchange mechanisms.

Table 4: Mean values with standard deviation of pH, Electrical Conductivity, Water holding capacity and Salinity with different treatments

Treatments	pH	EC (µs cm^{-1})	Water holding capacity (%)	Salinity (PSU)
T_0	7.43 (0.04)^{f}	121 (3.51)^{g}	33.33 (2.31)^{d}	1.000 (0.624)^{a}
T_1	8.60 (0.02)^{b}	198.0 (3.61)^{f}	44.00 (0.00)^{a}	0.00 (0.00)^{c}
T_2	8.16 (0.04)^{c}	1541.67 (5.51)^{e}	40.33 (2.31)^{b}	0.400 (0.200)^{b,c}
T_3	8.04 (0.02)^{d}	2579.33 (2.08)^{a}	36.00 (0.00)^{b,c}	1.100 (0.173)^{a}
T_4	8.08 (0.03)^{c,d}	2170.67 (1.15)^{b}	34.67 (2.31)^{c}	1.2667 (0.057)^{a}
T_5	7.83 (0.04)^{e}	1980.00 (3.00)^{c}	34.67 (2.31)^{c}	0.967 (0.208)^{a,b}
T_6	8.80 (0.03)^{a}	1841.00 (3.00)^{d}	40.33 (2.31)^{b}	0.800 (0.400)^{a,b}

Note: Means in each column that do not share a letter are significantly different

Figure 4. showed the sodium ion concentration in coastal saline sandy soil was low (0.028%) and the addition of biochar to saline-induced soils showed decreased Na (0.026%) in T_1 i.e., 1% biochar turns out to be effective in lowered the salt stress. However, excess level of biochar (2%) showed no significant effect in salinity (10 PSU) induced sandy soil. Total potassium was lower in control (0.019%) while increasing the dose of biochar remarkably increased potassium content (0.033%–0.068%). The highest Ca content (0.44%) was observed in T_3 treatment, with 1% dos of biochar in 10 PSU salinity. Results indicate biochar critically binds to the nutrients in the soil and prevents

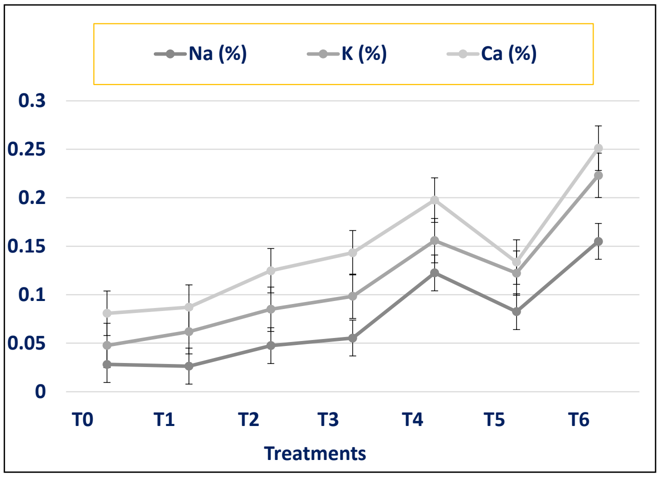

Figure 4: Available sodium and nutrients (K and Ca) under different biochar and salinity treatments in sandy soil before sowing

the leaching of potassium and calcium which resulted an increase in availability to plants (Hossain et al., 2020).

Table 5. showed the mean values of pH, EC, Salinity, and WHC of control and biochar treated soil after 14 days of sowing. pH of biochar treated soils gradually decreased after 14 days, which indicate leaching of salts and higher infiltration rate. However, with increased biochar doses there was an increasing trend of pH. (Shi et al., 2017) the mechanism behind the increment in soil pH was due to biochar application. Biochar surface where the dissolution of carbonates and cation release due to the protonation of carboxyl groups which indirectly added alkaline character to treated soil. After 14 days of treatment the EC decreased, as from the previous studies, it was evident that biochar enhances the leaching of soluble salts by decreasing EC of saline soils (Lashari et al., 2015; Yue et al., 2016). EC of control soil increased from 58 µs cm^{-1} to 635 µs cm^{-1} in biochar treatment in lower doses of 0.5%. An increase in EC of biochar treated soil indicates increased dissolved salt concentrations in soil. The bulk density of amended soil gradually decreased to 0.8 g cm$^{3-1}$ while unamended soil depicts bulk density of 1.65 g cm$^{3-1}$. The water holding capacity (WHC) of control sample 33.33% which further increased from 44% to 48% with biochar treatments. An increase in WHC of soil after biochar treatment indicates the potential for improvement in moisture, nutrient retention capacity, and drought resistance of soil. Biochar treatment also previously reported to enhance water retention capacity of soils due to its high surface area, porosity and water sorption capacity (Karhu et al., 2011; Ippolito et al., 2016).

