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Sugarcane bagasse biochar: Suitable amendment for inland aquaculture soils

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Abstract

The salt-affected soils cover vast area in more than 100 countries and increasingly decrease the arable land. It may lead to the global food insecurity that is needed to be solved urgently. Concurrently, these degraded areas are suitable for inland saline aquaculture on the conditions of improvement in sediment characteristics. In this connection, an experiment was conducted for 60 days to study changes in physicochemical properties of inland saline aquaculture pond sediments through biochar application. The biochar prepared from dried sugarcane bagasse at 500°C with 33% biomass recovery was characterized for its physicochemical properties and applied over surface and by mixing with the sediment. There was a significant ($p < .05$) increase in organic carbon (3.82%), available-P (2.13%), available-K (18%), Ca (5.62%), Mg (14%) and water-holding capacity (1.8 times), and decrease in pH (0.41 unit), EC (17%) and bulk density (7%) when biochar (18 t/ha) was mixed with sediment (T2 treatment), whereas increase and decrease in CEC (59%) and available-N (1.01 times), respectively, when biochar (18 t/ha) were applied over sediment surface (T4 treatment). Thus, mixing of sugarcane bagasse biochar with sediment at 18 t/ha is recommended for the improvement of soil characteristics in saline soils for aquaculture through this study. Furthermore, the *SEM* and FT-IR analysis of treatments showed that sediment aggregation and functional group characteristics improved over a short period of incubation along with microbial biomass.

KEYWORDS

aquaculture, biochar, degraded soils, organic carbon, sugarcane bagasse

1 | INTRODUCTION

Increasing soil salinity is a global issue, and most susceptible areas include semi-arid to arid regions of the USA, Australia and Israel, and developing countries, for example Pakistan, India, China, Thailand and countries in the Middle East where large-scale irrigated agriculture is practised. The globally degraded land varies from less than 1 billion ha to over 6 billion ha, with equally wide distribution in their spatial distribution (Gibbs & Salmon, 2015). It is estimated that 380 million ha of land is unusable for agriculture globally because of salinization of soils and groundwater (Lambers, 2003). It has been inferred that 85% of global salt-affected soils (SAS) can be used for different agriculture productions by intervention of suitable technologies (Wicke et al., 2011) and inland saline aquaculture is one among them.

The sediment of inland saline pond has loose soil aggregates due to comparatively lower soil organic carbon (OC) content, which leads to high seepage rate and low water-holding capacity (WHC) of sediment (Raul et al., 2018). These soils are generally N, P and K deficient due to loss of organic matter especially in sodic soils (Wong et al., 2010). Also, low cation exchange capacity (CEC) in sediment leads to continuous leaching of nutrients (Stumm & Morgan, 2012) required for maintenance of productivity (Sharma & Tyagi, 2004) and osmoregulation in culture organisms (fish and shrimp) (Evans et al., 2005; Shiau & Hsieh, 2001). The electrical conductivity (EC) of inland saline sediment increases due to high exchangeable sodium percentage (ESP) and makes K^+ unavailable to the water column (Dahlawi et al., 2018). The high concentration of sodium deposits in saline sediment in the form of sodium carbonate/ bicarbonate (Chhabra, 1996) leads to high fluctuation in pH and buffering capacity of inland saline pond water. Ultimately, all these changes lead to reduction in productive of the inland saline aquaculture.

In this regard, it is believed that biochar may prove to be a helpful tool for amendment of inland saline soil (Laird et al., 2010). Biochar is a fine-grained carbon-rich, porous product, can be produced from any agro, urban and animal waste (Lehmann & Joseph, 2009) through pyrolysis at temperature 350–600°C in the absence of oxygen. It acts as a soil conditioner to boost soil fertility (Lashari et al., 2015; Lehmann, 2007). Furthermore, biochar has ability to sequester carbon and reduce GHG emissions from soil (Gaunt & Lehmann, 2008; Laird, 2008; Woolf et al., 2010). Biochar has novel physicochemical properties such as the high surface area-to-volume ratio, water-holding capacity, stable aromatic carbon skeletal structure, functional groups, trace elements and absorption property among others (Bharti et al., 2018). Biochar improves the fertility status (Drake et al., 2016), increases the relative abundance and distribution of phosphate-solubilizing bacteria (Liu et al., 2017) and also improves the physical properties of salt-affected soils (Saifullah et al., 2018).

Biochar produced from different sources do not exert similar affect on a particular soil (Cornelissen et al., 2013; Lehmann & Joseph, 2015). Also, the type of biomass and temperature are the deciding factors for physicochemical properties and nutrient content of biochar (Dias et al., 2014). According to Srinivasarao et al. (2013), biochar can be applied to farm and degraded soils by different methods including broadcasting, band application, spot placement and deep banding. The majority of biochar field trials reported to date used is broadcasting and incorporating method into soil (Major, 2010). Broadcasting can be done by hand on small scales, or on larger scales by using lime/solid manure spreaders or broadcast seeders. Moistened biochar materials may be better suited to application with manure spreaders than lime spreaders. Incorporation can be achieved using any ploughing method (Blackwell et al., 2009). In the published literature, several studies have reported positive effects of biochar application on crop yields with rates of 5–50 tonnes of biochar per hectare, with appropriate nutrient management (Major, 2010; Srinivasarao et al., 2013) and when the biochar produced from animal waste required comparatively very lose dose (<10 tn/ha) than agro-waste (Chan et al., 2007). In aquaculture, there are only reports of bamboo biochar incorporated as feeding supplement of striped catfish to observe effects on water quality (Jahan et al., 2014; Lan et al., 2016).

