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Beneficial impacts of biochar as a potential feed additive in animal husbandry

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ABSTRACT

In the last decade, biochar production and use have grown in popularity. Biochar is comparable to charcoal and activated charcoal because it is a pyrogenic carbonaceous matter made by pyrolyzing organic carbon-rich materials. There is a lack of research into the effects of adding biochar to animal feed. Based on the reviewed literature, including its impact on the adsorption of toxins, blood biochemistry, feed conversion rate, digestion, meat quality, and greenhouse gas emissions, adding biochar to the diet of farm animals is a good idea. This study compiles the most important research on biochar's potential as a supplement to the diets of ruminants (including cows and goats), swine, poultry, and aquatic organisms like fish. Biochar supplementation improves animal growth, haematological profiles, meat, milk and egg yield, resistance to illnesses (especially gut pathogenic bacteria), and reduced ruminant methane emission. Biochar's strong sorption capacity also helps efficiently remove contaminants

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Animal nutrition

and poisons from the animals' bodies and the farm surroundings where they are raised. Animal farmers are predicted to make greater use of biochar in the future. Biochar could potentially be of value in the healthcare and human health fields; hence research into this area is encouraged. The present review highlights the potential benefits of biochar as an additive to animal feed and demonstrates how, when combined with other environmentally friendly practices, biochar feeding can extend the longevity of animal husbandry.

1 Introduction

Carbonaceous substances from heating wood include charcoal, activated charcoal, and biochar (BC). All three items are made under identical conditions and have similar characteristics and applications. Bio-based carbon materials are solids high in carbon created via pyrolysis from biomass high in carbon. Wood-based charcoal has been a heating and cooking fuel for thousands of years (Dayang et al. 2022). The term "activated charcoal" refers to charcoal that has been subjected to either a physical activation process or a chemical activation process. Activating charcoal improves its physicochemical qualities (Hagemann et al. 2019; Shi et al. 2021; Haider et al. 2022). Biochar has multifunctional values due to its use for various purposes as a nutrient and microbial carrier, soil amendment to enhance soil quality, heavy metal and organic pollution immobilizing agent for water and soil remediation, porous material for reducing the emissions of greenhouse gas and odorous compounds, catalyst for industrial uses, and feed additives to enhance animal production, health and feed efficiency (Bolan et al. 2022). Further, water treatment, biodiesel production, syngas upgrading, composting of organic waste, and soil conditioning are just a few of the many applications of BC. Soil remediation also uses it due to its enhanced water-holding capacity, adsorption ability, and microbial variety. Biochar is an effective soil addition for cleaning up polluted areas. In the remediation of contaminated soils like mine tailings, it has been used to eliminate heavy metals/metalloids and pesticides. BC improves soil moisture retention and nutrient movement by limiting runoff and altering soil biota (Huang et al. 2021; Kumar et al. 2021; O'Reilly et al. 2021; Patel et al. 2022).

Biochar is created by pyrolyzing organic matter. Hydrogen, water vapour, methane, carbon dioxide, ethane, carbon monoxide, and "char" are generated when biomass is heated in an oxygen-free environment. The ability of BC to bind to a wide variety of chemicals and adsorb bacteria and toxins makes it a promising ingredient for use in animal feeding systems to improve animal performance while having a more negligible environmental impact. Much of that stuff is left over from municipal or agricultural waste management and must be thrown away (Man et al. 2021; Yang et al. 2021). Energy and carbon may be recovered by using this waste to make BC with superior qualities for environmental protection, agriculture and animal husbandry. The properties of BC are determined by the feedstock material and the pyrolysis conditions, especially the temperature and process duration (O'Reilly et al. 2021; Dayang et al. 2022). Biochar reduced bulk density, more porosity and surface area, less oxygen and hydrogen, and higher carbon content as the pyrolysis temperature is raised. The BC, made from various biomass sources, has many properties. The bulk of BCs is alkaline, suggesting they can act as a pH buffer in the rumen and increase weight gain in livestock-fed high-energy diets. BC's cascading utility was proved by its addition to various feeds, beddings, and liquid manures in small increments (Huang et al. 2021). Interestingly, they have gotten special attention due to the ease of manufacturing BCs. Further, BC's eco-friendly and economically profitable nature and its use as a sustainable bio-adsorbent must also be considered (Haider et al. 2022; Patel et al. 2022). Adding organic nutrients to BC helps with animal husbandry, boosts the province's economy, and has many positive (reverberating) effects on the natural world.

Over the past decade, various studies have been conducted to study the impact of a BC-supplemented diet on ruminants, pigs, poultry, and fish (Winders et al. 2018; Wang et al. 2019; Jinija et al. 2022). Biochar can increase both the quantity and quality of eggs laid by hens. Improved mineral intake from BC can help minimise cracked eggs' occurrence when wood charcoal is added to the hens' diet. It boosts growth and survival, as well as high-density lipoprotein, and lowers low-density lipoprotein, all linked to enhanced immunity. Due to its adsorption capabilities, it was also able to diminish the prevalence of chicken diseases such as *Campylobacter hepaticus* and *Gallibacterium anatis*. Because of this, it can be used in animal husbandry as ab antibiotic (Shehata et al. 2013; Wilson et al. 2019). The high porosity of Biochar could help the host gut bacteria like methanogenic archaea lower the methane emissions from ruminants, contributing to global warming. Emissions of greenhouse gases are an essential contributor to the planet's warming. Biochar has been found to reduce methane production from ruminants, which significantly contribute to agricultural GHG emissions, and increase microbial fermentation. In addition, the ability of BC to absorb nutrients from the digestive tracts of cattle and then excrete them as soil fertilizer might lead to increased farm output even if it also helps in decreasing the input of chemical fertilizer (Man et al. 2021; Dayang et al. 2022; Haider et al. 2022).

