Review Article

Biochar production technologies from agricultural waste, its utilization in agriculture and current global biochar market: A comprehensive review

Abstract

This review comprehensively describes biochar, the term which is gaining exponential attention nowadays. The technologies to convert the agriculture waste to biochar include slow pyrolysis, flash pyrolysis, and hydrothermal carbonization. Biochar production methods are based on batch processes and continuous processes. Biochar production processes and steps involved are also discussed. Different biochar reactors are also revived, including the continuous type of biochar reactor and microwave pyrolysis reactors. Kinetics of biochar, bio-oil, and syngas production is also revived briefly with kinetic equations. Uses of biochar are comprehensively revived and discussed, including advanced applications such as catalyst production, activated Carbon production, water treatment, soil amendment, etc. All biochar characterization methods are briefly described, including proximate analysis, ultimate analysis, physiochemical analysis, surface analysis, and molecular structure analysis. Factors affecting biochar production are revived in this article. Biochar yield from different crop waste s is tabulated with temperatures involved. Post-production processing methods of biochar are included in this review. The global biochar market and current status and opportunities are also revived, the data of biochar manufacturers in India are compiled. The utilization of biochar in agriculture is revived in two subcategories: the effect of biochar application on soil health and the effect of biochar application on crop yield. At last engineered or designed biochar concept is revived.

Key Words- Agricultural waste, Biochar, Activated Carbon, Continuous Biochar Reactor, pyrolysis, Biomass, Kinetics of pyrolysis.

Abbreviations: GW: Giga watt, GHG's: Green house gases, GDP: Gross domestic product, ASTM: American Society for Testing and Materials, TGA: Thermogravimetric analysis SEM EDX:Scanning electron microscopy with energy dispersive X-ray spectroscopy, FT-IR: spect: Fourier-transforminfrared spectroscopy, BET: Brunauer–Emmett–Teller, t/ha: tonnes per hector, CEC: Cation exchange capacity, EC: electrical conductivity, carbon monoxide (CO), carbon (C), hydrogen (H), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), sulfur (S), silicon (Si), potassium (K), aluminum (Al), calcium (Ca), phosphorous (P).

* Introduction

Globally, 140 billion metric tons of biomass is generated every year from agriculture[1]. According to recent MNRE-sponsored research, India's current biomass availability is projected to be over 750 million metric tonnes per year. According to the study, surplus biomass availability is anticipated to be over 230 million metric tonnes per year for agricultural wastes, equating to a renewable energy generation potential of around 28 GW[2].
Scientists and policymakers increasingly recognise biochar's potential significance in carbon sequestration[3]. Converting agricultural wastes into environmentally acceptable low-cost biochar is a sensible recycling method and cure for pollution control[4]. Agricultural waste biochar can be an efficient alternative strategy for managing pollutants because of its cheap cost, high efficiency, ease of use, ecological, and public safety reliability. India has taken the commitment of reducing GHG's emission intensity of its GDP by 33-35% from 2005 levels by 2030[5]. Biochar application can help reduce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions in the environment by increasing the carbon sink in soil[6]. Biochar has achieved significant advances in lowering greenhouse gas emissions, soil nutrient management, sequestering atmospheric carbon into the soil, enhancing agricultural output, and reducing environmental pollutants [7]. Biochar is becoming increasingly popular for soil fertility improvement because of its ability to enhance soil quality, boost crop production, and sequester carbon from the atmosphere-biosphere pool into the soil 8]. By storing atmospheric carbon in the soil for a long time, the application of biochar can reduce GHG emissions[9].

Objective

1. To study the existing biochar preparation technologies
2. To study recent advances in biochar technologies
3. To study the application of biochar in agriculture and allied sector
4. To study characterization method of biochar

1. What is Bio Char?

The term ‘biochar’ was coined by ‘Read’ (Read et al., 2004) to describe charcoal used for soil improvement[10]. Biochar is a carbon-rich substance produced by heating up organic materials without oxygen or in a limited supply of oxygen. In other words, bio char is produced by dry carbonisation or pyrolysis and gasification of biomass [11][12]. Pyrolysis is thermal decomposition process takes place in inert atmosphere. The pyrolysis process usually takes between 400 to 850 ℃ [13]. The thermal decomposition in a pyrolysis reactor takes place in order of hemicellulose, cellulose and lignin destruction in increasing order of temperature. during the pyrolysis hemicelluloses decomposes below 350 ℃ while cellulose the degradation occurs at temperature between 250 - 500 ℃ since the decomposition temperature of hemicellulose and cellulose overlap their degradation represented by only one peak is defined the primary pyrolysis [14]. The biochar is produced by various methods like slow pyrolysis, flash carbonisation, hydrothermal carbonisation etc[15]. In matters of hydrothermal carbonisation water is used as a medium for carbonisation while all other methods oxygen-free atmosphere is used for heating or biomass and then biochar is obtained[16]. The pyrolysis process is a process in which the biomass is converted into the biochar where; the first step is the moisture reduction step which occurs below 200 degrees℃ temperature. After moisture removal, the cellulose decomposition takes place in a temperature of two 400-500℃. At this temperature, biochar is produced [17].

