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Research article

Investigating the properties and agronomic benefits of onion peel and chicken feather-derived biochars

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ABSTRACT

Biochar production from unconventional biomass, specifically onion peel (OP) and chicken feathers (CF), was investigated in this study. Two distinct biochars were produced by doping each biomass with the other, with the aim of exploring the synergistic effects of different feedstock combinations on biochar properties. The biochar production process was conducted using a retort heating method and characterized using several techniques. A yield of 36 % was obtained for OP-doped biochar (OP92CF8-BC) and 23 % for CF-doped biochar (F92OP8-BC). Fourier Transform Infrared Spectroscopy analysis revealed characteristic functional groups from cellulose, hemicellulose, and lignin in OP92CF8-BC, while CF92OP8-BC displayed keratin-related peaks. Scanning Electron Microscopy imaging showed surface morphology differences, with OP92CF8-BC exhibiting a rougher and more porous structure compared to CF92OP8-BC. Energy-Dispersive X-ray Spectroscopy analysis confirmed the elemental composition, with OP92CF8-BC having higher carbon, calcium, and sulfur contents and CF92OP8-BC having higher nitrogen and oxygen contents. The biochar had specific surface areas of 342.4 and 200.80 m^2/g for OP92CF8-BC and CF92OP8-BC, respectively. According to the results, using biochar treatments-more especially, CF92OP8-BC-can significantly enhance cob weight. This could be good for agricultural productivity. These findings highlight the influence of feedstock composition on the properties of biochar and provide insights for its potential applications in soil amendment and pollutant removal.

1. Introduction

Biochar, a carbon-rich solid material produced through the process of pyrolysis, has gained significant attention in recent years due to its potential applications in various fields, including agriculture, environmental remediation, and energy production [1,2]. Biochar exhibits unique physicochemical properties that make it a promising candidate for soil amendment [3], carbon sequestration [4], and

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pollutant adsorption [5-7]. To optimize its performance, biochar production and characterization need to be thoroughly investigated.

The choice of feedstock plays a crucial role in determining the properties and potential applications of biochar. Lignocellulosic biomass, such as onion peel, is abundantly available as an agricultural residue [8,9]. It consists mainly of cellulose, hemicellulose, and lignin, which can undergo pyrolysis to produce biochar [10,11]. On the other hand, non-lignocellulosic biomass, like chicken feather, possesses a high nitrogen content and unique structural characteristic [12]. By combining different types of biomass as feedstocks, the resulting biochar can exhibit enhanced properties compared to single-source biochar [13].

The production of biochar from onion peel and chicken feathers have been individually reported in the literature with unique properties and applications [14,15], while their combined thermal processing are uncommonly reported. Devi et al. [16] investigated the efficiency of a cobalt-onion peel biochar-based composite with doping for shielding electromagnetic interference. The composite exhibits improved properties, including enhanced relative permittivity, mechanical strength, and effective wave shielding. Prajapati and Mondal [17] synthesized Fe_3O_4-onion peel biochar nanocomposites using a green method at low-temperature pyrolysis in N_2 and CO_2 atmospheres. The nanocomposites showed enhanced surface functionality and pollutant removal ability, exhibiting higher adsorption capacity for Cr(VI), Methylene blue, and Congo red dyes.

Similarly, recent valorization of chicken feather have been reported in biochar [18] and functional composite applications for heavy metal sorption [19] and other mineral based applications [20,21]. Chen et al. [22] used waste chicken feathers to produce low-cost N-enriched biochar. Modified with KOH, the resulting biochar (KNB) demonstrated rapid adsorption rates for Cd and Pb, with significantly higher capacities compared to the original biochar. KNB's effectiveness stems from various adsorption mechanisms and surface functional groups, making it a promising adsorbent for wastewater treatment. Li et al. [23] used waste chicken feathers to produce multilayered graphene-phase biochar (MGB) for removing tetracycline (TC) from wastewater. MGB exhibited a large surface area, rapid TC removal, and tolerance to various pH and ionic strength conditions. The MGB showed potential for wastewater treatment even after multiple regeneration cycles.

The addition of CF as a doping material to the onion peel biochar aims to enhance its nitrogen content and structural integrity. CF, a waste product from poultry processing industries, contains a substantial amount of keratin, a proteinaceous polymer [21]. The incorporation of CF into the biochar matrix may contribute to improved nutrient retention and adsorption capacities, making it a potential material for soil fertility enhancement and pollutant removal. Similarly, the addition of OP as a doping material to the chicken feather biochar aims to introduce lignocellulosic components and enhance its carbon content. OP, a by-product of the food processing industry, consists primarily of cellulose and hemicellulose [24], which can serve as carbon sources during pyrolysis. The incorporation of OP into the biochar structure may result in increased carbon sequestration potential and stability, making it suitable for long-term carbon storage applications.

Furthermore, it has been demonstrated that the co-carbonization of lignocellulosic and non-lignocellulosic biomass wastes to create mineral-fortified biochar can significantly enhance soil and increase food security when the proper mixtures from various biomass sources are used [18,25]. In order to mitigate the effects of cost and the nearly disappearing fertilizer subsidies in emerging economies, mineral-fortified biochar has been used as a sustainable substitute for organic fertilizers. Consequently, a sustainable and multifaceted method for improving soil and ensuring food security is provided by co-carbonizing biomass, both lignocellulosic and non-lignocellulosic, to create mineral-fortified biochar. This strategy has great potential to advance agricultural sustainability and resilience since it addresses waste management, improves soil health, increases crop yields, and benefits the environment.