Biochar has shown promise as a feed supplement, with studies finding that it improves various animal health and production

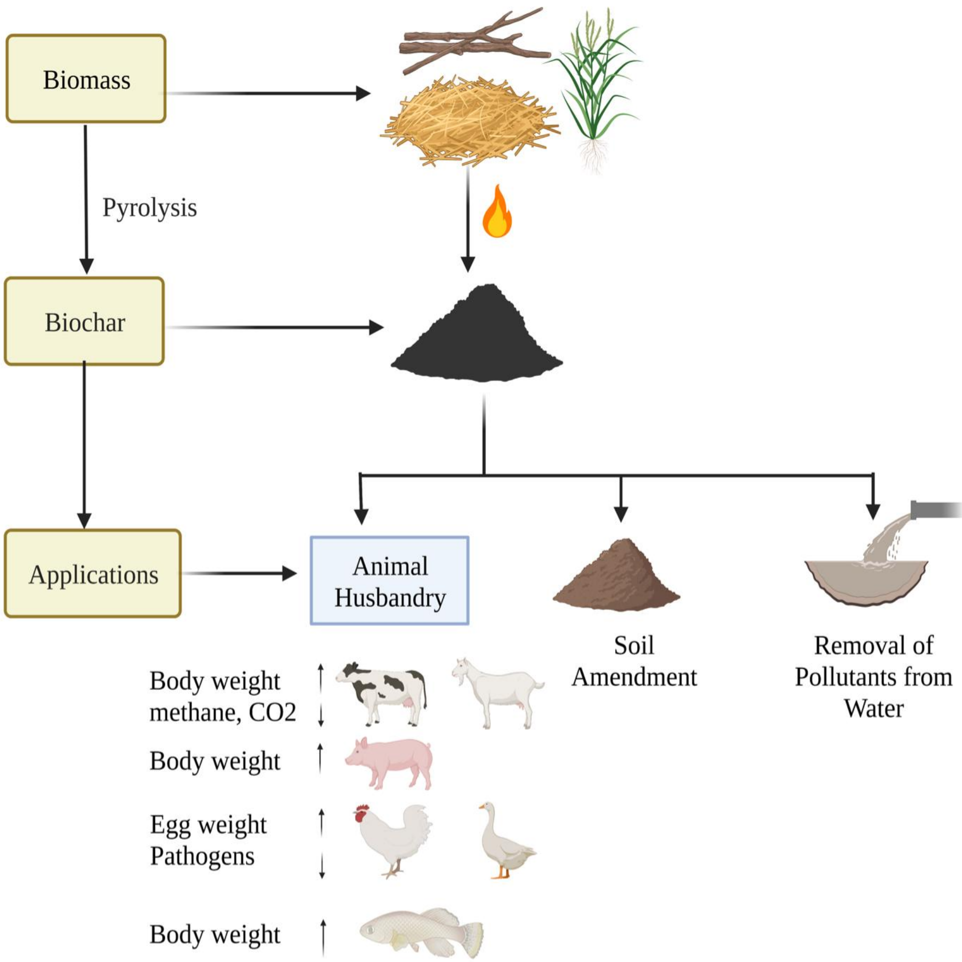

Figure 1 Biochar for livestock farming, from production to final uses

indices. Biochar for animal husbandry, from production to final applications, is depicted in Figure 1. Biochar production and its potential use in environmental cleaning have generated a lot of data in recent years. However, the use of BC produced from various feedstocks severely lacks data. This review article summarizes the present knowledge about BC feedstocks and their effects as feed additions for livestock and poultry production and identifies knowledge gaps and future research priorities in this area.

2 Raw materials used for the production of biochar

Biochar's primary constituents come from food production, preparation, and consumption. Aquaculture, livestock, poultry breeding, and agricultural output contribute to total output (Schmidt et al. 2019; Schmidt et al. 2021; Dayang et al. 2022). Depending on the raw materials used, BC can be roughly categorized as straw BC, shell BC, wood BC, sludge BC, animal fecal BC, bamboo BC, and others (Dai et al. 2019), and most of these are part of some of the food chain. Agricultural wastes, as well as animal and poultry manure, are always produced while creating food. Using rice straw, Yang et al. (2021) produced BC at temperatures between 500 and 900 °C, with the surface area of the BC reaching a maximum of 520.71 m^2/g at the highest temperature. Shi et al. (2021) pyrolyzed cow dung at temperatures between 350 and 750 °C for two hours to create BC. The pyrolysis process produced BC with a specific surface area of up to 308.1 m^2/g at 750 °C. Produced and consumed goods can generate a wide variety of trash, such as banana peels, eggshells, apple chip pomace, sugarcane bagasse, walnut shells, peanut hulls, grape pomace, etc. Those that eat eggs tend to make eggshells as a by-product of their diet (Xu et al. 2020; Li et al. 2016, Jiang et al. 2018). The final stage of the food chain, the kitchen, generates the most garbage. The trash from kitchens can consist of a wide variety of items; BC can be made, in part, from kelp, tea leaves, and crab shells. For instance, Huang et al. (2021) used kelp as raw material and high-temperature pyrolysis to create BC. The BC used by Altaf et al. (2021) was created by pyrolyzing tea leaves at 500 °C. Across a temperature spectrum of 300–900 °C, Dai et al. (2017) synthesized calcium-rich BC from crab shells. Furthermore, BC can be manufactured from everyday household waste by pyrolyzing food at temperatures between 300 and 700 °C for two hours (Kumar et al. 2021). By pyrolyzing kitchen waste at 300-600 °C for two hours, Xu et al. (2021) created BC with a surface area of 1.19-10.27 cm^3/g. Up the food chain, wastes can be used as BC source materials. The food chain's solid waste can be managed by converting these wastes into BC.

Feedstock for the production of BC includes different types of organic resources. Raw resources for BC production include cow dung, wood chips, wheat straw, rice husk, grass, and cassava rhizome (Ronsee et al. 2013; Kiran et al. 2017). Various input materials and pyrolysis settings have been shown to affect the synthesis of BC with high nutritional value (Chan et al. 2007). BC is produced from waste biomass by modern pyrolysis technology. This waste biomass includes agricultural, manure, wood, and green waste. Producing and utilizing agricultural, industrial and urban/municipal wastes has also contributed to waste management (Novotny et al. 2015; Kameyama et al. 2016). Several authors have discussed the prevalence of different feedstock materials in BC manufacturing (Reddy 2015; Sohi et al. 2009; Tumuluru et al. 2011). Peterson et al. (2012) found that 40% BC was extracted from maize stover. Sullivan and Ball (2012) noted that most of the biomass used to produce BC consists of the polymers such as cellulose, hemicellulose, and lignin. It has been found that cellulose is the primary component of plant-based biomasses, while lignin plays a substantial role in woody biomass.

3 Production of biochar as a feed additive or feed supplement

Biochar can be produced on a small scale with inexpensive adapted stoves or kilns and on a large scale with costly larger pyrolysis facilities and more feedstocks. As noted above, BC may be made from various biomass feedstocks via pyrolysis (Zhu et al. 2018). The acquired dry trash is chopped into bits no bigger than three centimetres before being put to use. It is heated to 350 and 700 °C (662 and 1292 °F) to prepare either oxygen-free or with deficient oxygen concentrations feedstock. Over 500°C (heating rates of 1000 °C/min), fast pyrolysis can occur in seconds. Classifying pyrolysis processes according to the required heating temperature and time are standard practices. In these conditions, bio-oil production is at its peak. On the other hand, slow pyrolysis takes longer to complete (30 minutes to several hours at heating speeds of 100 °C/min), but more charcoal is produced (Brown et al. 2011).