2. Methods of Biochar production based on technology

Biochar is produced by the method of pyrolysis[18]., Pyrolysis of biomass is the thermal degradation of organic material in the absence of an oxidising agent, or in such a quantity that gasification does not occurs, to produce solid, liquid, and gas by products[19]. The following are the methods of biochar production according to technology employed.

2.1. Slow pyrolysis

The feedstock is heated slowly at a low heating rate (0.1 to 2°C per second) to moderate temperatures (400°C) for a long time in slow, or conventional, pyrolysis. The biomass is progressively devolatilized during slow pyrolysis, resulting in the generation of tar and char as the major products. Methane dominates the gas produced, with minor hydrogen, propane, ethylene, CO, and CO_2. Torrefaction is a slow pyrolysis process that is also known as mild pyrolysis[20]. Torrefaction of biomass is moderate pyrolysis that occurs under air conditions at temperatures ranging from 200 to 320°C, with primary pyrolysis beginning at 200°C. Even at the low heating rates used in torrefaction, the warm-up period is relatively short for the low temperatures used in torrefaction[21].

2.2. Flash carbonisation

The adjective "flash" is defined as of sudden origin and short duration a fire. By this, we can say that carbonisation occurs at higher heating rates and higher temperature for short period. The temperature involved in flash carbonisation are up to 1000 °C. for time duration up to few seconds[22].

2.3. Hydrothermal carbonisation

Among all conversion technologies, hydrothermal carbonisation is a promising technique[23]. It takes place in a closed reactor at a temperature of 180–280°C and a pressure of 2–6 MPa for 5–240 minutes[24]. Hydrothermal carbonisation creates a coal-like product called hydro char and aqueous (nutrient-rich) and gas phases (mainly CO_2) as by-products. The advantage of hydrothermal carbonisation is that biomass can be converted to carbonaceous solids without using an energy-intensive drying technique[25]. Figure 1 shows the process of hydrothermal carbonisation.

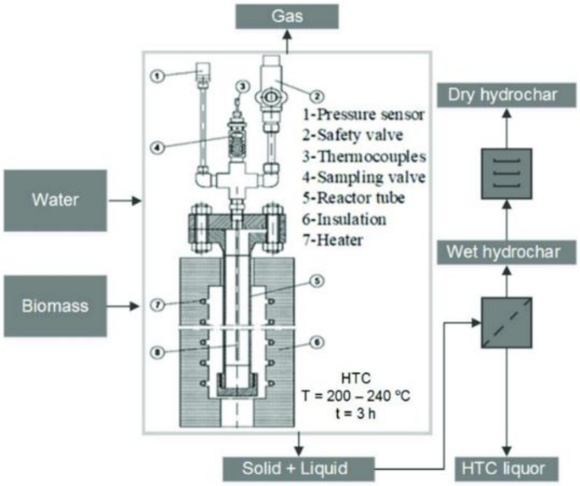

Fig.1 Hydrothermal Carbonization reactor [26]

3. Methods of Biochar production based on process

Based on the mode of operation, pyrolysis reactors can be classified as batch, semi-batch and continuous. There are some different biochar production processes as shown in Figure 2

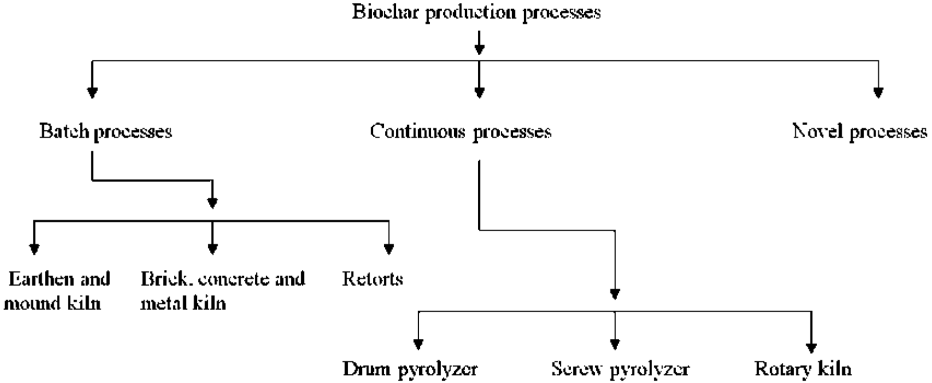

Fig. 2 Biochar production processes [27]

3.1. Batch Type Biochar Reactors

The batch type pyrolysis plant doesn’t need pre-treatment devices and the raw materials can be put into the reactor directly. In the batch-type biochar reactors, feed biomass materials are fed in different batches, and biochar preparation is achieved[28]. Biochar yield in batch type varies from 12.5 – 30%.

3.2. Continuous Biochar Reactor

As the name indicted the reactor, the biochar produced in the continuous uninterrupted way in the continuous biochar reactor[29]. It consists of the feed hopper, screw conveyor, heating mechanism etc, as shown in Figure 3 [30]. These types of reactors are suitable for uninterrupted commercial production of biochar.

