

# Camel Vs Cow Dung Biochar: A Review on Production, Characterization, And Application Potential

Vinika Manglani<sup>1</sup>, Teena Pareek<sup>2</sup>, Prity Sharma<sup>3</sup>

<sup>1</sup>Assistant Professor, Department of Physics, Parishkar College of Global Excellence, Jaipur

<sup>2,3</sup>Assistant Professor, Department of Chemistry, Parishkar College of Global Excellence, Jaipur

**Abstract**—Biochar derived from animal manure has emerged as a promising material for sustainable environmental management and agricultural applications. This review provides a comprehensive analysis of recent research (2024–2026) on the production, properties and applications of biochar derived from camel dung and cow dung based on 155 published studies. The findings reveal a clear disparity in the research maturity of the two feedstocks. Cow dung biochar has been extensively studied with well-established physicochemical properties including surface areas upto 117.57 m<sup>2</sup>/g at a pyrolysis temperature of 550°C, pH values ranging from 6.49 to 10.19, and biochar yields between 30.63% and 64.81%, depending on pyrolysis conditions. Its applications are diverse including soil fertility enhancement and environmental remediation through adsorption of heavy metals and organic pollutants. In contrast, camel dung biochar

represents an emerging research area with limited but promising finding particularly in the removal of copper and chromium from aqueous solutions. However, detailed characterization and large-scale application studies remain scarce. This review identifies significant research gaps in camel dung biochar and highlights the need for further investigations to optimize production processes, enhance material properties and expand practical applications. Overall, animal manure-derived biochar demonstrates strong potential as a sustainable solution for waste management, soil improvement and environmental protection.

**Index Terms**—Biochar, Camel dung, Cow dung, Pyrolysis, Physicochemical properties, Environmental remediation, Heavy metal adsorption, Sustainable agriculture

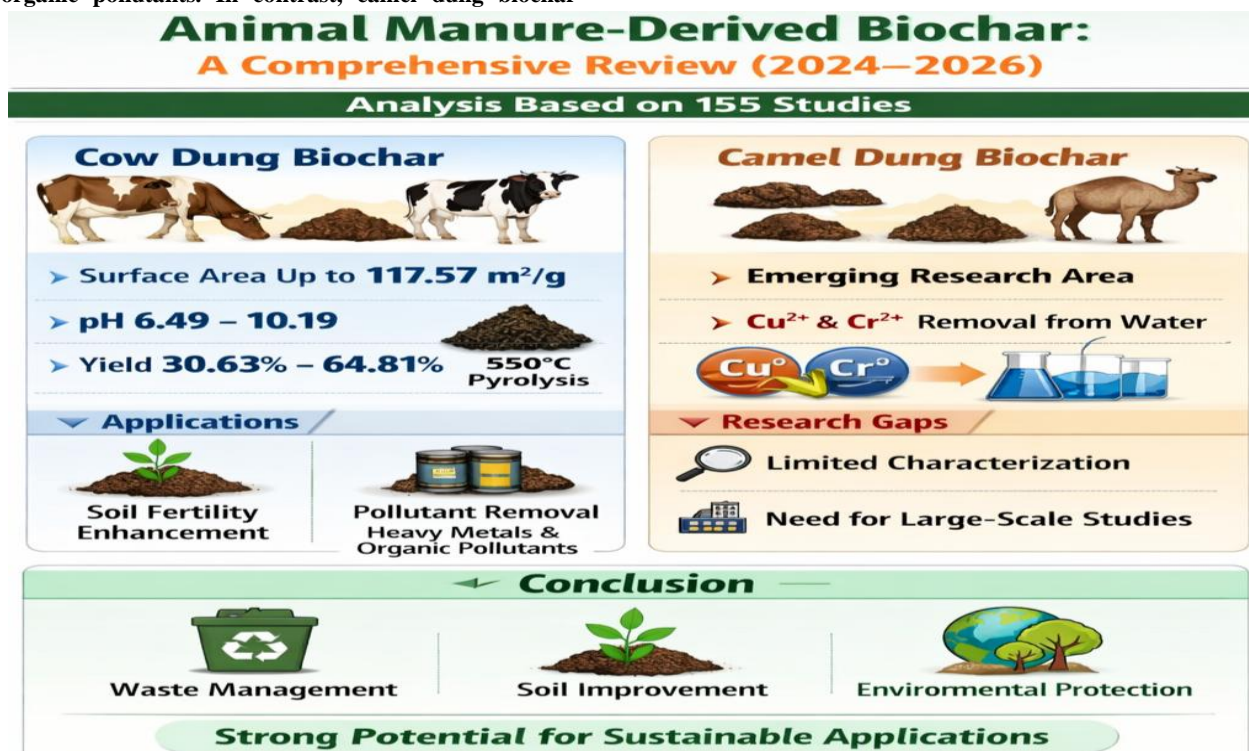


Figure-1 Graphical Abstract

## I. INTRODUCTION

Animal manures are another rich feedstock for biochar as a sustainable source due to their abundance, good chemical composition and ability to solve several issues of interest at the same time. The extensive research on biochar derived through camel dung and cow dung as livestock feeds has drawn serious attention as a viable source of biochar production since the two livestock feeds have regional significance and environmental impact particular to them (8). The worldwide livestock population generates huge amounts of manure which should be handled properly to avoid environmental pollution and to recover maximum resources, which is essential as livestock provides transportation, milk, meat and fiber (9).

Camel husbandry is of great significance in arid and semi-arid areas within Africa, the Middle East and parts of Asia where camels form an important livestock for millions of people, offering transportation, milk, meat and fiber. Meanwhile, cattle rearing is among the biggest sources of animal waste in the world and the environmental impacts may be very serious unless it is well controlled, such as greenhouse gases, water contamination and soil erosion among others (15). Pyrolysis of these organic wastes into biochar can be used in several ways such as reduction in the volume of wastes, sequestration of carbon, eradication of pathogens, and generation of a valuable soil amendment with a variety of environmental uses (2). The process of its formation is thermal decomposition under oxygen-restricted conditions at temperatures most commonly between 300°C and 900°C, which leads to the formation of a carbon-rich material with increased stability and porosity as well as special physicochemical characteristics (9).