Table 5: Mean values with standard deviation and grouping of pH, electrical conductivity, water holding capacity, and Salinity in soils with different salinity levels and biochar treatments after 14 days

Treat-ment	pH	EC (µs cm^{-1})	Water holding capacity (%)	Salinity (PSU)
T_0	7.21 (0.03)^{d}	58.0 (11.14)^{a}	33.33 (2.31)^{e}	0.967 (0.208)^{a}
T_1	7.78 (0.04)^{b}	135.3 (48.5)^{a}	48.00 (0.00)^{a}	0.000 (0.000)^{b}
T_2	7.78 (0.01)^{b}	89.00 (1.00)^{a}	44.00 (0.00)^{b}	0.066 (0.115)^{b}
T_3	7.83 (0.07)^{b}	66.00 (0.00)^{a}	40.33 (2.31)^{c}	0.200 (0.200)^{b}
T_4	7.74 (0.10)^{b}	88.3 (31.5)^{a}	37.33 (0.00)^{c,d}	0.300 (0.265)^{a,b}
T_5	7.48 (0.06)^{c}	635 (451)^{a}	36.67 (2.31)^{d}	0.267 (0.306)^{b}
T_6	8.23 (0.005)^{a}	522 (406)^{a}	44.33 (2.31)^{b}	0.400 (0.400)^{a,b}

Note: Means in each column that do not share a letter are significantly different

Figure 5. represents decrease in Na (0.013%–0.024%) than the control (0.025%), explains their decrease in pH among biochar treated soils. The low Na content of biochar treated soil is mainly due to the high potential of biochar to adsorb salt (Na+). From the previous studies it was evident that biochar increases cation exchange capacity by substituting Ca in place of Na at exchangeable sites in saline soil. Potassium showed no significant variation in treated and untreated soil. However, the after post harvesting results showed a lower % of potassium content i.e., (0.022%–0.031%) than the control (0.019%) and it may be because of biochar alters potassium uptake by plants (Farrar et al. 2019; Wang et al., 2018). An increase in calcium content

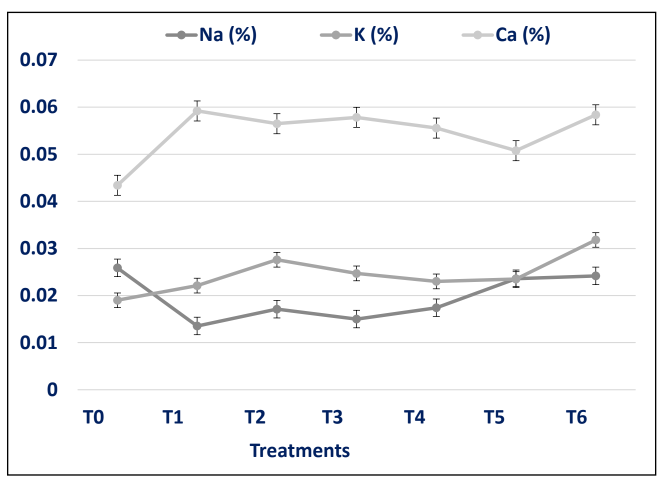

Figure 5: Available sodium and nutrients (K and Ca) in biochar-treated and untreated coastal saline sandy soil after 14 days

was observed in both treated and untreated soils after 14 days. However, the control showed higher Ca % (0.063) than amended soils (0.50–0.59%). As active calcium ions replaced hydrogen, sodium, and other cations by mass action which resulted in higher exchangeable calcium in soils.

3.3. Effect of biochar on plant growth

Figure 6 and Figure 7 showed the influence of biochar treatment on germination, biomass weight, leaf count, leaf area, shoot length, and root length of mung bean plants under different salinity condition. Plants in control and 1% biochar treatment soil with zero and moderate salinity i.e., T_1 and T_2 respectively showed higher germination rates. However, emergence % was showed highest in 1% biochar treated soil with no external salinity introduced i.e., T_1 having 100%, followed by the 1% biochar treatment (T_2) with 5 PSU salinity showed 93% emergence. The biochar (1%) treated soil having extremely severe salinity of 20 PSU showed fewer (20%) emergence. It can be concluded that salinity impact on the emergence of mung bean but it can be obviated through 1% biochar dose. The plant biomass weight was found to be 3.6 g in the control sample; soil treated with 1% biochar at 10 PSU showed increased biomass of 5.12 g. While application of 1% biochar treated

