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A Study on Biochar Preparation and Characterization of Broiler's Poultry Litter

ANJALI, T.B.[1*], ASWIN K. VIJAY[2], AKHILESH, K.B.[1] AND ANAND, M.[1]

[1]*School of Environmental Studies, Cochin University of Science and Technology, Cochin, Kerala, India.*
[2]*Department of Chemistry, T M Jacob Memorial Government College, Manimalakunnu, Kerala, India.*
E-mail: *anjalitb50@gmail.com, aswinkvijay007@gmail.com, akhilesh.kb7@gmail.com, anandm@cusat.ac.in*
***Corresponding author**

ABSTRACT

Poultry litter is being generated in huge amounts from small-scale as well as medium poultry industries all around the world. It is a potential soil fertilizer; however, its unscientific and improper management practices lead to a lot of environmental problems. The mass generation of poultry litter with excess moisture has become a burden to farm holders due to the lack of sustainable disposal methods. This study deals with the biochar preparation and characterization of broiler's poultry litter to identify its potentialities. The litter was pyrolyzed at five different temperatures (200, 300, 400, 500 and 600°C) with 60 minutes residence time. Both the proximate and ultimate analysis of poultry litter biochar (PLB) was performed. The proximate parameters were correlated either positively (ash content and fixed Carbon (C)) or negatively (yield and volatile matter %) with the pyrolysis temperature. The pH and EC values were increased in biochar, whereas the elemental compositions such as Hydrogen (H wt %), Nitogen (N wt %), and Sulfur (S wt %) were decreased. In comparison to raw poultry litter, the percentage weight of carbon (C wt %) was found to be high in all biochar samples. The SEM analysis has shown numerous macropores compared to micropores and mesopores in poultry litter biochar prepared at all temperatures. From the EDAX spectral analysis, high yield atomic Carbon percentage (C %) were identified in PLB. In terms of yield, it was observed that 200°C with 60 minutes residence time was the optimum temperature for poultry litter biochar preparation. This study confirmed that conversion of raw poultry litter to biochar can be considered as a suitable waste management practice and the PLB a potential organic supplement for sustainable agriculture and favourable adsorbent in soil remediation applications.

Keywords: Poultry litter; Waste Management; Biochar; Pyrolysis; Characterization; Soil Remediation.

INTRODUCTION

Poultry farming is one of the largest and fastest-growing agricultural businesses worldwide; this is mainly due to its economic and health benefits (Adeoye et al. 2004). The global population has shown an increasing trend in recent years which in turn, lead to increasing demand for agricultural and livestock products. It could be the reason for the accumulation of a large amount of agricultural and livestock wastes in the environment (McMichael et al. 2007). Livestock manure, a good source of nutrients like nitrogen (N) and phosphorus (P), is often applied to croplands to increase the content of soil organic matter and to raise soil fertility. From an agricultural point of view, poultry litter is a mixture of poultry excreta, spilled feed, feathers, and material used as bedding in poultry operations. Sawdust, peanut hulls, shredded sugar cane, straw, and other low-cost organic materials are the common bedding materials used. Poultry litter contains considerable amount of nutrients and other excreted substances such as hormones, antibiotics, pathogens, and heavy metals which are introduced through feed (Steinfeld et al. 2006). The direct land application of poultry litter might be a reason for several environmental problems such as the deterioration of groundwater and surface water quality through nutrient leaching, runoff, and associated odor problems to the natives. To achieve sustainable development in agriculture, the nutrients in livestock manure are needed to be recycled and reused to meet the need for fertilizers for crop production (Tewolde et al. 2011, Jn-Baptiste et al. 2012). At the same time, proper management strategies have to be developed for livestock manure to avoid potential problems such as the emissions of odorous gases to local residential areas and the release of heavy metals into the environment (Petersen et al. 2007). Poultry farms are one of the livestock sectors that have faced criticism because of the negative influence on the environment.