In this study, the focus is on the production and characterization of two distinct biochars. The first biochar will be produced from onion peel (OP) with a doping quantity of chicken feather, while the second biochar will be produced from chicken feather (CF) with a doping amount of onion peel. By utilizing a lignocellulosic biomass as the base material and doping it with a non-lignocellulosic biomass, or vice versa, we aim to explore the synergistic effects of different feedstock combinations on the resulting biochar properties. By studying the production and characterization of biochar from unconventional biomass, such as onion peel and chicken feather, with different doping amounts, this study aims to contribute to the understanding of how feedstock combinations and doping materials can influence the properties and potential applications of biochar. The findings of this study will help expand the knowledge base in the field of biochar research and provide insights for sustainable waste management and resource utilization.

2. Materials and methods

2.1. Feedstock preparation

Two main biomass feedstocks, namely OP and chicken feather, were selected for this study. OP waste was obtained from a local food market, while chicken feathers (CFs) were acquired from a local poultry farm. The OP waste was thoroughly washed to remove any impurities and dried to reduce moisture content. Subsequently, it was finely ground to achieve a uniform particle size suitable for biochar production. The CFs were cleaned to eliminate dirt and debris, sterilized to remove pathogens, and then dried before being finely ground.

2.2. Biochar production

Two distinct biochars were generated using a doping strategy, where specific amounts of dopants were added to each biomass feedstock. The choice of doping amounts (8 % w/w) for each feedstock was determined based on preliminary studies, aiming to achieve a well-balanced composition, and to capture the interactive effects. For the production of the CF-based biochar, a mixture of 460 g of CF and 60 g of OP was thoroughly mixed, resulting in a composition of 92 % CF and 8 % OP. Similarly, in the case of the OP-based biochar, a blend of 460 g of OP and 60 g of CF as a dopant was prepared, leading to a composition of 92 % OP and 8 % CF.

The production of biochar was conducted using a retort heating method in a top-lit updraft reactor. The biomass mixtures were loaded into the reactor and operated under controlled conditions to limit the availability of oxygen and avoid combustion. The process took place at ambient temperature and pressure. To monitor the temperature variations within the reactor, an infrared thermometer (Cason, CA380, Singapore) was employed. Further details about the reactor can be found in our previous research papers [26-28]. Temperature measurements were recorded at 10-min intervals throughout a total duration of 120 min. The biochar yield was determined using the following equation:

$$Yield(\%) = \frac{W_{CB}}{W_{RB}} \times 100 \tag{1}$$

Where the carbonized biomass weight is denoted as W_{CB} and the weight of the raw biomass is denoted as W_{RB}. The biochar resulting from a mixture of 92 % CF and 8 % OP is labeled as CF92OP8-BC, whereas the biochar produced from a combination of 92 % OP and 8 % SB is designated as SB92OP8-BC.

2.3. Characterization techniques

Fourier Transform Infrared Spectroscopy (Scimadzu, FTIR-8400S) analysis was performed using a spectrometer equipped with appropriate software and accessories. Biochar samples were ground and mixed with potassium bromide (KBr) powder to form pellets for analysis. FTIR spectra were recorded to identify the functional groups and chemical bonds present in the biochar samples. The analysis was done at a wavelength range of 650-4000 cm^{-1}. Scanning Electron Microscopy (SEM; Phenom-World BV, Netherlands) imaging was performed to observe the surface morphology and microstructure of the biochar samples. The samples were prepared by mounting them on conductive stubs and coating them with a thin layer of conductive material. SEM images were captured at various magnifications to visualize the surface features, pore structure, and particle morphology of the biochars. Energy-Dispersive X-ray Spectroscopy (EDS) analysis was conducted using a scanning electron microscope coupled with an energy-dispersive X-ray detector. The biochar samples were coated with a conductive material (carbon) and subjected to SEM-EDS analysis. This technique allowed for the collection of elemental composition data to determine the distribution and content of elements in the biochars. The specific surface area and porosity of the biochars were determined using Brunauer-Emmett-Teller (BET; Quantachrome NovaWin Instruments v11.03) analysis. The biochar samples were degassed at a controlled temperature to remove any adsorbed moisture or gases. The degassed samples were then subjected to nitrogen adsorption-desorption isotherm measurements using a surface area analyzer. The BET method allowed for the calculation of specific surface area, pore volume, and pore size distribution of the biochars.

