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RESEARCH ARTICLE

BIOCHAR AS A FEED ADDITIVE FOR IMPROVING THE PERFORMANCE OF FARM ANIMALS

Emanuel Joel Lao[a,b*], Ernest Rashid Mbega[a]

[a] Department of Sustainable Agriculture, Biodiversity and Ecosystem Management, The Nelson Mandela African Institution of Science and Technology (NM-AIST). P. O. Box 447, Tengeru, Arusha - Tanzania.
[b] Centre for Research, Agriculture Advancement, Teaching Excellence and Sustainability (CREATES), The Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania
** Corresponding Author's E-mail: laoemanueljoel@gmail.com*

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ABSTRACT

Biochar, also known as biomass-derived char or charcoal is a dark/black carbonaceous material generated from the pyrolysis process under temperature averagely 700 ^{0}C and low oxygen levels. Depending on the intended objectives and conditions of the pyrolysis, the biochar, syngas and bio-oils are the three primary products generated. The quality of biochar is a function of its primary biomass source, residence time and temperature during pyrolysis which in turn results in variations of its physicochemical characteristics such as porosity, carbon content, elemental composition, surface area, retention capacity, and overall applications. The physical and chemical activation techniques to produce the activated charcoal is often done to improve the effectiveness of these carbonaceous materials. The biochar has broadly been used globally in agro-environmental management including in livestock production. Its inclusion at 1 - 3 % of DM of animal feed rations have been studied to improve health conditions and performance of farm animals such as weight gain, immunity response, feed intake, feed conversion rates, carcass characteristics and overall quality of animal products. The mechanisms associated with the beneficial impacts rely on adsorption ability of these materials in detoxifying the mycotoxins in feed, regulating plant-produced toxins, having a high affinity to pollutants as well as improvement of the beneficial microbial populations in animals' gastrointestinal tract. However, the current literature indicates there is still a need for more investigation on the effectiveness of biochar in animal production due to either limited knowledge or contrasting findings reported. Also, there are imperative challenges which need to be addressed such as safety standards, specificity, potential contamination, affordability, and level of awareness by farmers who are end-users of biochar and its products.

KEYWORDS

Activated charcoal, Adsorption, Animal performance, Biochar, Detoxification, Pyrolysis.

1. INTRODUCTION

1.1 Background

Even though research and biochar usage has gained considerable attention from the late 19th century, its application for different purposes such as detoxification of animal feed is acknowledged to have been practiced back in ancient times among different global cultures (Gerlach and Schmidt, 2012). The inclusion of biochar in the production of pigs has widely been used from the 1880s while also near mid 20th centuries (the 1940s), it has reportedly been applied in poultry feeding (Totusek and Beeson, 1953). From the current literature, the benefits that can be obtained by animals are quite diverse which range from detoxification of animal feed, enhancing feed intake and digestion, promoting animal live weight gain as well as improving the quantity and quality of animal products such as milk, eggs and meat (Toth and Dou, 2016). While most of the current research on biochar and activated charcoal are more focusing on its potential in mitigating climate change, improving soil characteristics, managing the wastes and modulating environmental pollution, relatively little attention is being paid to its role as a feed additive to farm animals' productivity (McHenry, 2010). This article has therefore reviewed the current knowledge on the production of biochar, its conversion to activated form and the primary factors influencing its characteristics and hence the application. Also, mechanisms of biochar as a potential feed additive as well as the benefits related to the improvement of the health and performance of farm animals specifically the ruminants, swine and poultry being thoroughly presented. Additionally, its limitations as a feed supplement and future suggestions for improvement are briefly highlighted.