Recent studies have shown that animal manure-based biochar has the potential to be used in different applications such as improving soil fertility by retaining nutrients, heavy metal fixation in polluted soils, adsorbing organic pollutants in water and soil and reducing greenhouse gas emissions in agricultural systems (12). The porous nature and large surface area of biochar allow contaminants to be adsorbed effectively, and its alkaline nature can neutralize soil acidity, thereby increasing the nutrient availability of the soil (18).

Nevertheless, little work has been done on the comparative evaluation of camel dung versus cow dung biochar with most studies concentrating on individual feedstocks instead of systematic comparison under controlled conditions. This prevents the best choice of feedstock for a particular application and also restricts understanding of the effect of animal type and diet on biochar properties and performance. Additionally, geographical variation in livestock management, climatic factors, and the availability of feedstock require localized research to inform actual application (16).

The purpose of this review is to summarize contemporary information about camel dung and cow dung biochar, their production routes, physicochemical characteristics, nutrient profiles, their environmental uses and a comparative performance evaluation. This analysis will be conducted with references to recent publications (most of them published in 2024–2026) that provide information about the latest trends, technological changes, and gaps in research in this rapidly developing area. Special focus is put on pyrolysis conditions yield of biochar, surface area, porosity, pH, cation exchange capacity (CEC), nutrient content, effects on soil fertility, as well as the application of biochar in environmental remediation such as adsorption of heavy metals and organic pollutants (18).

There is a scanty comparative data available between camel dung and cow dung as biochar feedstocks under controlled experimental conditions (49). The two substances are organic waste materials of ruminant animals, yet their structural variation might be due to different dietary habits, digestive physiology, and environmental adaptation. Camel dung can be rich in fibre because of consumption of desert vegetation and more effective extraction of nutrients whereas cow dung composition depends widely on feeding practices, including pasture to concentrate ratios.

## II. FEEDSTOCK CHARACTERISTICS

### 2.1. Camel Dung Characteristics:

Camel dung is a special type of feedstock that has its peculiarities due to the specific physiology and adaptation of its animals to desert conditions. The properties of camel dung have received less research attention than other livestock manures, both due to the

concentration of camel populations in specific areas and the lower level of research investment in these regions. A single study on dromedary dung based on various modes of husbandry in the Ouargla area offered qualitative assessment data, but no particular compositional information is exhaustively collected in the existing literature (23). The fibrous structure of camel dung, due to the dietary constituents of the animal such as drought-resistant vegetation and thorny shrubs, could regulate the pyrolysis characteristics and subsequent biochar characteristics. Camels have effective digestive systems that help them extract most of the nutrients from sparse vegetation, which may influence the composition of leftovers used as manure (25), but systematic data on elemental analysis, proximate analysis and moisture content of camel dung feedstock remain a knowledge gap (28). Thermogravimetric studies of camel dung have been carried out to learn about its pyrolysis behavior, kinetics and thermodynamic features but particular compositional information is not comprehensively described in the available literature. The analysis of camel dung mixed with date stone indicates that there may be a possibility of using co-pyrolysis to improve biochar properties and increase the range of feedstocks that can be used where both date stones and camel dung are available (29).

## 2.2. Cow Dung Characteristics

The concept of cow dung as a biochar feedstock has been widely described in the scope of several studies throughout the world. The content is usually rich in organic matter and variable in moisture content, 60–80 percent in fresh manure with moisture content varying based on the method of storage the diet consumed and management methods. The composition of cattle manure can be significantly dependent on factors such as the diet of animals (pasture-based feed systems vs. grain-fed feed systems), age of animals, seasonal changes and post-collection processes (45). It has been found that cattle dung is a good source of plant nutrients, such as phosphorus (P), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg) and other micronutrients, which may concentrate during pyrolysis to improve the nutritional value of the resulting biochar (37). Chemical studies have revealed that cattle dung has high levels of these elements, which can be concentrated during pyrolysis and give it nutritional

agricultural benefits (38). The physical properties of cattle manure have been systematically assessed, including bulk density, particle size distribution, water holding capacity and thermal properties. Fresh cow manure usually has a bulk density of 800–1000 kg/m<sup>3</sup> and a specific heat capacity with reference to moisture content. These physical properties have an influence on the handling, storage and preprocessing needs for biochar production (53). Another key characteristic is the microbial composition of cow dung, which can contain a variety of bacteria and fungi, and that can change the nature of decomposition and needs to be taken into account when producing biochar, to guarantee the absence of pathogens. The organic composition contains cellulose, hemicellulose, lignin, proteins and lipids in different proportions depending on the dietary content and efficiency of digestion among the animals (42).

## 2.3. Comparative Feedstock Analysis

Transitioning from pasture-based grazing to concentrated feed systems involves moving livestock from a forage-based diet to an intensive, energy-dense feeding strategy, often featuring total mixed rations (TMR) or high grain supplementation (57). The quantity of ash in animal manure that concentrates in the form of inorganic biochar during the pyrolysis process varies with the feedstocks used and can greatly alter the characteristics of biochar, such as pH, nutrient content and biochar use. An increase in ash content will usually cause greater alkalinity and higher nutrient levels in biochar but may reduce carbon levels and stability (75). The regionality and seasonal changes of these feedstocks also vary considerably, with camel dung being more widespread in desert arid parts of Africa, the Middle East and some parts of Asia whereas cow dung is distributed globally. This geographical determinant will affect the research priorities but will also affect the feasible aspects of biochar production systems in terms of their practical application, logistics and economic viability. The manure properties are influenced by climatic conditions in various areas as drier weather may lead to a decrease in moisture content and an increase in stability in storage (64).

### III. PYROLYSIS CONDITIONS AND YIELD

#### 3.1. Camel Dung Pyrolysis

The camel dung pyrolysis research has been minimal in the reviewed literature which represents a huge gap in knowledge relative to cow dung biochar production. Thermogravimetric analysis has been used to study the nature of pyrolysis, kinetics and thermodynamic behavior of camel dung to provide a baseline of thermal decomposition behavior. The experiment studied camel dung as a feedstock and in mixtures with date stone, implying its possible use in co-pyrolysis to maximize biochar properties and processing rate (45). Camel manure blends have been studied for biochar production and pyrogas production was reported at 623.78 kg/hr. after a specific production context. Nonetheless, the specifications of the optimal pyrolysis temperature, residence time, heating rate and percentage of biochar yielded are not fully identified in the current literature. This absence of systematic process optimization data is a serious research gap that restricts commercial development and active implementation (36). Co-pyrolysis of camel dung with other biomass in the region, including date palm waste, has also been proposed as a method of enhancing biochar properties as well as improving the economic viability of the process in areas where both feedstocks occur. The properties of biochar such as surface area, porosity and ash composition can be changed by co-pyrolysis under the influence of synergistic reactions during thermal conversion (48).