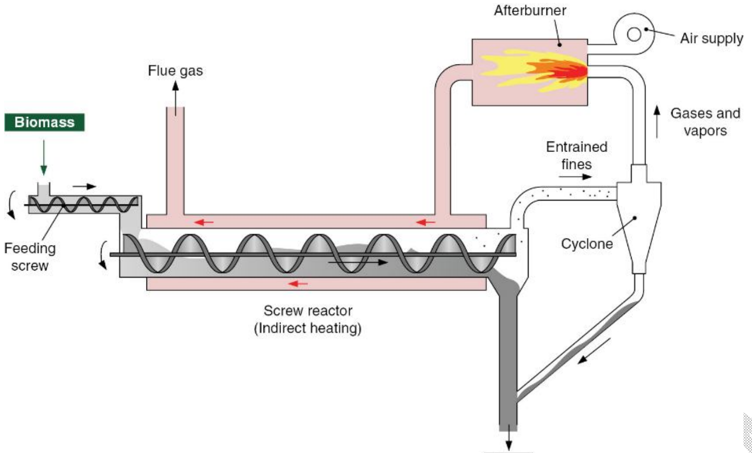

Fig. 3 Continuous Type Biochar reactor[30]

4. Steps involved in biochar Formation

4.1. Heating and Drying

The biomass is heated in this process until it reaches the necessary drying temperature. This procedure takes place at a temperature of 100 ℃ until all the moisture in the biomass has evaporated[32]. Ideally biomass should have a moisture content less than 15% when it enters the pyrolysis kiln to ensure high yield and quality biochar.

4.2. Torrefaction

Torrefaction is a thermochemical pretreatment process at 200–300 °C in an environment with low oxygen, which transforms biomass into a relatively superior handling, milling, co-firing and clean renewable energy into solid biofuel (coal-like pellets). It takes place at 200 to 300 ℃, and a constant temperature is achieved throughout the process. In this process the biomass is carbonised, and biochar is formed[33]. The steps involved in torrefaction process as shown in Figure 4.

4.3. Cooling

After the biochar is formed, the temperature is reduced before it is exposed to the air to stop further biomass degradation due to high temperature[34].

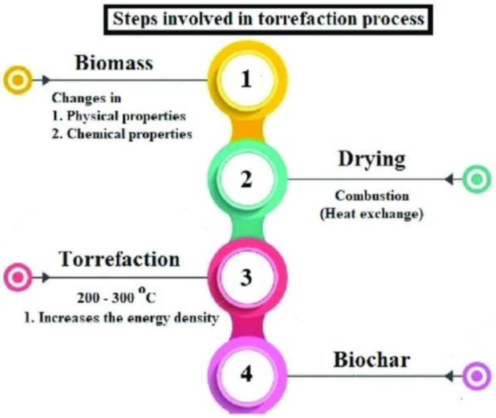

Fig. 4 Steps involved in torrefaction methods [34].

5. Biochar Production Units

5.1. Missouri type charcoal kiln

One typical batch system, the Missouri type charcoal kiln (Figure 5) takes charge of about 16,300 kg (18 tons) of wood and requires about 3 weeks for the complete cycle of manual loading, heating the kiln, carrying out the carbonisation over the temperature range of 260–370 °C, cooling and manually unloading the kiln[36].

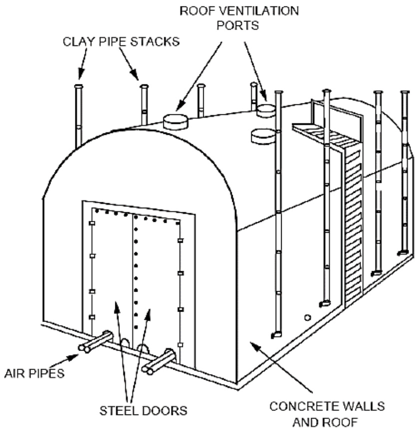

Fig. 5 Missouri type charcoal kiln[36]

5.2. *Continuous multiple hearth kiln*

In continuous multiple hearth kiln (Figure 6) produces about 2495 kg/hr (2.75 tons/hr) of charcoal [36].

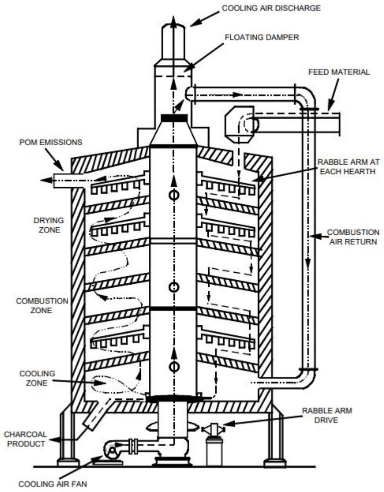

Fig.6 Continuous multiple hearth kiln[36]

5.3. *Horizontal auger continuous biochar production unit*

This type of unit uses the screw auger to convey the biomass in the hot reactor in which biomass is heated in inert conditions. The inert conditions are maintained by providing inert gases supply such as nitrogen, as shown in Figure [37].