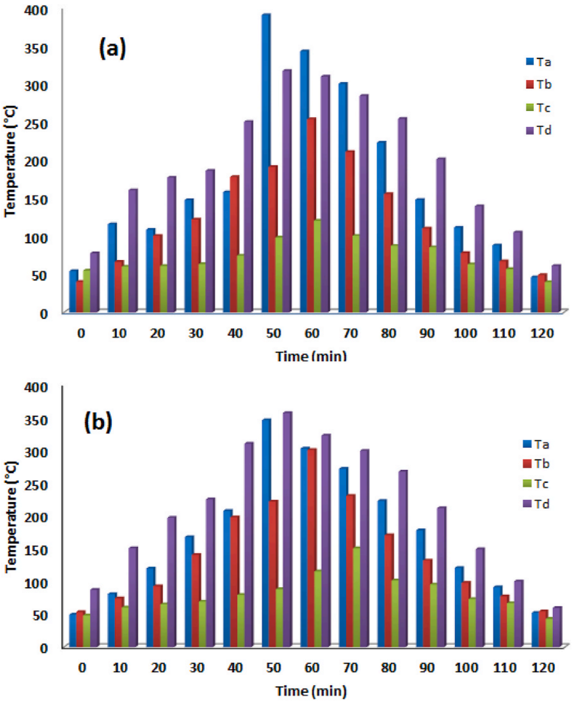


Fig. 1. Temperature profile for (a) OP92FC8-BC (b) CF92OP8-BC

2.4. Pot experiment

The nutrient deficient experimental soil of semiarid properties was collected from the Institute of Sugar Research in Ilorin, and was dried until air-dry and then sieved through a sieve with a mesh diameter of 500 μm. Pots with a capacity of 10 L were prepared. In the pots, biochar fortified soil samples and control were made on 500 g basis. Consequently, the mixtures were prepared by mixing 450 g of soil with 50 g of biochar until the capacities of the pots were achieved. The samples were marked as follows: CF92OP8-BC (a), OP92CF8-BC (b), and Control (c). There were 3 pots filled only with soil. The prepared soil-biochar substrates were left for 30 days. During this period, they were watered once every 7 days using 150 mL of distilled water. After this time, maize seeds were placed in the soil at a depth of 5 cm. Samples were prepared in three repetitions. The pots were placed in the open farm space and left for 70 days, watered once daily with 2 L of water.

3. Results and discussion

3.1. Effect of temperature

Temperature readings were collected at four different points within the reactor: T_a, T_b, T_c, and T_d. These points represent the bottom, middle, center, and top of the reactor, as previously reported [27]. The temperature readings were taken every 10 min over a