Numerous studies confirm suitable application of biochar in improving the nutrient status and physicochemical and biological properties of crop fields (like maize, rice and wheat) (Chen et al., 2010; Lashari et al., 2013; Sun et al., 2017). However, there is need to derive the method and dosage of suitable biochar in inland saline soils and sediments. Keeping in view the availability of vast area of degraded land suitable for inland saline aquaculture, this study was conducted to characterize the biochar produced from sugarcane bagasse and its potential effects on physicochemical parameters and nutrient status of inland aquaculture soils and sediments.

2 | MATERIALS AND METHODS

2.1 | Biochar preparation

The biochar was prepared in an electric heating kiln. The kiln had a diameter of 45 cm and a height of 70 cm with an arrangement of central heating plates. There was a removable perforated steel chamber inside the kiln for holding biomass during pyrolysis. The raw biomass of sugarcane bagasse waste was dried to achieve the moisture level below 15%. The dried bagasse was filled in the biomass holding chamber (Figure 1a) of the kiln, covered with airtight steel plate (Figure 1b), and the gas valve opened for releasing volatile gases produced during pyrolysis. The kiln was operated for 4 hr at 500°C using the relay method. The coverlid of the kiln was opened when the kiln reached room temperature (Figure 1c). The biochar producing kiln has a controlling heating system called relay system. Once the temperature is fixed, the kiln temperature increases gradually and attains the final desirable temperature. If the chamber temperature increases, the relay system decreases the heating rate and maintains the required temperature. The biochar produced was collected and examined for different physicochemical characteristics.

2.2 | Characterization of biochar

The pH and EC analysis of biochar were done by mixing distilled water to biochar samples (1 g of biochar: 20 ml deionized water) and agitated with a reciprocal shaker for 1.5 hr. The pH of the suspension was recorded using a pH electrode then filtered with Whatman 42-mm filter paper. The filtrate was used for EC determination by EC meter (Rajkovich et al., 2012). The bulk density (BD), particle density and porosity of biochar were measured by the weighing bottle method (Kadam & Shinde, 2005).

Total elemental nutrient analysis was done after diacid digestion of 0.5 g of biochar. In a conical flask, 10 ml of HNO_3 and 2 ml H_2SO_4 were added to biochar and digested at 150°C until it turned to white colour (Amaral, 1992). P was estimated by spectrophotometer, while as Na^+ and K^+ estimation in flame-photometer, and Ca^{++} and Mg^{++} determined by EDTA titrimetric method. The heavy metal concentration (Cd, Cr, Pb) was estimated using ICP-OES. The WHC, P, Na^+, K^+, Ca^{++} and Mg^{++} were estimated based on the ASTM D1762-84 standard methods (American Society for Testing and Material [ASTM], 2013). The available nitrogen of biochar was estimated by Kjeldahl distillation method (Subbaiah, 1956). Cation

FIGURE 1 Biochar preparations in the electrical heating kiln (a) biomass holding chamber. (b) coverlid of kiln. (c) removal of biochar. (d) bagasse biochar)

exchange capacity (CEC) of biochar was quantified according to the modified method of Song and Guo (2012).

Ash and volatile matter content of the biochar were measured using a gravimetric method (Novak et al., 2009). Scanning electron microscopy (*SEM*, JEOL JSM-7600F) was used to detect the surface morphology of biochar. Micromeritics ASAP 2010 was used for BET (Brunauer–Emmett–Teller) surface area analysis by automated nitrogen absorption system. Functional groups were identified after spectrophotometer analyses in the infrared region, with Fourier-transform infrared (FT-IR) spectroscopy (SHIMADZU, FT-IR 4,100). The C, H and N contents of sugarcane bagasse biochar were analysed with CHNS elemental analyser (Carlo-Erba NA-1500).

2.3 | Experimental setup and sediment analysis

An experiment was conducted over a period of 60 days at ICAR-CIFE Rohtak Center, Haryana, India. The bagasse biochar was applied @ 9 t/ha and 18 t/ha as sediment mixing in T1 and T2 treatments and sediment surface application in T3 and T4 treatments, respectively, to the inland saline pond sediment in 300-L capacity FRP tank. The treatments were in triplicate manner. FRP tanks without addition of bagasse biochar served as control. The sediment was collected from inland saline pond area having very fine soil texture (sand 45%, silt 34%, clay 20.67%). The initial and final physicochemical parameters of sediment were analysed by standard methods of ASTM (2013).

2.4 | Statistical analysis

All data statistical analyses were performed using SPSS version 19.0 (SPSS Inc., USA). The statistical significance was determined at the 0.05 probability level. The data were analysed by one-way analysis of variance (ANOVA), followed by Duncan's multiple range test to determine differences among treatments.

2.5 | Ethical approval

This study does not involve any animal experimentation and thus no need existed for ethical approval.

3 | RESULTS

3.1 | Characterization of sugarcane bagasse biochar

The biochar production rate was 33% of the initial dried sugarcane bagasse biomass. The BD and particle density of sugarcane bagasse biochar were 0.34 and 0.45 g/cm^3 with high WHC of 185% (Table 1). Biochar had a total porosity 55%, microporosity 5.6% and total pore volume of 0.027 cm^3 g^{-1}. The BET surface area of biochar was 33.1 m^2 g^{-1}. The average pore diameter and micro-pore volume of bagasse biochar were 32.62 Å and 0.0015 cm^3 g^{-1} respectively.

The pH of sugarcane bagasse biochar was neutral (i.e. 7.1). The EC and CEC of biochar were 0.62 dSm^{-1} and 52.7 $cmol^{(+)}kg^{-1}$ respectively. The volatile matter and ash content of biochar were 92% and 7.9% respectively. Among the mineral nutrients, the total and available potassium was higher than other minerals (Table 1). The sugarcane bagasse biochar was rich in carbon (56.6%), hydrogen (2.8%) and nitrogen (1.2%). The C:N ratio was 47.1:1, whereas C:H ratio was 20.2:1. The amount of Cd, Cr and Pb detected in biochar is given in supplementary file.