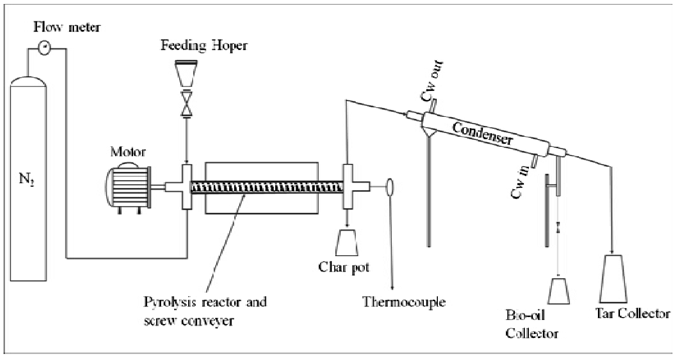

Fig. 7 Continuous screw auger Biochar reactor [37]

5.4. Microwave pyrolysis

Microwave-assisted pyrolysis (MAP) is a novel thermochemical technique for converting biomass into biofuel. MAP pyrolysis is faster, more efficient, selective, controlled, and adaptable than traditional electrical heating pyrolysis [38].

6. Kinetic model of Biochar Production

The pyrolysis process is divided into two parts in the pyrolysis model primary and secondary reactions[39]. The biomass decomposes into three product categories during the primary reaction: gas, bio-oils, and char (reactions K1, K2 and K3) as shown in Figure 8. Two parallel reactions (reactions K4 and K5) in the following figure further degrade the bio-oil into gas and char, referred to as secondary reactions [40].

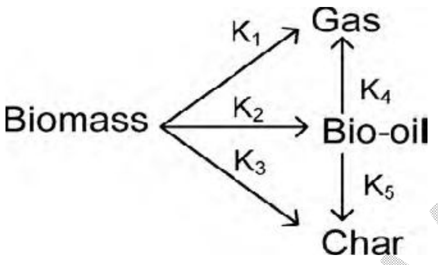

Fig.8 Biomass Pyrolysis kinetics [40]

Pyrolysis Kinetics Reactions which we can use for the prediction of the number of different compounds of pyrolysis are as follows [40]:

$$\frac{dm_{Gas}}{dt} = w_{gas} = (k1)(mBio) + (k4)(mOil) \qquad \text{….. Eq. 1}$$

$$\frac{dm_{Oil}}{dt} = w_{Oil} = (k2)(mBio) - (k4 + k5)(mOil) \qquad \text{….. Eq. 2}$$

$$\frac{dm_{Char}}{dt} = w_{Char} = (k3)(mBio) + (k5)(mOil) \qquad \text{….. Eq. 3}$$

$$\frac{dm_{Bio}}{dt} = (-k1 + k2 + k3)(mBio) \qquad \text{….. Eq. 4}$$

7. Uses of biochar

Biochar is a black charcoal-like substance[41]. It has been the subject of much discussion in recent days due to its remarkable benefits on soil and compost, is beneficial to more than just your garden. Biochar is one of the most essential elements for the earth's long-term sustainability. It may be incorporated into new organic systems for farming, construction, textiles, electronics and electricals, and various products[42]. The use of biochar as a soil supplement in agriculture has been the emphasis of these early uses, but other applications in environmental remediation engineering may be equally essential[43]. The following are the some of the uses of biochar are discussed here.

7.1. Biochar for Water treatment

Biochar has also been shown to be capable of removing a wide range of chemical and microbiological pollutants from aqueous systems[44]. Biochar's integration into the water-sanitation-nutrient-food nexus has numerous unique features[45]. it provides water security and health advantages, providing a low-cost adsorbent for water treatment. Biochar can be used for drinking water purification and can be used for the treatment of wastewater[46].

8.2 Biochar for soil health

Biochar's use in soils offers a lot of promise for enhancing soil fertility and encouraging plant development. Biochar can be used to manage a variety of soils because a variety of biomass sources can be employed as biochar feedstocks, and the feedstocks can be pyrolyzed at different temperatures. Biochar also has a large surface area, a well-developed pore structure, a high concentration of exchangeable cations and nutritional elements, and a high liming content[47]. Soil characteristics can be improved following biochar treatment. The large surface area and well-developed pore structure could boost water holding capacity and microbial abundance[48]. The number of exchangeable cations and nutrient elements could boost cation exchange capability and nutrient availability[49]. The abundance of liming in biochar is responsible for the elevated pH of soils. As a result, improving the soil's physical, chemical, and biological qualities boosts plant productivity [50]. Biochar products from various sources exhibited a wide range of capabilities and efficiency for soil contaminant stabilisation[51].

8.3 Textile industry Uses

Textiles are one of the most important industries in many low- and middle-income nations, particularly in Asia. Due to a lack of economical alternatives, leftover dye solution from textile industry dye facilities is frequently discharged to drains or into the environment. These colours have the potential to harm the environment and human health[52]. Effective filtration conditions were proven to remove the hazardous dyes followed by high dye adsorption onto pine-derived biochar (both in batch and column tests), and recommendations for water reuse were made [53].

8.4 Biochar as Fuel

Biochar made from corn cob and coconut shell biomass samples pyrolyzed at 800 ℃ displayed varied physical and chemical properties. Biochar made from these wastes has a higher volatile matter, fixed carbon, C, and H content, and a higher heating value or gross calorific value. This pyrolysis-to-biochar conversion can be used to replace fossil-derived fuels (coal, oil, etc.) with green renewable energy sources [54].