#### 3.2. Cow Dung Pyrolysis

Pyrolysis of cow dung has been widely researched under different temperatures, residence times and reactor types. A comprehensive systematic description of cow manure biochar production at temperatures of 400°C, 550°C and 700°C under a nitrogen atmosphere of 3 hours duration has been reported. These parameters are common slow pyrolysis settings for livestock manure transformation that balance biochar product output, land development and economics of the process (69). Pyrolysis temperature has a strong effect on biochar yield of cattle manure, which is in agreement with the basic principles of biomass thermochemical conversion. It has been found that yields declined at 300°C to 56.10–64.81 % and at 500°C to 30.63–41.98 % in biochars made from different feedstocks, including cattle dung. This drop

in yield with increasing temperature occurs because organic material is being broken down through the degradation of organic matter and volatile matter is released to a greater extent as the temperature increases (42). The influence of pyrolysis temperature on physicochemical and structural properties of biochar derived from agricultural wastes has been thoroughly studied and it has been found that, in general, increased temperature leads to lower yields but improved properties such as surface area, aromaticity and carbon stability. A temperature range of 300 to 700°C is the most researched for cow dung biochar production (64). Pyrolytic transformation of cattle manure under various atmospheric conditions (nitrogen, carbon dioxide) has been explored to understand the effects of pyrolysis environment on the distribution of products and biochar properties. The study focused on value-added product production, which included bio-oil and syngas in addition to biochar, supporting the idea of integrated biorefinery (45). Livestock manure pyrolysis has been investigated using factorial experimental designs to statistically optimize the operating conditions to achieve desired biochar properties.

#### 3.3. Pretreatment Effects

Pretreatment method can have a major effect on pyrolysis behavior and biochar properties. A study on production of porous biochar using cow dung with phosphoric acid and sodium hydroxide chemical pretreatments has shown an improvement in pore development and surface area over untreated feedstock (44). Pre-processing alters the feedstock structure and composition, which favors certain pyrolysis processes and biochar properties. Acid washing pretreatment with dilute acids has been investigated in terms of its influence on thermogravimetric properties and pyrolysis kinetics of cattle manure in micro-tubing reactors (45). The effect of moisture content and drying techniques on pyrolysis behavior is also identified, but no systematic studies have been performed on camel and cow dung in particular. Heat transfer and the development of volatile products during pyrolysis can be influenced by preprocessing such as reduction of particle size (46).

#### 3.4. Process Optimization

A comparison of various thermochemical conversion pathways such as pyrolysis and hydrothermal

carbonization has been performed using cow dung digestate and shows that biochar produced by pyrolysis has a higher surface area and carbon content whereas that produced by hydrothermal carbonization preserves a greater number of oxygen-containing functional groups and nutrients (47). In order to optimize pyrolysis conditions for particular biochar uses, various goals must be balanced such as yield, property development, energy usage and emissions control (48). Multi-objective optimization methods based on response surface methodology and machine learning are becoming tools of process development (49). Reactor design, heating rate gas flow patterns and heat transfer mechanisms affect the efficiency and properties of biochar production using manure feedstocks, whereas emphasis is placed on liquid generation in fast pyrolysis (50). Biochar production systems can be made more efficient and economical by energy integration and heat recovery approaches, especially at large scale. Effective thermal management and utilization of pyrolysis gases to generate combined heat and power are of primary importance to biochar production processes in the long run (52).

#### IV. PHYSICOCHEMICAL PROPERTIES (PH, SURFACE AREA, POROSITY, CEC)

##### 4.1. Surface Area and Porosity

One of the most important factors influencing the adsorption capacity and reactivity of biochar for environmental applications is its surface area. The surface area characteristics of cow manure biochar vary according to the pyrolysis conditions, especially temperature. Among the temperatures tested (400°C, 550°C, and 700°C), systematic characterization showed that cow manure biochar produced at 550°C (CMB550) had the largest specific surface area of 117.57 m<sup>2</sup>/g. (38) In contrast to the original feedstock, which usually has very little surface area this shows substantial surface development. (38)

Manure-derived biochar's temperature-dependent surface area development follows a pattern whereby moderate temperatures (500–600°C) frequently result in maximum surface area due to ideal pore opening without excessive pore collapse, which can occur at higher temperatures. (53) Depending on feedstock characteristics and production conditions, surface area

values for animal manure biochar typically range from 10 to 200 m<sup>2</sup>/g. (54)

Scanning electron microscopy (SEM) analysis has confirmed extensive porous network formation in the production of porous biochar from cow dung using chemical pretreatment with phosphoric acid and sodium hydroxide. (44) In chemically treated samples, X-ray diffraction analysis showed the development of graphitic carbon and porous morphology. (44) Chemical activation is a useful method for increasing surface area beyond what thermal treatment can accomplish on its own. (55)

Applications of biochar are greatly impacted by porosity characteristics, such as pore size distribution — micropores (<2 nm), mesopores (2–50 nm), and macropores (>50 nm). While larger pores enable mass transfer and can hold larger molecules, micropores offer a large surface area for the adsorption of gases and small molecules. (56) When biochar is added to soil, its porous structure influences microbial colonization, aeration, and water retention. (57)

##### 4.2. pH Characteristics

Biochar pH represents a crucial property affecting soil amendment applications, environmental interactions, and chemical reactivity. Research indicates that biochar pH increases progressively with pyrolysis temperature due to the concentration of basic ash components and decomposition of acidic functional groups. (59) Cattle dung-derived biochar showed pH increases from 6.49–8.94 at 300°C to 9.84–10.19 at 500°C, demonstrating strong alkaline character at higher pyrolysis temperatures. (39)

This alkaline nature makes animal manure biochar particularly suitable for acidic soil amendment applications where pH correction is beneficial for crop production. (60) The liming effect of biochar can neutralize soil acidity and reduce aluminum toxicity in highly weathered tropical soils. (61)