Frequent usage of poultry litter has become a critical issue in sustainable agriculture. Over the past three decades, the poultry sector's growth and intensification have given rise to many environmental concerns. The poultry sector was growing at a rate of more than 5 percent per annum (compared to 3% for pig meat and 1.5% for bovine meat) and its share in world meat production increased from 15% to 30% (FAO 2006). The Indian poultry sector has shown spectacular growth since the late seventies (Soubhagya et al. 2019). South and West Indian states have been the leading states in this regard. The state of Kerala stands uniquely in the seventh position in the list of largest meat producing states in India (Abayomi 2019). The state is actively involved in the broiler chicken rearing as the demand for chicken consumption is significantly high and fetches huge income for the farmers. A common problem found in Kerala is that poultry farming and waste management were not linked and they were working in different sectors. Also, massive waste generation, disposal issues and associated environmental problems are the greatest challenges faced by these sectors. A recent study on poultry waste management in Kerala has reported that 83.33% of the waste was sold for different purposes. The amount of waste was huge and the cost and facilities for waste processing were high. Hence most of the owners were not willing to dispose of waste on their own. Out of the total waste sold, 66.67 % was utilized as fertilizer, 30% as fish feed, 23.33% as biogas, 16.67% as pig feed, and 3.33% as dog feed and also some ended up in landfills (Bimal et al. 2019). Dry rendering is one of the latest scientific disposal methods for producing value-added products using poultry farm and slaughterhouse wastes (Abraham et al. 2015).

From a waste management perspective, conversion of poultry litter to biochar is a sustainable management practice for the disposal of large quantity waste biomass from poultry sectors. The pyrolysis of poultry litter can potentially convert nutrients into less soluble forms in poultry litter biochar and thereby reducing the leaching and runoff from the agriculture field. According to the International Biochar Initiative (IBI), biochar is defined as a thermally converted material produced from different processed and unprocessed biomass under an oxygen-limited environment. Biochar is gaining worldwide attention as an environmental management tool because of its unique physicochemical and structural properties. It is highly porous with a large internal surface area and often a negative surface charge resulting in enhanced sorption capacity (Mohan et al. 2006, Downie et al. 2009). Before biochar supplementation in agro soil, both the physical and chemical characterization study must be performed to obtain actual knowledge on biochar application rates and thereby better yield. The proximate analysis includes determining physical properties such as moisture content (%), ash content (%), volatile matter (%), and fixed carbon (%). The ultimate analysis consists of pH, Electrical conductivity (EC), and elemental composition such as C, H, N, and S. The physico-chemical characteristics of biochar are generally influenced by the type of feedstock used and the temperature at which pyrolysis occurs (Lehmann et al. 2007).

In the present study, biochar was prepared from Poultry Litter (PL) at five different temperatures: 200, 300, 400, 500 and 600^{o}C, with 60 minutes residence time, using a laboratory Muffle Furnace and subjected to physicochemical characterization. The study rationales include identifying the physicochemical characteristics and the temperature influence on biochar properties. It is envisaged that biochar preparation from poultry litter will be a sustainable waste management approach to small and large scale poultry farm holders and a good soil supplement in agriculture. The poultry litter to biochar conversion can solve various environmental consequences raised from the direct land application. The poultry litter biochar (PLB) could enhance soil health and improve the crop yield when applied as a soil amendment at a certain concentration. During the last two decades, Biochar has received immense attention as a soil amendment and an eco-friendly waste management tool.

MATERIALS AND METHODS

Feedstock Collection

Poultry litter (with bedding material) was selected as a feedstock for biochar preparation. Raw poultry litter was collected at beginning of the summer season in Kerala. Poultry litter (PL) of 45 days old broilers were collected from a medium-scale poultry farm at the Ernakulam District of Kerala. The farm consists of more than 100 broilers on a rectangular plot with an area of 404.7 m^2. Representative samples were collected by a stratified random sampling method, in which, samples were taken from four corners and the center of the farm. Later thoroughly mixed the contents, and packed them in sterile polythene bags. The poultry litter was air-dried for two days to remove the excess moisture content and then stored in airtight polythene bags for further use. The physico-chemical properties like pH, Electrical Conductivity (EC), and temperature (^oC) as well as the microbial analysis such as Total Heterotrophic Bacterial Count (THBC) of collected poultry litter sample was analyzed (Ananthanarayan 2000). The chemical composition and surface morphology of this feedstock material was analyzed by CHNS elemental analyzer and Scanning Electron Microscope- Energy Dispersive X-Ray Analysis (SEM-EDAX). C, H, N and S elemental analysis was performed using Elementar Vario-EL-III analyzer.