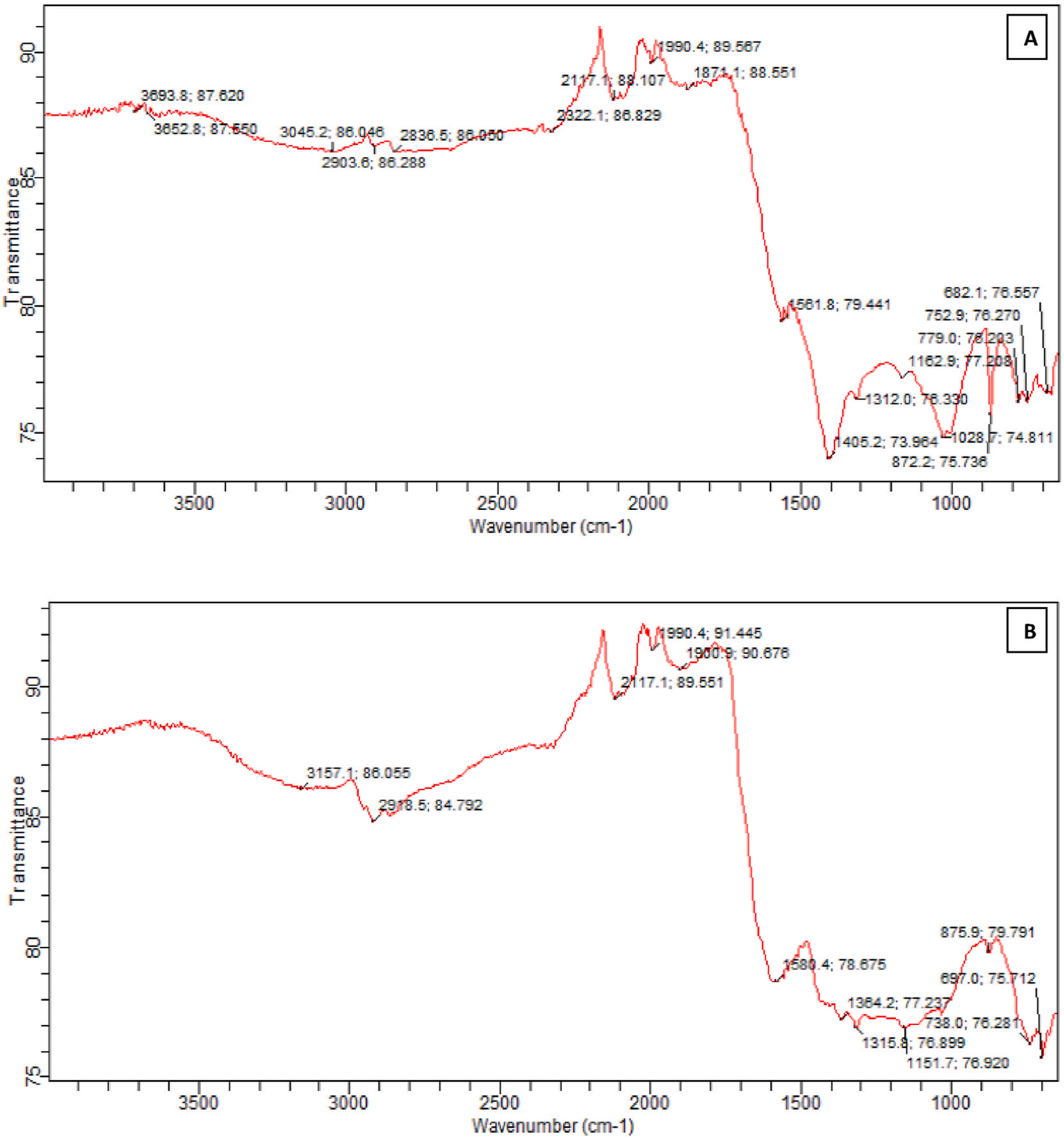


Fig. 2. FTIR spectra (a) OP92CF8-BC (b) CF92OP8-BC

period of 120 min. To create the temperature-time plot in Fig. 1a and **b** for SB92CF-BC and CF92SB-BC, respectively, the average temperature measurement for each point was calculated.

By examining the plots, it is evident that the temperature gradually increases from the beginning of the process until it reaches a peak temperature, after which it starts to decrease. The process is considered complete when the ambient temperature is recorded once again. Retort carbonization, being a self-regulating process, typically exhibits variations in temperature profiles depending on the feedstocks used. In the case of biomass carbonization, achieving a temperature of 250 °C or higher for a duration of 30 min is indicative of a successful process [29,30]. In this study, the temperature measurements exceeded the specified threshold, confirming the efficiency of the carbonization process and the production of high-quality biochar. Notably, a peak temperature of 390 °C and 357 °C was observed for SB92CF-BC and CF92SB-BC, respectively. The relatively low temperatures observed in the process are advantageous for generating biochar with a high yield.

3.2. Biochar yield

The biochar yield is an important parameter that reflects the efficiency of the biochar production process and determines the amount of biochar obtained from a given amount of biomass feedstock. In this study, the production process of OP92CF8-BC resulted in a biochar yield of 36 %. This indicates that 36 % of the initial OP biomass was successfully converted into biochar, while the remaining percentage was lost as gases, volatiles, and ash during the carbonization process. The relatively high biochar yield of 36 % suggests a proficient conversion of OP biomass into biochar, highlighting the potential of OP as a viable feedstock for biochar production. This high yield signifies that a significant portion of the biomass is transformed into a carbon-rich and stable material. Moreover, the yield indicates the preservation of carbon content during pyrolysis, which is a desirable outcome for effective biochar production.

On the other hand, the biochar production process for CF92OP8-BC yielded 23 % biochar. This comparatively lower yield can be attributed to the distinctive composition of CFs, primarily composed of keratin, which possesses a different chemical structure compared to lignocellulosic materials such as OP. Keratin-rich materials generally exhibit lower biochar yields due to the presence of nitrogen and sulfur, which have a tendency to volatilize during the pyrolysis process. A comparative yield of 28.2 % at 417 °C was observed by Adeniyi et al. [31] for CF-based biochar, while at a temperature of 300 °C, a higher yield of 40 % was reported by Almutairi et al. [32]. Despite the relatively lower biochar yield observed from CFs in this study, they still hold potential as a viable feedstock for biochar production. The conversion of a significant proportion (23 %) of CFs into biochar contributes to waste valorization and aids in reducing the environmental impacts associated with their disposal. Moreover, the resulting biochar may contain valuable nutrients, such as nitrogen, which can have positive effects when utilized as a soil amendment.

3.3. Characterization of biochar

The characterization of the produced biochars from onion peel and chicken feather, both as standalone feedstocks and with doping amounts of each, involved several techniques, including FTIR, EDS, SEM, and BET analysis. The obtained results shed light on the properties and characteristics of the biochars, enabling a comparative analysis and understanding of the influence of the feedstock composition.

3.3.1. FTIR analysis

FTIR analysis was conducted to investigate the functional groups present in the biochars. Fig. 2a and **b** displays the spectra of OP92CF8-BC and CF92OP8-BC, respectively. The FTIR spectra provided valuable insights into the chemical bonds and functional groups present in the biochars. In the case of OP92CF8-BC, characteristic peaks associated with cellulose, hemicellulose, and lignin were evident, indicating the presence of these components derived from lignocellulosic sources. Peaks at 3693 cm^{-1} and 3652 cm^{-1} corresponded to O–H stretching, representing free hydroxyls, alcohols, and phenol groups within the biochar [33]. Minor peaks were also observed at 2903 cm^{-1} and 2836 cm^{-1}, indicating aliphatic C–H stretching vibrations. The strong peak at 2117 cm^{-1} indicated the stretching vibrations of $C\equiv C$ in alkyne compounds. The peak at 1561 cm^{-1} could be attributed to the stretching vibrations of C=C in aromatic rings [34]. The fingerprint region of the spectrum displayed prominent peaks, including those at 1405 cm^{-1} and 1312 cm^{-1}, which indicated C–O bending and stretching vibrations of carboxylic acids, respectively [13]. The presence of C=O stretching vibrations from aromatic primary and secondary alcohols was observed at 1028 cm^{-1}, indicating the presence of cellulose, hemicellulose, and lignin components in the original OP feedstock. Peaks at 779 cm^{-1} and 752 cm^{-1} were attributed to out-of-plane C–H deformations, while the peak at 682 cm^{-1} indicated the N–H deformation of primary and secondary amine groups, similar to findings reported by Patra et al. [35] for OP extract.