Characterization of bone and dung biochars revealed alkaline properties with pH values ranging between 9 and 11, consistent with the high ash content typical of animal waste materials. (22) The alkaline nature of manure-derived biochars is attributed to the concentration of basic cations including calcium, magnesium, and potassium during pyrolysis, which form oxides and carbonates contributing to high pH. (22)

Co-pyrolysis studies with chicken manure and tree bark showed biochar pH varying between 7.96 and 10.2, demonstrating consistent alkaline behavior across different manure sources and co-pyrolysis conditions. (62) While this study did not specifically examine camel or cow dung, it indicates that manure-derived biochars generally exhibit alkaline characteristics regardless of specific animal source. (62)

The pH of biochar can influence its effectiveness for various applications including metal adsorption, nutrient retention, and organic compound sorption. (63) Higher pH generally enhances heavy metal immobilization through precipitation mechanisms but may reduce adsorption of some organic compounds that are less ionized under alkaline conditions. (64)

#### 4.3. Cation Exchange Capacity (CEC)

Cation exchange capacity represents an important property for nutrient retention applications, quantifying the biochar's ability to retain and exchange positively charged ions including essential plant nutrients. Biochar's CEC enables retention and exchange of nutrients including potassium, calcium, magnesium, and ammonium, reducing nutrient leaching and improving fertilizer efficiency (10).

However, specific CEC values for camel dung or cow dung biochar are not explicitly and systematically reported in the available literature, representing a significant knowledge gap. This absence of data limits quantitative comparison between feedstock types and hinders optimization for nutrient management applications. (65)

Comparative analysis and prediction of cation exchange capacity via summation methods have been investigated, examining the influence of biochar type and nutrient ratios on CEC development and measurement. This research contributes to understanding CEC variation among different biochar sources and suggests that summation approaches using elemental composition can provide CEC estimates when direct measurements are unavailable (11).

The CEC of biochar generally increases with oxidation and aging processes as oxygen-containing functional groups develop on carbon surfaces, providing negatively charged sites for cation attraction (66). Fresh biochar often has relatively low CEC compared to aged biochar or traditional soil organic matter (67).

Contrasting effects of pre-pyrolysis and post-pyrolysis incorporation of bentonite clay into manure biochar have been investigated for their impacts on nutrient availability, carbon stability, and physicochemical properties including CEC (68). Clay incorporation represents a strategy to enhance CEC and nutrient retention capacity of biochar materials (68).

#### 4.4. Structural Characteristics and Composition

X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR) characterization of biochar from manure and sewage sludge has been conducted to understand crystalline structure and functional group composition. (69) These analytical techniques provide insights into mineral phases, carbon structure, and surface chemistry that determine biochar behavior and applications. (69)

Comprehensive characterization studies have revealed that cattle manure-derived biochar contains various elements including calcium, phosphorus, magnesium, oxygen, sulfur, iron, manganese, chlorine, sodium, and aluminum, with zinc also present in analyzed samples. (22) This diverse elemental composition contributes to biochar's agricultural value as a nutrient source and to environmental applications including metal immobilization. (22)

The carbon structure of biochar becomes increasingly aromatic and graphitic with higher pyrolysis temperatures, as evidenced by XRD analysis showing graphitic carbon peaks. (44) This structural transformation contributes to the enhanced stability and environmental persistence of biochar carbon. (70) Surface functional groups including carboxyl, hydroxyl, carbonyl, and phenolic groups can be identified through FTIR analysis and influence biochar's chemical reactivity, adsorption behavior, and interaction with soil minerals and organic matter. (71) The abundance and type of functional groups vary with pyrolysis temperature, with lower temperatures retaining more oxygen-containing groups. (72)

Higher surface areas offer more sites for chemical reactions, nutrient adsorption, and microbial attachment. Surface area and porosity characteristics are crucial for biochar reactivity and adsorption capacity. (10) However, there is a substantial knowledge gap that prevents direct comparison with cow dung biochar, because specific surface area data for camel dung biochar is not systematically available in the reviewed literature. (58)

## V. NUTRIENT COMPOSITION AND SOIL FERTILITY

### 5.1. Nutrient Content and Release

The large surface area and porous nature of biochar allow nutrients to be retained and released in a controlled manner, minimizing nutrient losses through leaching and volatilization while maintaining nutrient availability to crops through slow release processes.(2) Bone and dung biochar characterization showed a wide variety of nutrient composition, with bone char containing calcium, phosphorus, magnesium, oxygen, nickel, chlorine and sodium, and dung char containing calcium, phosphorus, magnesium, oxygen, sulfur, iron, manganese, chlorine, sodium and aluminum.(22) Silicon in biochar is another valuable nutrient that has not received much attention in farming. Comparison tests of silicon forms and leaching properties indicated that the pyrolysis biochar and hydrochar of cow dung digestate are silicon-rich materials that can be used as soil supplements in silicon-enhancing foliage plants. The problem of phosphorus availability and conversion in biochar-amended soils has been widely researched because of the significance of phosphorus in crop yields and the environmental issue of phosphorus losses. Studies have been conducted systematically to determine the effects of biochar on soil inorganic phosphorus components and available phosphorus using cow dung-derived biochar. (73) The study revealed that the application of biochar considerably increases the available phosphorus content in the soil, thereby increasing soil fertility and the overall nutrient composition of the soil.

### 5.2. Soil Amendment and Crop Production Effects

The addition of cow manure biochar has been demonstrated to positively impact plant growth and biomass, store organic carbon in the soil, and help reduce the levels of heavy metals in plants by adsorbing metals in contaminated soils.(38) Characterization of cow manure biochar depicted beneficial effects on the growth of *Salicornia herbacea* L., whereby the application of biochar increased the biomass of the plants and enhanced the overall health of the plants in saline soils.(38) *Calopogonium caeruleum* and maize growth have been enhanced with the use of functionalized and cross-linked biochar made from cow dung, functionalized with phosphoric acid, and cross-linked with urea to establish a superior

compound with better nutrient delivery and soil conditioning properties.(74) The interaction between biochar and organic fertilizer derived from burning cow dung at 400°C and 700°C demonstrated synergistic effects in terms of reducing phosphorus leaching and increasing crop productivity.(75) Modified biochars made using agricultural waste have been found to exhibit different effects on the growth of maize (*Zea mays* L.) plants depending on modification methods and biochar properties; biochar matched to soil type and crop requirements can yield the best results.(76) The impact of biochar on the composting of cow manure and kitchen waste has been studied, and it has been shown to increase the rate of stabilization of organic matter, improve the quality of compost, and reduce composting greenhouse gas emissions.