3.2 | Fourier-transform infrared (FT-IR) spectroscopy analysis of bagasse biochar

FT-IR analysis of sugarcane bagasse biochar was done to identify the functional groups produced during the pyrolysis by modification of the skeletal structure of molecules. The surface functional groups of biochar at different wavelength are shown in Figure 2. The major functional groups present were non-polymeric hydroxyl ($-OH^{NP}$), methyl ($-CH_3$), primary amine ($-NH_2$), secondary amine ($-N = H^+$), ketone (-C = O), carbonate (CO_3^{2-}) and ether (=C-O-C=) at wavelengths of 3,421, 2,928, 2,372, 1,707, 1,600, 1,431 and 1,112 cm^{-1} respectively.

3.3 | Scanning electron microscopy (SEM) image analysis of sugarcane bagasse biochar and biochar amendment sediment

The *SEM* analysis of sugarcane bagasse biochar was done to know the surface morphology. Sugarcane bagasse biochar surface morphology is shown with different magnifications in Figure 3. At 50× magnification, *SEM* image shows biochar-like fine crushed particle whereas at 120× magnification flat layered type surface structure is visible. The macro- and micropores are visible at 800× and 1,500× magnification of *SEM* images respectively. The biochar from bagasse has longitudinal pores in sizes ranging from 10 to 20 µm (Figure 3).

The *SEM* images of control at 800x (Figure 4a,b) show flat top surface, absence of pore space and no changes in surface morphology and sediment aggregates (size range 22-36 µ), after 60 days of experimental duration. There was an increase in sediment aggregation of T1 and T2 treatments that can be noticed in *SEM* images at 800x (Figure 4c,d), and the aggregation was more pronounced in

TABLE 1 Chemical and physical characteristics of sugarcane bagasse biochar pyrolysed at 500°C

Chemical properties	Value	Physical properties	Value
pH	7.1 ± 0.5	Bulk Density (gcm^{-3})	0.24 ± 0.03
EC (dSm^{-1})	0.62 ± 0.06	Particle Density (gcm^{-3})	0.45 ± 0.06
Ash (%)	7.89 ± 0.8	Moisture (%)	1.24 ± 0.2
Volatile mater (%)	92 ± 2.4	WHC (%)	185 ± 3
Available nitrogen (%)	0.24 ± 0.02	Surface area (m^2g^{-1})	33.1 ± 0.9
CEC ($cmol^{(+)}kg^{-1}$)	52.7 ± 0.5	Total pore volume (cm^3g^{-1})	0.027 ± 0.003
Total phosphorus (gkg^{-1})	2.4 ± 0.06	Average pore diameter (Å)	32.62 ± 1.1
Available phosphorus (gkg^{-1})	1.8 ± 0.09	Micro-pore volume (cm^3g^{-1})	0.0015 ± 0.0001
Total potassium (gkg^{-1})	24 ± 0.9	Total porosity (%)	55 ± 0.7
Available potassium (gkg^{-1})	19.7 ± 0.8	Micro porosity (%)	5.6 ± 0.09
Total sodium (gkg^{-1})	0.5 ± 0.01	Biochar recovery (%)	33
Available sodium(gkg^{-1})	0.3 ± 0.02		
Total calcium (gkg^{-1})	6 ± 0.07		
Available calcium (gkg^{-1})	4.4 ± 0.08		
Total magnesium (gkg^{-1})	5.1 ± 0.04		
Available magnesium (gkg^{-1})	3.8 ± 0.08		
Cadmium (Cd) (ppm)	0.005 ± 0.00		
Chromium (Cr) (ppm)	0.038 ± 0.001		
Lead (Pb) (ppm)	0.017 ± 0.00		

*Mean values ± S.E. of triplicate sugarcane bagasse biochar sample.