Contrarily, CF92OP8-BC displayed distinct peaks associated with keratin, the main protein component found in feathers. A minor peak at 3157 cm^{-1}, indicating O–H stretching, confirmed the minimal contribution of hydroxyl groups to the CF backbone. The peak at 2918 cm^{-1} could be attributed to C–H asymmetric stretching vibrations of alkenes [36]. A peak at 2117 cm^{-1} suggested the formation of triple bonds ($C\equiv N$), indicating successful carbonization [37]. The peak at 1580 cm^{-1} corresponded to N–H bending vibrations of primary amines. Additionally, the peak at 1364 cm^{-1} represented C–N stretching vibrations of amides [38]. A minor peak at 1151 cm^{-1} indicated the asymmetrical stretching of S–O groups [39]. Peaks observed at 875 cm^{-1} and 697 cm^{-1} indicated the deformation vibration of the C–S bond, which originated from the amino acid cysteine [40]. The presence of various functional groups, including amino, carbonyl, and sulphonates, in the structure of CF92OP8-BC provides numerous adsorption sites for pollutants in water treatment. The incorporation of CF into the OP biochar and vice versa resulted in combined FTIR spectra, demonstrating the presence of characteristic peaks from both cellulose and keratin.

3.3.2. *SEM analysis*

SEM imaging provided insights into the surface morphology and microstructure of the biochars. The result of the findings, taken at varying magnifications, is shown in Fig. 3a–d. The OP92CF8-BC displays a rougher and less distorted morphology, although the surface remains irregular with variations in particle sizes. Additionally, white patches are visible in certain areas of the surface. Upon closer inspection, some pores and interstices can be observed on the surface. The presence of these pores, along with the surface roughness, is consistent with the lignocellulosic nature of the base biomass, and they indicates a higher surface area for the biochar, making it suitable for diverse applications such as wastewater treatment and soil remediation [28,41].

In contrast, the CF92OP8-BC, depicted in Fig. 3 (C) and **(d)**, exhibits a heterogeneous and distorted surface morphology, characterized by various particle sizes. The larger particles possess a smooth and crystalline appearance. The scattered arrangement of particles results in significant empty space between them, and no distinct pores are visible. This lack of particle aggregation is consistent with previous findings on biochar derived from CF [18,42]. Although the CF structure appears to be preserved, the absence of well-defined pores can be attributed to the filling of voids by the OP dopant, which has been observed in previous studies [18]. The doped biochars displayed a combination of these morphological characteristics, indicating a blending of the two feedstocks' microstructures.

3.3.3. *EDS analysis*

EDS analysis was conducted to determine the elemental composition of the biochars. The result is presented in Fig. 4. The OP92CF8-BC showed a higher carbon content, which can be attributed to its lignocellulosic nature. However, both biochar samples demonstrate significant carbon concentrations, with weight percentages of 80.67 % and 67.55 % for OP92CF8-BC and CF92OP8-BC, respectively, indicating the effectiveness of the biochar production process. The chicken feather-doped biochar exhibits a nitrogen