1.2 Production of Biochar by Pyrolysis

Biochar is a highly porous, recalcitrant and non-soluble organic powder material that is generated when biomass has undergone pyrolysis at temperatures averagely 700 ^{0}C and low oxygen levels (Toth and Dou, 2016; Tang et al., 2013). A wide range of biomass sources has been globally used which include animal manure, crop residues, agro-industrial by-products as well as forestry wastes (Toth and Dou, 2016; Ahmad, 2014; Jindo et al., 2014; Olieveira et al., 2017; Weber and Quicker, 2018). The common characteristics for all the biomass sources are their cost-effectiveness, environmentally friendly as well as ability to enhance the

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recycling of organic wastes generated from agricultural, forestry and processing industries. The first step of biochar production is the conversion of biomass into char (Tang et al., 2013; Oliveira et al., 2017). The components of biomass will be degraded by depolymerization of biomass components which are primarily cellulose, hemicellulose, and lignin (Weber and Quicker, 2018). This process involves drying of the biomass by heating where volatile organic matters are released from the solid fraction which can be permanent gases (methane, carbon dioxide, carbon monoxide, and hydrogen gas) or some organic compounds that can be condensed such as acetic acid and methanol (Weber and Quicker, 2018; Novak, 2009; Cantrell and Martin, 2012). The production of three fractions of gas, liquid-oil or solid fractions depends highly on pyrolysis conditions especially temperature and residence time of the biomass. With fast pyrolysis, where the temperature of nearly 1000 ^{0}C is used, the main product is liquid oil since these volatile compounds are fast released from the biomass (Tang et al., 2013). This kind of pyrolysis can produce a significant quantity of liquid oil which can be up to three-quarters of dry matter of the biomass (Tang et al., 2013).

However, to generate biochar, temperatures around 700 ^{0}C is usually applied with longer residence time and can result in production of biochar of up to 95% carbon content (Tang et al., 2013; Mukome et al., 2013). In producing biochar, the temperatures vary with the nature of biomass that is being used. For example, woody-based materials may require a higher temperature of 1000 ^{0}C to obtain good biochar as compared to the biomass obtained from agro-industrial wastes where temperatures around 300 ^{0}C are sufficient (Weber and Quicker, 2018). The activation of biochar by using physical or chemical treatment techniques involves the conversion of biochar into activated carbon which is more porous, having improved carbon content and surface area, low ash, low moisture content, and long life span (Borchard, 2012; Romanos, 2011). Biochar and activated charcoals cover a wide range of application which varies from the manufacturing of medicine, filtration of water, carbon sequestration, ameliorate environmental pollution, water treatment, crop production, livestock husbandry and improvement of soil characteristics (Weber and Quicker, 2018; Guo et al., 2016).

1.3 Conversion of Biochar to Activated Charcoal

The activated carbon constitutes mainly with carbon which varies between 87 to 97 % with the rest being other elements greatly depend on biomass source and employed methods of its production (Jankowska et al., 1991). Its pore volume usually range from 0.2 - 0.6 m^2 per gram of charcoal while the network micropores contain pores with diameters of less than 2 nm (Bansal and Goyal, 2005; Beguin and Frackowiak, 2009). To produce biochar with improved surface area and considerable adsorption aptitude, these materials need to undergo treatment or activation and hence the final product is referred to as the activated charcoal, or also known as activated carbon (Chada et al., 2012). The surface area as high as 500 - 3000 m^2 per gram of activated carbon can be produced by either physical or chemical treatment (Dillon et al., 1989; Soo et al., 2013). With physical treatment, the first phase involves carbonization of the biomass whereby these materials undergo pyrolysis at temperatures range between 300 - 1000 ^{0}C in inert conditions constitutes of nitrogen gas (H_2) and argon (Ar).

The activation of the carbonized materials is done by subjecting them in the oxidizing condition in the presence of either oxygen gas or steam at temperatures that can be as high as 1200 ^{0}C. For the case of chemical activation, the biomass to be used in pyrolysis is impregnated with selected chemicals, preferably strong alkali, acid or salt such as sulphuric acid (H_2SO_4), caustic potash (KOH), zinc chloride ($ZnCl_2$), sodium hydroxide (NaOH) and calcium chloride ($CaCl_2$) (Romanos, 2011). The biomass then goes through the carbonization process at temperatures slightly lower compared to physical activation (≈ 700 ^{0}C). The chemical activation is the most preferential over physical treatment as the former technique requires relatively lower temperatures as well as short residence time for activating the biomass (Romanos, 2011).

