NATIONAL AGRICULTURAL AND FOOD CENTRE
RESEARCH INSTITUTE FOR ANIMAL PRODUCTION NITRA

Slovak J. Anim. Sci., 56, 2023 (1): 46–60
ISSN 1337-9984, E-ISSN 1338-0095
SciCell

EFFECTS OF ACTIVATED CHARCOAL ON LIVESTOCK PRODUCTION: A REVIEW

Micheal Taiwo AYANKOSO, Damilola Miracle OLUWAGBAMILA*, Olugbenga Samson ABE

Department of Animal Science, Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria

ABSTRACT

The exploration of the inclusion of activated charcoal in the diet of livestock or through other means is now important due to the recent development in the used of feed additives to condition the utilization or efficiency of diets and arrest of mycotoxin in animal feeds. The need for production of organic livestock, without synthetic chemicals (antibiotics) of which ban has been placed on, necessitate the use of organic materials such as activated charcoal which is capable of mitigating the effect of toxins. This review proffers a critical look into the effect of activated charcoal, its working mechanisms, levels of inclusion in animal feed, improvement on feed utilization, optimization of animal performance and detoxification of harmful substance in both feeds and animal. Its influence on methanogenesis during rumination to prevent energy wastage and global warming effect was critically considered. Likewise, its effects soil mineralisation on crop and forage productivity, and subsequent influence on livestock performance. From this review, it could be concluded that inclusion of activated charcoal was observed to improve the performance, feed efficiency and utilization, and efficiently serve as toxin binder in livestock feed and drinking water.

Key words: activated charcoal; biochar; adsorption; redox activity; sustainability; toxicity; mycotoxins

INTRODUCTION

Activated charcoal is a stimulated or activated carbon or biochar which is a carbon-rich solid substance derived from biomass or other carbonaceous materials like coal or tar pitch, using pyrolysis. During the process of producing activated charcoal, carbon material is galvanized and this greatly increased the surface of the substance to allow for adsorption of larger quantity of molecules. High adsorption capability allows activated carbon to be effective removal of contaminants from water and air, which is responsible for recognizing it as a universal poison antidote. Carbon could be derived from several sources and activated by different procedures (Hagemann *et al.*, 2018).

Biochar is made by pyrolysis of numerous kinds of biomass in a low oxygen thermal process at temperature ranging from 350 to 1,000 °C. European Biochar Foundation (EBC) (2012; 2018) and International Biochar Initiative (IBI) (2015) stated that when water vapour or carbondioxide is used at a temperature above 850 °C or chemical compounds like phosphoric acid and potassium chloride is used on biomass, it results in activation process leading to activated biochar (i.e., activated carbon) (Hagemann *et al.*, 2018). Activated carbon can be produced from a number of agricultural commodities which include hardwoods, grain hulls, corncobs, and nutshells (Cheng and Lehmann, 2009), steam activation of food-grade carbonaceous material (Hagemann *et al.*, 2018) and acid treatment is also common. For instance, pecan shells can be activated by treatment with hydrochloric acid, then heated in an electric furnace for four hours at 800 – 1,000 °C in an atmosphere of carbondioxide (Hagemann *et al.*, 2018). When biocar is produced from pure woody stem, the solid phase of the pyrolysis process is known as charcoal. In contrast, the term biochar indicates that a broad spectrum of biogenic materials can serve as feedstock.

***Correspondence:** E-mail: oluwagbamilad@gmail.com
Damilola Miracle Oluwagbamila, Department of Animal Science, Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria

Received: November 3, 2022
Accepted: March 21, 2023

https://doi.org/10.36547/sjas.791

Activated carbon or charcoal can be considered as pyrogenic carbon materials.

Activated charcoal is also considered to exhibit redox wheel purpose in the gastrointestinal tract (GIT), like conversion of Iron III to Iron II. Redox wheel act mutually as an electron acceptor and donator in addition to various biotic and abiotic redox-reactions (Davidson *et al*., 2003). It has polyaromatic backbone properties and a lots of volatile organic carbons (VOCs) depending on the production process adopted (Spokas *et al*., 2011). Some of the pyrolytic VOCs are strong electron acceptors and may act like a redox wheel which can be likened to quinone acts (Van Der Zee *et al*., 2003). Some pyrolytic VOCs do experience oxidative alterations during maturation of biochar (Cheng and Lehmann, 2009) which is called redox-active moieties (RAMs) and had contributed to the biodegradation of some poisons (Yu *et al*., 2015).

In the GIT of livestock animals, numerous RAMs are adsorbed on the surfaces of biochar particles which act as redox-wheel with different microbes and also produce buffers electrons with stable micro-habitats with various redox-pH-milieus for different species of microorganisms (Yu *et al*., 2015). Furthermore, biochar adsorbs some feeds and plant secondary metabolites such as tannins, phenols or thionin, flavonoids which are also electron acceptors and which might further increase the electron buffering of biochar particles during its passage through the digestive tract (Kracke *et al*., 2015). The use of activated charcoal has been observed to gain more attention from 19th century till this 21st century with the intention of using it for detoxification of animal feed (Gerlach and Schmidt, 2012), Although, the term biomass and activated charcoal are used inter-changeably, but activated charcoal is produced from further activation or treatment of biochar to obtain material of finer pores and high surface area ranging from 0.2 – 0.6 m^2 per gram and 500 – 3000 m^2 per gram, respectively (Beguin and Frackowiak, 2009; Soo *et al*., 2013). Numerous importance had been attached to the use of activated charcoal in livestock production, which ranges from detoxification of contaminated animal feed, increase feed consumption and digestibility, improvement of animal weight gain, enhancement of quantity and quality of animal products such as milk, eggs and meat (Retour and Beeson, 1953; Toth and Dou, 2016). Also, the use of biochar and activated charcoal is currently focusing on how it can be used in mitigating the menage of climate change, waste management and pollution (McHenry, 2010). Similarly, the use of activated charcoal has been extended to the production of drugs, water treatment therapy, improvement of water filtration and soil characteristics, increment of crops and/or forage yield and reduction of methane gas production in ruminant animals (Guo and Lua, 2003; Weber and Quicker, 2018). Therefore, it is very important to critically look at the effect of activated charcoal or biochar on the diet of livestock, how it can be used and recommended dosages if used as an additive.

ACTIVATED CHARCOAL: ITS CHEMICAL AND PHYSICAL EFFECTS

Some materials are often burnt to obtain activated carbon under chemical activation at high temperature steam. This activated charcoal possesses numerous linkage of pores and large surface area which provide spots for adsorption of chemical contaminants in gases or liquids (Sun *et al*., 1997). Activated charcoal has an extremely large surface area and pore volume which permits a special adsorption capacity (Di Natale *et al*., 2009). Burdock (1997) reported that there are some commercial food grade products that possess pores ranging from 300 to 2,000 m^2 104/g. Their explicit style of action is extremely complex, and has been a subject of much study and debate. Activated carbon has both chemical and physical effects on substances where it is used as a treatment agent and these activities can be separated into:

Adsorption

This is the most studied of these properties in activated carbon. Most applications of activated carbon can be characterized by the adsorption that occurs when components of a liquid poison attach to it. It could be either physical or chemical in nature but frequently involves both. Physical adsorption involves the attraction by electrical charge differences between the adsorbent and the adsorbate. Chemical adsorption is the product of a reaction between the adsorbent and the adsorbate.

Adsorption capacity depends on:

a) Physical and chemical natures of the adsorbent (carbon),
b) Physical and chemical natures of the adsorbate (the food or beverage),
c) Quantity of the adsorbate in the solution,

d) Features of the liquid state (e.g., pH, temperature),
e) Duration of period the adsorbate is having interaction with the adsorbent (residence time) (Di Natale *et al*., 2009).