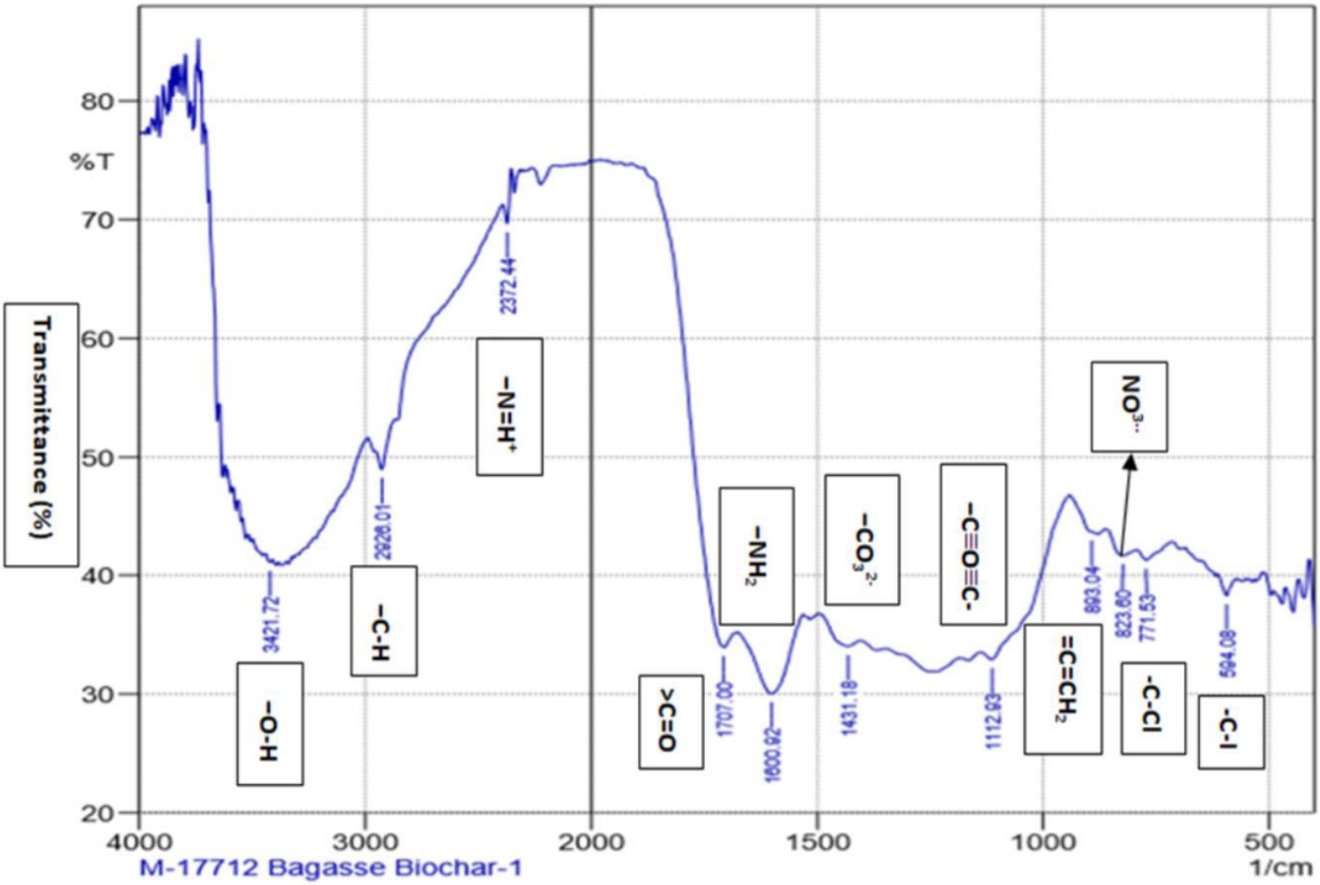

FIGURE 2 Molecular absorption in the infrared region with Fourier-transform infrared (FT-IR) spectroscopy of the biochars produced at 500°C

T2. The *SEM* images of T3 (Figure 4e) and T4 (Figure 4f) treatments at 500× magnification showed less sediment aggregation than T2 treatment.

3.4 | Effects of bagasse biochar on physicochemical properties of inland saline pond sediment

The WHC of inland saline pond sediment significantly increased in all the treatments by 1.36, 1.8, 1.2 and 1.55 times in T1, T2, T3 and T4 (Figure 5), respectively, and no changes were observed in control after 60 days of incubation period. BD of inland saline pond sediment decreased after biochar addition, but no changes were observed in control sediment (Figure 5). The initial pH and EC (Figure 5) of the inland saline sediment were significantly reduced in all treatments after 60 days of the experiment except control. The T2 treatment in which biochar was mixed with sediment showed much reduction in pH (6.94) and EC (4.44 dSm^{-1}) among all treatments. CEC of inland saline sediment in all the biochar treatments significantly increased, and there was no change in control (Figure 5) after the 60 days of incubation. It was observed that the increase in CEC was highest in T4 treatment (59%) and lowest in T1 treatment (6.2%). There was a significant ($p \le .05$) increase in OC in all the treatments of inland saline pond sediment due to the presence of high labile carbon in biochar except in control.

The available nitrogen of pond sediment decreased (Figure 6) but no change was observed in control saline sediment. It was observed that available phosphorus in final saline pond sediment sample (Figure 6) increased by 0.5% and 2.1% in T1 and T2 treatments, respectively, but decreased in control and other treatments. The application of bagasse biochar caused no changes in availability of macronutrient concentrations like sodium in all treatments (Figure 6) but increased potassium concentration (Figure 5) in treatments T1, T2, T3 and T4 by 12.3%, 18%, 3.5% and 4.78% than control respectively. There was an increase in available calcium and magnesium (Figure 6) in T2 by 5.62% and 14% respectively.

4 | DISCUSSION

4.1 | Characterization of sugarcane bagasse biochar

The pyrolysis time and the temperature are a crucial factor for the recovery rate of biochar (Lehmann & Joseph, 2009). The yield of biochar was 33% whereas the weight loss of water hyacinth biochar is 50% at 300–350°C for 45 min (Bordoloi et al., 2018) (Figure 1d).