With existing complexity in their physical structure, the activated charcoal classification can be grouped due to their micropores network, applications and techniques or methods used in its production. For pore size, they can be powdery (< 1 mm in size), granular with relatively larger particles often used for treating polluted water or can be extruded charcoals (between 1 - 130 mm diameter size). There are also impregnated carbons that contain inorganic compounds (e.g. some cations as well as iodine and silver) which are made for special applications such as regulation of air pollution. Therefore, all the activated charcoals are biochar in nature, and the difference which is due to "activation" is what makes the activated charcoal having improved surface area, porosity, as well as being 5 to 10 times expensive compared to biochar (Gerlach and Schmidt, 2012). Given that biochar can be produced from a wide range of biomass resources which range from forestry/woody materials, agricultural and industrial processing byproducts, there is a need for more exploration in research and utilization to capitalize on these valuable resources.

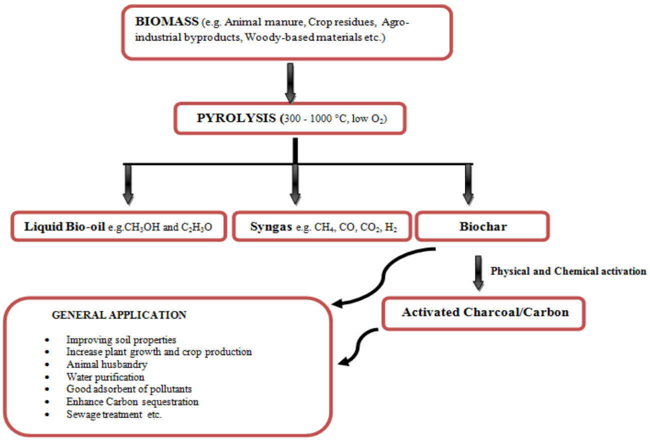

Figure 1: The graphic illustration highlighting biomass sources, pyrolysis and general applications of biochar and activated charcoal

1.4 Factors influence Physicochemical Characteristics of Biochar

The temperature used during pyrolysis, residence time and biomass sources are the three acknowledged factors having considerable influence on characteristics of the generated biochar (Weber and Quicker, 2018). The higher temperatures during pyrolysis frequently result in biochar with the larger surface areas as compared to when low temperatures are used. For instance in a study that analyzed the sorptive capacity of crop residues observed wheat residues heated between 500 to 700 ^{0}C was relatively well carbonized and having the larger surface area of nearly 300 m^2/g compared to the 300 to 400 ^{0}C during pyrolysis where the surface area was less than 200 m^2/g (Chun et al., 2004). Similarly, with pine needle as biomass source reported the pyrolysis temperature of 700 ^{o}C had a significant surface area (490.8 m^2/g) and adsorption capacity as compared to when lower temperatures were used in pyrolysis which was 600 ^{0}C (206.7 m^2/g), 500 ^{0}C (236.4 m^2/g), 400 ^{0}C (112.4 m^2/g) and 100 ^{0}C (0.65 m^2/g) (Chen et al., 2008).

Variations of biomass sources have been studied to affect the characteristics of the biochar produced. For instance, in a study whereby three different sources were used (soot, black carbon from coal and rice straws), the authors observed that both surface area and porosity (234.9 m^2/g and 0.4392 ml/g, respectively) were significant in rice straw charcoal compared to the other two biomasses (Luo, 2011). Additionally, the literature has shown variations of physicochemical characteristics of biochar when the same temperature was applied using different sources of biomass. For example, at the pyrolysis temperature of 600 ^{0}C studies have shown different values for the specific surface area which include 179.03 m^2/g for soybean stalk, 527 m^2/g for poultry manure, 642 m^2/g for oak wood chips and 206.7 m^2/g for pine needles (Chen et al., 2008; Kong et al., 2011; Nguyen et al., 2010; Nguyen et al., 2009).