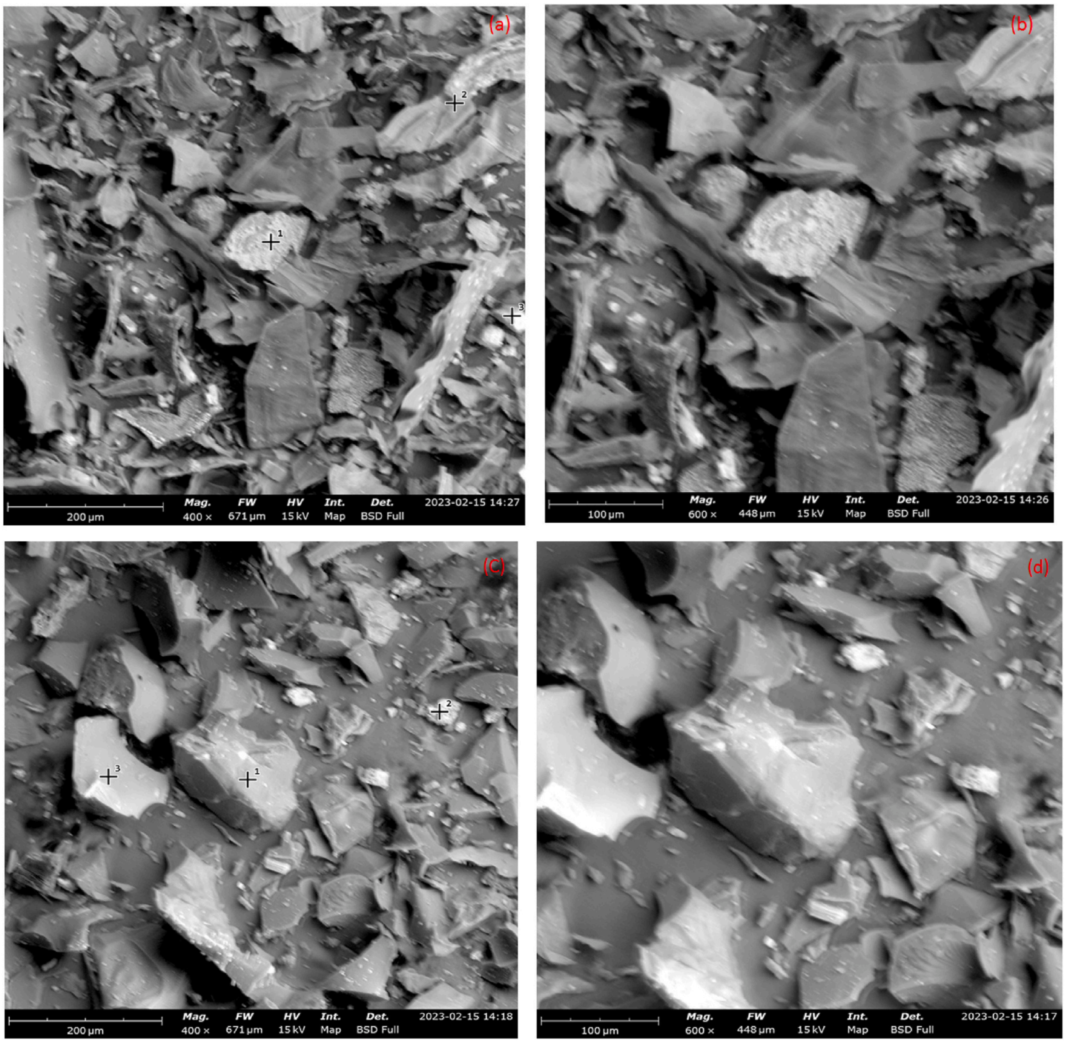
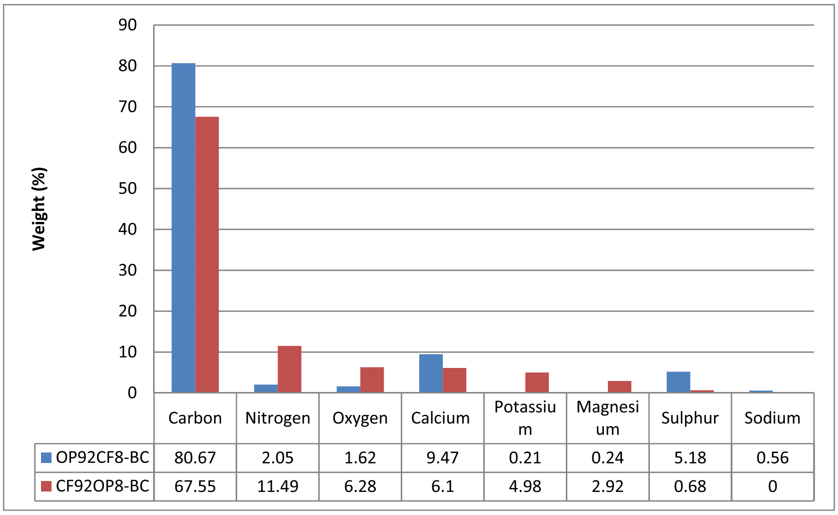


Fig. 3. SEM photographs of (a) OP92CF8-BC 400x (b) OP92CF8-BC 600x (c) CF92OP8-BC 400x (d) CF92OP8-BC 600x



	Carbon	Nitrogen	Oxygen	Calcium	Potassium	Magnesium	Sulphur	Sodium
🟦 OP92CF8-BC	80.67	2.05	1.62	9.47	0.21	0.24	5.18	0.56
🟥 CF92OP8-BC	67.55	11.49	6.28	6.1	4.98	2.92	0.68	0

Fig. 4. Elemental compositions of the biochars.

content of 11.49 wt%, confirming the nitrogen-rich keratin composition of CF. Previous studies have reported higher nitrogen contents in biochar derived from CF, such as 14.15 % [23] and 18.90 % [22]. The lower nitrogen content in the present study can be attributed to the doping method employed, suggesting that the SB dopant had an influence on the resulting biochar. Oxygen and calcium are additional elements found in notable amounts in the CF92OP8-BC sample. Conversely, OP92CF8-BC demonstrates relatively high concentrations of calcium (9.47 wt%) and sulfur (5.18 wt%). Other elements are present in trace amounts in both samples, as indicated in Fig. 2. These results validate the enrichment of specific elements in each biochar, reflecting the contribution of the respective feedstock materials. These variations in elemental composition highlight the influence of the dopant material on the biochar's elemental profile.

Furthermore, it is well recognized that soil mineral deficits have a major effect on maize productivity. Nitrogen (N), phosphorus (P), potassium (K), and, to a lesser degree, magnesium (Mg), sulfur (S), and micronutrients like zinc (Zn) are common mineral shortages that impact maize [43,44]. Since it was discovered that OP92CF8-BC and CF82OP8-BC biochar types were essential mineral fortified products, at the combinations of onion peels and chicken feather under study. Their applications can be used to fill in gaps and enhance soil health in order to increase grain output.