Depending on the used biomass, heating rate and heating temperature, several types of BC can be produced. Incontrovertibly, higher temperatures increase char yields. The carbon structure of BC produced at moderate temperatures (550°C) is less aromatic than that of BC produced at high temperatures (Joseph et al. 2015). Char yield is reduced in all pyrolysis methods as the temperature increases (Antal et al. 2003). According to Peng et al. (2011), BC yield was affected by charring time, with yield decreasing with increasing charring time at a constant temperature. Biochar quality and its capacity for carbon sequestration or agronomic performance are greatly affected by pyrolysis. Slow pyrolysis of biomass yields 24–77% BC (Dutta et al. 2010). All biomass used to produce BC should be pyrolyzed (Mohan et al. 2006), regardless of whether activation is used. To create BC, raw materials will be pyrolyzed at temperatures between 200 to 1000 °C in an oxygen-depleted atmosphere. Because of this, the final goods will have different characteristics and capabilities (Brendova et al. 2012; Koltowski et al. 2017). Biochar products' performance as feed supplements depends on heating rate, temperature and residency duration (Waheed et al. 2013).

4 Use of biochar as a feed additive

The organic matter used to create BC feed additives is heated at rates between 7 °C/min and 40 °C/min for durations ranging from 3 minutes to 12 hours, with temperatures ranging from 350 °C to 1100° C (McFarlane et al. 2017). A pyrolysis temperature variation of no more than 20 °C is required to comply with European Union requirements for BC as animal feed. Activation is not necessary for BC products intended for use as feed additives. As early as the turn of the last century, veterinarians in Germany were looking into the health benefits of both activated and non-activated BC feed for animals. Since 1915, studies by Skutetzky and Starkenstein (1914) on activated BC have shown that it can decrease and absorb dangerous clostridial toxins from *Clostridium botulinum* and *C. tetani*. Mangold (1936) researched the effects of BC when fed to animals and reported that charcoal in young animals' diets appears to have a prophylactic approach. Coccidiosis and other coccidial diseases in pets can be efficiently treated by adding BC to their diet. Totusek and Beeson (1953) later remarked that charcoal by-products had been used in American hog breeding since 1880 and in chicken feed since 1940. Steinegger and Menzi (1955) reported around the same time that BC was given to Swiss chick feed and laying hen meal to avoid digestive disorders and achieve a regulating action on digestion. BC has been thought to purge water and soil of chemicals, heavy metals and other pollutants (Tan et al. 2016; Shakoor et al. 2020). Most pollutants and toxins are found in the animal's regular feed, which several sources, including ambient pollution, insects, and microbial activities, can taint. Reduced mortality and improved development were two positive outcomes of feeding broilers a diet supplemented with 0.5% BC to mitigate the harmful effects of aflatoxins. Carbon enterosorbents (biochar) made from rice husks

Table 1 Research studies investigating the beneficial effects of different feedstock materials as biochar

Feedstock material	Biochar dose	Beneficial effects	References
Woody green waste	1% to 4% by mass of laying hens' feed	Gains in egg weight of upto 5% Egg production could rise by up to 13% Decrease in feed consumption by 7% Upto 14% better feed conversion ratio 19% boost in the shell's tensile strength Excreta nitrogen content decreased by upto 26%	Prasai et al. (2016)
Activated charcoal	1% of goats' typical diet in dry matter	Aflatoxin elimination was cut by 76% The composition of the milk remained unaffected	Nageswara Rao and Chopra (2001)
Charcoal	Daily doses of up to 1g of charcoal for each cow	Reduced levels of *Clostridium botulinum* antibodies by up to 30%	Gerlach et al. (2014)
Poultry litter	7% of BC's total tonnage of feed for chicken broilers	Intake of feed increased by 8% Reduction in body weight gain by 2% Feed conversion efficiency drops by 11%	Evans et al. (2015)
Poultry litter	2–4% of the total weight of feed given to chicken broilers	Improved feed conversion efficiency by 7% Weight growth slowed by 9%	Evans et al. (2017)
Bamboo	BC at a rate between 0.5 and 1.0 g/kg of goat body weight	Weight gain of 17% each day Decreased urine nitrogen content by 61%	Van et al. (2006)
Oakwood	Feed for chicken broilers and laying hens, between 1 and 10% by mass	Increased feed conversion rates by as much as 7% Gain in body weight of up to 23% Egg cracking can be reduced by up to 65%.	Kutlu et al. (2001)
Jarrah wood	Cows are given a mixture of BC and molasses, 3:1, on a regular basis.	Sorption of toxins Facilitate the recycling of cow manure and digestive byproducts	Joseph et al. (2015)
Woody green waste	Laying hens' feed at the rate of 4% by mass	Productivity of eggs rose by 1.2% Weight gain of 3% in eggs Feed efficiency improved by 8% Feed consumption decreased by 2%	Prasai et al. (2016)
Woody green waste	1-4% of the total amount of feed given to layer chickens and broiler chickens	Lower levels of water in laying hen poop Excreta nitrogen content can be reduced by up to 27% Carbon concentration in excreta increase by upto 45%. Increased ammonia emission of upto 47%	Prasai et al. (2018b)
Whole pine trees	In terms of feed mass, the range is between 0.8 to 3%	Improved digestion Reduction in methane emissions of upto 18.4% Possible reduction in carbon dioxide output of upto 9.7%	Winders et al. (2019)

Source: Kalus et al. (2019)

reduced uremic toxins to a clinically significant level, just like commercial enterosorbents. The carbon surface of these enterosorbents was treated with ozone oxidation and then ammonia to modify their characteristics. Figure 2 depicts the uses of biochar as a supplemental feed ingredient for livestock and poultry, and Table 1 displays the findings of some of the most significant studies investigating different feedstock materials as biochar.