Table 1: The summary of variations of biochar characteristics with different biomass sources and production conditions from selected literature

Biomass source	Pyrolysis temperature	Total Carbon (%)	pH	Volatile matter (%)	Ash (%)	References
Green waste	300°C	64	8.1	6.8	6.8	(Ronsse et al., 2013)
	600°C	77	11.3	8.8	13	(Ronsse et al., 2013)
	750°C	81	11.6	1.9	13	(Ronsse et al., 2013)
Sugar cane bagasse	350°C	75	5.0	39	3.6	(Spokas, 2011)
Rice straw	300°C	55	9.2	40	23	(Wu, 2012)

	500°C	56	10.5	23	32	(Wu, 2012)
	700°C	65	10.8	14	29	(Wu, 2012)
Poultry litter	350°C	46	8.7	37	36	(Novak, 2009)
	700°C	44	10.3	14	52	(Novak, 2009)
Pigs Litter	350°C	52	8.2	50	33	(Cantrell and Maretin, 2012)
	700°C	44	8.2	13	53	(Cantrell and Martin, 2012)
Switchgrass	250°C	55	5.4	74	2.6	(Novak, 2009)
	500°C	84	8.0	13	7.8	(Novak, 2009)
Wood	300°C	71	5.7	43	0.5	(Ronsse et al., 2013)
	450°C	85	6.7	17	1.2	(Ronsse et al., 2013)
	600°C	91	9.1	6.4	1.3	(Ronsse et al., 2013)
	700°C	92	10.4	2.6	1.1	(Ronsse et al., 2013)

2. Mechanisms of Activated Biochar in Relation to Farm Animals' Productivity

2.1 Detoxification of Mycotoxins in Feed

About 25 % of all the cereals in the world are estimated by the United Nation's Food and Agriculture Organization (FAO) to be annually affected by mycotoxins contaminations (Mezes et al., 2010). The contamination by these secondary metabolites can occur while crops are still in the field, during storage and when feeding animals (Wild et al., 2015). The mycotoxin groups acknowledged to be of great importance to humans, crop yields and animal health are aflatoxins B_1 (AFB_1), deoxynivalenol (DON), zearalenone (ZEN) and ochratoxin A (OCHRA) (Keller et al., 2012). When animals consume contaminated feed for an extended period, they are associated with numerous health-related complications and diseases notably the teratogenic, immunosuppressive disorders, carcinogenic and mutagenic effects while also gastrointestinal activity impairment and overall reduced production (Wild et al., 2015; Anukul et al., 2013; Misihairabgwi et al., 2017). Human beings contact the mycotoxins through the contaminated animal products including milk, eggs, meat, and liver (Sobrova et al., 2010).

The use of adsorbents such as biochar, activated carbon and other non-charcoal adsorbents including zeolites, bentonites, and aluminosilicates have shown promising results in reducing the assimilation of these toxic compounds into animal bloodstream (Dakovic et al., 2005). The adsorption capacity of biochar and activated charcoal as influenced by total surface area and pore size distribution is reported to bind the mycotoxins and hence reduce the bioavailability and meanwhile improve animal productivity (Galvano, 1996; Galvano et al., 2001). An *in vitro* study done whereby two types of adsorbents (activated charcoal and aluminosilicates) were supplemented at the rate of 2 % of DM of dairy cows diet observed the significant reduction of aflatoxins B_1 of up to 70% (Galvano, 1996). In this feeding study that was conducted for 14 days, the levels aflatoxin in milk were also reduced by 45 % as compared to control cows which didn't receive any adsorbents.