Biochar Preparation by Pyrolysis

Biochar was prepared using a laboratory muffle furnace to optimize the pyrolysis conditions. 25 g of air-dried and chopped feedstock materials were accurately weighed in silica crucibles and pyrolyzed at 200, 300, 400, 500 and 600^{o}C with 60 minutes residence time under oxygen-limited condition. The biochar samples produced after pyrolysis were cooled in desiccators and then used for further analysis.

Characterization of Poultry Litter Biochar (PLB)

The proximate and ultimate analyses were performed to find out the temperature influence in the physical and chemical properties of prepared biochar samples as per the ASTM D5142 methods. The proximate analysis comprises Bulk density (gcm^{-3}), Moisture content (%), Ash content (%), Volatile matter (%), Biochar yield (%), and Fixed Carbon (%). The ultimate parameters include pH, EC, and elements such as C, H, N, and S. The pH and EC were analyzed by potentiometric method using pH meter and conductivity meter (Rajkovich et al. 2011). The percentage moisture in biochar samples were analyzed as per the method described by Maiti (2003).

Elemental Analysis

The weight percentage (wt %) of elements such as Carbon, Hydrogen, Nitrogen, and Sulphur (CHNS) in raw poultry litter and biochar produced at different pyrolysis conditions was determined using the ELEMENTAR Vario EL III analyzer at Sophisticated Test and Instrumentations Centre (STIC), Cochin University of Science and Technology, Cochin.

Scanning Electron Microscope- Energy Dispersive X-Ray Analysis (SEM-EDAX)

The structural modifications by the influence of pyrolysis method and atomic percentage composition of metals distributed in the feedstock material as well as in biochar particles were analyzed by Scanning Electron Microscope with Energy Dispersive X-ray Spectroscope Jeol 6390LA/ OXFORD XMX N model. The SEM images were observed at 2 μm, 10 μm, and 50 μm resolutions, respectively.

RESULTS AND DISCUSSION

The feedstock poultry litter was characterized and pyrolyzed at five different temperatures followed by physico-chemical and morphological characteristic studies.

Feedstock Characterization

The poultry litter sample was collected from a medium-scale poultry farm in Ernakulam district of Kerala. At the time of sampling the temperature of raw poultry litter was found to be 19.1°C, because the poultry farm holders try to keep the temperature in the range of 20 to 30°C. The ambient temperature during the sampling period was found to be 32°C. The farm holders were implementing several modern ventilation techniques to reduce the temperature to a desired level. The pH and EC (mS/cm) of poultry litter sample were 7.61 and 8.97 mS/cm. The total heterotrophic bacterial count was found to be $25*10^5$ CFU/g.

Biochar Characterization

The physicochemical properties were determined in terms of proximate and ultimate analysis. The results showed that the values of both proximate and ultimate parameters were correlated (Pearson correlation coefficient) either positively or negatively with the pyrolysis temperature.

Proximate Analysis

The proximate analysis results of PLB samples were listed in Table 1. The physical appearances of all the biochar samples are quite different from their feedstock materials under different pyrolysis conditions. The temperature influence in each proximate parameter was very visible from the data given in this table. The yield (%) and volatile matter (VM%) content exhibited negative correlation with the pyrolysis temperature during poultry litter biochar (PLB) preparation (Pearson correlation coefficient=-0.98). It was found that as temperature increases from 200 to 600^{o}C the biochar yield (%) and volatile matter (%) were reduced. The yield (%) and volatile matter (VM %) were found to be maximum in PLB200 and minimum in PLB600 with 58.56%, 64.04%, and 27.84%, 32.86% respectively. While the ash content and fixed C were found to be positively correlated (*Pearson correlation coefficient = +0.95*) with the pyrolysis temperature. Percentage ash was increased from 35.08 to 55.25% in samples of PLB200 to PLB600. The fixed C increased from 0.88% to 11.89% with the increase in temperature from 200°C to 600°C (Table 1). The ash content and fixed carbon were higher in PLB600 (55.20% and 11.89%). The bulk density varied between 0.383 g cm^{-3} to 0.446 g cm^{-3} and it was highest in PLB300 (0.446 g cm^{-3}) and lowest in PLB400 (0.383 g cm^{-3}). The moisture content of PLBs varied from 0.23% to 4.04%, which was found to be high in PLB300 (4.04%) and lowest in PLB500 (0.23%). An optimum pyrolysis temperature for biochar preparation from poultry litter with maximum yield (58.56%) was obtained at 200^{o}C with 60 minutes residence time.