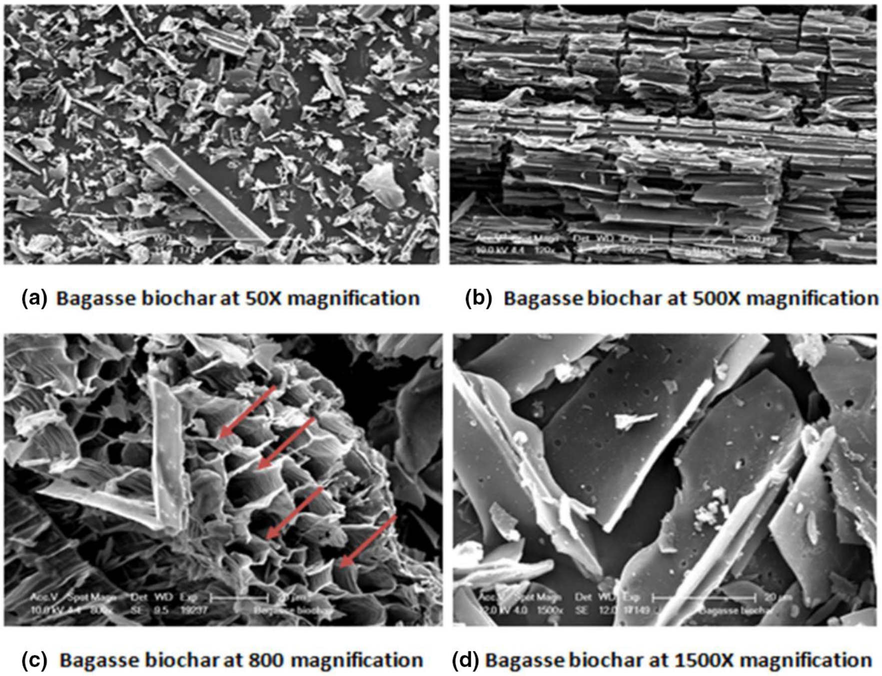

FIGURE 3 Images (*SEM*) of bagasse biochar at different magnifications

Kumar et al. (2013) prepared biochar from *Parthenium* temperatures ranging from 200 to 500°C and residence time 30–120 min and reported that the biochar yield decreased with temperature and time, with increase in biochar carbon stability at higher temperatures. The BET surface area of bagasse biochar was 33.1 m^2 g^{-1}. This surface area depends upon types of dried bagasse biomass used and pyrolysis temperature (Dias et al., 2014). The pH of sugarcane bagasse biochar was neutral (i.e. 7.1), and most of the biochar produced in high pyrolysis temperature is in neutral or alkaline pH range (Fig ueredo et al., 2017; Wu et al., 2019) as the acid functional group decreases with increasing temperature (Reeves et al., 2007). The EC of biochar was 0.62 dSm^{-1} due to the salts concentrated with the non-volatile aromatic carbon biomass during the pyrolysis of dried sugarcane bagasse. CEC of biochar was 52.7 $cmol^{(+)}kg^{-1}$ due to the negatively charged functional groups produced during the thermo-chemical change in chemical skeleton during pyrolysis, which is identified through FT-IR analysis (Figure 2). Nitrogen is most sensitive to volatilization during the heat pyrolysis (Gundale & DeLuca, 2006), so the available nitrogen of bagasse biochar is very low (0.24%) than total elemental nitrogen (1.2%). The ash content of biochar was 7.9% and produced due to the accumulation of different mineral elements of raw biomass during pyrolysis (Huanliang, 2013). Among the mineral nutrients, the total and available potassium was higher than other minerals (Figure 6). Fig ueredo et al. (2017) also reported the pH, ash, CEC, total phosphorus, total potassium, total calcium and total magnesium of sugarcane bagasse biochar at 500°C equal to 7.16, 7.07%, 52.1 $cmol^{(+)}kg^{-1}$, 1.6 gkg^{-1}, 39 gkg^{-1}, 12 gkg^{-1} and 9 (g/kg) respectively. The sugarcane bagasse biochar was rich in carbon (56.6%), hydrogen (2.8%) and nitrogen (1.2%). The C:N and C:H ratio was found to be 47.1:1 and 20.2:1. The former determines the microbial mineralization process of organic matter in the sediment and later determines the rate of carbonization of biomass (Uchimiya et al., 2011) during the pyrolysis process. The amount of Cd, Cr and Pb detected in biochar (supplementary file) was below the permissible limit set by WHO (1993) in drinking water and in this way, the application will not lead to any metal toxicity in cultured organisms in an aquaculture pond system.

4.2 | Fourier-transform infrared (FT-IR) spectroscopy analysis of bagasse biochar and biochar amended sediment

The functional groups, especially the ketone and polymeric hydroxyl groups, can be ionized and influence the formation of soil charges and CEC (Fig ueredo et al., 2017). The carbonate functional group contributes to the total alkalinity and helps in buffering capacity of sediment–water solution (Fidel et al., 2017). There is also the presence of nitrate-*N* (NO_3^-) at wavelength 823 cm^{-1} which contributes the direct source of available nitrogen nutrient to sediment and water column. The ether and methyl groups can serve as nutrient exchange sites after oxidation (Novak et al., 2009). Other than this, amine groups contribute to AEC and play a major role in metal absorption. All these characteristic features are the required inputs for betterment of the pond management and production systems. Functional groups reported in sugarcane bagasse biochar from this study have also been reported from sugarcane bagasse, eucalyptus (*Eucalyptus globulus*) bark and sewage sludge (Fig ueredo et al., 2017).

The FT-IR peak wavelength with its corresponding functional groups of initial and final control and biochar-treated sediment after 60 days of incubation. There was presence of both aromatic hydroxyl ($-OH^A$) and non-polymeric hydroxyl ($-OH^{NA}$) functional groups in inland saline sediment. The terminal methyl ($-CH_3$) and secondary