Mechanical filtration

This deals with the physical separation of suspended solids from a liquid passing through carbon arrayed as a porous media in a column or bed. While this accounts for some of the clarification properties of carbon, it is seldom the sole reason for the selection of carbon as a clarification medium. The effectiveness of filtration depends on the particle size, bulk density, and hardness (Ahmedna *et al*., 2000). Although, smaller particle sizes result in a clearer liquid but retardates the rate of preparation. Bulk concentration regulates the quantity of carbon that can be confined in a particular vessel. Also, hardness is crucial because adequate strength is required for particles to block the particulate matter being filtered (Steiner *et al*., 2007; 2010).

Ion exchange

Coal is a natural ion exchanger (Li *et al*., 2012). Ion exchange can be enhanced by chemical activation. Carbon surfaces have both the negative (anionic) and positive (cationic) charges to attract free ions in solution or suspension, depending on how they are treated. Treatment of carbon with a base increases the capacity of carbon to exchange anions while acidulation of the surface makes carbon a powerful cation exchanger (Li *et al*., 2012).

Surface oxidation

This involves the chemical adsorption of atmospheric oxygen to the carbon and the further reaction of the surface oxidation that chemically react with other substances that are oxidized. Activated carbon removes the poison from the skin or alimentary tract by all of these methods, and is then shed or excreted (Radostits *et al*., 2000).

WORKING MECHANISM OF ACTIVATED CHARCOAL ADSORPTION IN DIET DEGRADATION

Activated charcoal had been used and still relevant due to its high adsorption potential for diverse categories of toxins like mycotoxins, plant toxins, pesticides as well as toxic metabolites or pathogens. Adsorption therapy, which involves application of activated biochar as a non-digestible adsorbent, and is recognized as a vital means of averting harmful or fatal effects of orally drenched toxins (McKenzie, 1991). Based on the toxicologists' point of view, working mechanisms of biochar are based on one or several of the following procedures: selective adsorption of some toxins like dioxins, co-adsorption of toxin containing feed substances, adsorption followed by a chemical reaction that destroys the toxin and desorption of earlier adsorbed substances in later stages of digestion (Gerlach and Schmidt, 2012). However, classifiable distinctions need to be made to the time-dependent and partly overlapping processes of adsorption, biotransformation, desorption and excretion of the toxic substances throughout the digestive system of animals. Schirrmann (1984) described the effects of activated carbon on bacteria and their toxins in the gastrointestinal tract as:

1. Adsorption of proteins, amines and amino-acids.
2. Adsorption of digestive tract enzymes, as well as adsorption of bacterial exo-enzymes.
3. Binding, via chemotaxis, of mobile germs.
4. The selective colonization of biochar with gram-negative bacteria might result in decreased endotoxin release as these toxins could be directly adsorbed by the colonized biochar when gram-negative bacteria dying-off.

ADSORPTION EFFECTS ON MYCOTOXINS

The spoilage or adulteration of animal feeds with mycotoxins is a universal challenge that affects up to twenty-five percent of the world's feed production (Mézes *et al*., 2010). Mycotoxins are specifically derived from mold fungi, whose development and multiplication on newly harvested and stored animal feed is hard to avert, more importantly in wet season. Mycotoxin-contaminated feed can result in serious diseases in farm animals. To protect the animals, adsorbents are usually added to the feed to bind the mycotoxins before ingestion (Huwig *et al*., 2001).

One of the most common mycotoxins is aflatoxin (Alshannaq and Yu, 2017), which has been used in numerous studies as a model substance to investigate the adsorption behaviour of biochar and how it reduces the uptake of the toxin in the digestive tract and also in the ruminant animal blood and milk (Galvano *et al*., 1996) while Piva *et al*. (2005) reported no safety value against the adverse effects of fumonisin (a deadly toxic mycotoxin) when one percent inclusion of biochar is added to the feed of piglets. Rao and Chopra (2001) said supplementation of biochar to aflatoxin infected feed of goats lowered the transfer of the toxin (100 ppb) to 76 % in milk. Also, the effectiveness of activated biochar was better compare with bentonite when used as an additive (Rao and Chopra, 2001).

Infection of mycotoxins occur while the crop is on the field, store or during feeding of animals (Wild *et al*., 2015). These mycotoxins (especially aflatoxin) are of high economic value to human beings, crops and animal welfare when consumed (Keller *et al*., 2012). They cause several challenges such as teratogenic, immunosuppressive disorders, carcinogenic and mutagenic effects, abnormal gastrointestinal activities and complete reduction in animals' performance (Wild *et al*., 2015; Anukul *et al*., 2013; Misihairabgwi *et al*., 2017).

To combat these challenges, use of adsorbents like biochar or activated charcoal have been reported to be of great value in reducing the toxicity of these mycotoxins in the blood system of animals (Daković *et al*., 2005). Based on the adsorption capacity of biochar due to total surface area and pore sizes distribution bind the mycotoxin and ameliorate the animal's health and productivity (Galvano *et al*., 1996; Galvano *et al*., 2001). In an *in vitro* study conducted on two types of adsorbents involving activated charcoal and Aluminosilicates, supplemented at the rate of 2 % of DM of dairy cows' diet with significant reduction up to 70 % (Galvano *et al*., 1996). At 14th day, the levels of aflatoxin were observed to be reduced by 45 % in milk produced compare with control that did not receive any adsorbent. In another related research conducted on Holstein cows breed shown up to 65 % decrease of aflatoxin in milk with the inclusion of 0.25 % of activated charcoal (Diaz, 2004). Similarly, in a study conducted on small ruminants, it was observed that inclusion of activated charcoal at 0.1 % for two weeks in the diet goats shown 76 % reduction of aflatoxin in their milk compare with the control (Rao *et al*., 2004). Also, in a situation when lethal doses of aflatoxins were fed to goats, activated charcoal prevent significant damage to their internal organs (Hatch *et al*., 1982). The researcher attributed this to the inability of aflatoxins to be assimilated through the intestines of the animals and the physiochemical properties of the activated charcoal.

DETOXIFICATION OF PLANT TOXINS BY ACTIVATED CHARCOAL

Additional advantage in which biochar is regularly used for, is the mitigation of negative effects of naturally occurring but potentially harmful ingredients present in plants or feeds such as tannins and phenol (Struhsaker *et al*., 1997). Tannins are multifarious and extremely varied compounds that are partially useful but can also be injurious particularly to ruminants that eat large proportion of roughages. Tannins are often found in high protein feeds such as legumes and its strong taste repel the animals, which reduces digestibility and weight gain (Naumann *et al*., 2013). Several studies have investigated how biochar feeding alters the impact of tannin-rich foods. Van *et al*. (2006) found that in goats, feeding 50 − 100 g of bamboo biochar per kg of a tannin-rich acacia leaf diet increased daily weight gain by 17 % compared to the control without biochar, and digestion of crude proteins and nitrogen conversion were significantly improved in the same study.

Plants are known to possess some structural features such as thorns, spines, and prinkles and some other toxins as a defense mechanism against physio-biological disturbance (Wittstock and Gershenzon, 2002). Many of these compounds have hazardous effect when consumed by ruminant animals, thereby inflict injuries, sickness and death on animals. Addition of activated charcoal can be used to avert the menace caused by these structural features in plants.

ADDITION OF BIOCHAR TO GOAT FEED

Van *et al*. (2006) reported that the inclusion of bamboo biochar in a 12-week experiment with 42 growing goats at 1 gram per kg body weight showed significant improvement in crude protein intake and weight gain. The entire quantity of digestible nitrogen improved and invariably reduced urine and faeces passed out by the animals compared to the control without biochar. Roughages are the major components of goats' diets with high amount of tannin e.g. *Acacia mangium* leaves. Therefore, biochar can be used to ameliorate the effects of the plant secondary metabolites through adsorption to improve crude protein and total dry matter (DM) intake of the animals.