5 Positive effects of biochar on livestock farming

Charcoal's purported detoxifying abilities have been the subject of numerous studies. Mycotoxins of several types can be bound to charcoal through a process proposed (Galvano et al. 1996a; 1997; 1998). A wide surface area, low surface acidity, and mesopores are ranged between 2 and 50 nm in size. Microporous charcoals (2 nm)

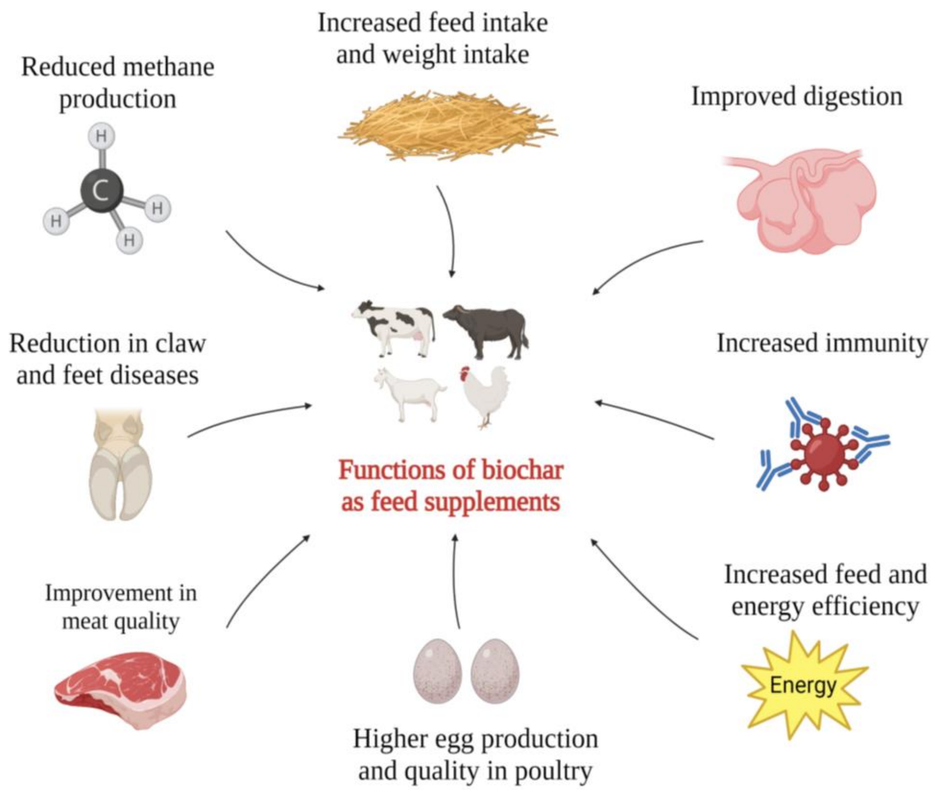

Figure 2 Functions of biochar as livestock and poultry feed supplements

exhibit reduced sorption capabilities due to slower mycotoxin diffusion and the repulsion of electrons by the positively charged surface of aflatoxin molecules. Mycotoxin contamination of animal feed can affect up to 25% of global feed production (Mézes et al. 2010). Fungal toxins are typically created in humid environments, making it challenging to prevent mold fungus from growing on freshly prepared and stored animal feed. Feed tainted with mycotoxin poses a significant health danger to farm animals. Adsorbents are often added to the diet to prevent animals from becoming ill from ingesting mycotoxins. There has been an increase in the use of activated carbon and specific polymers in addition to the more typical aluminosilicates (Huwig et al. 2001).

The adsorption behaviour of BC has been studied using aflatoxin, one of the most common mycotoxins, as a model drug (Galvano et al. 1996a). Researchers have deduced that BC blocks the absorption of aflatoxins in the intestines and, by extension, in the blood and milk of animals. When added to animal feed, 2% activated BC lowered the concentration of extractable aflatoxin by up to 74% and reduced aflatoxin concentration in milk by up to 45% (Galvano et al.1996b). However, the adsorption effectiveness of various BCs varied greatly, as demonstrated by a random sampling of activated BCs. In an *in vitro* batch study of sorption, four different activated carbons absorbed 99.9%. At a concentration of 0.5% aflatoxin B in a solution, 1.11 g of aflatoxin B per 100 ml of activated BCs was toxic (Diaz et al. 2004). In contrast to the 1% concentration in *in-vitro* experiments, the *in vivo* test fed a poorly defined BC at a low concentration of 0.25% of the meal's fresh weight without a feed matrix. Interestingly, Rashidi et al. (2020) found that when biochar made from poultry litter is fed to broiler chickens suffering from aflatoxicosis at the rate of 5g/ kg, body weight is restored. Side by side, the performance of the birds also increased. Galvano et al. (1996a) also evaluated the adsorption capabilities of 19 activated carbons for two mycotoxins, ochratoxin A and deoxynivalenol, and found that activated BC adsorbed 0.80–99.86% of ochratoxin A and up to 98.93% of deoxynivalenol, depending on the type of activated BC. The wide range of findings unequivocally demonstrates the value of thorough analysis and classification of BC characteristics. Activated BC was shown to have the highest toxin reduction capacity of the adsorbent feed additions studied by Di Natale et al. (2009) to lower aflatoxin levels in milk produced by dairy cows. Researchers found some positive effects by examining the milk's organic acid, lactose, chloride, protein, and pH levels. The authors explained the high specific surface area of the BC, its optimal micropore size distribution, and the great affinity of aflatoxin for the polyaromatic surface.

Zearalenone is an extremely dangerous estrogenic metabolite produced by the *Fusarium* fungus. Bueno et al. (2005) examined its binding with different concentrations of activated BC (0.1%, 0.25%, 0.5%, and 1%) at various concentrations. No cure for this drug had been found before that time. The zearalenone could be bound *in vitro* at the four BC concentrations. Many chemical molecules, including mycotoxins, compete with the free adsorption surfaces of BC, making selective adsorption difficult or impossible to achieve *in vivo*. In the *in vitro* studies utilizing swine digestive juices, activated charcoal showed high adsorption of Fusarium toxins (Avantaggiato et al. 2004; Döll et al. 2004). In contrast, no noticeable effect was observed when activated BC at a concentration of 0.3% was given to pigs' diets. Supplementation with uncharacterized industrial BC at this low dose did not affect ochratoxin levels in the body's fluids (Jarczyk et al. 2008). However, no unfavourable outcomes were uncovered either.

Liver damage caused by mycotoxins is common in chickens. Biochar at 0.02% of body weight daily improved critical liver enzyme activity (Ademoyero and Dalvi 1983; Dalvi and Ademoyero 1984 Dalvi and McGowan 1984). Broiler chickens' feed intake and weight increase were unaffected by aflatoxin (10 ppm) when fed 0.1% BC (w/w). Activated BC performed better than hydrated sodium calcium aluminosilicate. The alumina product did not significantly increase aflatoxin B levels in the liver or blood when paired with 0.25 and 0.5% BC therapy (Kubena et al. 1990; Denli and Okan 2006). In another investigation by Edrington et al. (1996), fattening chicks' feces had less aflatoxin B when activated BC was given with its diet. Kim et al. (2017) revealed that three BCs administered at 0.5% to the same basal meal reduced aflatoxin absorption by up to 100%.