8.5 Biochar as a Catalyst

Various physical and chemical procedures can fine-tune biochar. Biochar has a high potential to replace costly and non-renewable conventional catalysts in this regard. Biochar-derived catalysts are effective in a variety of processes, including biodiesel generation, tar removal in bio-oil and syngas, NOx, syngas production, and biomass hydrolysis[55]. Surface functionality, surface area, porosity, and acidity of biochar catalysts, on the other hand, are strongly dependent on biomass origin, biochar formation circumstances, and pre/posttreatments [56].

9 Activated Carbon production from biochar

Because of its enormous specific surface area, activated carbon has been widely employed as a flexible adsorbent for gas separation, organic pollutant removal, and other applications. it has a large surface area, a porous structure, and excellent adsorption characteristics[52]. Numerous studies have been conducted on the preparation of adsorbents made of carbon with a large surface area for adsorption and gas separation is an important step in the process. Manufacturing may be done in two ways [57].

9.1 Physical Techniques

Physical activation or thermal activation refers to a process in which an increase in porosity is triggered by a high temperature in an oxidative environment[58]. Temperature, degree of activation, and kind of precursor all have a role in physical activation., It is preferred to activate biochar since oxygen in the air takes less activation energy than CO_2 or steam, making the total process more cost-effective [59].

9.2 Chemical Techniques

Chemical activation is a heat treatment method in which raw biochar combines with a chemical activating agent at 450 to 900 ℃. Inside the biochar, two sorts of reactions occur dehydration and oxidation, resulting in microspores. Chemical activation has the benefits over physical such as lower temperature, higher carbon yield, large surface area (3600 m^2/g), qualitative and quantitative microporosity (highly developed and regulated), and higher efficiency [59].

10 Carbon Sequestration

Biochar incorporation into the soil not only aids in carbon sequestration, but it also gives a better choice for agricultural waste management[60]. Due to its priming impact on the soil, biochar has been shown to reduce a significant amount of methane and nitrous oxide emissions from agricultural fields[61]. The kind of feedstock and pyrolysis condition affect biochar output, physical characteristics, and carbon content[62].

11 Biochar Characterisation and its methods

There are different biochar characterization methods as shown in Figure 9. The physicochemical features of biochar can alter soil nutrient and carbon availability, as well as providing physical protection from microorganisms from predators and pathogens[63]. This may change the soil's microbial diversity and taxonomy. The biochar produced by relatively low-temperature pyrolysis has a high amount of volatile matter, which includes Analytical elements and both hydrogen-Carbon and oxygen-Carbon ratios are measured on readily decomposable substrates that can sustain plant growth[64]. Biochar's are excellent markers of their nature. In order to assess the characteristics of biochar, the following characterisation methods are used. The characterisation of biochar includes the proximate analysis, ultimate analysis, physicochemical analysis, surface analysis and molecular of structural analysis, in these various tests are involved for the characterisation of biochar[65]. There are ASTM standards for characterisation of biomass and biochar[66].

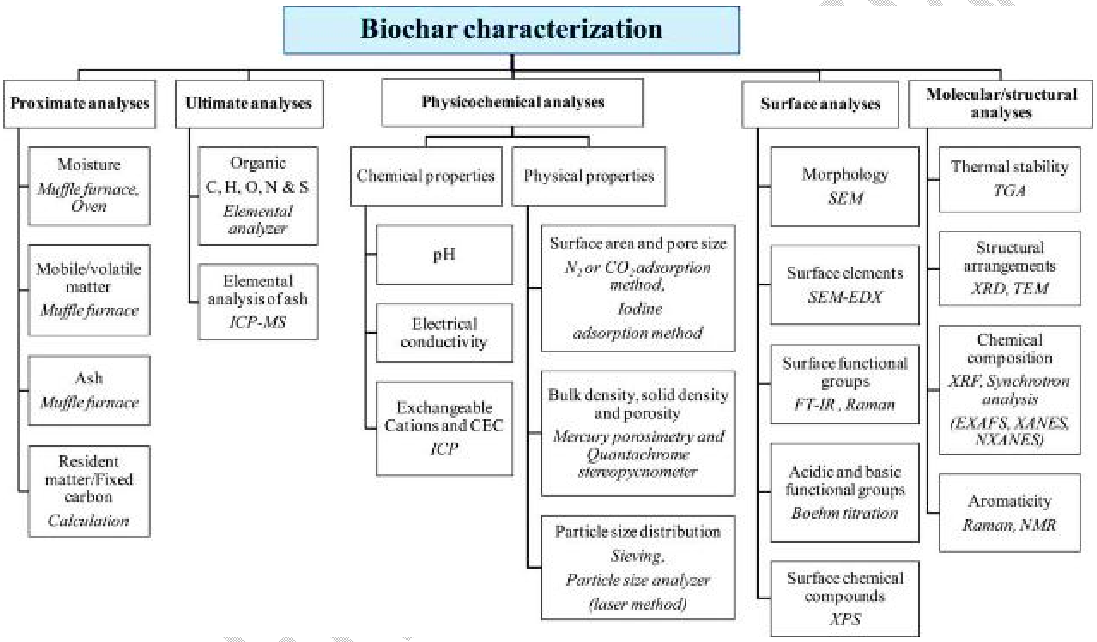

Fig.9 Biochar Characterisation[67][68]

11.1 Proximate analysis

Proximate analysis is a method of determining the entire biomass components of solid fuel in terms of moisture content (ASTM D 1762-84), ash content, volatile solids, and fixed carbon (ASTM D1762-84) [69].