### 5.3. Microbial Community and Enzyme Activity of Soil

The use of biochar has a significant impact on the microbial communities of soil, enzyme activity, and the overall biology of soil. Biochar research studies showed that cow dung biochar application raises soil pH and elevates soil phosphorus functional gene copy numbers including *phoC*, *phoD*, *gcd* and *pqqc*. These genetic markers demonstrate an increased ability of microbes to dissolve and mineralize phosphorus. Phosphate solubilizing bacteria populations such as *Fusarium* and *Sphingomonas*, which help to make unavailable phosphorus accessible to plants, are also increased by biochar. (73) This is another important way biochar increases nutrient availability, beyond the direct provision of nutrients. Examination of the effects of biochar additives on the manure-compost-soil process has shown that biochar creates a beneficial environment that supports beneficial microorganisms and modifies environmental conditions such as pH, moisture, and aeration that affect microbial activity.(78) Studies have established that biochar is able to reduce ammonia volatilization, decrease odor emission, and prevent pathogenic activity in manure handling systems.(2) The porosity and adsorption properties of biochar also lead to better environmental quality, safer working conditions and less nitrogen released to the surrounding environment as a result of farming operations. Increased nitrogen retention in cow manure composting with biochar has been studied, and its application rate and biochar

characteristics demonstrate substantial environmental and economic gains. (80)

#### 5.4. Long-term Soil Quality Effects

Effects of biochar derived from biomass on the physical, chemical, and biological characteristics of soils have been thoroughly reviewed, citing various advantages to agricultural sustainability.(2) The material has been shown to balance soil pH levels towards neutral, increase porosity and pore connectivity, and improve nutrient cycling efficiency, which can be beneficial in improving soils irrespective of soil texture.(81) The conversion of biochar into a platform that increases manure carbon residence time in soil has been explored and found to significantly increase the longevity of manure-derived carbon relative to direct manure application.(82) The agronomic and environmental potential of biochar derived from various organic wastes has been considered, and the performance of biochars has been found to be best in relation to various indicators such as crop yield, nutrient retention, and contaminant immobilization, depending on the relationship between biochar properties and the target application objectives and site requirements.(83)

## VI. ENVIRONMENTAL APPLICATIONS (HEAVY METAL ADSORPTION AND ORGANIC POLLUTANTS ADSORPTION)

### 6.1. Heavy Metal Adsorption

An example of such application of camel dung biochar to copper (II) and chromium (III) ion removal in aqueous solutions has already been demonstrated using adsorption and kinetics studies. (84) This is one of the few specific applications of camel dung biochar found in the reviewed literature and indicates potential success in water treatment and remediation applications.

Biochar made from cow manure has been widely researched for heavy metal adsorption and immobilization in water and soil systems. The porous structure, high surface area, alkaline pH, and various functional groups are associated with effective metal binding under several mechanisms such as surface complexation, electrostatic attraction, precipitation, and ion exchange.(85) Studies have shown that cow manure biochar is capable of reducing heavy metal levels in plants through its adsorption of metals in

polluted soils, consequently limiting the uptake of these metals by plants and thus eliminating risks of food chain contamination. Biochar production techniques and their effects on physicochemical properties and heavy metal adsorption capacity have been comparatively analyzed, involving slow, fast, and hydrothermal carbonization techniques, with each technique producing biochar possessing unique characteristics and properties to perform metal immobilization tasks.(86) The adsorption of heavy metals on biochar surfaces is a complex process that depends on the metal species, the nature of biochar itself, and the solution chemistry. Surface functional groups of carboxyl, hydroxyl, and phenolic groups may form complexes with metal ions, and mineral constituents in high ash biochars may precipitate metals as carbonates, phosphates, or hydroxides depending on pH and metal concentration. (87)

### 6.2. Adsorption of Organic Pollutants

The adsorption of organic pollutants depends on the number and types of available surfaces. Pyrolytic conversion of cattle manure to biochar has been reported to be effective in the adsorption of organic pollutants in the form of antibiotics, in particular sulfamethoxazole, in contaminated water, through hydrophobic interaction and  $\pi$ - $\pi$  bonding on the aromatic carbon surfaces of biochar, which can efficiently absorb organic contaminants in water.(42) The chemical pretreatment of cow dung into porous biochar for use in the dye removal process, using methylene blue as a model pollutant, has been reported,(44) and the results indicated that the cow dung porous biochar had a greater surface area and porosity, leading to better removal of synthetic dyes from industrial wastewater. However, there is no systematic comparison of the efficacy of camel and cow dung biochar in the removal of organic pollutants in water treatment systems, as the present literature only reports results of high surface area and porosity properties that create vast adsorption sites.(10) The structure-activity relationships that govern the adsorption of modified biochar for the removal of humic acid from water have been reviewed, and surface modifications that can optimize adsorption capacity for specific contaminants have been elaborated.(91)

The removal of petroleum hydrocarbons can be achieved by applying either synthetic or biological

methodology. The bioremediation of petroleum-contaminated soils with the assistance of biochar was demonstrated using cattle dung biochar prepared at 300°C, which exhibited a 33.01% rate of total petroleum hydrocarbon (TPH) degradation, which was much higher than the control treatment where biochar was not applied.(39) Enhanced petroleum degradation in biochar-amended soils is influenced by many factors such as improvement of soil aeration and moisture, creation of microbial habitat, adsorption of toxic compounds, and possible co-metabolic processes.(93) Amendments for the optimization of diesel and crude oil degradation in soils using organic waste such as biochar have been studied under specific conditions of the regions under investigation.(94) Findings are useful in the practical remediation of petroleum-contaminated soils.(94)

### 6.3. Combined Environmental Applications

The characteristics of biochar allow management of several environmental problems concurrently in a systemic manner. The design of production and post-processing modifications of biochar into more engineered materials has been reviewed with special attention given to applications in environmental sustainability, including water treatment, soil remediation, and emission control.(95) The development of biochar as an application and research topic in the control of environmental pollution has been thoroughly reviewed and records progress in the areas of heavy metal fixation, organic contaminant removal, and greenhouse gas emissions reduction.(96) The system of biochar-supported microorganisms is one approach to persistent organic pollutant remediation, where the adsorptive properties of biochar in combination with the degradation ability of microorganisms can be used to achieve higher rates of pollutant degradation and lower bioavailability of contaminants in the environment.(97) Challenges in the safe environmental use of biochar have been surveyed, and risks and unintended effects have been identified that should be addressed in the case of responsible deployment of biochar.