Another study showed the importance of dose by reducing the amount of aflatoxin B1 in the birds' livers by 16-72% by adding 0.25 or 0.5% activated BC to a meal contaminated with the toxin (Bhatti et al., 2018). There is conflicting evidence, and the study by Toth and Dou (2016) adds to the confusion. Most *in vitro* studies of sorption in water showed discrepancies with corresponding *in vivo* examinations (Huwig et al. 2001). Matrix variables significantly affect mycotoxin sorption; therefore, *in vitro* trials must be thoroughly assessed. Activated carbon was found by Jaynes et al. (2007), for example, to adsorb up to 200 g/kg of aflatoxin. Matrix effects led to a one-hundredfold reduction in sorption capacity when maize meal was suspended in water. Matrix effects are anticipated to be far more nuanced in the digestive tract, which features a wide range of pH and redox conditions. Different studies have shown that while activated BC did not affect aflatoxin, it mitigated the hazardous effects of other fungal toxins like zearalenone to a large extent (Avantaggiato et al. 2004) and deoxynivalenol (Devreese et al. 2012; Devreese et al. 2014; Usman et al. 2016). The most important benefits of using biochar in animal husbandry are shown in Figure 3.

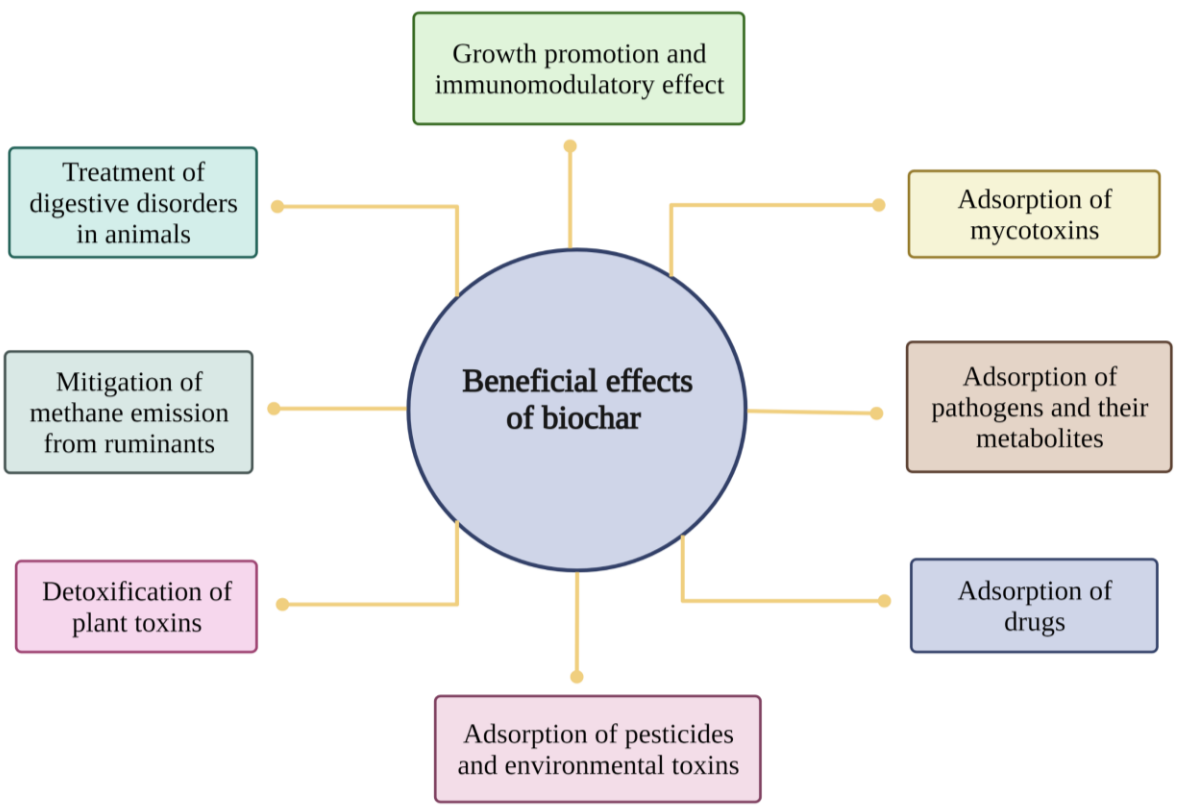

Figure 3 Major positive implications of biochar inclusion in livestock management

6 Adsorption of drugs

Numerous 1980s human medical research shed light on using activated BC as feed, especially for feed toxicity treatment (Erb et al. 1989). Most medications and toxins can be prevented from entering the gastrointestinal tract by activated carbon's adsorption. Cardiac glycosides, aspirin, dextropropoxyphene, carbamazepine, dapsone, and others were removed faster after an overdose when BC was ingested repeatedly, according to Neuvonen and Olkkola (1988). More quickly removed industrial and environmental contaminants were also identified. Adults are given 50–100 g of activated BC for acute poisoning, while children get 1 g/kg of body weight. The inadvertent consumption has no devastating repercussions. Finnish medical professionals recommend multiple doses of activated carbon given orally in acute poisoning to reduce the likelihood that poisons will be absorbed from the BC-toxin combination during digestion (Olkkola and Neuvonen 1989). The ability of BC to remove toxins from the body is enhanced when it is taken orally on multiple occasions (Crome et al. 1977; Dawling et al. 1978). Antibacterial drugs (namely tylosin and doxycycline), as well as the coccidiostats (namely salinomycin and diclazuril), were not significantly affected by the daily inclusion of 0.2% activated charcoal in the chicken feed. It was found that the use of activated carbon-enhanced feed and pharmaceutical products worked synergistically (De Mil et al. 2017).

7 Adsorption of pesticides and environmental toxins

Biochar is increasingly employed in animal feed due to its significant adsorption of insecticides, herbicides and pesticides (Shehata et al. 2013; Safaei Khorram et al. 2016; Cederlund et al. 2017). This is especially important when considering the absorption of glyphosate, a herbicide that has contaminated nearly every feed. While it has been illegal in Germany to use crop desiccation herbicides for pre-harvest treatment since May 2014, this is not the case in many other countries. Glyphosate has a powerful antimicrobial impact and can also immobilise magnesium and zinc (which may explain why it is linked to or promotes botulism) (Shehata et al. 2013). Effective sorption of glyphosate by BC particles is pH (high sorption at low pH) and temperature dependent (high sorption on high-temperature BC) (Herath et al. 2016). Hall et al. (2018) showed that a 0.1M monopotassium phosphate solution could remobilize the glyphosate charcoal had sorbed from pure water. The results of this study suggest that glyphosate from biochar-sorbed feed could be remobilized in the intestines due to ion competition. Due to the possibility that low pH, such as that found in the gastrointestinal tract, could enhance glyphosate sorption, additional *in vivo* and/or *in vitro* study in relevant matrices is necessary. Research with 380 dairy cows found that the intake of 200 g of BC and 500 g of sauerkraut juice per day (for four weeks) significantly decreased the amount of glyphosate in the cows' urine when they were fed glyphosate-contaminated silage (Gerlach et al. 2014). In the 1970s, BC was used in very few studies for pesticide adsorption (Smalley et al. 1971; Humphreys and Ironside 1980). Activated BC was employed to adsorb pesticides in the gastrointestinal tracts of ruminants, which were subsequently ejected (Wilson and Cook, 1970). However, similar trials in hens did not demonstrate any meaningful impacts on the residual quantities in tissues and eggs (Foster et al., 1972). A significant amount of contaminated BC was fed an organochlorine pesticide called Dieldrin, which was commonly used until the 1970s and is still traceable in the environment despite being outlawed.