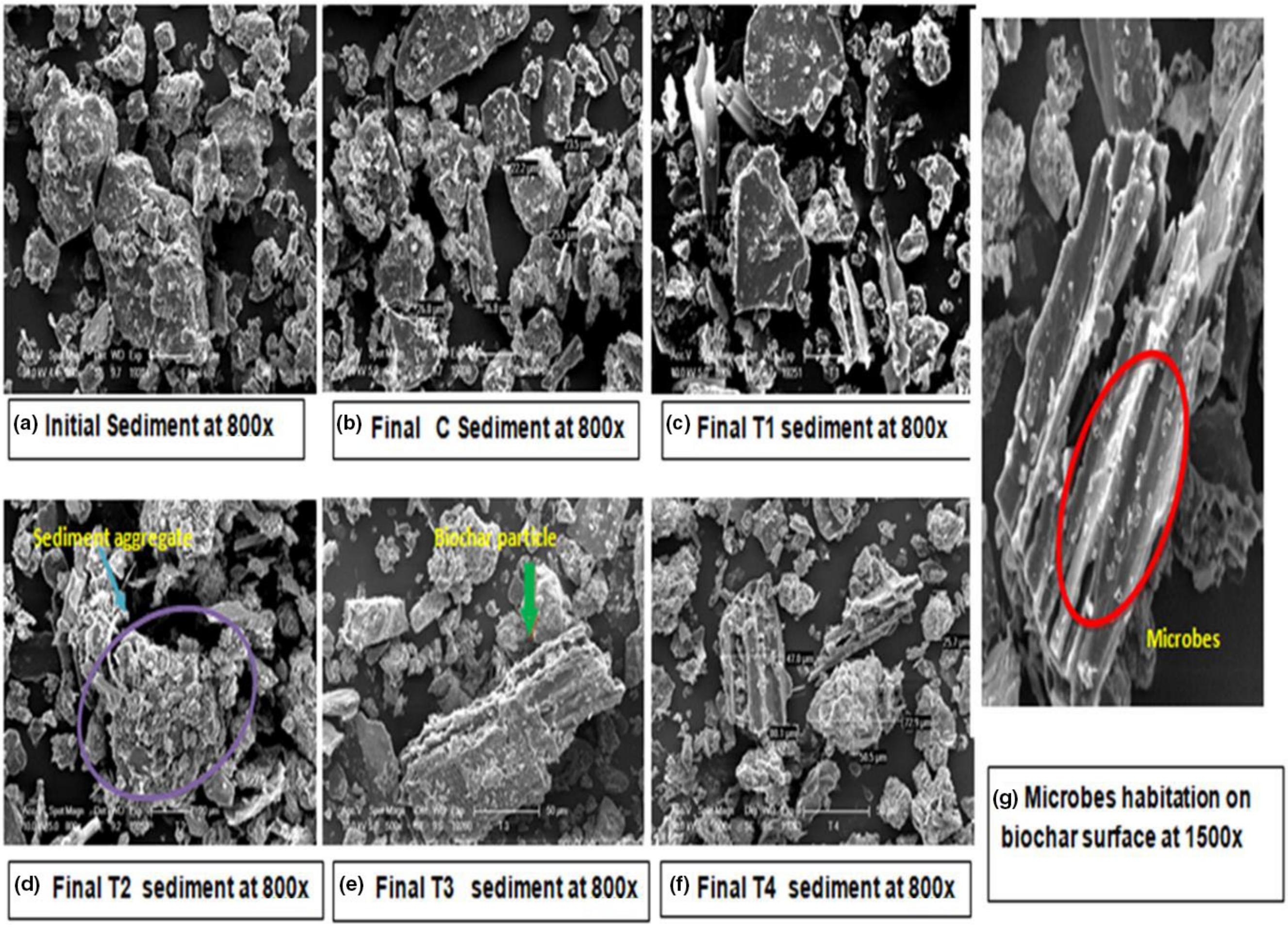

FIGURE 4 *SEM* images of control and biochar amendment sediment treatments at different magnifications (a) initial control at 800×; (b) final control at 800×; (c) final T1 sediment at 800×; (d) final T2 sediment at 800×; (e) final T3 sediment at 500×; (f) final T4 sediment at 500× and (g) microbes habitation on biochar surface at 500×)

amine (-N = H^+) groups were exclusively found in biochar-treated sediments. This secondary amine group plays major role for AEC. Similarly, methylene (-CH_2) and methylyne (-C≡C-C^A-) groups were only found in the sediment sample. The presence of ketone (-C = O) and carbonate (CO_3^{2-}) functional groups was present both in biochar and in sediment, which plays a major role in CEC and total alkalinity, respectively.

4.3 | *Scanning electron microscopy* (SEM) *image analysis of sugarcane bagasse biochar and biochar amendment sediment*

The longitudinal pores in biochar (10–20 μm) (Figure 3) originate during the pyrolysis from the vascular structure of the raw biomass (Lee et al., 2013). These pores may help to increase WHC and serve as sites for microbial adsorption (Pietikäinen et al., 2000; Steiner et al., 2004) and nutrient interaction. There was an increase in sediment aggregation of T1 and T2 treatments (Figure 4c,d), and the aggregation was more pronounced in T2 due to the higher amount or organic carbon and sediment–biochar interaction (Amini et al., 2016; Kim et al., 2016). The SEM images of T3 (Figure 4e) and T4 (Figure 4f) treatments had shown less sediment aggregation than T2 treatment. This may be due to improper sediment–biochar interaction (as sediment surface application of biochar in T3 and T4) during the incubation period. The biochar having larger particle size and surface area than inland saline sediment particles (Figure 4f) may contribute to the retention of mineral nutrients and microbes (Figure 4g). Biochar application shows increases in soil availability of nutrient (particularly K+, Ca++, Mg++), promoted microbial activities and bacterial community shift in saline and coastal saline soils respectively (Akhtar et al., 2015; Zheng et al., 2018). The increase in diverse group of microbes may help in nutrient mineralization and maintenance of the sediment–water quality of inland saline pond environment (Al-Wabel et al., 2019).

4.4 | Effects of biochar on chemical properties of inland saline pond sediment

The sediment-treated sugarcane bagasse biochar is highly porous material that may have caused the effective increase in WHC of all the