## VII. COMPARATIVE ASSESSMENT

### 7.1. Research Maturity and Data Availability

The comparative analysis indicates that there is a marked difference in the research maturity and

availability of data between camel dung and cow dung biochar. Research on cow dung biochar has been widely conducted with detailed studies, systematic application studies, multi-scale process optimization, and field validation work,(99) compared to camel dung biochar, which is a relatively new area and needs to be investigated further in the future.(100) Among the 155 papers reviewed in this study, most touched upon cow dung, cattle manure, or bovine waste biochar with different applications and production conditions, but few studies (less than 5) addressed camel dung applications or properties. The geographical distribution of research is also highly concentrated in regions with well-established agricultural research systems such as North America, Europe, East Asia, and parts of South America, with research on arid regions being under-represented in the scientific literature.

### 7.2. Physicochemical Property Comparison

According to the available information in the reviewed literature, cow dung biochar has well-reported physicochemical characteristics across various studies and production conditions. Biochar produced at 550°C has been reported to have surface areas of up to 117.57 m<sup>2</sup>/g, which falls within a moderate range of values for animal manure biochar. (38) The alkaline pH range of 6.49 to 10.19 is consistent with the range observed in animal manure biochar products. (39) Biochar yield distribution of 30.63–64.81 percent at different temperatures provides strong evidence of the significant impact of pyrolysis temperature on biochar properties. These properties are systematically defined under varied production conditions, allowing optimization for different applications and providing reliable data for process design and economic evaluation.(15) A consensus in property trends with pyrolysis temperature has been reported in multiple independent studies, confirming the reproducibility and generalizability of results among different research groups and facilities.(16) The properties of camel dung biochar are not fully reported in the existing literature, and most of its physical and chemical properties remain unquantified or have not been compared with cow dung biochar functionality.(17) The available literature only hints at the possibility of applying camel dung biochar for heavy metal adsorption, particularly in the removal of copper and chromium from aqueous solutions, but

quantitative adsorption capacity data are not provided, limiting comparison of its performance with that of cow dung biochar. The lack of systematic characterization data on camel dung biochar represents the most important knowledge gap identified in this review and prevents meaningful quantitative comparison of feedstock types across most property dimensions following pyrolysis under controlled and varied conditions. (18) The main priority of future research should be to provide thorough physicochemical characterization of camel dung biochar under controlled and varied pyrolysis conditions.

### 7.3. Application Scope and Performance

The applications of cow dung biochar described in the reviewed literature span several fields, including improvement of soil fertility through nutrient retention and stimulation of microbial activity, immobilization of heavy metals in polluted soils and sediments, adsorption of organic pollutants in water and wastewater, removal of petroleum hydrocarbons, reduction of greenhouse gas emissions in agricultural systems, enhancement of the composting process, and carbon sequestration to mitigate climate change. (10–12) An understanding of how production conditions affect performance in specific applications can be used to optimize the use of cow dung biochar, whereby low temperature biochar (300–400°C) may be better suited for nutrient retention applications due to higher CEC and nutrient content, whereas high temperature biochar (500–700°C) may be more appropriate for contaminant adsorption applications due to its high surface area and stability. The most commonly reported application of camel dung biochar involves its use in the treatment of aqueous solutions, specifically for copper(II) and chromium(III) ion removal via adsorption. (84) Although this represents a promising application area with potential implications for water treatment in arid regions, the limited scope indicates substantial untapped potential in the application of camel dung biochar for arid soil agricultural amendment, other environmental remediation processes, and integrated waste management systems. The lack of comparative performance data under controlled conditions prevents conclusive determination of the relative merits of camel and cow dung biochar with regard to particular applications. (17) The various properties of each

feedstock may lead to different benefits for specific applications, and scientific testing is essential to define these correlations. (18)

### 7.4. Regional Implications and Real-life Applications

The geographical distribution of studies is indicative of realistic considerations regarding feedstock availability. Research on cow dung biochar has been distributed worldwide, consistent with global cattle farming practices. (83) Research on camel dung biochar has been found to be concentrated in regions with high camel populations. (84) This regional aspect affects not only research priorities but also implementation strategies. Camel dung biochar may provide specific benefits in arid regions where camel farming is common and other soil amendment solutions are not readily available. (85) Economic factors such as feedstock collection, processing costs, transportation, and market value play an important role in determining the feasibility of implementation. (86,87)

## VIII. FUTURE PROJECTIONS AND CONCLUSION

### 8.1. Research Gaps and Opportunities

The review finds that there are some significant research gaps. Comprehensive physicochemical characterization of camel dung biochar under varying pyrolysis conditions would be a priority. (88) Comparative research studies on camel and cow dung biochar under the same experimental conditions would contribute to better biochar production efficiency. There is a widespread need to examine the agricultural uses of camel dung biochar in terms of soil amendment effects, crop yield and nutrient dynamics. (91)

### 8.2. Sustainability and Policy Considerations

Camel and cow dung biochar systems need to be evaluated concerning life cycle sustainability (93) and have been considered alongside the principles of the circular economy (94) to create value from waste streams. The climate change implications of biochar systems should be carefully considered. (96) Sustainable functions of biochar in the process of carbon sequestration and climate change mitigation have been discussed. (97) Regional climate adaptation strategies could also determine the most effective biochar application strategies. (98)

### 8.3. Conclusion

This extensive review indicates that there is considerable disparity in research development between camel dung and cow dung biochar. Some of the physicochemical properties of cow dung biochar, such as surface areas of up to 117.57 m<sup>2</sup>/g, alkaline pH properties, and various applications including soil fertility enhancement and environmental remediation, have been well documented.(27,28) The scarcity of research on camel dung biochar suggests potential for its application in heavy metal removal, however, without significant characterization and application investigation, its sustainable application in waste management and soil improvement in the arid regions of the world remains to be established.(52) The priorities of future research are the systematic characterization of camel dung biochar properties comparison under controlled conditions, and investigation into agricultural and environmental applications.(100) The synthesis of existing knowledge highlights both the maturity of cow dung biochar studies and the underexplored potential of camel dung biochar.