Many common environmental toxins, namely dibenzo-p-dioxin (PCDD), dibenzofuran (PCDF), and polychlorinated biphenyls (PCBs), are fat-soluble organochlorine compounds. Adipose (fat) tissue accumulates these chemicals in humans and other animals. Several studies have used activated BC to remove these contaminants from water in Japan (Yoshimura et al. 1986; Takekoshi et al. 2005). Organochlorine compounds were found to have a strong affinity for activated charcoal in every experiment (Iwakiri et al. 2007). Twenty-four egg-laying hens participated in a controlled experiment in which they were administered feed containing the aforementioned organochlorine compounds for 30 weeks, with or without 0.5% BC. The organochlorine compounds' structure and aromaticity can lower PCDDs and PCDFs, non-ortho PCBs, and mono-ortho PCBs in eggs laying hens and tissues by more than 90%, 80%, and 50%, respectively (Fujita et al. 2012). Biochar binds many organochlorine chemicals, according to previous studies of polluted fish oil (Kawashima et al. 2009). Polycyclic aromatic hydrocarbons, in general, and higher aromatic molecules, in particular, show a substantial attraction to BC, as reported by Bucheli et al. (2015). Olkkola and Neuvonen (1989) found that supplementing human and animal diets with BC can considerably increase the elimination of PCB and dioxins. In terms of efficacy, BC may remove heavy metals and harmful elements and increase the use of biochar technology in water treatment (Inyang et al. 2016).

8 Detoxification of plant toxins

Regular BC consumption has various positive impacts, including reducing the negative outcomes of consuming naturally existing but potentially hazardous components like tannins, which are present in many diets (Struhsaker et al. 1997). Tannins are a chemical class spanning a broad spectrum, from being useful to poisonous, especially ruminants. Animals avoid eating beans and other high-protein foods because their tannins have a strong flavour that makes it difficult for them to digest and put on weight (Naumann et al. 2013). Some research has examined how BC feeding modifies the effect of tannin-rich diets. Goats fed a diet rich in tannins from acacia leaves gained 17% more weight per day when given 50-100 g of bamboo BC per kg in addition to their regular diet, compared to goats fed a control diet without BC (Van et al. 2006). Both nitrogen conversion and crude protein digestion were found to have improved significantly. Weight increases of goats fed 50 or 100 g of bamboo BC feed additives were similar, indicating an optimum BC dose.

Banner et al. (2000) found that the absorption of compounds rich in tannins and terpenes was considerably enhanced by adding 10-25 g of activated charcoal to rye daily. Sage and other terpenic and tannin-rich bushes showed comparable results for Rogosic et al. (2006; 2009); however, Villalba et al. (2002) could not prove that lambs ingested significantly more sage because of BC-enhanced feed. Since there aren't enough new pasture plants for sheep to graze on during the winter, they eat bitterweed containing toxic amounts of sesquiterpene lactones. That's why Poage et al. (2006) experimented with feeding bitter weed to lambs at a rate of 0.5-1.5 g of BC per lamb per day. The lambs refused to take the feed containing bitter weed when BC was not there, but when BC was present, they ingested up to 26.4% of the total amount of feed given to them without exhibiting signs of toxicosis. The toxic effects of the invasive flowering plant *Lantana camara* are mitigated in sheep and goats by supplementation with BC at 5g/kg body weight (Pass and Stewart 1984; McLennan and Amos 1989). In a study on *L. camara* toxicity, five of six calves survived after receiving activated charcoal therapy, while all six of the untreated calves died (McKenzie 1991). Bentonite therapy had a similar success percentage in curing patients, albeit it took twice as long for patients to recover fully. Treatments for oleander poisoning in sheep and yellow tulip (*Moraea pallida*) poisoning in cattle yielded comparable, highly significant results (Snyman et al. 2009; Tiwary et al. 2009; Ozmaie 2011). In this regard, biochar is recognized as an essential candidate for treating common contaminants like inorganic contaminants, heavy metals, microbial contaminants, pharmaceuticals, endocrine-disrupting chemicals, volatile organic compounds, and personal care products occurring in drinking water (Palansooriya et al. 2020).

9 Mitigation of methane emission from ruminants

In support of production in the agricultural sector in a sustained manner, mitigation of the emission of methane from ruminants is a crucial concept (O'Reilly et al. 2021). An important source of atmospheric methane (CH_4) comes from the digestive tracts of ruminants (animals having four-compartment stomachs that ferment food as a major element of the digestive process). In omnivores like chickens, pigs, fish, and others, the breakdown of solid and liquid wastes is the primary source of greenhouse gas emissions, but in ruminants, waste results in direct gaseous emissions from gas and belching (burping) (Johnson and Johnson 1995). Hristov et al. (2013) found that ruminants account for about 81% of all greenhouse gases emissions from livestock production. Greenhouse gases are major contributors to air pollution. Some 1.7 billion cattle, buffalo, and 2.2 billion sheep and goats make up the world's ruminant population (Searchinger et al. 2021). Tapio et al. (2017) found that 90% of cattle-related greenhouse gas emissions come from methane emissions, predominantly from rumen microbial methanogenesis. Livestock enteric fermentation produced 171 million metric tons of carbon dioxide equivalents in 2016. Manure management accounts for 10% of methane emissions, whereas enteric fermentation in ruminants accounts for 26%. The symbiotic relationships between these ruminants and the bacteria, fungus, and protozoa in their rumen allow them to get their energy from a fibrous diet (Castillo-Gonzalez et al. 2014). Microorganisms that can break down cellulose are abundant in the rumen of ruminants. When anaerobic microbes in the rumen break down organic matter, "enteric methane" is produced. Domestic animal enteric methane emissions are expected to grow by 50% by 2050, from a projected 100 million tonnes of carbon dioxide-equivalent in 2018 to more than a fifth of all agricultural emissions (Searchinger et al. 2020). Approximately 85% of worldwide emissions come from cattle and buffalo, while just 12% comes from sheep and goats (FAO 2019; Searchinger et al. 2021). Most methane is expelled through belching, while some make their way into the bloodstream and is expelled through the lungs (Danielsson et al. 2017).