The underlined mechanism suggested by authors is the ability of adsorbents being able to convolute these toxic metabolites and hence reduce their intestinal adsorption which in turn lessens their levels in animal products. A similar study was done using Holstein cows breed observed up to 65% reduction in aflatoxin in milk with the supplementation of 0.25% activated charcoal (Diaz, 2004). Comparable findings on the detoxification potential of mycotoxins have been reported in small ruminants as well. With supplementation of activated charcoal at 1.0 % of the feed for 2 weeks, the aflatoxins levels in goat milk have been able to be reduced by 76 % which was higher compared to other types of adsorbents used in the study, the bentonite with 65% (Rao et al., 2004). Even when lethal doses of aflatoxins were fed to goats together with activated charcoal, observed no significant indication of internal organ damage while the levels of these toxic compounds were high (Hatch et al., 1982). The authors suggested the main reason behind was the inability of aflatoxins to be absorbed by the goats' intestines.

2.2 Control of Pathogenic activity

The two mechanisms associated with the reduced pathogenic activity are related to physicochemical characteristics of activated charcoal and microbial status in animals' gastrointestinal tract (GIT). A study reported that the inclusion of 5 mg/ml of activated charcoal in feed can reduce the levels of *Escherichia coli* and *Salmonella* as low as 10 mg/ml (Naka, 2001). The authors suggest the importance of a combination of pore size and its diameter in binding these microscopic organisms. However, a subsequent study using matured ewe observed contrasting results that the activated charcoal didn't bind of either *E.coli* nor the *Salmonella typhimurium* (Knutson et al., 2006). Another possible mechanism is the increased activity of beneficial microbes in the GIT particularly species from three genera *Bifidobacterium, Enterococcus* and *Lactobacillus*. Through the improved activity, these beneficial bacteria colonize the gut environmental niches and with the competitive exclusion principle they tend to outweigh the pathogenic population (Knutson et al., 2006; Callaway et al., 2012). Given that there is currently, no sufficient evidence to support the role of activated charcoal in controlling these hazardous microbes, there is a need for further in vivo research to be done.

2.3 Regulation of Plant-derived Toxins in Feed

Apart from having structural features such as thorns, spines, and prickles, plants also produce hundreds of toxins that serve as a means of protection by deterring any kind of physio-biological disturbances (Wittstock and Gershenzon, 2002). However, while these compounds are beneficial to plants, they have detrimental impacts when consumed by herbivores as they often result in injuries, illness or even death. The high affinity of activated charcoal in binding the plant-produced toxins and mycotoxins is associated with a combination of its physicochemical characteristics that include pore network, surface area, and surface acidity. Studies have shown that activated charcoal with predominant micropores structure (less than 2 nm pore size) tend to have lower adsorption rate due to reduced diffusion of these toxic compounds while also high surface acidity of charcoal has repulsing effect of the positively charged of some mycotoxins such as aflatoxins. On the other hand, as suggested, the improved adsorption efficiencies can be achieved with activated charcoal constitutes mesopores network (between 2 - 50 nm pore sizes) as well as low acidic surface areas which favors the binding of mycotoxins and other toxic compounds produced by plants (Galvano, 1996). However, the overall efficiency will depend on numerous factors including physicochemical characteristics of activated charcoal, amount of charcoal supplemented to an animal, concentration of toxins in feed, species, and animal breed used as well as feeding management (Bansal and Goyal, 2005; Dillon et al., 1989; Hatch et al., 1982; Kim, 2006). The current literature indicates the promising results of biochar and activated charcoal in detoxifying plant toxins especially those produced by some shrubs and forbs which are feed sources for livestock as shown in table 2.

Table 2: The summary from selected literature indicating the effect of activated carbon in regulating plant-produced toxins

Animal subjects	Types of Feed	Plant-produced toxins	Composition of activated charcoal	Observed effects	References
Dairy heifers and steers	*Lantana camara*	Triterpene acids, lantadene A and lantadene B	5.0 g/kg of live weight	Recovery times from liver damage for animals consumed activated charcoal was less than 2 weeks compared to 3 weeks for control animals	(McLennen and Amos, 1989)