In a trial with groups of 12 goats, tested with a tannin-rich basal diet leaves of *Bauhinia acuminate*, which were provided either with or without 1 % biochar showed improved nutrient assimilation which led to a 27 % increase in daily weight gain over the 100-day period of the trial (Silivong and Preston, 2016). In another study, a goat feed additive of 1.5 % and 3 % activated coconut biochar did not produce significant improvement of feed intake nor did it alter the microbial community structure compared with the control (Al-Kindi *et al*., 2017) but the activated biochar increased the faecal concentration of slowly decomposable carbohydrates while reducing fecal Nitrogen.

Biochar should not be fed without complete biochar analysis and control of all relevant parameters of current feed regulations as provided by the European Biochar Certificate (EBC, 2018). The analysis should be carried out by an accredited laboratory specialized in biochar and feed analytics. In addition, as required by the EBC, biochar should always be processed and administered moist to avoid the formation of dust (EBC, 2012). If this is respected, biochar can be added to all common feed mixes and is usually mixable with all common feeds. Good quality biochar may also be added to animal drinking water, and in the case of acute intoxication, activated biochar should be administered in aqueous suspension (Neuvonen and Olkkola, 1988). Depending on livestock species, biochar may also be provided in freely accessible troughs on the pasture or in the stable, without previous mixing into daily feed. Often, biochar is mixed with popular supplements such as molasses (Joseph *et al*., 2015). Some German and Swiss farmers inject 1 % (volume) of biochar into silage towers or silage bales via automated equipment (O'Toole *et al*., 2005).

In most experiments, biochar was not administered alone, but in a combination with additional useful feed supplements such as humic acid, wood vinegar, sauerkraut juice, eubiotic liquids, stevia, nitrate or tannins. This is because it is more efficient when used in combination with other ingredients compare with when used singly. This amalgamation of biochar in conjunction with other feed supplements could advance the scope of further research, and reasonable prospect suitable for feed mixtures could be developed for specific purposes and animal species. The adsorption capacity of biochar depends in particular on the specific surface area, surface charge and the pore size distribution.

SUPPLEMENTATION OF ACTIVATED CHARCOAL IN FISH DIET

Use of activated charcoal supplementation in feed ingredients has shown improved growth performance and intestinal function of both land and water organisms (Mekbungwan *et al*., 2004a; Van *et al*., 2006; Thu *et al*., 2010). Though, it is important to know that, activated charcoal supplemented in diet could adsorb not only various harmful chemicals but also useful nutrients which must be critically considered. Researches on fish had shown that, the highest weight gain was recorded with bamboo charcoal inclusion at 4 % in tiger puffer fish and 0.5 % in juvenile Japanese Flounder (*Paralichthys olivaceus*) (Thu *et al*., 2010). Thus, the optimal level of activated charcoal supplementation in fish diet seems to be variants among fish species and growth stages.

In an experiment conducted by Pirarat *et al*. (2011) on the effects activated charcoal supplementation on tilapia diet on growth performance and intestinal morphology of Nile Tilapia, where the fish received varied level of supplementation (1 %, 2 % and 3 % of activated charcoal in diet) fed at 3 % of their body weight for 30 days. The group that received 2 % showed highest growth performance in terms of percentage weight gain, specific growth rate (SGR) and feed conversion ratio (FCR) while intestinal villi heights in terms of foregut and midgut villi heights were similar to those that received 3 % and 2 % activated charcoal supplementation. Therefore, it could be concluded from the study that 2 % supplementation of activated charcoal performed best even than the control and found to be the most suitable for improving the growth performance and intestinal morphology in tilapia.

EFFECTS OF ACTIVATED CHARCOAL ON GROWTH PERFORMANCE OF SHEEP

Researches have shown that biochar enhances body weight gains and feed efficiency in cattle (Leng *et al*., 2012) and goats (Silivong and Preston, 2016).

Nevertheless, in the study by Darren *et al*. (2020), there was no significant differences among groups of lambs in terms of average daily weight gain, feed conversion ratio and digestibility in a trial on biochar addition carried out on sheep which may be due to the type of biochar used and the prevailing environmental condition of the area in which the trial was performed. This is because different types of biochar of known and unknown sources have significantly varied effect on livestock performance. Johnson and Johnson (1995) reported that the addition of biochar to alfalfa barley diets enhanced diet digestibility and influenced ruminal factors in sheep, with some positive effects on nutrition, although it aggravated the production of volatile fatty acids (VFA) and acetate which suggested that it favours increase methane production and reduction in microbial effectiveness.

SUPPLEMENTATION OF ACTIVATED CHARCOAL IN DAIRY CATTLE DIET

In an experiment on feeding trial carried out by Erickson *et al*. (2011), on activated carbon supplementation in dairy cows' diets, on apparent nutrient digestibility and taste preference, it was discovered that the adverse effects of feeding poor-quality forages could be alleviated by adding activated carbon as a feed additive. The experiment involved feeding of a basal diet with approximately 60 % poor-quality corn silage containing the mycotoxin deoxynivalenol. The cows were subjected to 0, 20, or 40 g activated carbon top-dressed once in a day at evening time, and the results of those that received varied levels of activated charcoal showed increased dry matter intake, apparent total-tract nutrient digestibility of neutral detergent fibre, hemicellulose, and crude protein were observed with increased milk fat content whereas those placed on good quality forages showed no significant differences in apparent total-tract nutrient digestibility or milk composition and yield.

Feeding biochar has been shown to decrease production of CH_4 from *in vitro* systems for hay (Hansen *et al*., 2012), cassava root meal-based diets (Leng *et al*., 2012), and barley silage diets (Saleem *et al*., 2018). However, the feedstock and process used to produce the biochar may affect results (Leng *et al*., 2013; McFarlane *et al*., 2017). Leng *et al*. (2012) reported a decrease in CH_4 production from cattle fed diets based on cassava root chips and foliage whereas Erickson *et al*. (2011) measured an increase in diet digestibility when activated carbon was added to poor quality corn silage diets with the objective to determine the effects of biochar on CH_4 production and diet digestibility *in vivo* growing and finishing beef cattle diets of commonly used feed. Activated charcoal improves milk production in goats and dairy cows, circumventing bloat, plummeting parasitic infections, and lowering methane emissions during digestion (Aerts *et al*., 1997).

ADDITION OF ACTIVATED CHARCOAL IN DIET OF BROILER CHICKENS

Impact of nutritional wood charcoal on growth performance, nutrient efficiency and excreta quality of male broiler birds was assayed by Louis *et al*. (2018) The birds were placed on commercial broiler finisher diet with 0, 1.5, 3, and 6 % wood charcoal which was to establish the fact that a level of dietary wood charcoal can be added to a commercial broiler feed without adverse effects on growth performance, nutrient utilization and losses through birds' excreta under hostile environment. The feed intake, body weight gains and excreta of the birds were measured. No difference in feed intake and body weight gain was observed between those that received biochar and those without, meaning that, it could be added without any adverse effect on the performance of broilers.

Also, in two different researches conducted by Kana *et al*. (2011) and Majewska *et al*. (2011), no improvement of feed efficiency was observed in broiler chickens when charcoal was included in the diet, but they recorded an increase in body weight gain with the inclusion of charcoal of up to 0.4 %. In contrast, Bakr (2008) reported that wood charcoal increased the feed conversion efficiency and other growth performance parameters in broiler chickens if the inclusion rate does not exceed 2 %. However, this effect was age-dependent, limited to birds younger than 29 days, which might explain the missing effect in this study. Likewise, Odunsi *et al*. (2007) observed a negative impact of feeding wood charcoal on growth performance of broilers and did not recommend dietary inclusion of wood charcoal. This was also in line with the report of Oso *et al*. (2014) who concluded that the inclusion of dietary wood charcoal did not influence the apparent dry matter and crude protein digestibility of broilers, but stated in the same study that inclusion of charcoal into unpeeled cassava root meals could counterbalance the negative effect of dietary cyanide on the crude protein utilization. In contrast, the crude protein digestibility of broilers fed aflatoxin infested diets was improved using charcoal as toxin binder (Rafiu *et al*., 2014).