3.3.4. BET analysis

To determine the specific surface area and porosity of the biochars, a BET analysis was performed, and the results are presented in Table 1. OP92CF8-BC and CF92OP8-BC were found to have specific surface areas of 342.41 m^2/g and 200.80 m^2/g, respectively. Notably, OP92CF8-BC exhibited a relatively higher specific surface area and porosity. This can be attributed to the presence of cellulose and lignin in the structure of OP, which promote the formation of pores during the carbonization process [45]. On the other hand, the compact nature of keratin in CF92OP8-BC contributed to its lower specific surface area [37]. Comparing with previous studies [18,22,46], the doped biochars demonstrated intermediate specific surface areas and porosities, suggesting a blending effect resulting from the combination of the feedstock materials. Furthermore, OP92FC8-BC displayed a larger pore diameter (3.456 nm) compared to CF92OP8-BC (2.10 nm). The high surface area and porosity observed in these biochars are desirable characteristics for applications such as water purification and carbon storage [47,48].

4. Agronomic benefits of CF92OP8-BC and OP92FC8-BC

CF92OP8-BC (a), OP92CF8-BC (b), and Control (c) were applied to the nutrient-deficient experimental soil of semiarid properties. Fig. 5 displays the results of the various referenced treatments after nine weeks of maize planting, and Fig. 6 shows the harvested maize in its fully dried form. Table 2 summarizes the weight of the dried maize.

The weights of corncobs treated with biochar-both with and without cornhusks-across several treatment types are contrasted in

Table 1
Surface area and porous properties of the biochars.

Property	OP92FC8-BC	CF92OP8-BC
Surface area	342.41	200.80
Micropore volume	0.071	0.058
Total pore volume	0.101	0.082
Pore diameter	3.456	2.10

Fig. 5. Picture of the treatments at 9th weeks after planting with CF92OP8-BC (a), OP92CF8-BC (b) and Control (c).

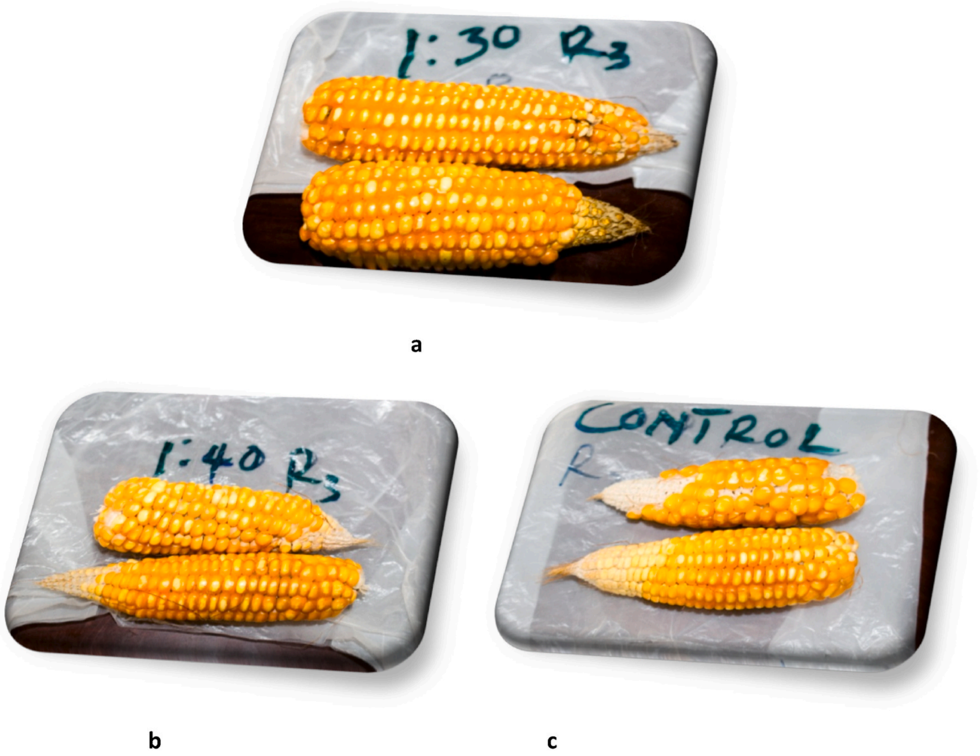


Fig. 6. Effect of CF92OP8-BC (a), OP92CF8-BC (b) and Control (c) treatments on yield of maize experiment.

Table 2
Effects of biochar treatment type on the cob weights.

Biochar Treatment Type	Cob Weight Without Cornhusk (g)	Cob Weight With Cornhusk (g)
CF92OP8-BC	299.37	434.64
OP92CF8-BC	239.75	395.02
Control	225.22	376.45

Table 2. The cob weight without cornhusk (g) produced with the treatment types CF92OP8-BC, OP92CF8-BC, and control were 299.37 g, 239.75 g, and 225.22 g, respectively. Additionally, for cases of cob weight with cornhusk, the proportional weights increased at 434.64 g, 395.02 g, and 376.45 g, respectively.