Cattle	Shrubs known as yellow tulp (*Moraea pallida*)	Glycoside	2.0 g/kg of live weight	All cattle provided activated charcoal shown relatively faster recovery from the posterior paresis (clinical condition characterized with limited voluntary movement) within 48 hours.	(Snyman et al., 2009)
Sheep and goats	Mediterranean shrubs	Terpene and tannins	0.7, 0.8 and 1.0 g/kg of live weight	A general increase in shrub consumption for both goats and sheep supplemented with charcoal	(Rogosic et al., 2006)
Goats	Juniper (*Juniperus pinchotii* Sudw) and (*Juniperus ashei* Buch)	Terpenoids	1.0 g/kg of live weight	Increased consumption of Juniper during early exposure in a 10 days study	(Bisson et al., 2001)
Sheep	Alfalfa, maize diet and Bitter rubberweed (*Hymenoxys*	Sesquiterpene lactones	0.5,1.0 and 1.5 % of feed DM	Continuous consumption of treated bitterweed in which suggests reduced toxicity	(Poage et al., 2000)

2.4 Regulating Heavy metals, Organic pollutants and residues from Pesticides and Herbicides

Heavy metals (e.g. lead, arsenic, chromium, mercury, cadmium, chromium), organic pollutants (e.g. polycyclic aromatic hydrocarbons and sulfamethoxazole) and residues from pesticides and herbicides are of great health risk to animals and human being (Pandey and Madhuri, 2014; Uchimiya et al., 2012). These pollutants that originate from both natural to anthropogenic activities can emanate from the feed, food, air and water with their toxicity result from bioaccumulation tends to disrupt balance and activity of ecosystems of most living organisms (Schwarzenbach et al., 2010). Consumption of these pollutants don't assist in any physiological conditions and can lead to the formation of toxic soluble compounds but also being detrimental when they are in specific form in animals' bodies (Pandey and Madhuri, 2014).

A significant number of research studies have documented the effectiveness of biochar and activated charcoal in reducing the levels of these pollutants in soil and water where the majority of animal feed is obtained. The mechanism behind the existing potential is ascribed to the electrostatic interaction between biochar, heavy metals and soil conditions. When added to the soil, the biochar induces the cation exchange capacity which increases negatively charged ions and with the metals possessing positively charged ions, the latter tend to be bound to biochar surface areas (Peng et al., 2011). Also, as the biochar incorporation increases the water retention which in turn increase the pH levels of the soil and as a result, these conditions lead to decreased mobility of heavy metals and so is their effects (Peng et al., 2011). There exist variations of biochar effectiveness as summarized in table 3 and the main influential factors include the type of biomass source, pyrolysis conditions, type and concentration of pollutants and general experimental setup.

Table 3: The effectiveness of different sources of biochar in modulating the pollutants

Primary Biomass Sources	**Pyrolysis Temperature**	**Groups of Contaminants**	**Names of Contaminants**	**Effect of Biochar and Activated Charcoal**	**References**
Cattle manure	≤ 500 ^{0}C	Heavy metals	Lead and atrazine	Nearly 100 % Lead deduction and about 77 % atrazine	(Cao and Harris,
Rice straw	NR	Heavy metals	The acid extractable Copper and Lead	The decrease of 20 - 100 % Copper, and 19 - 77 % Lead	(Jiang et al., 2012)
Green waste compost	NR	Heavy metals	Copper and Lead	Significant reduction of Cu and Pb levels from the soil to the plants (which plant)	(Karami et al., 2011)
Sewage sludge	500 ^{0}C	Heavy metals	Copper, Cadmium, Zinc, Lead, and Nickel	Reduced plant availability for Pb, Cd, Zn and Ni. Also the Ni, Zn and Cu in leached decreased significantly	(Mendez et al., 2012)
Bamboo, bagasse and hickory wood	450 - 600 ^{0}C	Organic pollutants	Sulfamethoxazole (an antibiotic)	≤ 14 % of Sulfamethoxazole transported with incorporation of biochar compared to 60 % with no biochar	(Yao, 2012)
Sewage sludge and maize stover	600 ^{0}C	Organic pollutants	Polycyclic aromatic hydrocarbons (PAH)	The reduction of up to 57 % of PAH can be achieved depend on the amount of biochar used while for activated charcoal the PAH were reduced by 56 - 95 %	(Oleszczuk et al., 2012)
Sewage sludge	500 - 900 ^{0}C	Organic pollutants	Polychlorinated biphenyls (PCB)	The potential of 5 % of bamboo biochar to reduce leaching of PCB up to 65 % have been observed	(Mendez et al., 2012)
Deciduous hardwood	600 ^{0}C	Organic pollutants	PAH	Reduction of between 306 to 449 mg/kg of PAH while also up to 45 % of PAH was reduced in earthworm species called *Eisenia fetida* (red or earthworm)	(Gomez-Eyles et al., 2011)
Hardwood	600 ^{0}C	Pesticides and Insecticides	Pesticides (enta-chlorobenzenes and carbofuran) and insecticides (chlorpyrifos and fipronil)	Inclusion of 0.5 to 1.0 % of biochar significantly reduce the toxicity and levels of contaminants in the soil	(Kookana, 2010)
Cotton straw and woodchips	> 400 ^{0}C	Pesticides	Fipronil, Chlorpyrifos and Carbofuran	About 0.1 to 1.0 % biochar was able to reduce 32-51% mobilization of the pesticides from the contaminated soil	(Yang, 2010)