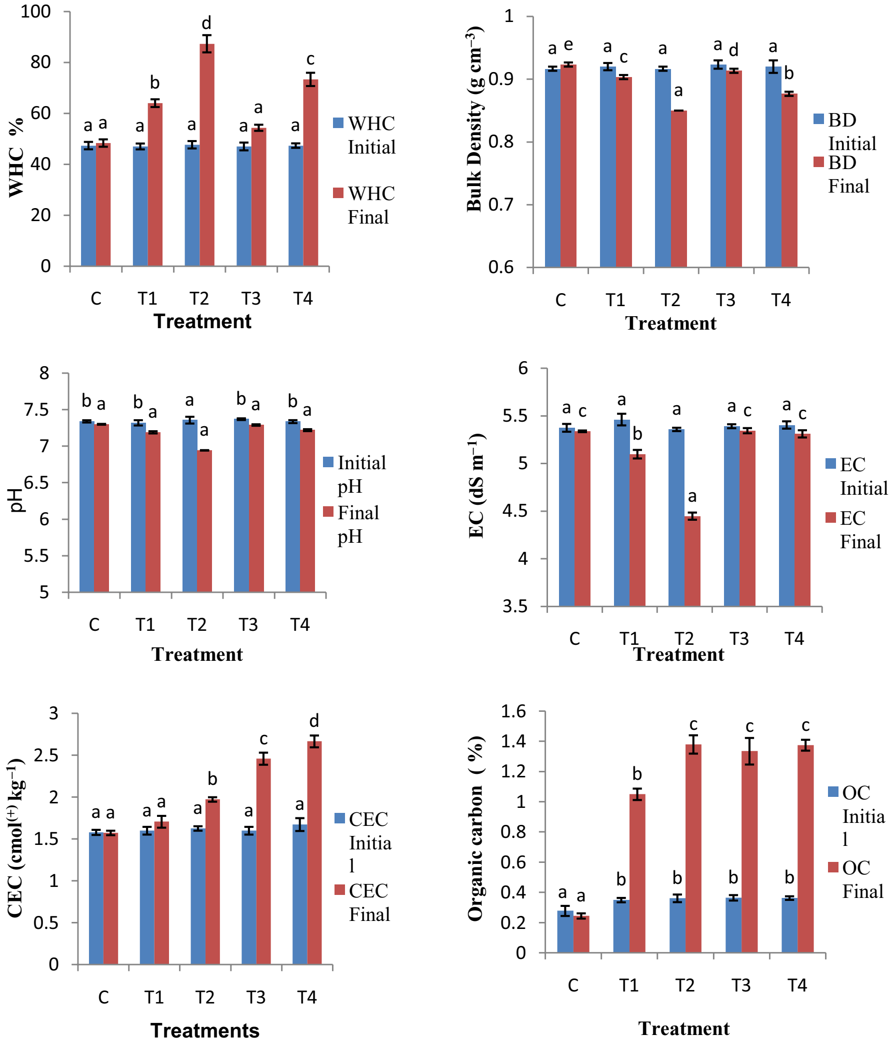

FIGURE 5 Effects of bagasse biochar on physicochemical properties of inland saline pond sediment in 60 days of incubation

treatments at the end of the experiment (Asai et al., 2009; Bordoloi et al., 2018; Sun et al., 2018). Bagasse biochar increases WHC (85%) in saline pond sediment which is much higher that biochar produced from water hycin (48%) in bare soil (Bordoloi et al., 2018). Sediment aggregation due to presence of OC in biochar (Saifullah et al., 2018) also leads to an increase in WHC (Figure 5). The biochar BD varies from 0.08 g/cm^3 to 0.43 g/cm^3 (Pastor-Villegas et al., 2006) depending on feedstock biomass and process conditions. It is lower than that of mineral soil ranging from 1.16 to 2.00 g/cm^3 (Chaudhari et al., 2013). The applied bagasse biochar BD is 0.24 g/cm^3 which is very less than the saline sediment 0.92 g/cm^3, so a reduction in soil BD is anticipated due to biochar low BD and its highly porous structure (Obia et al., 2016). Decrease in bulk density on biochar addition is helpful in improving the soil structure (Sharma et al., 2016).

The difference between pH values of biochar and sediment may be the main reason for soil pH change in the final sample (Liu & Zhang, 2012). The growth of acid-producing microbes (Kim et al., 2016) and an increase in acid functional group due to biochar application (Srekalen, 2015) can also be considered as a factor of decrease in sediment pH. The FT-IR analysis of bagasse biochar also confirmed the presence of acid functional groups in bagasse biochar (Figure 2).

The positive effect of biochar on reducing soil EC values may be due to the improvement of soil porosity (macro- and micro-pores) and hydraulic conductivity which causes physical entrapment (adsorption/retention) of salts into biochar pores (Thomas et al., 2013). The increased calcium in T2 treatment might have effectively reduced the ESP by aggregation of sodium which leads to decrease in EC (Huang et al., 2019; Thomas et al., 2013). Though biochar application rate is same, the sediment–biochar interaction caused the highest decrease in EC in T2 than T4, and similar type of result was observed by Chaganti and Šimůnek (2015) by applying biochar in saline–sodic soil. Bagasse biochar reduced up to 17% in saline pond sediment which is much higher than rice straw, sunflower straw and cow dung biochar (Yue et al., 2016). The decrease in pH due to biochar application may help in availability of cations such as K^+, Ca^{++} and Mg^{++} by increasing CEC (Hasan, 2018), and the decrease in EC (mainly contributed by Na^+ in saline areas) favours more availability of K^+ (Hafeez et al., 2019; Lashari et al., 2013) essential for growth and maintenance of haemolymph ionic concentration of shrimps.

The biochemical basis for the increase in CEC of sediment is due to the presence of oxidized functional groups of biochar,