Ultimate Analysis

The ultimate parameters such as pH, EC, C (wt %), H (wt %), N (wt %), S (wt %), H/C ratio, and C/N ratio of raw poultry litter (PL) and poultry litter biochar (PLB) were given in the Table 2. The pH of raw poultry litter was slightly acidic (06.11), while poultry litter biochar (PLB) samples were alkaline ($\pm$07.00). It was observed that pH of all poultry litter biochar increased with increase in pyrolysis temperature and which was significantly higher in PLB400 (10.15) (Figure 1a). This alkaline nature of PLBs helps to increase the pH of acidic soils to an optimum level for cultivation. The presence of high ash content in biochar samples might be a reason for its alkalinity. Chun et al. (2018) investigated the PLB supplemented effects on soil pH and found the soil pH get shifted from 5.4 to 6.7. Electrical conductivity (EC) was high for PLB600 (19.54 mS/cm) and low for PLB200 (9.40 mS/cm) (Figure 1b). A similar characterization study of cattle dung biochar conducted by Sukartonu et al. (2011) has reported that the cattle dung biochar had a pH of 8.90, EC of 1.75 dSm^{-1} and bulk density of 0.710 g cm^{-3}.

The elemental composition except for C (wt %) was very less in poultry litter biochar compared to raw poultry litter. The element C (wt %) was found to be high in PLB200 (36.92%). As the temperature increases from 200^{o}C to 600^{o}C, the hydrogen,

Table 1. Proximate analysis of Poultry Litter Biochar (PLB)

Pyrolysis Temperature	Biochar Sample Code	Proximate Parameters					
		Moisture Content (%)	Bulk Density (gcm^{-3})	Ash Content (%)	Volatile Matter (%)	Fixed C (%)	Yield (%)
200 ^{o}C	PLB200	2.07	0.385	35.08	64.04	0.88	58.56
300 ^{o}C	PLB300	4.04	0.446	35.72	61.91	2.37	39.88
400 ^{o}C	PLB400	0.43	0.383	47.30	41.96	10.74	33.87
500 ^{o}C	PLB500	0.23	0.389	52.72	35.23	12.05	30.87
600 ^{o}C	PLB600	0.55	0.389	55.25	32.86	11.89	27.84

Table 2. Ultimate analysis results of Poultry Litter (PL) and Poultry Litter Biochar (PLB)

Pyrolysis Temperature	Biochar Sample Code	Ultimate Parameters							
		P^{H}	EC (mS/cm)	C (wt %)	H (wt %)	N (wt %)	S (wt %)	H/C	C/N
-	PL	07.61	08.97	28.12	3.32	3.17	0.70	0.118	8.87
200 °C	PLB200	07.00	09.40	36.92	0.09	3.81	0.01	0.002	9.69
300 °C	PLB300	08.14	17.55	35.12	0.32	3.06	0.33	0.009	11.70
400 °C	PLB400	10.15	17.38	29.78	0.41	2.30	0.01	0.013	12.94
500 °C	PLB500	09.95	10.96	33.81	0.51	1.96	0.00	0.015	17.25
600 °C	PLB600	09.65	19.54	35.39	1.28	1.76	0.68	0.036	20.10