11.2 Ultimate analysis

It includes the analysis of the organic Carbon, oxygen, nitrogen, sulphur, and on the instrument called elemental analyser, the ultimate analysis also includes the analysis of the ash contents of the sample[70].

11.3. Physiochemical analysis

The physicochemical analysis is divided into two subcategories for the determination of physical properties and chemical properties, chemical properties include the determination of pH, Electrical conductivity, and cations exchange capacity, this physical property can be determined on calibrated electric instruments instantly (ASTM D 4972–01)[71]. In physical properties surface area and porosity is determined by either $CO_{2,}$ and N_2 absorption methods or Iodine absorption methods. Physical properties also include the determination of bulk density (ASTM D 7263-09) and particle size distribution (ASTM D 422-63) which are done by an instrument called a particle size analyser [67][68]. Agriculture application studies have shown that biochar particle size affects soil water storage by change of pore space between particles (interpore) and by adding pores that are part of the biochar (intrapore)[72]. The determination of physicochemical properties of biochar gives a strategy of application as an additive to improve soil quality[73].

11.4 Surface analysis

The surface analysis of biochar includes the determination of the following properties:

11.4.1 Morphology by SEM

Surface morphology is analysed by technique called scanning electron microscopy[74], this technique is used for the visualisation and characterisation of surfaces of various materials including biochar[75].

11.4.2 Surface Elements by SEM-EDX

SEM-EDX does the surface elements analysis. It is the analytical instrument called energy-dispersive X-ray spectroscopy (EDX). It is used to characterise materials analytically or chemically; these systems are typically used in conjunction with an electron microscope, such as a transmission electron microscope (TEM) or a scanning electron microscope (SEM). The EDX method is based on the emission of a specimen's unique X-rays. The peaks connected to the elemental makeup of the studied sample are shown in an EDX spectrum[76].

11.4.3 Surface functional groups by FT-IR and Raman

Recording the infrared spectra of biochar samples, Fourier Transform Infrared Spectroscopy (FT-IR) is used to determine the chemical composition of biochar[77]. Surface functional groups such as Hydroxyl-, aldehyde- and ketone-groups are most important for surface binding of polar contaminants. The appearance of these functional groups can be derived from Fourier-transform-infrared spectroscopy[78]. Raman spectroscopy is an inelastic scattering phenomenon that examines molecular vibrations to determine a material's molecular fingerprint[79].

11.4.4 Acidic and basic functional groups

Acidic and Basic functional groups are determined by Boehm Titration[80]. This method is evaluated for obtaining reliable results in quantifying O_2 containing surface groups in less time[81].

11.4.5 Surface chemical compounds (XPS)

The elemental composition, chemical states, and electronic states of the elements inside the material are measured using X-ray photoelectron spectroscopy (XPS), a surface-sensitive quantitative spectroscopic approach[31]. XPS spectra are acquired by irradiating a material with an X-ray beam while measuring the kinetic energy of electrons that escape from the top 0–10 nanometre of the substance under investigation[82].

11.5 Molecular/Structural analysis

The molecular or structural analysis includes the study of biomass thermal analysis in which TGA is an effective method for determining the thermal stability of materials[83]. Changes in the weight of a specimen are measured as its temperature is raised in this procedure. TGA can determine a sample's moisture and volatile content[84]. The structural analysis is done by X-ray diffraction (XRD), which offers extensive information on materials crystallographic structure, chemical composition, and physical characteristics 85].

12 Factors affecting biochar production

Several technical factors, including pyrolysis temperature and feedstock type, influence biochar characteristics, resulting in products with a wide range of pH, specific surface area, pore-volume, CEC, volatile matter, ash, and carbon content[86].

The following factors mainly influence biochar properties:

- Type of feedstocks,
- Feedstock properties
- Temperature of pyrolysis,
- Size of the particle,

- Heating rate, etc.

These factors have a direct effect on the yield of biochar rather than its quality[87].