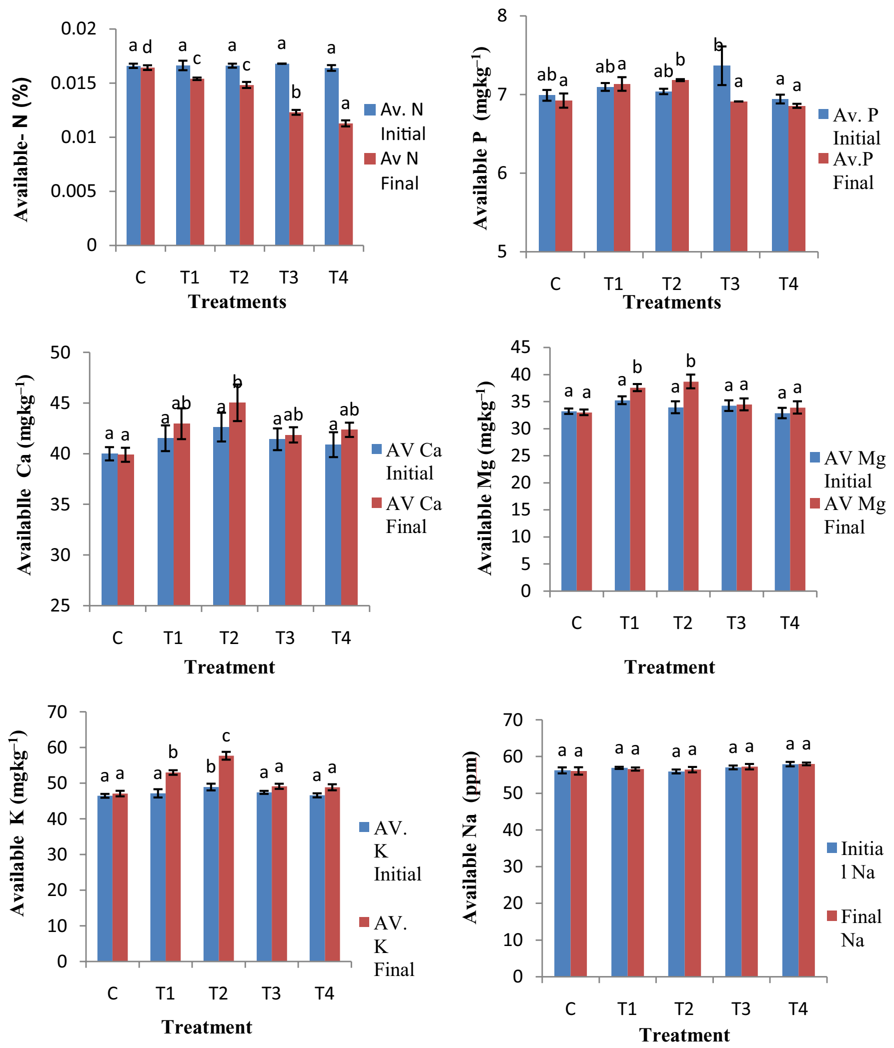

FIGURE 6 Changes in nutrient parameters of biochar-treated inland saline pond sediment in 60 days of incubation

whose presence is indicated by high oxygen and carbon ratios on the surface of charred materials following microbial degradation (Liang et al., 2006; Preston & Schmidt, 2006). FT-IR analysis of bagasse biochar (Figure 2) also showed the presence of oxidized functional groups (-C = O, -C = O=C-) which contributes to effective CEC of sediment. The increase in CEC of sediments due to organic amendment in the form of sugarcane bagasse biochar indirectly reduces EC (Figure 6) as it decreases ESP of sediment solution (Rengasamy & Olsson, 1991) and retains different polyvalent cationic nutrients necessary for growth of primary producers and fishes (Rajkovich et al., 2012). The OC increase has multidimensional encouraging effects such as improving soil physical structure by sediment aggregation (Figure 4), increases CEC and WHC (Figure 5), and releases of phosphorous to sediment solution (Figure 6) by enhancing sediment porosity (Lashari et al., 2013; Sharma et al., 2016; Zheng et al., 2018). This reduction may be due to the release of available nitrogen (NH_4^+/NO_3^-) from sediment to sediment–water solution as there was an increase in CEC (Lehmann et al., 2003) and hydraulic conductivity (Downie et al., 2009) of sediment by biochar application. High biochar application rates were reported to increase N losses as NH_3 from both normal (Feng et al., 2017) and salt-affected soils (Sun et al., 2017). The decrease in available nitrogen in all biochar-treated sediments indicates the increase in microbial population as nitrogen is required for metabolism to increase their biomass, which is also identified from SEM image (Figure 4g) (Norton & Firestone, 1996).

The decrease in sediment pH (Figure 5) facilitated the available phosphorous in biochar mixed sediment (T1, T2) than surface application sediment (Lashari et al., 2013; Taghavimehr, 2015). The AEC created by the primary amine ($-N-H_2^+$) (Figure 3) and secondary amine ($-N = H^+$) functional groups of bagasse biochar may facilitate the faster release of phosphorus from sediment to water column resulting a final decrease in available phosphorus in T3 and T4 treatments (Figure 6). The release of available-P in sediments facilitates nutrient availability for primary productivity (Raul et al., 2018). Bagasse biochar was found to be a rich source of available potassium (Supplementary file) than other mineral elements such as sodium, calcium and magnesium which resulted in more availability of potassium in sediment than other minerals. Taghavimehr (2015) also showed that biochar application (16 t/ha) to the saline soil increases exchangeable K^+ ion concentration by 44%. The increase in availability of K^+, Ca^{++} and Mg^{++} in sediment–water system increases the primary productivity, and maintains body fluid ionic concentration and mineral availability for post-moulting shell formation of shrimps cultured in inland saline ponds (Evans et al., 2005; Raul et al., 2018; Shiau & Hsieh, 2001).

5 | CONCLUSION AND RECOMMENDATIONS

Application of sugarcane bagasse biochar through mixing in inland saline pond sediment increases organic carbon, CEC, available-P and minerals such as K^+, Ca^{++} and Mg^{++} and decreases pH, EC and available-N. Biochar improves sediment aggregates, WHC and decreases BD thus could reduce water seepage, leaching of nutrient in aquaculture pond and improve microbial habitation. This study indicates biochar mixed with the sediment at 18 t/ha dose improved most of the sediment quality parameters necessary for culture of fish and related species in inland saline ponds. Thus, it is concluded that the vast area of salt-affected degraded land can be changed into viable aquaculture production by application of biochar. This is a preliminary study into the usage of biochar in inland saline soils, the future studies should focus on using different species of fish and shrimp along with the biochar prepared from different sources.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

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