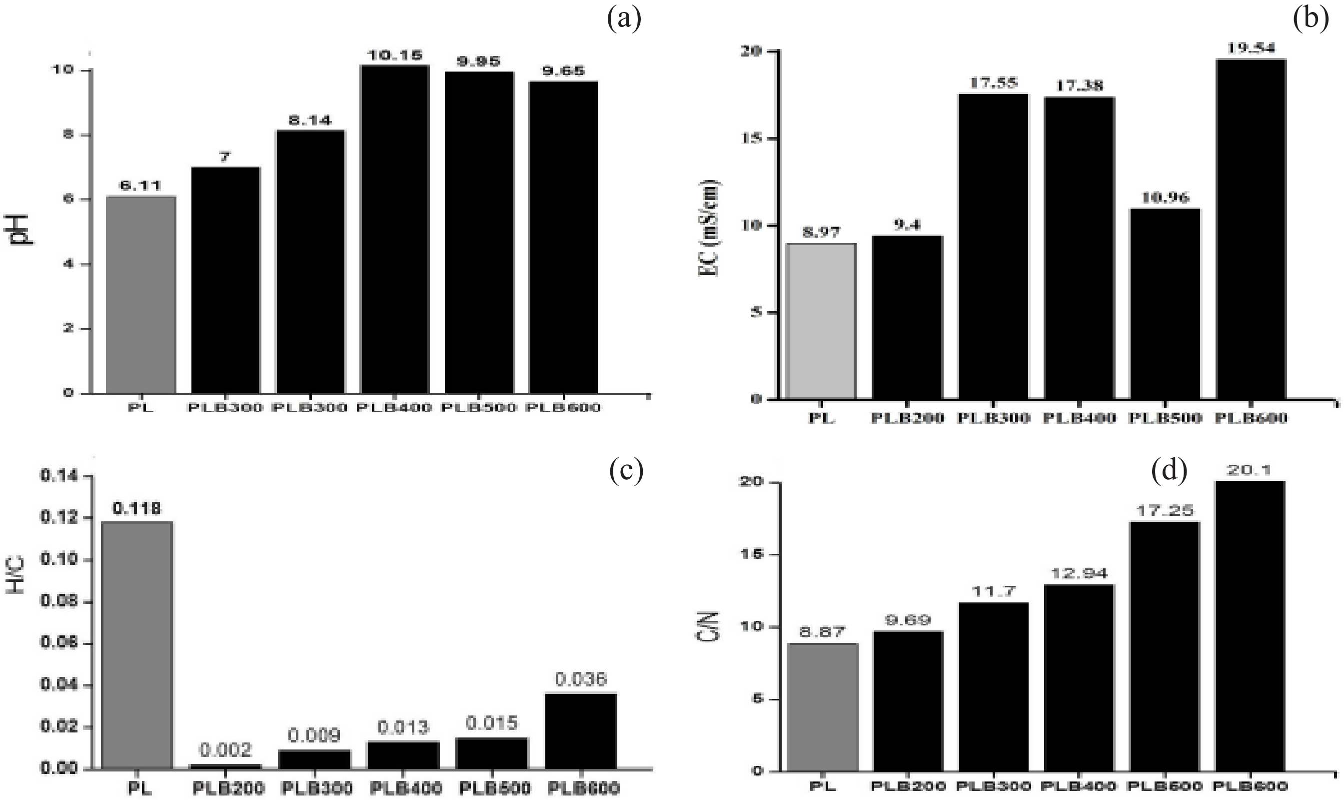

Figure 1. (a) Values of pH, (b) Electrical Conductivity- EC, (c) Hydrogen/Carbon ratio- H/C and (d) Carbon/ Nitrogen ratio- C/N of Poultry Litter (PL) and Poultry Litter Biochar (PLB)

nitrogen, and sulfur contents showed a decreasing trend in all biochar samples. The ratio between Hydrogen to Carbon (H/C) was high for poultry litter (0.118) and varied between PLB200 and PLB600 from 0.002 to 0.036 (Fig. 1c). The Carbon to Nitrogen ratio (C/N) was gradually increased from low temperature biochar samples at a value of 9.69 to high-temperature samples at a value of 20.1, whereas the lowest C/N ratio of 8.87was obtained in raw poultry litter (Fig. 1d).

Biochar prepared from poultry litter has shown an increase in the elemental and atomic carbon percentage, which indicates its high carbon sequestration potential when amended in soil. In comparison to raw poultry litter, the percentage composition of hydrogen, nitrogen and sulphur elements were lower in biochar samples, which attributes to some chemical transformations like dehydration and depolymerization reactions in feedstock material during the thermal decomposition process. However, an optimum pyrolysis temperature could influence the percentage of nutrients in the biochar samples. Biochar is considered as a good soil amendment due to the degradation of excess nitrogen and sulphur content in the raw poultry litter sample. When poultry litter directly added to the cultivable soil as it has high amount of nitrogen and sulphur, which may impart the microbial metabolism in the soil. The soil microorganisms have an optimum Carbon to Nitrogen (C/N) ratio around 8. They must acquire enough carbon and some amount of nitrogen from the soil to maintain that ratio in their cells and