### REFERENCES

- [1] A. Majumder *et al.*, “Biochar from animal waste and its applications,” in *Waste-to-Energy*, Singapore: Springer, 2025. doi: 10.1007/978-981-95-0425-1\_7.
- [2] K. S. Ramesh *et al.*, “Impacts of biomass-derived biochar on plant nutrition, soil function, and agricultural sustainability: A review,” *Environ. Qual. Manage.*, 2025. doi: 10.1002/tqem.70198.
- [3] A. Kushwaha *et al.*, “Deciphering cleaner and sustainable frontiers in scientific cow waste valorization: A review,” *Environ. Monit. Assess.*, 2024. doi: 10.1007/s10661-024-13120-0.
- [4] BOURENANE, “Qualitative assessment of dromedary (*Camelus dromedarius*) dung according to husbandry systems in the Ouargla region,” 2024.
- [5] V. Kalra *et al.*, “Cow dung-based economy: The future technological prospects,” in *Advances in Agriculture*, 2024. doi: 10.58532/v3bcag20p4ch1.
- [6] S. M. Fakhar *et al.*, “Advancing modified biochar for sustainable agriculture: A comprehensive review on characterization, analysis, and soil performance,” *Biochar*, vol. 7, 2025. doi: 10.1007/s42773-024-00397-0.
- [7] A. Ingle *et al.*, “Biochar: A comprehensive review of production, properties and applications,” *Int. J. Adv. Biochem. Res.*, vol. 8, 2024. doi: 10.33545/26174693.2024.v8.i1sa.282.
- [8] A. I. Hassan *et al.*, “Biochar application for soil quality improvement: An overview,” in *Soil Science*, IntechOpen, 2024. doi: 10.5772/intechopen.114192.
- [9] M. A. Khan *et al.*, “Biochar production and characteristics, its impacts on soil health, crop production, and yield enhancement: A review,” *Plants*, vol. 13, no. 2, p. 166, 2024. doi: 10.3390/plants13020166.
- [10] J. A. Antonângelo *et al.*, “Comparative analysis and prediction of cation exchange capacity via summation: Influence of biochar type and nutrient ratios,” *Front. Soil Sci.*, vol. 4, 2024. doi: 10.3389/fsoil.2024.1371777.
- [11] W. Munzeiwa *et al.*, “Influence of biomass baseline potential on biochar properties and performance for targeted applications,” *Discover Water*, vol. 5, 2025. doi: 10.1007/s43832-025-00254-6.
- [12] A. Sharma *et al.*, “Policies and strategies for sustainable use of biochar in Indian agriculture,” *BioResources*, vol. 19, no. 3, 2024. doi: 10.15376/biores.19.3.sharma.
- [13] P. Parthasarathy *et al.*, “Pyrolysis characteristics, kinetic, and thermodynamic analysis of camel dung, date stone, and their blend using thermogravimetric analysis,” *Biomass Convers. Biorefinery*, 2022. doi: 10.1007/s13399-021-02249-4.
- [14] H. Mupambwa *et al.*, “Vermicomposting of camel manure with fly ash and microbial inoculants: Effects on nutrients and heavy metals,” 2024.
- [15] M. Wilson *et al.*, “What’s in cow dung manure? Insights into its potential for supporting plant defense system,” *bioRxiv*, 2024. doi: 10.1101/2024.11.20.624574.
- [16] A. I. Hassan *et al.*, “Evaluation of some physical properties of cattle manure,” *Soil Stud.*, vol. 13, 2024. doi: 10.21657/soilst.1601783.
- [17] A. Nekhubvi, “Investigation of chemical composition and specific heat capacity of cow dung and water mixture,” in *Environmental*