3. Improvement of Farm Animals' Performance by Biochar and Activated Charcoal

Biochar and activated charcoal are important in modulating different farming practices. Up to 90 % of the produced biochar in Europe is used in various farming practices including treatment of slurry, in production of silage, as a vital feed additive, as a litter component, in production of compost, while also in some fish farming has been included to treat water from pollutants (Gerlach and Schmidt, 2012). Regarding farm animals particularly poultry, pigs and ruminants, studies have come up promising findings that highlight biochar and activated charcoal being vital feed additive material for enhancing their health and performance.

3.1 Poultry

A feeding experiment using broiler chicks that were fed biochar made from hardwood at the inclusion rate of 0, 2, 4 and 8 % of total DM were done (Bakr, 2008). The study that lasted for 6 weeks observed that the 2 % biochar having a significantly higher return in terms of feed intake of chicks, body weight gain and overall feed conversion rates. Similar results on broiler chicks were observed of when up to 1.0 % of DM of biochar produced from maize cob was used (Kana et al., 2011). Also, two different studies were done using hardwood biochar in a six to seven weeks study reported that the chicks that received diets having biochar tended to have improved feed conversion rates and weight gain (Majewska and Zaborowski, 2003; Majewska et al., 2011). The mechanisms behind these benefits as postulated by these authors are due to detoxification potential of biochar of the feed as well as the reduced surface tension of the digesta inside the animal's gastrointestinal tract. Another mechanism as acknowledged by other researchers includes the biochar potential to bind to antinutritional factors in the feed (Kutlu, 1998).

On the other hand, the studies that involve laying hens, biochar inclusion has been studied to improve the quality and quantity of eggs and egg components. A studied that inclusion of 1 - 4% of biochar have a significant reduction of number cracked eggs as compared to hens received no biochar (Kutlu et al., 2001). Moreover, the 1 % of biochar mix (a mixture of carbonaceous biochar and woody vinegar) showed an augment of membrane collagen of eggs by more than 33 % (Yamauchi et al., 2010). Increasing the production of eggs by nearly 5 % as well as the strength of eggshells have been also observed (Kim, 2006; Yamauchi et al., 2013). Additionally, a study involving ducks with biochar rates used at 0.1, 0.5 and 1.0 % of DM in a diet composed of seaweed and with the control diet which included the chlortetracycline antibiotic ($C_{22}H_{23}ClN_2O_8$) was done (Islam et al., 2014) The results from this study shown the best outcomes in terms of feed intake by ducks and the feed efficiency for all the diets contain biochar as compared to control, which suggests these carbonaceous materials can be used as a potential alternative to antibiotics.