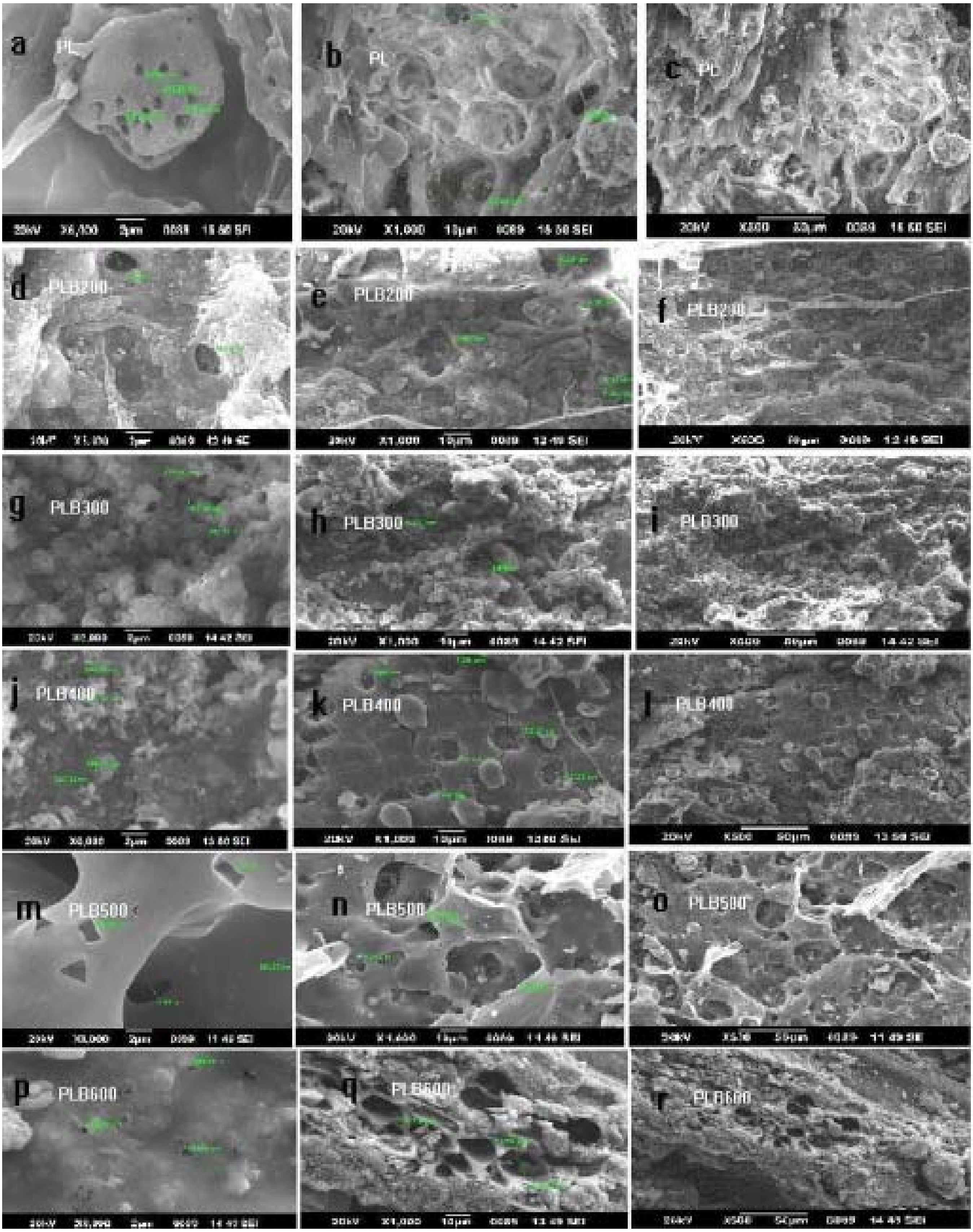

Figure 2. SEM Images of Poultry Litter (PL) and Poultry Litter Biochar (PLB) at 2µm, 10µm and 50µm resolution.

have been found to do best on a diet with a C:N ratio of 24 (Howell and Puckhaber 2005). In the present study the C/N ratio of PLBs ranges from 9.69 to 20, which when supplemented with soil will help to optimize carbon and available nitrogen for plant growth.