13 Biochar yield from different crop waste

The cellulose and lignin contents significantly influence the biochar production. The pyrolysis temperature is responsible for variations in physiochemical attributes, structure of the biochar and yield of biochar. If the pyrolysis temperature increased the volatile matter oxygen and hydrogen content of biochar and yield of biochar decreased, while fixed carbon is increased. The effect of pyrolysis temperature and feedstock on the biochar yield are presented in Table 01

Table 01 Biochar yield from different crop waste

Sr. No.	Biomass	Temperature (℃)	Yield (%)	Ref.
1	Cotton stock	400	46.5	[88]
2	Groundnut shells	450	34.1	[89]
3	Paddy straw	400	49.5	[90]
4	Wheat straw	400	32.9	[91]
5	Coconut shell	300-400	28	[92]
6	Bamboo	400	32.20	[93]
7	Pigeon Pea stock	350	24.5	[94]
8	Corn cob	600	26.55	[95]
9	Maize straw	600	19.65	[95]
10	Eucalyptus	300	21.26	[96]
11	Sugarcane bagasse	600	75	[97]
12	Orange peel	300	25.54	[98]
13	Palm Kernel Shell	400	43.13	[99]
14	walnut shell	500	28.9	[100]

14. Optimisation of Biochar Production

Optimisation of biochar production involves the increase in the yield, quality and quantity of the biochar produced in the process, this involves the trails of biochar production on different temperature heating rates moisture contents and other process parameters. Biochar with a greater yield can be created by pyrolysis of pomegranate peel by using the optimal conditions such as temperature of 300 °C, a yield of optimised biochar of 54.9 percent was produced. The reaction time is 20 minutes, and the particle size is 3 mm[101]. High-performance biochar can be produced using a simple and low-cost method, i.e., Optimising pyrolysis parameters[102]. Response surface approach can optimise biochar preparation from the stem of Eichhornia crassipes for Cd^{2+} adsorption[103]. Biochar production can be optimised by Co-Torrefaction of Microalgae and Lignocellulosic Biomass Using Response Surface methodology[104].

15. Postproduction processing of biochar

To use the produced biochar, it needs to process in the form in which it is used for specific application, following are the some of the postproduction processing done on the biochar.

- **Grinding-** The size of the biochar is important for the final application. In order to achieve the desired size, size reductio may be required, in which grinding operations are carried out[105].
- **Densification-** Densification is required to increase the density of biochar, for rase of storage and transportation purpose biochar densification is important. Biochar densified into briquettes or pallets and it can be used for combustion fuel[105].
- **Activation-**It the process in which the surface area and the porosity of the char is increased in order to use biochar as absorbent material[105].
- **Blending-**Blending is the process in which biochar is added to various chemicals and fertilisers for increasing its characteristics and application efficiency[43].

16. Global Biochar Market

Biochar is a rapidly growing business that is predicted to substantially impact agricultural crop output and productivity[106]. It improves soil fertility and provides nutrients to crops. Furthermore, new income streams for the biochar industry are projected to emerge from uses in energy generation and greenhouse gas mitigation[107]. The worldwide Biochar market was worth USD 406.5 million in 2020, and it is predicted to grow to USD 885.2 million by 2027, with a CAGR of 11.8 percent between 2021 and 2027[108]. According to a new report by EMR titled, 'Global Biochar Market Report and Forecast 2021-2026', the global biochar market size was valued at USD 1.67 billion in 2020. The market is further expected to reach USD 3.24 billion by 2026[109]. India's National Policy for Management of Crop Waste (NPMCR) has the objective of "Diversified use of crop waste for various purposes like charcoal gasification, power generation, as industrial raw material for production of bio-ethanol, packing material, paper/board/panel industry, composting and mushroom cultivation etc. it shows that Indian government is also promoting the biochar production [46]. Table 02 contain different biochar manufacturer in India

Table 02 Commercial Biochar plants in India

Sr. No.	Manufacturer	Address	Ref.
1.	farm2energy PVT. LTD	VPO Bija, Tehsil Khanna, Bija, Punjab 141401	[111]
2	Agrobiochar	Prime Specialities 203, 6-3-652 D/28, 2nd Floor, Dhruvatara, Amrutha Estate, Somajiguda, Hyderabad, Telangana, India. Pin Code-500082.	[112]
3	Appropriate Rural Technology Institute ARTI	Maharashtra	[113]
4	ArSta eco	102/3, Sri Jenu Giri, Bennayakanahalli, K G Palya Post, Tiptur 572201 Tumkur Karnataka	[114]
5	Anulekh Agrotech Pvt. Ltd	Anulekh Agrotech Pvt. Ltd. 207,Shivam Chambers, S.V Road, Goregaon-West, Mumbai-400104	[115]
6.	Greenfield Eco Solutions Pvt. Ltd	Greenfield Eco Solutions Pvt. Ltd. 11/895, CHB, Nandanvan Jodhpur, Rajasthan. India 342001	[116]

17. Utilisation of biochar in agriculture

Biochar is a carbon-sequestering material that can be applied to soils to increase soil health, fertility, and carbon sequestration[117]. The different effects studies of biochar application in agriculture by different researchers are summarised below:

17.1 Effect of biochar application on soil properties

Biochar application reduces bulk density and enhanced the the porosity of the soil considerably when compared to the control[118]. After applying biochar, the rate of soil erosion can be reduced by at least 50%. A significant component in reducing soil losses is the growth of macroaggregates[119]. Biochar can also improve the soil microbial ecology by influencing the community structure and quantity of soil bacteria and regulating the interaction between soil environmental variables and microorganisms[120]. In fine-textured soils, biochar can improve water infiltration and hydraulic conductivity. On the other hand, biochar increases hydraulic conductivity in coarse-textured soils[121]. Biochar can increase soil moisture content, reduced soil bulk density, and increased soil Phosphorus and pH[122]. Increasing biochar application rates shows significant increase in

Soil Organic Matter[123]. The use of biochar increases the soil's accessible water content[124]. Organic wastes and biochar can help to improve trace element mobility and toxicity in polluted soils[125].