EFFECTS OF DIETARY WOOD CHARCOAL ON EXCRETA QUALITY OF BROILER CHICKENS

Feeding charcoal increased the carbon concentration in total excreta compare with the dietary treatment without wood charcoal. Charcoal is inert and indigestible and therefore is excreted together with the undigested feed residues (Al-Kindi *et al*., 2017). In contrast to the carbon concentration, the phosphorous concentration of the excreta decreased while the organic matter and nitrogen concentrations of the total excreta were not altered by substituting part of the commercial broiler feed with dietary wood charcoal. This is in agreement with Kutlu *et al*. (2001), who also detected a similar effect of dietary charcoal on the composition of excreta of broiler chickens, with the exception of the nitrogen concentration. It is also plausible, that the reduction in phosphorous concentration in the excreta was as a result of the change in gastrointestinal tract microbiota, as proven by Prasai *et al*. (2016b) in layer chickens.

Although, the addition of charcoal had no additional influence on the phosphorus utilization by broiler chickens in the study conducted by Prasai *et al*. (2016a), but the lower phosphorus concentration in excreta of birds fed high levels of dietary wood charcoal demonstrates the potential of dietary wood charcoal to increase the assimilation of phosphorus in poultry diets that is generally limited due to an insufficient production of endogenous phytase in poultry (Maenz and Classen, 1998). Looking from another perspective, it reduces level of phosphorus available in birds' droppings as organic fertilizer (Bolan *et al*., 2010), but reduces the level of surface water contamination, thereby making the water safe for domestic and industrial utilization. Biochar influences the appearance of fresh excreta in terms of colour from light grey to dark grey, nevertheless, the consistency of excreta was not affected by the addition of charcoal and no signs of indigestion or health related challenges were noticed in broiler birds given dietary treatments with wood charcoal.

ADDITION OF ACTIVATED CHARCOAL IN DIET OF TURKEY

Hinz *et al*. (2019) in a study on effect of enriched charcoal at 0.2 % level as feed additive using standard and low-protein diets of 18 weeks old male turkeys in an on-farm study to assess its potency in reducing faecal wettness, they observed no difference in performance and health even though, high dry matter content was present in the litter. Whereas, the weight of those received protein-reduced diet was decreased significantly throughout the trial though slaughter weight was not affected and mortality was reduced by 0.5 % among the experimental group. Thus they concluded that 0.2 % of enriched charcoal was not a beneficial level of feed-additive regarding turkeys' health, while temporary protein reduction might have positive effects. However, Majewska *et al*. (2009) reported significant positive results in the body weight and mortality of turkey toms, this was corroborated by Kutlu *et al*. (2001) who had significant results in growth performance of broiler chickens from day 8 to 28 of life. The variation in these researches might be due to lower dose of charcoal. Additionally, the value of charcoal is greatly inconsistent due to the method of production and the original material, which influence carbon efficiency (Kana *et al*., 2011). However, reports of Hinz *et al*. (2019) corroborates Rattanawut (2014) and Kana *et al*. (2011) where they found no significant effect on the growth performance, which might be due to small number of turkeys used compare those where large number were used which required different conditions for housing, space and infection risks.

Hinz *et al*. (2019) showed the status of footpad dermatitis to be improved by dietary charcoal in broiler chickens. However, turkey and broiler chicken husbandry differ in housing conditions such as bedding material and fattening period. In turkey fattening, the common litter material is long-stalked straw, while in the aforementioned study by Hinz *et al*. (2019), the birds were kept on straw and wood pellets. Straw is a more detrimental bedding material compared to substitutes such as wood shavings, dried maize silage, straw pellets and rice shells. Straw is inferior to other materials resulting in high litter moisture (Benabdeljelil and Ayachi, 1996) and footpad dermatitis (Youssef *et al*., 2010 and Berk, 2009) due to its to lose water through evaporation. Moreover, the duration of the fattening period of turkey toms is far longer than that of broiler chickens, which might be responsible for predisposing turkeys to more severe lesions.

EFFECTS OF ACTIVATED CHARCOAL ON MYCOTOXINS IN SWINE

Chu *et al*. (2013b) researched on the feeding of bamboo biochar to young pigs. They reported that the average weight gain during the trial period was 750 g per day in the control without biochar and 877 g per day in the 0.3 % biochar treatment; this corresponded to a significant feed efficiency increase of 17.5 %. The biochar group showed significant positive effects on total protein, albumin, cholesterol, high density lipoprotein, and low-density lipoprotein cholesterol levels in the blood plasma differed significantly ($P < 0.05$), while the heamatological indices which included leucocytes, erythrocytes, hemoglobin, hematocrit and platelets did not differ significantly ($P < 0.05$) between the experimental groups.

In a related study, the same authors showed that feeding 0.3 % and 0.6 % bamboo biochar improved the quality of marketable meat and the composition of pig fat, with an increase in unsaturated fatty acid content and a decrease in saturated fat (Chu *et al*., 2013b). Chu *et al*. (2013a) concluded by reporting that feeding 0.3 % bamboo biochar gave the same growth rate in fattening pigs as the standard antibiotic treatment and that, without the negative side effects to the environment that antibiotics usually possess. Several other authors reported that 30 g of biochar plus 30 g of stevia had higher daily weight gain, feed efficiency and immune responses as well as significantly higher meat quality and storage capacity of meat products (Lee *et al*., 2011; Choi *et al*., 2012).

Sivilai *et al*. (2018) reported that a diet consisting of ensiled banana pseudo stem and ensiled taro foliage increased the feed conversion rate by 10.6 % compared to the control. They posited that the total weight gain of the piglets was on average higher by 20.1 % ($p = 0.089$) after three months of the experiment. Lavrentyev *et al*. (2021) in a study on the use of activated charcoal feed supplement in diets of pig reported that, the use of an active carbon feed additive during rearing and fattening of pigs contributed to an increase in the average daily gain in live weight, a reduction in the fattening period, an increase in the massiveness and churn index, and an improvement in hematological and biochemical blood parameters. They also reported that, a dose of 0.025 $g.kg^{-1}$ of live weight had a weak effect on the growth and development of young animals, while doses of 0.050 – 0.075 $g.kg^{-1}$ favorably affected the growth and development of animals.

INTERACTIONS OF ACTIVATED CHARCOAL WITH OTHER MATERIALS

It is of importance to consider the interactive effect of activated charcoal with other feed ingredients, this is because any activated charcoal added directly to a feed would act like any other organic source of carbon. Problems could arise from the chemicals confiscated by the activated carbon when used on sick livestock. However, the purpose of activated carbon is to absorb toxins accidentally ingested by livestock, allowing these toxins to safely pass through the gastrointestinal tract of the animal without being assimilated into the body. These toxins could therefore be egested from the body through the animal's faeces or excreta (Scharman *et al*., 2001).