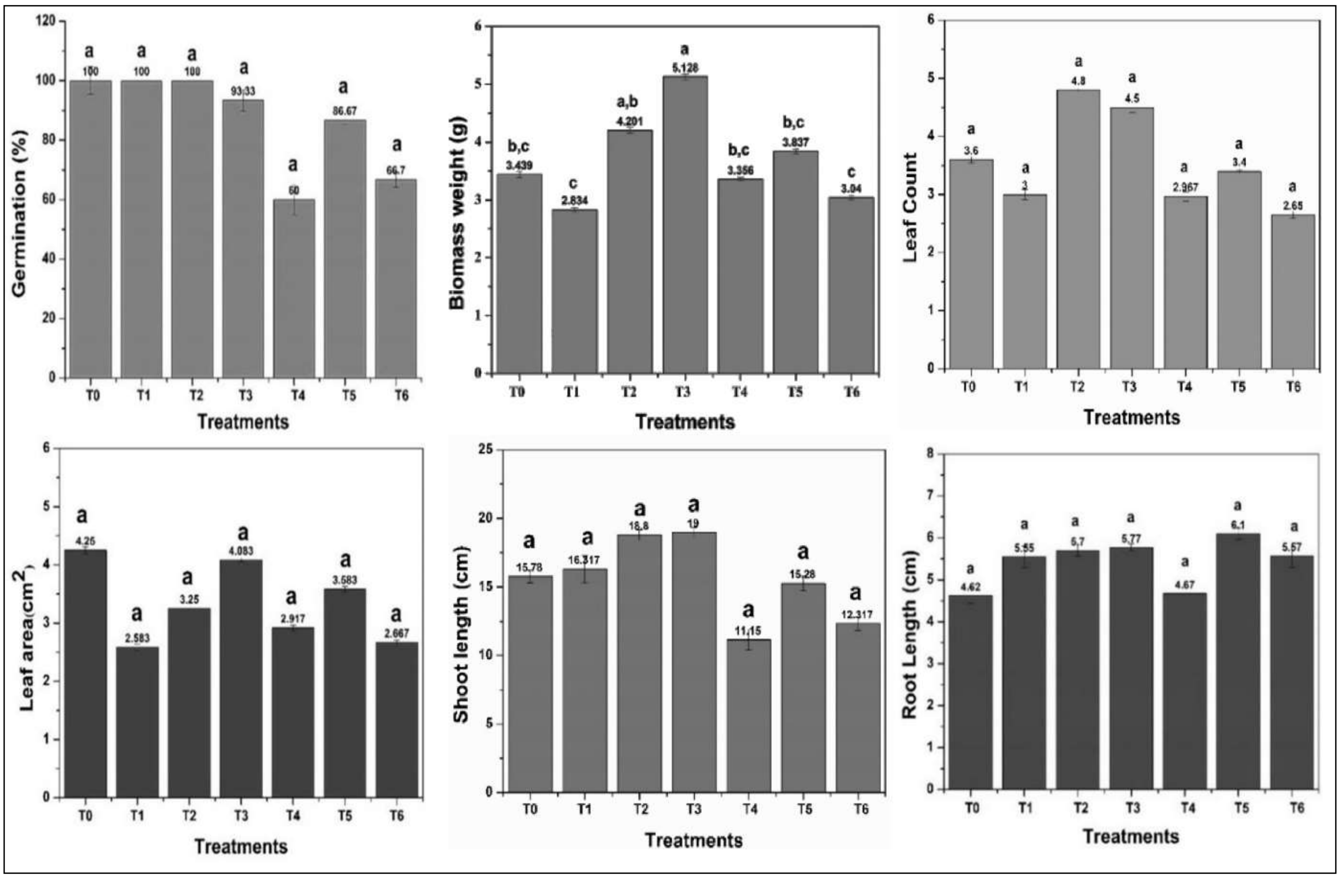

Figure 6: Treatments effect on growth and development parameters of mung bean plants. Means that do not share a letter are significantly different; all treatments were on weight^{-1} basis. Error bars represent standard deviations

Figure 7: Mung plant growth images after 14th days of sowing (uprooted plant images from experimental pots)

soil with no salinity showed minimal biomass weight, which may be due to the high alkalinity of biochar that provide an unfavourable condition for plant growth (Liu et al., 2023). The number of leaves was found to be highest at 1% biochar treated soil with the lowest salinity level of 5PSU. The lowest leaf count was observed 2.6 in high salinity levels with the highest biochar application rate, which may be due to the higher salt stress. The leaf area was found to be highest in control 4.25 cm^2 and lowest in soil treated with 1% biochar. Biological and physical stress such as higher water retention can affect leaf area. Shoot length was found to be highest 19 cm in 1% biochar treatment soil having 10 PSU salinity and lowest 11cm in highest salinity treated with 1% biochar. The minimum root length was found in control, due to salinity. While root length increased in the lowest biochar treatment in 10 PSU salinity up to 6.1 cm. From the above results, 1% biochar i.e., 5 g biochar in 500 g coastal saline sandy soil enhanced plant growth by alleviating salt stress. Previous studies also reported limited application of biochar to be more efficient in crop production (Nikpour-Rashidabad et al., 2019)