Intestinal methane is produced by bacteria known as methanogenic archaea and methanotrophic archaea, respectively. Containing BC in soil amendments encourages the growth of methanotrophs, which in turn reduces methane emissions from the intestines of livestock by providing a habitat for methane oxidation in the stomach (Leng et al. 2012a). Methanotrophic proteobacteria and methanogenic archaea mostly carry out intestinal methane production. It was shown that methanotrophs produced more methane than they consumed (Feng et al. 2012). BC's ability to adsorb and absorb gases is crucial in lowering intestinal methanogenesis (Pereira et al. 2014; Danielsson et al. 2017). Thus, providing animals with BC can efficiently reduce their methane production in the digestive tract. Methane emissions were reduced by 15% when BC was incubated with rumen fluid (Leng et al. 2012b,c; Leng 2018). Furthermore, 9% BC (w/w) reduced intestinal methane emissions by 11%-17% (Hansen et al. 2012). Adding 1% BC (w/w) to cow diets has been shown to reduce methane output by 11-13% (Leng et al. 2012a). Using BC alone or in combination with nitrates lowered methane emissions by 22% and 41%, respectively (Leng et al. 2012b,c). When cows were co-fed with BC at a concentration of 3.8% (w/w), methane emissions were reduced by 12.6L per cow per day (Khoa et al. 2018). Adding 0.8% BC to a cattle's diet during the growth and fattening stages resulted in a 9.5% and 18.4% reduction in gut methane emissions, respectively, and improved digestion (Kalus et al. 2019; Winders et al. 2019). Adding 0.5% BC to *in vitro* rumen testing reduced methane generation by 25% (Saleem et al. 2018). Dairy ewes can minimize methane emissions and ammonia concentrations using BC made from chicken manure and walnut shells. Due to this reason, the incorporation of BC can be done effectively in the diet of dairy ewes as a cost-effective feed additive (Mirheidari et al. 2019). In conclusion, BC has been found to dramatically lower intestinal lumen methane emissions in both *in vivo* and *in vitro* experiments.

10 Treatment of digestive disorders in animals

O'Toole et al. (2016) noted that charcoal had been used for decades to cure diarrhoea in people and animals. Feeding animals with charcoal was common in the late 19th and early 20th centuries. Horses can suffer from colic (Edmunds et al. 2016), dogs can experience flatulence (Giffard et al. 2001), and horses can absorb toxins (Kaye et al. 2012). Claw and foot disease causes substantial economic loss due to decreased body weight, milk output, dry matter intake, herd lifespan, and reproductive efficiency in chickens. The severity of the disease is significantly reduced by BC, which positively impacts animal health and productivity. Material "cow fortifiers" were commonly promoted in the late 19th and early 20th-century agricultural literature. The makers of these tonics claim to improve milk production, appetite, and stomach issues. It is a universal antidote for venoms and has been used to treat various venomous animal diseases, including botulism in chickens, tetanus, and *Campylobacter jejuni* bacterial toxin (Toth and Dou 2016).

11 Growth promotion and immunomodulatory effect

Like the mechanisms by which antibiotics boost growth, the mechanisms by which charcoal does so are likely to be convoluted (Van et al. 2006; Allen et al. 2013). Charcoal has been shown to improve nutrient absorption, fat digestion, complex plant secondary metabolites (Mekbungwan et al. 2008), promote the development of intestinal villi, and decrease stress hormones (Kana et al. 2010; Chu et al. 2013a). Weight increases (live) and feed conversion rates have been observed in fattening pigs supplemented with biochar in the diet (Lao and Mbega 2020). Growing pigs fed a diet containing 2% BC had no detrimental effects on the measured performance metrics (Schubert et al. 2021). In particular, Chu et al. (2013b) and Islam et al. (2014) investigated whether charcoal products might substitute antibiotics in enhancing the development of food animals and found that they could. Most of Europe's BC output—90%—goes toward animal husbandry, including cattle and poultry production, where it is utilized as a feed additive (Gerlach and Schmidt 2012; Kammann et al. 2016). The use of BC in agriculture is expected to increase at a CAGR of about 12.5% over the next eight years, starting in 2018. O'Toole et al. (2016) found that 0.1% to 4.0% of the daily feed intake was blended with feed grade BC. According to a plethora of studies, including those by Leng et al. (2013), Winders et al. (2018), and Khoa et al. (2018), adding BC to feed has many benefits, including increased body weight gain and feed consumption, decreased usage of antibiotics, neutralization of chemical residues and other toxins in feed, and reduced gaseous methane emissions from the digestive tract.

12 Removal of pollutants and toxins in animals

According to Tan et al. (2016), BC can adsorb and remove heavy metals and contaminants (both organic and inorganic) from water and soil. Environmental pollutants and toxins can enter the body of animals through the food they consume. This contamination can be from human activity, pests, or even microorganisms. Including 0.5% BC in broiler diets improved growth and reduced the detrimental effects of aflatoxins (Teleb et al. 2004). The harmful bacterium *Campylobacter jejuni* was reduced in the gut microbiome of pullets after BC administration, as Prasai et al. (2016) reported. After oxidation by ozone and ammonia, carbon enterosorbents from rice husks could remove clinically relevant levels of uremic toxins (urea and creatinine) from the *in vitro* uremic toxin adsorption model tests (Jandosov et al. 2017). Biochars can catalyze abiotic reactions, particularly in the rhizosphere, that improve nutrient supply and absorb by plants, stimulate plant development, reduce phytotoxins, and increase resistance to environmental stressors and disease. On average, by Meta-analyses, biochars improve phosphorus availability by 4.6; decrease the concentration of heavy metals in plant tissues by 17%–39%, and reduce the emissions of non-CO_2 greenhouse gas from the soil by 12%–50% (Joseph et al. 2021). Also, biochar addition increased the average crop yield by 10%–42% (Joseph et al. 2021).

13 Biochar feed management and quality assurance

Raw resources for making BC mostly come from biomass and organic materials. Similar ones are employed in the production of activated charcoal. The European Biochar Feed Certificate states that a complete BC analysis and control of all applicable feed regulation criteria must be performed before using BC in animal feed. If BC has been treated with an alkali or acid before its use as a feed supplement, the activator must be flushed out with water analysis. Furthermore, the EBC suggests preventing dust generation by constantly preparing and delivering BC when damp. We usually blend BC with all standard feed mixes because it may be applied to any feed. Animals fed BC may also be exposed to BC in their drinking water. When treating acute poisoning, an aqueous suspension of activated BC is recommended (Neuvonen and Olkkola 1988). BC can also be supplied to animals at pasture or stable drinking holes without being mixed in with regular feed, though this varies by species. Molasses and sweeteners such as saccharin, sugar, and related compounds are common BC additions

(Cooney and Roach 1979). O'Toole et al. (2016) found that some farmers in Germany and Switzerland employ mechanized injection systems to add 1% (vol.) BC to silage towers and silage bales. In many cited tests, the combined effect was greater than that of the individual components fed separately (Galvano et al. 1996a).