SEM-EDAX Analysis

The SEM images of raw poultry litter and five different poultry litter biochar samples are shown in Figure 2. The surface morphology of poultry litter was found less fragmented and contained fewer pores than its charred forms. It was found that numerous macropores were distributed throughout the surface of biochar samples uniformly. The pore structure was more visible under 10 µm and 50 µm resolutions and the SEM images of PLB500 contains the largest macropore with a diameter of 32.29 µm (Fig. 2m,n,o). The SEM micrographs of PLB400 contain the smallest macropore with a diameter of 0.235 µm under 2 µm resolutions (Fig. 2j,k,l). In comparison with the biochar particles, the surface porosity and the macropore distribution was found scarce in raw poultry litter (Fig. 2a,b,c). Following a primary analysis of SEM micrographs, it was found that micropores and mesopores were absent in feedstock and biochar particles. At sufficiently high temperatures, pyrolysis can induce some morphological changes in the micropore and mesopores mouth, where they open up into the macropore cavities identified in the SEM images of biochar.

Biochar produced from different biomass feedstocks (apple wood or corn stover) exhibited different reactivity patterns in the kinetic control regime, mainly because of the presence of supplementation of orderly distributed micropores (Hao et al. 2011). The environmental action of biochar depends on its ability to absorb, retain and release water, gases, and nutrients. All these properties are generally controlled by their porosity and surface chemistry, which can vary with the feedstock composition and pyrolysis conditions employed during biochar preparation. Highly porous structures could be able to absorb nutrients from the soil and make it available for plants. The porosity and surface projections in biochar could enhance the surface area, which facilitates the applications such as removal of contaminants from water and the remediation of heavy metals from soil. The reason for the highly porous structure of biochar is due to the escape of volatile organic compounds from their surfaces with increasing pyrolysis temperature which forms more disordered surfaces (Haykiri-Acma et al. 2013).

The EDAX spectra of poultry litter and poultry litter biochar samples are shown in Figure no.3. Different atomic (%) compositions were listed out in Table 3. In comparison with the raw poultry litter, the atomic percentage was found to be high in poultry litter biochar irrespective of their pyrolysis temperature. From an overall analysis of EDAX spectra, the highest peak was obtained for atomic C (%) under PLB200 (64.37%). In addition to carbon, the EDAX spectrum also provides the atomic percentage of Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulphur (S), Chlorine (Cl), Potassium (P), Calcium (Ca), Iron (Fe) and Oxygen (O). In comparison with the atomic spectrum of raw poultry litter, all the atoms were more concentrated in poultry litter biochar prepared at five different temperatures (200 to 600°C). Among the five PLBs, the atomic percentage of Oxygen (O) and Sulphur (S) was found highest in PLB300 (30.01 and 1.61%), Sodium (Na), Magnesium (Mg), Silicon (Si), Phosphorous (P), Chlorine (Cl), Potassium (K), Calcium (Ca) and Iron (Fe) in PLB500 were 0.88, 1.74, 1.18, 3.57, 2.79, 8.0, 6.35 and 0.38%, respectively, while Aluminium (Al) in PLB400 was 1.67%.

CONCLUSIONS

The study concludes that the conversion of raw poultry litter to biochar will be a sustainable approach to mitigate the issues related to poultry farm waste management and soil health. Pyrolysis can be a preferred method for biochar preparation and the selection of suitable pyrolysis conditions, especially the temperature and residence time, are important to obtain sufficient biochar yield and quality. The biochar pH was alkaline in nature (≥ 7) which may help to neutralize the sensitive acidic soils prevalent in Kerala. The CHNS elemental analysis has shown a decreased weight percentage of hydrogen, nitrogen, and sulfur, whereas an increased carbon (wt %) in