- Sciences*, IntechOpen, 2024. doi: 10.5772/intechopen.112168.
- [18] F. J. S. Calça *et al.*, “Durability and nutritional aspects of feces to dung-inhabiting fungi development,” *Sci. Rep.*, vol. 14, 2024. doi: 10.1038/s41598-024-82059-6.
- [19] W. C. Lepodise *et al.*, “Characterization of bone and dung biochars for potential use as precursors for artificial fertilizers,” *Spectrosc. Lett.*, vol. 57, 2024. doi: 10.1080/00387010.2024.2353725.
- [20] N. Kanagasuppurathinam *et al.*, “Production and analysis of physical, chemical and physicochemical properties of biochar from various feedstock sources,” *Int. J. Plant Soil Sci.*, vol. 36, 2024. doi: 10.9734/ijpss/2024/v36i44484.
- [21] A. Al-Rumaihi, “Production of biochar from pyrolysis blends: Techno-economic analysis and life cycle assessment,” 2024.
- [22] M. A. Shin *et al.*, “Systematic characterization of cow manure biochar and its effect on plant growth,” *Sustainability*, vol. 16, no. 8, p. 3396, 2024. doi: 10.3390/su16083396.
- [23] J. Hu *et al.*, “Bioremediation of petroleum-contaminated soils with pyrolysis biochar,” *Clean Soil Air Water*, 2025. doi: 10.1002/clen.70018.
- [24] S. Sathyabama *et al.*, “Effect of pyrolysis temperature on physicochemical properties of biochar,” *ACS Omega*, vol. 10, 2025. doi: 10.1021/acsomega.5c00120.
- [25] I. Rizianiza *et al.*, “Investigation of process parameters in pyrolysis of sheep manure,” *AIMS Energy*, vol. 13, 2025. doi: 10.3934/energy.2025037.
- [26] R. Singh *et al.*, “Production of porous biochar from cow dung and its application,” *Int. J. Innov. Sci. Res. Technol.*, 2024. doi: 10.38124/ijisrt/ijisrt24apr2455.
- [27] C. Jeon *et al.*, “Influence of acid washing on pyrolysis kinetics of cattle manure,” *Korean J. Chem. Eng.*, vol. 41, 2024. doi: 10.1007/s11814-024-00308-w.
- [28] Y. Zheng *et al.*, “Silicon forms and leaching characteristics of biochar from cow dung digestate,” *J. Anal. Appl. Pyrolysis*, vol. 183, p. 106846, 2024. doi: 10.1016/j.jaap.2024.106846.
- [29] G. Ravindiran *et al.*, “Production and modification of biochar for environmental sustainability,” *Biochar*, vol. 6, 2024. doi: 10.1007/s42773-024-00350-1.
- [30] M. Chaudhary *et al.*, “Comparative analysis of biochar production methods and heavy metal adsorption,” *J. Environ. Chem. Eng.*, vol. 12, 2024. doi: 10.1016/j.jece.2024.113003.
- [31] H. Burezq, “Sustainable biochar production from date palms: A scoping review of solutions for Arab regions,” *Int. J. Agric. Nat. Resour.*, vol. 51, no. 3, 2024. doi: 10.7764/ijanr.v51i3.2526.
- [32] Y. Wang *et al.*, “Recent advances in the preparation and application of biochar derived from lignocellulosic biomass: A mini review,” *Polymers*, vol. 16, no. 6, p. 851, 2024. doi: 10.3390/polym16060851.
- [33] E. Dayoub *et al.*, “Chemical and physical properties of selected biochar types and application methods in agriculture,” *Agronomy*, vol. 14, no. 11, p. 2540, 2024. doi: 10.3390/agronomy14112540.
- [34] S. Yoon *et al.*, “Pyrolytic conversion of cattle manure into value-added products and application of biochar for adsorption of sulfamethoxazole,” *Chemosphere*, 2024. doi: 10.1016/j.chemosphere.2024.143493.
- [35] P. Machaieie, “Effect of pretreatment strategies on anaerobic digestion of dairy cow manure,” 2024.
- [36] S. Begum *et al.*, “Waste biomass-to-energy: Integrated thermochemical and biochemical conversion for resource recovery,” *Environ. Sci.*, 2024. doi: 10.1039/d4va00109e.
- [37] B. Mainali, “Combined thermochemical conversion as pretreatment of manure waste for environmental applications,” 2024.
- [38] A. Saylam, “Enhancing biomass conversion: Advanced modelling and process optimization for efficient biochar and heat production,” 2024.
- [39] A. K. Mensah *et al.*, “Impact of biochar application on soil physical and biogeochemical characteristics: A review,” *Appl. Environ. Soil Sci.*, 2025. doi: 10.1155/aess/3734167.
- [40] W. C. Otoni *et al.*, “Agronomic and environmental use of biochars derived from organic waste,” *J. Clean. Prod.*, 2024. doi: 10.1016/j.jclepro.2024.141826.
- [41] U. Nazim *et al.*, “Biochar as a climate-smart agricultural practice: Reducing greenhouse gas emissions and promoting sustainable farming,” *Phyton*, 2024. doi: 10.32604/phyton.2024.058970.

- [42] F. Amalina et al., "Environmental sustainability applications of multifunctional biochar developments: Current trends and advances," 2025. doi: 10.1016/j.grets.2025.100174.
- [43] M. Iqbal et al., "Effect of biochar on soil properties," in *Soil Science*, 2024. doi: 10.2174/9789815238068124010005.
- [44] A. Upadhyay et al., "Biochar as a sustainable agronomic tool, its limitations and environmental impact: A review," *Discover Agric.*, 2024. doi: 10.1007/s44279-024-00033-2.
- [45] B. C. Okoro et al., "Role of biochar in soil amelioration," in *Soil Science*, IntechOpen, 2024. doi: 10.5772/intechopen.1002906.
- [46] A. Lataf et al., "Co-pyrolysis of chicken manure with tree bark for reduced biochar toxicity and enhanced plant growth," *Sci. Rep.*, vol. 14, 2024. doi: 10.1038/s41598-024-62468-3.
- [47] Y. Ding, "Sustainable roles of biochar in carbon sequestration and climate change mitigation," *Appl. Comput. Eng.*, 2025. doi: 10.54254/2755-2721/2026.ka27142.
- [48] A. Mashwani et al., "Characterization and evaluation of different biochars as soil amendment under polluted environment," in *Environmental Science*, 2024. doi: 10.1016/b978-0-443-21562-9.00011-6.
- [49] T. Rupngam et al., "Impacts of bentonite incorporation into manure biochar on nutrient availability and carbon stability," *Agronomy*, vol. 15, 2025. doi: 10.3390/agronomy15082015.
- [50] B. A. Bezabeh et al., "Characterisation of biochar from manure and sewage sludge using XRD and FTIR," 2025. doi: 10.5194/egusphere-egu25-20231.
- [51] C. Banik et al., "Biochar-assisted agriculture: From healthy soil to healthy plants," 2025. doi: 10.20944/preprints202509.0214.v1.
- [52] A. B. Evaristo et al., "Biochar from lignocellulosic biomass: Importance of physicochemical characterization and decision analysis," 2024. doi: 10.20944/preprints202404.0916.v1.
- [53] S. K. Samal et al., "Approaches of biochar in ecosystem management: Current scenario and future perspectives," in *Environmental Science*, IntechOpen, 2024. doi: 10.5772/intechopen.1004288.
- [54] X. Han et al., "Enhancement of nitrogen retention in cow manure composting with biochar," *Agronomy*, vol. 15, no. 2, p. 265, 2025. doi: 10.3390/agronomy15020265.
- [55] V. R. Thapa et al., "Improving soil health through manure and biochar amendments under climate-smart agriculture," *Soil Sci. Soc. Am. J.*, 2025. doi: 10.1002/saj2.70129.
- [56] C. Banik et al., "Biochar as a platform to increase manure carbon residence time in soil," *GCB Bioenergy*, 2025. doi: 10.1111/gcbb.70055.
- [57] M. Zhao, "Research status and prospects of biochar materials for remediation of soil heavy metal pollution," *Appl. Comput. Eng.*, 2025. doi: 10.54254/2755-2721/2026.ka27121.
- [58] A. Kumar et al., "Biochar for nitrate removal from contaminated soil and water: Feasibility and future perspectives," *Biochar*, 2025. doi: 10.1007/s42773-025-00486-8.
- [59] T. M. C. Martiny et al., "Biochar's role in environmental remediation and resource optimization," *J. Clean. Prod.*, 2024. doi: 10.1016/j.jclepro.2024.142237.