EFFECT OF ACTIVATED CHARCOAL ON RUMINATION

Quantum of energy lost due to methane (CH_4) production in ruminants could range from 2 to 12 % of total energy consumed, although it varies based on the energy density of the diet consumed by the animals (Johnson and Johnson, 1995). CH_4 formation is a necessary section of rumen fermentation, but results in loss of energy available for metabolism in animals and has contributed immensely to the global warming effect across the world (Boadi *et al*., 2004). Biochar reduces CH_4 eructation by increasing inert surface area in the rumen through improved microbial habitat, or altering the microbial community (Leng, 2014; Saleem *et al*., 2018). Feng *et al*. (2012) found

Table 1. Chemical properties of activated charcoal produced from a blend of agricultural waste materials

Ingredients	Composition
Carbon content (%)	79.43
Calcium (mg.kg^{-1})	6185.11
Phosphorus (mg.kg^{-1})	8,603.29
Sodium (mg.kg^{-1})	1722.47
Potassium (mg.kg^{-1})	10,275.48
Magnesium (mg.kg^{-1})	3980.14
Manganese (mg.kg^{-1})	721.00
Iron (mg.kg^{-1})	996.35
Zinc (mg.kg^{-1})	95.47
Copper (mg.kg^{-1})	33.69
Arsenic (mg.kg^{-1})	13.38
Nitrogen (mg.kg^{-1})	3008.04

Source: Stephen and Cosmas (2022)

that biochar escalates the ratio of methanotrophs to methanogens in paddy soils, and this process may also occur in the rumen.

ACTIVATED CHARCOAL'S COMPATIBILITY WITH SUSTAINABLE AGRICULTURE

With the recent development in advocating for organic agriculture, organic livestock farmers must avoid use of these synthetic chemicals that could poison livestock, of which human beings are always at the receiving end. Accidental poisoning can occur when livestock ingests poisonous plants or mycotoxins on forage or haylage (Huwig *et al*., 2001), use of activated carbon to bind these poisons is an expedient and safe emergency treatment in averting their effects on

Table 2. Chemical dosage, length of supplementation and effects of responses measured in different species of animals

S/N	Animals	Clinical Dosage	Feedstock	Length of supplementation (Days)	Effect of Responses Obtained	Source
1	Cattle	0.6 % of feed DM	Rice hull	21	Reduced enteric methane emissions	Islam *et al.* (2014)
2	Cattle	1 % of feed DM	Rice husk	56	15 % feed conversion rate increase	Phongphanith and Preston (2018)
3	Poultry	4 % of DM feed	Woody green waste	161	Egg weight increased by 5 %; feed conversion ratio by 12 %	Prasai *et al.* (2016)
4	Poultry	1 % of DM feed	Wood	37	Reduced foot pat and hook lesions by 92 % and 74 %	Albiker and Zweifel (2019)
5	Goat	1 % of body weight	Bamboo	84	DM, OM, CP digestibility and N retention increased	Van *et al.* (2006)
6	Pig	1 %, 3 % and 5 % of feed DM	Wood	30	Increased duodenal villus height	Mekbungwan, *et al.* (2004b)
7	Duck	1 % of DM feed	Wood	21	Feed conversion rate increased	Islam *et al.* (2014)
8	Duck	1 % of DM feed	Bamboo	49	Intestinal villus height increased	Ruttanavut *et al.* (2009)
9	Carp	0.5 %, 1 %, 2 %, 4 % of DM feed	Bamboo	63	Improved serum indicators	Mabe *et al.* (2018)
10	Stripfish	2 % of feed DM	Bamboo	50	Survival rate increase by 9 %	Quaiyum *et al.* (2014)

animals. The main threat to the organic system would come from the poison present in the animal manure, which can be easily managed in small quantities. Use of activated carbon in emergency situations is compatible with organic production which promotes animal health and welfare (Huwig *et al*., 2001).

Although, prophylactic use of activated carbon on a large group of animals to allow them to consume grain contaminated with toxins or forage on pastures known to contain poisonous plants does not promote animal health and welfare. This is because activated carbon absorbs much but not all of the toxins, some of the toxins will not be removed from the body and might had detrimental effect on the animals and consumers (Christophersen *et al*., 2002). Animals should be fed a nutritious ration, not a tainted ration with a poison remover added. Manure management becomes a larger problem with prophylactic feeding of activated carbon mixed with toxic feed. Large amounts of toxin carrying manure need to be composed or disposed of without contaminating the soil or water.

CONCLUSION

The use of activated charcoal or biochar as a feed additive has the potential to improve animal health, feed efficiency and livestock productivity, enhance soil fertility and reduce rumen methane production amongst others. In combination with other good farm practices, biochar could improve the overall sustainability of animal husbandry. This review has provided sufficient information as a guide with positive effects on livestock productivity and as an antidote to excessive expenses incurred on synthetic mycotoxin binders used as additives. It has elucidated on how biochar could be efficiently used and/or misused and that there is no distinctive hazard connected with activated charcoal.

AUTHOR CONTRIBUTIONS

Conceptualization: Ayankoso, M. T., Oluwagbamila, D. M.
Methodology: Ayankoso, M. T.
Investigation: Abe, O. S.
Data curation: Oluwagbamila, D. M., Ayankoso, M. T.
Writing-original draft preparation: Oluwagbamila, D. M., Ayankoso, M. T.
Writing-review and editing: Abe, O. S., Ayankoso, M. T.
Project administration: Ayankoso, M. T., Abe, O. S.

All authors have read and agreed to the published version of the manuscript.

INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author.

CONFLICTS OF INTEREST

There is no conflict of interest with any individual or organization regarding the materials discussed in this manuscript.

REFERENCES

Aerts, R. (1997). Nitrogen partitioning between resorption and decomposition pathways: a trade-off between nitrogen use efficiency and litter decomposability? *Oikos*, 80(3), 603−406.

Ahmedna, M., Marshall, W. E. & Rao, R. O. (2000). Granular Activated Carbons from Agricultural By-Products: Preparation, Properties, and Application in Cane Sugar Refining. LSU AgCenter: Bulletin Number 869.

Albiker, D. & Zweifel, R. (2019). Pflanzenkohle im Futter oder in der Einstreu und ihre Wirkung auf die Stickstoffretention und Leistung von Broilern. *Wissenschaftstagung Ökologischer Landbau. Kassel: Stiftung Ökologie and Landbau*, (15),276−283.

Al-Kindi, A., Schiborra, A., Buerkert, A. & Schlecht, E. (2017). Effects of quebracho tannin extract and activated charcoal on nutrient digestibility, digesta passage and faeces composition in goats. *Journal of Animal Physiology and Animal Nutrition*, 101(3), 576−588.

Alshannaq, A. & Yu, J. H. (2017). Occurrence, toxicity, and analysis of major mycotoxins in food. *Australian Veterinary Journal*, 68(4), 146−148.

Anukul, N. Vangnai, K. & Mahakarnchandkul, W. (2013) Significance of regulation limits in mycotoxin contamination in Asia and risk management programs at the national level. *Journal of Food and Drug Analysis*, 21(3), 227−241.

Bakr, B. E. A. (2008). The effect of using citrus wood charcoal in broiler rations on the performance of broilers. *An-Najah University Journal for Research – Natural Sciences*, 22, 17−24.

Beguin, F. & Frackowiak, E. (Eds.). (2009). *Carbons for Electrochemical Energy Storage and Conversion Systems*, (1st ed.). CRC Press. https://doi.org/10.1201/9781420055405

Benabdeljelil, K. & Ayachi, A. (1996). Evaluation of Alternative Litter Materials for Poultry. *Journal of Applied Poultry Research*, 5, 203−209.

Berk, J. (2009). Einfluss der Einstreuart auf Prävalenz und Schweregrad von Pododermatitis beimännlichen Broilern. (Effect of litter type on prevalence and severity of pododermatitis in male broilers). *Berliner und Münchener tierärztliche Wochenschrift*, 7, 257−263.

Bisson, M. G., Scott, C. B. & Taylor, C. A. (2001). Activated charcoal and experience affect intake of juniper by goats. *Journal of Range Management*, 54, 274−278.