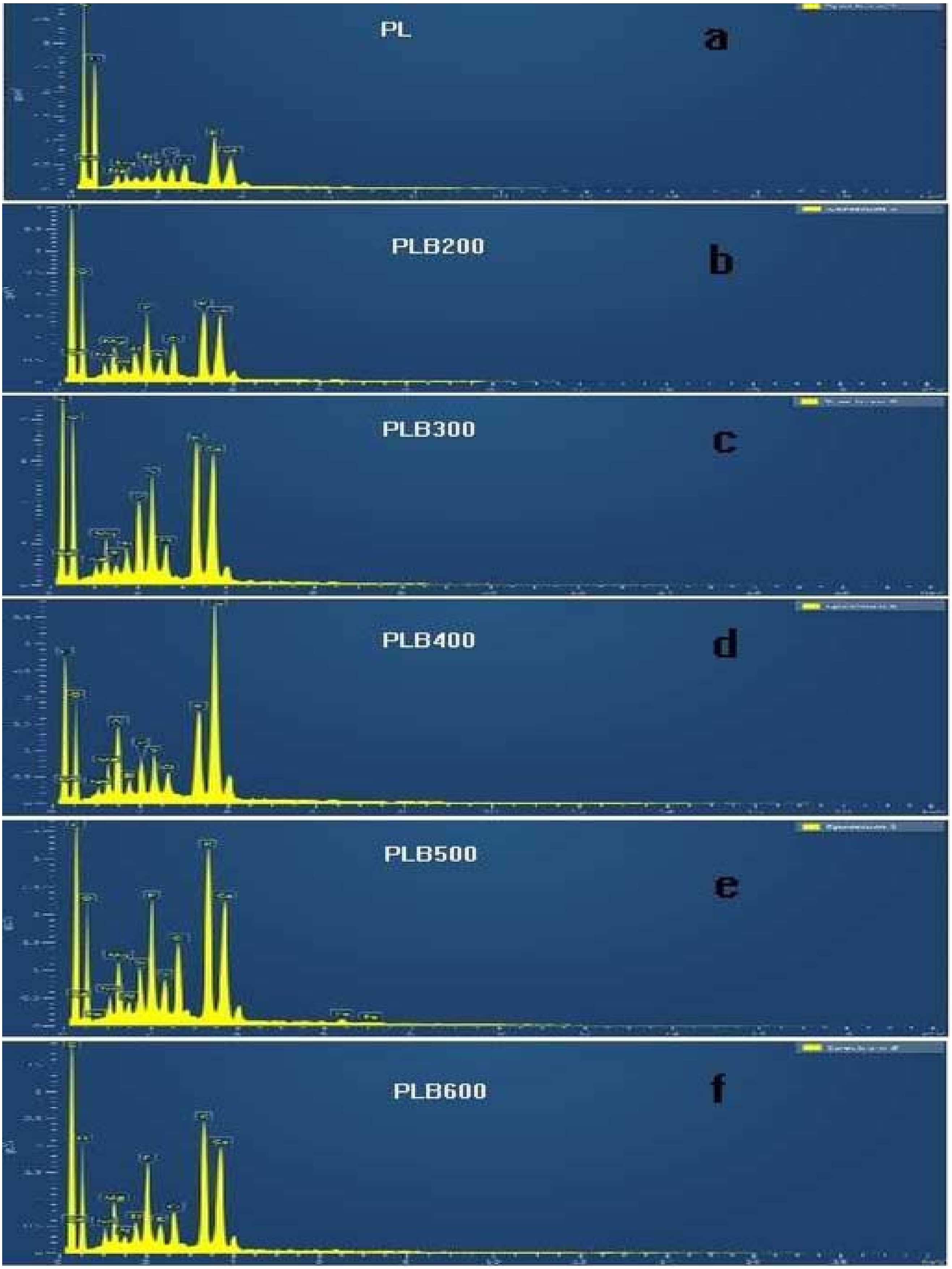

Figure 3. EDAX Spectra of Poultry Litter (a) and Poultry Litter Biochar (PLB) (b,c,d,e,f).

poultry litter biochar. The increase in carbon (wt %) in poultry litter biochar samples which helps to maintain an optimum C/N ratio in soil and this will enhance the microbial activity. The SEM micrographs showed the largest macropore in PLB500 and the smallest macropore in PLB400. These complex macropore structures could enhance the adsorption capacity, which is beneficial for soil remediation, wastewater purification, and bioremediation applications. From an overall analysis of EDAX spectra, the high yield atomic carbon in PLB200 will also help in long term carbon sequestration in soil. Poultry litter brings much attention if it is properly conditioned, otherwise, it could be a menace. The lack of suitable poultry litter management practices creates severe environmental pollution problems. Biochar prepared from a feedstock like poultry litter will be an effective waste management tool and it can be used for the enhancement of agriculture field, restoration of degraded land, and soil remediation needs.

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Conflict of interest: The authors declare that they have no conflict of interest.

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