Biochar may be combined with many other feed supplements to create compositions for specific purposes and animal types. Biochar’s chemical absorption capability depends on its pore size distribution, surface area and charge. Even if the total surface area of activated BC grows (from about 300 m to >900 m) (Galvano et al. 1996b), the specific surface area grows even more. Micropores are typically too tiny to transport large molecules or pathogens vital to animal digestion. When tested against non-activated BC, highly-activated BC did not appreciably reduce the harmful effects of aflatoxin in chickens (Edrington et al. 1997). This was similarly true for other toxic compounds being tested. Thus, activating BC may not increase the target compound or organism adsorption capability. BC with an incredibly high concentration of accessible meso and macro holes can be made by adjusting the pyrolysis settings, eliminating the need for downstream activation (Brewer et al. 2014). Depending on the invocation technique, BC's ability to mediate electrons (and protons) is drastically altered during activation and acidification (Chen and McCreery 1996). However, no comprehensive studies of the effects of feeding animals modified BCs have been conducted as of yet.

It appears that pyrolysis temperature is the sole major factor impacting redox behaviour, with temperatures between 600 and 800°C being the most effective (Sun et al. 2017). Keep PAH levels below approved limits and lessen condensate deposition on BC surfaces. For the pyrolysis procedure to end successfully, the cooling BC must be actively degassed for a significant amount of time. Using an inert gas or adequate counterflow ventilation during discharge constitutes two methods proposed for achieving this goal (Bucheli et al. 2015). Bamboo (Chu et al. 2013a), corncob (Kana et al. 2012), straw (Cabeza et al., 2018), coconut shells, rice husk, rice, and rice hull were also used to produce BC in addition to wood. Recent articles assert that solid evidence supports favouring one type of biomass over another when making high-quality feed BC. If certain conditions are followed, biochar from woody or non-woody precursors can be fed to animals. Polycyclic aromatic hydrocarbons, other organic contaminants, and the degree of carbonization are all measured and held to these requirements.

14 Possible side effects of biochar

According to the evidence reviewed here, neither activated nor unactivated BCs used as feed additives or veterinary treatments were hazardous or damaging to animals or the environment. No serious adverse effects were reported in the acute and chronic studies. There have been no reported adverse effects from the long-term, daily use of BC supplements by a rising number of farmers who give them to their cattle (Kammann et al. 2017). There have been few clinical studies of BC feeding over the long term (Struhsaker et al. 1997; Joseph et al. 2010). According to human studies, oral administration of activated carbon appears to pose few risks. However, long-term therapeutic feeding experiments using BC are lacking. Patients with uremia who were given 20-50 g of activated BC once or twice daily for 4-20 months saw no adverse effects (Yatzidis 1972). Human patients provided 10-20 g three times a day for several months by Olkkola and Neuvonen (1989) saw no adverse effects. There are two significant dangers associated with BC eating for an extended time: (1) alterations to the microbiome (the community of microorganisms that live in the digestive tract) and (2) the possible absorption of necessary feed ingredients and/or medications. Regarding the microbiome, research into the adsorptive potential of activated BC for gram-positive bacteria in dairy cow digestive tracts was conducted (Naka et al. 2001).

Adsorption of the harmful gram-negative *E. coli* O157: H7 strain was much higher on activated BC than adsorption of typical, benign bacterial flora strains. The beneficial to pathogenic microorganisms ratio seemed to improve once BC was introduced. However, before any broad conclusions can be formed, a more comprehensive range of digestive and pathogenic microbes must be rigorously researched and their mechanisms understood. The effect of BC on microorganisms depends on the cell envelope, as the gram stain indicates, with gram-positive bacteria being either not sorbed to BC or poorly sorbed to BC. Cell envelope structure and gram positivity or negativity are not, however, reliable indicators of whether or not a bacterium is pathogenic.

Unlike vitamin E, which was lowered by 40% when chickens were given 0.5% BC daily, vitamins A and D3 did not demonstrate a statistically significant trend toward decreasing egg yolk levels. The eggs' fatty acids, mineral content and oxidative stability, did not alter after BC feeding, but this was the first indication that BC feeding could severely drop vitamin levels. Changes in egg yolk color indicate a loss of carotenoids, lending credence to the idea that, before recommending industrial-scale, long-term BC co-feeding, more research is needed, specifically focusing on animal fat-soluble supplements. Some may argue that the hazards associated with routinely supplementing with quality-controlled BC are negligible in light of the prevalence of herbicide and fungal toxin contamination in the feed given to livestock animals (Prasai et al. 2018a).

Conclusion and future prospects

Biochar's use in animal farming as a feed supplement is founded on activated charcoal's application in treating animal gastrointestinal diseases. Biochar can be used as a supplemental feed ingredient after being pyrolyzed, chemically, or physically activated. Biochar's physiochemical qualities are strongly linked to the feedstocks used and the pyrolysis temperature at which they were produced. More BC is formed from feedstock with greater lignin content; hence this usually results in a higher BC production. Some feedstuffs improve animal development and flavour due to the presence of specific components. The low surface area in BC may come from micropores blocked by the ash in the non-wood feedstock. BC as a feed additive has been proposed as beneficial for agriculture, the environment, and the animal husbandry industry. Positive benefits on animal growth have been observed when feeding biochar to animals, including cattle, goats, pigs, poultry, and fish. Cattle, pigs, and chickens could all benefit from a diet that includes biochar made from rice husks. Biochar's ability to create hospitable environments for methanogenic-methanotrophic microbial interactions in the gut and increase anaerobic methane oxidation in ruminants' digestive systems contributes to its ability to mitigate the animals' enteric methane emissions.

Because of its porous structure and huge surface area, BC, like activated charcoal, has a high sorption potential for removing hazardous substances from animals and the environment. The physiochemical features of biochar and the method used to make it determine its sorption capacity for toxicants. The sorption capacity of biochar generated at higher temperatures was typically greater. Forage digestibility and rumen fermentation kinetics were improved due to the higher pyrolysis temperature, producing smaller biochar particles. Adsorption of pathogens from meals containing biochar is one way to enhance poultry blood profiles and lessen their need for antibiotics. Biochar supplementation of animal meals looks to be a highly effective method for animal husbandry. Food and Agricultural Organization, World Health Organization, and European Biochar Foundation have established classification and certification requirements for standard biochar for use as a feed supplement and soil amendment, and their use is on the rise. These findings may benefit future efforts to develop BC for human consumption and control its use in animal diets.

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