Bolan, N. S., Szogi, A. A., Chuasavathi, T., Seshadri, B., Rothrock, M. J. & Panneerselvam, P. (2010). Uses and management of poultry litter. *World's Poultry Science Journal*, 66(4), 673−698.

Burdock, G. A. (1997). *Encyclopedia of Food and Color Additives*. Boca Raton: CRC.

Cheng, C. H. & Lehmann, J. (2009). Ageing of black carbon along a temperature gradient. *Chemosphere*, 75(8), 1021−1027.

Choi, J. S., Jung, D. S., Lee, J. H., Choi, Y. I. & Lee, J. J. (2012). Growth performance, immune response and carcass characteristics of finishing pigs by feeding stevia and charcoal. *Korean Journal for Food Science of Animal Resources*, 32(2), 228−233.

Christophersen, A. B., Levin, D., Hoegberg, L. C., Angelo, H. R. & Kampmann, J. P. (2002). Activated charcoal alone or after gastric lavage: a simulated large paracetamol intoxication. *British Journal of Clinical Pharamacology*, 53, 312−317.

Chu, G. M., Jung, C. K., Kim, H. Y., Ha, J. H., Kim, J. H., Jung, M. S., Lee, S. J., Song, Y., Ibrahim, R. I. H., Cho, J. H., Lee, S. S. & Song, Y. M. (2013a). Effects of bamboo charcoal and bamboo vinegar as antibiotic alternatives on growth performance, immune responses and fecal microflora population in fattening pigs. *Animal Science Journal*, 84, 113−120.

Chu, G. M., Kim, J. H., Kang, S. N. & Song, Y. M. (2013b). Effects of dietary bamboo charcoal on the carcass characteristics and meat quality of fattening pigs. *Korean Journal for Food Science of Animal Resources*, 33(3), 348−355.

Daković, A., Tomašević-Čanović, M., Dondur, V., Rottinghaus, G. E., Medaković, V. & Zarić, S. (2005). Adsorption of mycotoxins by organozeolites. *Colloids and Surfaces B: Biointerfaces*, 46(1), 20−25.

Darren, J. M., Beth, B. & Juan, J. V. (2020). Use of biochar by sheep: Impacts on diet selection, digestibility, and performance. *Journal of Animal Science*, 98(12), 1−9.

Davidson, E. A., Chorover, J. & Dail, D. B. (2003). A mechanism of abiotic immobilization of nitrate in forest ecosystems: the ferrous wheel hypothesis. *Global Change Biology*, 9(2), 228−236.

Di Natale, F., Gallo, M. & Nigro, R. (2009). Adsorbents selection for aflatoxins removal in bovine milks. *Journal of Food Engineering*, 95(1), 186−191.

Diaz, S. (2004). The plant traits that drive ecosystems: Evidence from three continents. *Journal of Vegetation Science*, 15, 295−304. https://doi.org/10.1111/j.1654-1103.2004.tb02266.x

Erickson, P. S., Whitehouse, N. L. & Dunn, M. L. (2011). Activated carbon supplementation of dairy cow diets: Effects on apparent total tract nutrient digestibility and taste preference. *American Registry of Professional Animal Scientists*, 27, 428−434.

European Biochar Foundation (EBC). (2012). *European biochar certificate – guidelines for a sustainable production of biochar*. Version 8.2 of 19th April 2019: Accessed: 30th September, 2021.

European Biochar Foundation (EBC). (2018). *Guidelines for EBC-feed certification*. http://www.european-biochar.org/biochar/media/doc/ebc-feed.pdf: Accessed: 30th September, 2021.

Feng, F., Yang, F., Rong, W., Wu, X., Zhang, J., Chen, S., He, Ch. & Zhou, J. M. (2012). A *Xanthomonas* uridine 5'-monophosphate transferase inhibits plant immune kinases. *Nature*, 485(7396), 114−118.

Galvano, F., Pietri, A., Fallico, B., Bertuzzi, T., Scirè, S., Galvano, M. & Maggiore, R. (1996). Activated carbons: *in vitro* affinity for aflatoxin B1 and relation of adsorption ability to physicochemical parameters. *Journal of Food Protection*, 59(5), 545−550.

Galvano, F., Piva, A., Ritiene, A. & Galvano, G. (2001): Dietary strategies to counteract the effects of mycotoxins: A review. *Journal of Food Protection*, 64, 120−131.

Gerlach, A. & Schmidt, H. P. (2012). Pflanzenkohle in der Rinderhaltung. *Ithaka Journal*, 1, 80−84.

Guo, J. & Lua, A. C. (2003). Textual and chemical properties of adsorbent prepared from palm shell by phosphoric acid activation. *Materials Chemistry and Physics*, 80, 114−119.

Hagemann, N., Joseph, S., Schmidt, H., Kammann, C. I., Harter, J., Borch, T., Young, R. B., Varga, K., Taherymoosavi, S., Elliott, K. W., Albu, M., Mayrhofer, C., Obst, M., Conte, P., Dieguez, A., Orsetti, S., Subdiaga, E., Behrens, S. & Kappler, A. (2018). Organic coating on biochar explains its nutrient retention and stimulation of soil fertility. *Nature Communications*, 8(1), 163.

Hansen, J., Sato, M. & Ruedy, R. (2012). Perception of climate change. *Proceedings of the National Academy of Sciences*, 109(37), E2415−E2423.

Hatch, T. P., Al-Hossainy, E. & Silverman, J. A. (1982). Adenine nucleotide and lysine transport in *Chlamydia psittaci. Journal of Bacteriology*, 150(2), 662−670.

Hinz, K. S. J., Schättler, J. K., Spindler, B. & Kemper, N. (2019). Foot pad health and growth performance in broiler chickens as affected by supplemental charcoal and fermented herb extract (FKE): An on-farm study. *European Poultry Science*, 83, 13. https://doi.org/10.2136/sssaspecpub63.2014.0043.5

Hinz, K., Stracke, J., Schättler, J. K., Kemper, N. & Spindler, B. (2019). Effects of Enriched Charcoal as Permanent 0.2 % Feed-Additive in Standard and Low-Protein Diets of Male Fattening Turkeys: An On-Farm Study. *Animals*, 9(8), 1−15.

Huwig, A., Freimund, S., Käppeli, O. & Dutler. H. (2001). Mycotoxin detoxification of animal feed by different adsorbents. *Toxicology Letters*, 122, 179−188.

International Biochar Initiative (IBI). (2015). Standardized product definition and product testing guidelines for biochar that is used in soil. *International Journal of Environmental Research and Public Health*, 14(6), 632.

Islam, M. M., Ahmed, S. T., Kim, Y. J., Mun, H. S., Kim, Y. J. & Yang, C. J. (2014). Effect of sea tangle (*Laminaria japonica*) and charcoal supplementation as alternatives to antibiotics on growth performance and meat quality of ducks. *Asian-Australasian Journal of Animal Sciences*, 27(2), 217–224.

Johnson, K. A. & Johnson, D. E. (1995). Methane emissions from cattle. *Journal of Animal Science*, 73, 2483−2492.

Joseph, S., Pow, D., Dawson, K., Mitchell, D., Rawal, A., Hook, J., Taherymoosavi, S., Zwieten, L., Rust, J., Donne, S., Munroe, P., Pace,B., Graber, E., Thomas, T., Nielsen, S., Ye, J., Lin, Y., Pan, G., Li, L. & Solaiman, Z. (2015). Feeding biochar to cows: an innovative solution for improving soil fertility and farm productivity. *Pedosphere*, 25(5), 666−679.

Kana, J. R., Teguia, A., Mungfu, B. M. & Tchoumboue, J. (2011). Growth performance and carcass characteristics of broiler chickens fed diets supplemented with graded levels of charcoal from maize cob or seed of *Canarium schweinfurthii* Engl. *Tropical Animal Health Production*, 43, 51−56.