17.2 Effect of biochar application on crop yield

According to studies, plants cultivated on soil altered with biochar showed yield and nutritional status reactions. Increased agricultural yields go hand in hand with enhanced soil health[126]. In salty sodic soils, adding charcoal to pearl millet compensates for yield loss and increases quality[127]. Combined biochar with NPK increased cucumber production, nutritional contents of cucumber fruit[128]. The biochar of grass and inorganic fertiliser application significantly shows increase in marketable bulb yield of onion[129]. The influence of biochar on the development of oil palm and rubber seedlings might aid in field replanting by boosting growth[130]. The application of biochar in the moderately acidic soil interrelates to ensure that the necessary conditions for cowpea growth are met, resulting increased growth, yield, and nutrient uptake[131]. A higher rate of biochar application shows higher soybean productivity[132]. Application of biochar shows improved soil fertility and enhanced eggplant crop growth in terms of height, leaf number, fresh and dry weight[133]. Field experiment increased the yield of maise by an average of; seven times for the biochar treatment[134]. Increased biochar input boosted rice output under water-saving irrigation. The rice production was best with a high biochar application (40 t/ha). The use of biochar increased the full grain number, productive panicle number, and seed setting rate, all of which increase dice output[135]. The retention and mobilisation of nutrients in biochar-applied soil significantly improve fertiliser efficiency. Furthermore, studies have revealed that most crops, mainly cotton and maise, have increased germination and biomass build up over time and superior yield characteristics 136]. Application of peanut shell derived biochar shows strong potential to improve peanut yield and leaf photosynthesis[137].

18. Engineered/designer Biochar

Engineered/designer biochar is a phrase that is often used to describe biochar modification or synthesis that is application-oriented and outcome-based. Biochar modifications using diverse procedures such as acid, base, amination, surfactant modification, impregnation of mineral sorbents, steam activation, and magnetic modification[138]. Engineered biochar might be used for a variety of purposes, including sustainable agriculture, environmental remediation, and catalytic reactions[139]. Engineered/designer biochar can also be used for the removal of phosphate in water and wastewater[140]. In another pyrolysis process, biochar is modified by ball milling and used to remove hazardous phenol and chlorophenols from polluted aqueous media[141]. Modified biochar is more successful in retaining water in the soil[142]. This shows that the engineered or designer biochar made for specific applications can be the further advancement in the biochar industry.

19. Economics of biochar production

Biochar manufacturing promotes a circular bioeconomy for agricultural waste[143]. Life cycle assessment of biochar production processes showed that it can bring environmental benefits[144]. Even if the biochar market prices become low farmers can apply it in the farms and can get benefits [145]. Biochar's influence in numerous applications is well proven, and the need of the hour is to build a continuous supply chain to commercialise biochar's use in these fields[146].

20. Environmental concerns and future directions for biochar applications

Biochar can enhance soil dust emissions or contain high quantities of contaminants[147]. Biochar amendment in soils may concern food safety and human health dueo polyaromatic hydrocarbons[148]. It is found that biochar produced at higher pyrolysis temperatures (>400 °C) is less hazardous and had lower potencies of AhR-mediated effects, It suggesting that they would be more suited for soil application[149]. The existing state of knowledge is mostly based on small-scale investigations conducted in laboratories and greenhouses. The properties of biochar vary depending on the feedstock used and the method used to make it[150]. Biochar has a low bulk density and a high porosity, making it vulnerable to air escape through natural or mechanical soil disturbance[151]. The Figure 10 explains about the environmental concerns and respective future directions for applications.

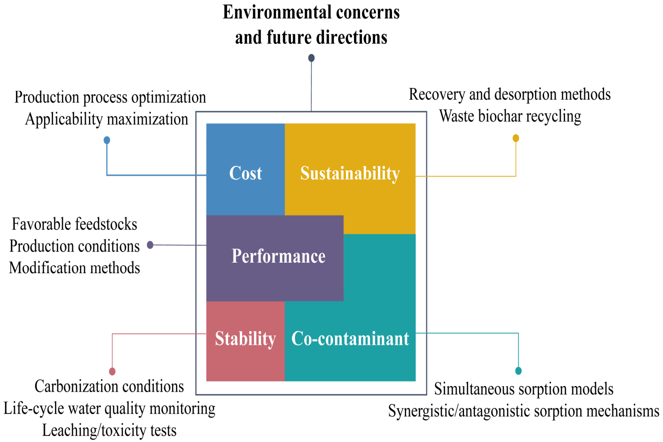

Fig. 10 Environmental concerns and future research directions of biochar application[152]**.**

Conclusion

From this review it can be concluded that although biochar has tremendous potential in the agriculture, industrial, pharmaceutical, and environmental sectors, its potential is undraped and needs more compressive research in the domains of biochar production and its utilisation. The cons of biochar such as toxicity environmental impacts need to be studied and accordingly, the promotion to biochar should be given.

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