The maize output without cornhusk for the CF92OP8-BC treated soil has the highest cob weight, 299.37 g, while the output with cornhusk also has the maximum cob weight with cornhusk, 434.64 g. When compared to the other treatments, the CF92OP8-BC treated soil appears to encourage the highest cob weight, both with and without cornhusk, suggesting potentially better effectiveness in boosting cob growth. Furthermore, soil treated with OP92CF8-BC produced without cornhusk, the weight of the cob is 239.75 g, and with cornhusk, it is 395.02 g. Although this treatment is less successful than the CF92OP8-BC treatment, it nevertheless improves cob weight as compared to the control. The as-received soil, also referred to as control Treated soil, yielded 225.22 g of maize in the Without Cornhusk case and 376.45 g in the with cornhusk case. In both categories, the cob weights of the control treatment are the lowest. Indicating that both biochar treatments (CF92OP8-BC and OP92CF8-BC) are successful in raising cob weight, this creates a baseline for comparison.

As previously positioned in the literature, the quantity of photosynthetic results that are converted to cobs is shown by the weight of the cob, with and without cornhusk for each treatment type, where the weight of the cob is directly correlated with the amount of photosynthate that translocated into grains [49,50]. As shown in Table, nutrients that are involved in the synthesis of chlorophyll are evenly distributed throughout grades. Prior research reports have also shown that biochar nutrients have comparable impacts on maize output [43,44].

Both of the biochar treatments (CF92OP8-BC and OP92CF8-BC) are successful in making the maize weigh more than the control at different grain yield manifestations. The CF92OP8-BC treatment is the most successful of these. The findings imply that cob weight can be greatly increased by using biochar treatments, specifically CF92OP8-BC, which may be advantageous for agricultural productivity. The use of biochar to boost crop yields is further supported by the increased cob weight with cornhusk.

5. Implication of the study

The implications of this study are significant for several reasons. Firstly, the production and characterization of biochars derived from unconventional biomass, specifically onion peel and chicken feathers, expand the range of potential feedstocks for biochar production. By utilizing these agricultural residues and waste materials, this study demonstrates the possibility of transforming low-value biomass into valuable carbon-rich materials. The results of this study provide insights into the properties and potential applications of the produced biochar. The characterization analyses, including FTIR, SEM, EDS, and BET, shed light on the chemical composition, surface morphology, elemental distribution, and porosity of the biochars. These findings contribute to the knowledge base of biochar research, allowing for a better understanding of how feedstock composition and doping materials influence biochar properties. This knowledge can be utilized in the design and optimization of biochar production processes to tailor biochar properties for specific applications.

The biochars produced from OP and CF exhibit promising properties for various applications. OP-based biochar, with its higher specific surface area and porosity, can be suitable for soil amendment, carbon sequestration, and pollutant adsorption. Its potential as a soil amendment can enhance nutrient retention and improve soil fertility. On the other hand, CF-based biochar, with its nitrogen-rich composition, holds promise for soil fertility enhancement and pollutant removal. The biochars derived from the combination of OP and CF through doping strategies provide a balance of carbon and nitrogen content, which can be advantageous for applications such as wastewater treatment and long-term carbon storage. Furthermore, the utilization of unconventional biomass feedstocks for biochar production offers environmental and economic benefits. Onion peel and chicken feathers are abundant agricultural residues and waste materials, and their conversion into biochar contributes to waste valorization and reduces environmental impacts associated with their disposal. This study showcases the potential for sustainable waste management and resource utilization by transforming these biomass feedstocks into value-added biochar materials.

6. Conclusion

In this study, the production and characterization of biochar derived from onion peel and chicken feathers with different doping amounts were investigated. The biochar production process was efficient, resulting in biochar with desirable properties. The introduction of CF into the OP biochar increased the nitrogen content and modified the surface morphology, while the addition of OP into the CF biochar influenced the carbon content and porosity. FTIR analysis revealed characteristic functional groups from both lignocellulosic and keratin sources in the respective biochars. SEM imaging showed distinct surface morphologies, with the OP-based biochar having a rough and porous structure, while the CF-based biochar displayed a heterogeneous and distorted surface. BET analysis indicated significant differences in surface areas and pore properties, highlighting the influence of feedstock composition on biochar properties. These findings contribute to the understanding of how different biomass combinations can affect the properties of biochar. The results also suggest that applying biochar treatments, particularly CF92OP8-BC, can significantly improve cob weight, which may be beneficial for agricultural productivity. Consequently, the produced biochars hold potential for applications in soil amendment and pollutant removal, showcasing the possibility of utilizing the combined lignocellulosic and non-lignocellulosic biomass sources for sustainable waste management and resource utilization.

Disclosure statements

Ethics approval and consent to participate

Not applicable.

Consent for publication

The authors have unanimously decided that this manuscript be sent for possible publication.

Consent to publish

Not applicable.

CRediT authorship contribution statement

Adewale George Adeniyi: Data curation, Conceptualization. **Ebuka Chizitere Emenike:** Writing – original draft. **Abdelrahman O. Ezzat:** Visualization, Funding acquisition. **Kingsley O. Iwuozor:** Investigation, Formal analysis. **Omar H. Abd-Elkader:** Resources, Formal analysis. **Hamad A. Al-Lohedan:** Resources, Data curation. **Toluwalase Ojeyemi:** Visualization, Data curation. **Harvis Bamidele Saka:** Methodology, Investigation. **Stephen Sunday Emmanuel:** Project administration, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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