Keller, A., Litzelman, K., Wisk, L. E., Maddox, T., Cheng, E. R., Creswell, P. D. & Witt, W. P. (2012). Does the perception that stress affects health matter? The association with health and mortality. *Health Psychology*, 31(5), 677−684. DOI: 10.1037/a0026743

Kracke, F., Vassilev, I. & Krömer, J. O. (2015). Microbial electron transport and energy conservation − the foundation for optimizing bioelectrochemical systems. *Frontiers in Microbiology*, 6, 575.

Kutlu, H. R., Ünsal, I. & Görgülü, M. (2001). Effects of providing dietary wood (oak) charcoal to broiler chicks and laying hens. *Animal Feed Science Technology*, 90(3), 213−226.

Lavrentyev, A., Sherne, V., Semenov, V., Zhestyanova, L. & Mikhaylova, L. (2021). Use of activated charcoal feed supplement in diets of pigs. *Earth and Environmental Science*, 935.

Lee, J. J., Park, S. H, Jung, D. S., Choi, Y. I. & Choi, J. S. (2011). Meat quality and storage characteristics of finishing pigs by feeding stevia and charcoal. *Korean Journal for Food Science of Animal Resources*, 31(2), 296−303.

Leng, R. A. (2013). Interactions between microbial consortia in biofilms: a paradigm shift in rumen microbial ecology and enteric methane mitigation. Perspectives on Animal Biosciences. *Animal Production Science*, 54(5), 519−543. https://doi.org/10.1071/AN13381

Leng, R. A., Inthapanya, S. & Preston, T. R. (2012). Biochar reduces enteric methane and improves growth and feed conversion in local "Yellow" cattle fed cassava root chips and fresh cassava foliage. *Livestock Research for Rural Development*, 24, 11.

Li, Y., Yu, S., Strong, J. & Wang, H. (2012). Are the biogeochemical cycles of carbon, nitrogen, sulfur, and phosphorus driven by the "FeIII-FeII redox wheel" in dynamic redox environments? *Journal of Soils and Sediments*, 12(5), 683−693.

Louis, A., Mohammed, A., Andreas, B. & Regina, R. (2018). Influence of dietary wood charcoal on growth performance, nutrient efficiency and excreta quality of male broiler chickens. *International Journal of Livestock Production*, 9(10), 286−292.

Mabe, L. T., Su, S., Tang, D., Zhu, W., Wang, S. & Dong, Z. (2018). The effect of dietary bamboo charcoal supplementation on growth and serum biochemical parameters of juvenile common carp (*Cyprinus carpio* L.).

Aquaculture Research, 49(3), 1142−1152.

Maenz, D. D. & Classen, H. L. (1998). Phytase activity in the small intestinal brush border membrane of the chicken. *Poultry Science*, 77, 557−563.

Majewska, T., Mikulski, D. & Siwik, T. (2009). Silica grit, charcoal and hardwood ash in turkey nutrition. *Journal of Elements*, 14, 489−500.

Majewska, T., Pyrek, D. & Faruga, A. (2011). A note on the effect of charcoal supplementation on the performance of Big 6 heavy torn turkeys. *Journal of Animal Feed Science*, 11, 135−141.

McFarlane, Z. D., Myer, P. R., Cope, E. R., Evans, N. D., Bone, T. C., Bliss, B. E. & Mulliniks, J. T. (2017). Effect of biochar type and size on *in vitro* rumen fermentation of orchard grass hay. West Central Research and Extension Center, North Platte. 110

McHenry, J. M. (2010). There is no trade-off between speed and force in a lever system. *Biology Letters*, 7(6), 878−879.

McKenzie, R. A. (1991). Bentonite as therapy for Lantana camara poisoning of cattle. *Medical Toxicology and Adverse Drug Experience*, 3(1), 33−58.

McLennan, M. W. & Amos, M. L. (1989). Treatment of lantana poisoning in cattle [*Lantana camara*; activated charcoal]. *Australia Veterinarian Journal*, 4(3), 45.

Mekbungwan, A., Yamauchi, K. & Sakaida, T. (2004b). Intestinal villus histological alterations in piglets fed dietary charcoal powder including wood vinegar compound liquid. *Anatomia, Histologia, Embryologia*, 33(1), 11−16.

Mekbungwan, A. Thongwittaya, N. & Yamauchi, K. (2004a). Digestibility of soyabean and pigeon pea seed meals and morphological intestinal alterations in pigs. *Journal of Veterinary and Medical Sciences*, 66(6), 627−633.

Mézes, M., Balogh, K. & Tóth, K. (2010). Preventive and therapeutic methods against the toxic effects of mycotoxins – a review. *Acta Veterinaria Hungarica*, 58 (1), 1−17.

Misihairabgwi, J. M., Ezekiel, C. N., Sulyok, M., Shephard, G. S. & Krska, R. (2017) Mycotoxin contamination of foods in Southern Africa: A 10-year review (2007–2016). *Critical Reviews in Food Science and Nutrition*, 59(1), 43−58. DOI: 10.1080/10408398.2017.1357003

Naumann, H. D., Muir, J. P., Lambert, B. D., Tedeschi, L. O. & Kothmann, M. M. (2013). Condensed tannins in the ruminant environment: a perspective on biological activity. *Journal of Agricultural Sciences*, 1, 8−20.

Neuvonen, P. J. & Olkkola, K. T. (1988). Oral activated charcoal in the treatment of intoxications. *Journal of Animal Science*, 83(8), 1939−1947.

O'Toole, A., Andersson, D., Gerlach, A., Glaser, B., Kammann, C. I., Kern, J., Kuoppamäki, K., Piva, A., Casadei, G., Pagliuca, G., Cabassi, E., Galvano, F., Solfrizzo, M., Riley, R. T. & Diaz, D. E. (2005). Qualitative analysis of volatile organic compounds on biochar. *Chemosphere*, 85(5), 869−882.

Odunsi, A. A., Oladele, T. O., Olaiya, A. O. & Onifade, O. S. (2007). Response of broiler chickens to wood charcoal and vegetable oil based diets. *World Journal of Agricultural Sciences*, 3(5), 572−575.

Oso, A. O., Akapo, O., Sanwo, K. A. & Bamgbose, A. M. (2014). Utilization of unpeeled cassava (*Manihot esculenta* Crantz) root meal supplemented with or without charcoal by broiler chickens. J*ournal of Animal Physiology and Animal Nutrition*, 98, 431−438.

Phongphanith, S. & Preston, T. R. (2018). Effect of rice-wine distillers' byproduct and biochar on growth performance and methane emissions in local "Yellow" cattle fed ensiled cassava root, urea, cassava foliage and rice straw. *Livestock Research for Rural Development*, 28, 178.

Pirarat, N., Pinpimai, K., Endo, M., Katagiri, T., Ponpornpisit, A., Chansue, N. & Maita, M. (2011). Modulation of intestinal morphology and immunity in nile tilapia (*Oreochromis niloticus*) by *Lactobacillus rhamnosus* GG. *Research in Veterinary Science*, 91, 92−97.

Piva, A., Casadei, G., Pagliuca, G., Cabassi, E., Galvano, F., Solfrizzo, M., Riley, R. T. & Diaz, D. E. (2005). Qualitative analysis of volatile organic compounds on biochar. *Chemosphere*, 85(5), 869−882.

Prasai, T. P., Walsh, K. B., Bhattarai, S. P., Midmore, D. J., Van, T. T. H., Moore, R. J. & Stanley, D. (2016b). Biochar, bentonite and zeolite supplemented feeding of layer chickens alters intestinal microbiota and reduces campylobacter load. *PLOS ONE*, 11(4), 406.