Figure 8 represents the available sodium and nutrients (K and Ca) in plant biomass. The Na content was found to be higher at lower 0.5% doses of biochar treated soil having higher salinity (10 PSU). Similarly it reflect a lower % of biochar could not effectively eliminate salt stress. However, the lowest sodium content was found in soil treated with 1% biochar in 5 PSU salinity. 2% biochar treated soil with a high salinity of 20 PSU showed the highest (4.76%) content of potassium, while the lower value was estimated in control having 3.26%. Ca content was found to be highest in low doses (0.5%) biochar treated soil with 10 PSU salinity and relatively lower content was found in higher biochar doses (2%) treated with high salinity of 20 PSU. From the above data it can be stated that high salinity of soil results in increasing sodium and calcium content of plants while biochar affects in decreasing sodium and calcium content

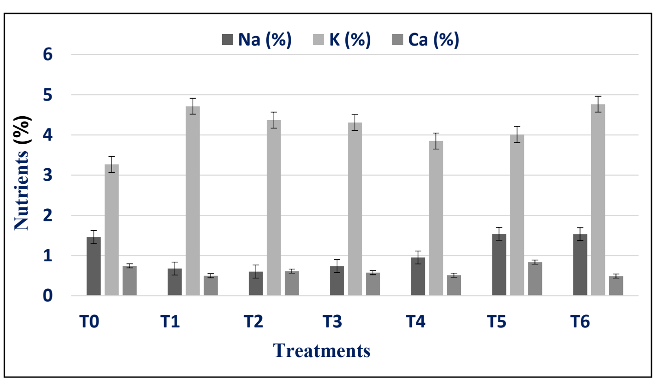

Figure 8: Available sodium and nutrients (K and Ca) in mung bean plants under different biochar and salinity treatments

and saimulteneously increases potassium content in plants.

Figure 9. presents the chlorophyll content of leaves in mung bean plants treated with different levels of biochar under four levels of salinity stress. Chlorophyll a, b, and total chlorophyll concentration showed 12.25 mg ml^{-1}, 3.75 mg ml^{-1}, and 16.01 mg ml^{-1} respectively with 1% biochar treatment at lowest level (5PSU) of salinity. The lowest value of chlorophyll a, b, and total chlorophyll content observed as 8.91 mg ml^{-1}, 2.78 mg ml^{-1}, 11.73 mg ml^{-1} respectively was seen at lowest application dose (0.5%) of biochar treatment at 10 PSU salinity. Hence, biochar treatment positively improved the chlorophyll content in plants, while a higher level of salinity tends to negatively affect the chlorophyll content of plants. In previous studies, it was found that salinity or excess Na^+, Cl^- causes swelling of chloroplast membranes in leaves affecting loss in chlorophyll content (Hameed et al., 2021) and simultaneously chlorophyll content of mung beans correlates with the findings of (Mithu et al., 2022).

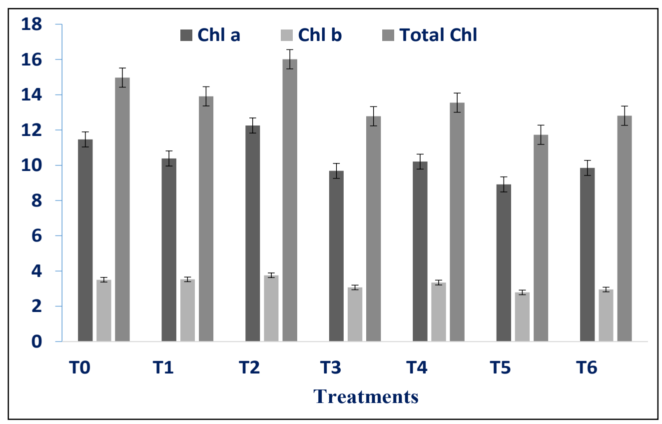

Figure 9: Chlorophyll content (mg ml^{-1}) of mung bean plant treated with different levels of biochar under salinity stress or add mg ml^{-1} in y-axis

4. CONCLUSION

The present work established the potential of paddy straw biochar production utilizing drum-kiln method and their resulting properties showed an ameliorative effect on physico-chemical properties of coastal saline sandy soil at 1% dose alleviating salt stress up to 5 PSU. It also enhanced the mung bean seed germination due to optimum condition in pH and EC along with improved water-holding capacity. The work highlights the need to explore the opportunity of utilizing biochar for managing soil salt stress.

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