Prasai, T. P., Walsh, K. B., Bhattarai, S. P., Midmore, D. J., Van, T. T., Moore, R. J. & Stanley, D., (2016a). Biochar, bentonite and zeolite supplemented feeding of layer chickens alters intestinal microbiota and reduces *Campylobacter* Load, *PLOS ONE*, 11(4), 0154061.

Quaiyum, M., Jahan, R., Jahan, N., Akhter, T. & Islam, M. S. (2014). Effects of bamboo charcoal added feed on reduction of ammonia and growth of *Pangasius hypophthalmus*. *Journal of Aquaculture Research and Development*, 5, 69−76.

Radostits, O. M., Gay, C. C., Blood, D. C. & Hinchcliff, K. W. (2000). Veterinary Medicine: A textbook of cattle, sheep, pigs, goats and horses, nona edizione. Saunders, London, UK.

Rafiu, T. A., Babatunde, G. M., Akinwumi, A. O., Akinboro, A., Adegoke, Z. A. & Oyelola, O. B. (2014). Assessment of activated charcoal vs synthetic toxin-binder on performance, nutrient utilization and meat-quality utilization of broilers fed infected diets. *International Journal of Agriculture and Biosciences*, 3(5), 219−224.

Rao, S. V. R., Raju, M. V. L. N., Reddy, M. R. & Panda, A. K. 2004. Replacement of yellow maize with pearl millet (*Pennisetum typhoides*), foxtail millet (*Setaria italica*) or finger millet (*Eleusine coracana*) in broiler chicken diets containing supplemental enzymes. *Asian-Australian Journal Animimal Sciences*, 17(6), 836−842.

Rao, S. B. N. & Chopra, R. C. (2001). Influence of sodium bentonite and activated charcoal on aflatoxin M1 excretion in milk of goats. *Small Ruminant Research*, 41(3), 203−213.

Totusek, R. & W. M. Beeson, W. M. (1953). The Nutritive Value of Wood Charcoal for Pigs. *Journal of Animal Science*, 12(2), 271−281. https://doi.org/10.2527/jas 1953.122271x

Ruttanavut, J., Yamauchi, K., Goto, H. & Erikawa, T. (2009). Effects of dietary bamboo charcoal powder including vinegar liquid on growth performance and histological intestinal change in Aigamo ducks. *International Journal of Poultry Science*, 8(3), 229−236.

Saleem, M., Law, A. D., Sahib, M. R., Pervaiz, Z. H. & Zhang, Q. (2018). Impact of root system architecture on rhizosphere and root microbiome. *Rhizosphere*, 6, 47−51.

Scharman, E. J., Cloonan, H. A. & Durback-Morris, L. F. (2001). Home administration of charcoal: can mothers administer a therapeutic dose? *The Journal of Emergency Medicine*, 21(4), 357−361.

Schirrmann, U. (1984). Aktivkohle und ihre Wirkung auf Bakterien und deren Toxine im Gastrointestinaltrakt.

Silivong, P. & Preston, T. R. (2016). Supplements of water spinach (*Ipomoea aquatica*) and biochar improved feed intake, digestibility, N retention and growth performance of goats fed foliage of *Bauhinia acuminata* as the basal diet. *Livestock Research for Rural Development*, 28, 113.

Sivilai, B., Preston, T. R., Leng, R. A., Hang, D. T. & Linh, N. Q. (2018). Rice distillers' byproduct and biochar as additives to a forage-based diet for growing Moo Lath pigs; effects on growth and feed conversion. *Livestock Research for Rural Development*, 30, 113.

Soo, J., Malik, B. A., Turner, J. M., Persad, R., Wine, E., Siminoski, K. & Huynh, H. Q. (2013). Use of exclusive enteral nutrition is just as effective as corticosteroids in newly diagnosed pediatric Crohn's disease. *Digestive Diseases and Sciences*, 58(12), 3584−3591. DOI: 10.1007/s10620-013-2855-y. Epub 2013 Sep 12. PMID: 24026403.

Spokas, K. A., Novak, J. M., Stewart, C. E., Cantrell, K. B., Uchimiya, M., DuSaire, M. G. & Ro, K. S. (2011). Qualitative analysis of volatile organic compounds on biochar. *Chemosphere*, 85, 869−882.

Steiner, C., Das, K. C., Melear, N. & Lakly, D. (2010). Reducing nitrogen loss during poultry litter composting using biochar. *Journal of Environment Quality*, 39(4), 1236.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., de Macêdo, J. L. V., Blum, W. E. & Zech, W. (2007). Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and Soil*, 291(1), 275−290.

Struhsaker, T. T., Cooney, D. O. & Siex, K. S. (1997). Charcoal consumption by Zanzibar red colobus monkeys: its function and its ecological and demographic consequences. *International Journal of Primatology*, 18(1), 61–72.

Sun, J., Hippo, E. J., Marsh, H., O'Brien, W. S. & Crelling, J. C. (1997). Activated carbon produced from an Illinois Basin 1080 Coal. *Carbon*, 35, 341−352.

Moe, T. Shunsuke, K., Manabu, I. & Yokoyama Saichiro, Y. (2010). Effects of Supplementation of Dietary Bamboo Charcoal on Growth Performance and Body Composition of Juvenile Japanese Flounder, *Paralichthys olivaceus*. *Journal of the World Aquaculture Society*, 255–262.

Toth, J. D. & Dou, Z. (2016). Use and Impact of Biochar and Charcoal in Animal Production Systems. In Guo, M., He, Z. and Uchimiya, M., Eds., *Agricultural and Environmental Applications of Biochar: Advances and Barriers, Soil Science Society of America*, Inc., Madison, 199−224.

Van Der Zee, F. P. & Cervantes, F. J. (2009). Impact and application of electron shuttles on the redox (bio) transformation of contaminants: a review. *Biotechnology Advances*, 27(3), 256−277.

Van Der Zee, F. P., Bisschops, I. A. E., Lettinga, G. & Field, J. A. (2003). Activated carbon as an electron acceptor and redox mediator during the anaerobic bio-transformation of azo dyes. *Environmental Science and Technology*, 37(2), 402−408.

Van, D. T. T., Mui, N. T. & Ledin, I. (2006). Effect of method of processing foliage of *Acacia mangium* and inclusion of bamboo charcoal in the diet on performance of growing goats. *Animal Feed Science and Technology*, 30(3−4), 242−256.

Weber, K. & Quicker, P. G. (2018). Properties of biochar. *Fuel*, 217, 240−261.

Wild, M., Folini, D., Hakuba, M. Z., Schar, C., Seneviratne, S. I., Kato, S. Rutan, D., Ammann, C., Wood, E. F. & Kong-Langlo, G. (2015). The energy balance over land and oceans: an assessment based on direct observations and CMIP5 climate models. *Climate Dynamics*, 44, 3393−3429. https://doi.org/10.1007/s00382-014-2430-z

Wittstock, U. & Gershenzon, J. (2002). Constitutive plant toxins and their role in defense against herbivores and pathogens. *Current Opinion in Plant Biology*, 5(4), 300−307. DOI: 10.1016/s1369-5266(02)00264-9. PMID: 12179963.

Youssef, M. A., El-Khodery, S. A., El-deeb, W. M. & El-Amaiem, W. E. A. (2010). Ketosis in buffalo (*Bubalus bubalis*): clinical findings and the associated oxidative stress level. *Tropical Animal Health and Production*, 42, 1771−1777.

Yu, L., Yuan, Y., Tang, J., Wang, Y. & Zhou, S. (2015). Biochar as an electron shuttle for reductive dechlorination of pentachlorophenol by *Geobacter sulfurreducens*. *Scientific Reports*, 5(1), 1−10.