3.2 Pigs

As discussed for poultry, biochar also provides benefits to pigs in terms of health and performance even though some studies didn't come up with consistent findings. A studied feed utilization, immunity response and carcass characteristics of finishing pigs with biochar supplemented at 0, 0.3 and 0.6 % of total DM of the feed (Choi et al., 2012). The authors observed the highest performance in terms of feed conversion rates, the carcass characteristics, live weight gain and immune response at 0.3 % supplementation as compared to all other treatments. The comparable findings were also reported with the study which investigated carcass quality of finishing pigs and apart from the above-mentioned improvements, the meat marbling, meat color traits as well as tenderness of the meat when cooked were significantly enhanced (Lee et al., 2011). Moreover, observed an increase of up to 13 % of live weight gain as well as about 15 % feed conversion rates when fattening pigs were supplemented between 0.3 and 0.6 % of DM of diet as biochar compared to control with no biochar (Chu, 2013). As experimented by series of studies, the pig's responses to biochar vary with the rate of biochar supplement, the primary source of biochar, the length/duration of the feeding experiment and specific parameter involved in the assessment (Chu, 2013a; Chu, 2013b; Chu et al., 2013).

Nevertheless, several studies involving pigs have also reported some contrasting findings. A feeding experiment involving piglets supplemented with biochar that is commercially prepared constitutes of woody vinegar and biochar (ratio of 4:1) at 0, 3 and 5 % of feed DM was conducted (Mekbungwan et al., 2004). Unlike the previous studies above which reported increased weight gain and feed utilization efficiency, this study found the two parameters were not different as when compared to piglets received no biochar. However, there was a reported improvement in gastrointestinal architecture for some features specifically the villi growth, especially at 1 and 3 % biochar supplementation. The results from this study are in agreement with other authors in subsequent research study whereby pigs received dietary feed constitute of pigeon pea (*Cajanus cajan*) (Mekbungwan et al., 2008).

3.3 Ruminants

Similar to poultry and pigs, studies have been done using ruminants where animal performances have been evaluated. An experiment done whereby the local cattle were supplemented with 1 % biochar in a diet composed of cassava foliage, cassava root and urea observed the increased growth of 20 % (Leng et al., 2012). Also, a feeding study has been done by Mui et al., (2006) using different levels of biochar at 0, 0.5, 1.0 and 1.5 % of DM in goats rations made of concentrate and forage. The study observed considerable the highest dietary protein digestion and dry matter intake ($p<0.05$) at 0.5% compared to 0 % as well as 1.5%. The authors suggested the unexpected lower DM intake and protein digestibility at 1.5% was due to impairment of optimum rumen activity. There are however some inconsistent results that showed no positive results with biochar inclusion such as the study done using goats and the other where studied parameters such as live weight gain and carcass quality of beef steers were not different from the animal subjects which received no biochar (Phongpanith et al., 2013; Kim and Kim, 2005).

4. Challenges of Biochar Utilization in Farm Animals

4.1 Inadequate and Contradictory Research Findings

The limited knowledge and contrasting research findings are of great concern especially when biochar is used as feed supplement to farm animals. While the underlined mechanisms of these adsorbent materials have mostly been done on a small scale, short duration and *in vitro* conditions, it is important to for the scientific community to investigate and establishing clear-cut mechanisms using *in vivo* studies done for an extended period of time. This is due to existing variations that result from characteristics of biochar itself, different responses to species and group of animals, climatic conditions and time factor. For instance, different findings have been reported on the role of biochar in regulating pathogens such as *E.coli* and *Salmonella* by similar studies that were done (Khutson et al., 2006; Naka, 2001).

4.2 Specificity of Biochar

A comparative study was done in evaluating the effectiveness of different adsorbents in regulating different groups of mycotoxins observed a specificity effect of biochar in mollifying these toxic metabolites (Huwig et al., 2001). In this study that involved activated carbon and other non-charcoal adsorbents such as hydrated sodium calcium aluminosilicates (HSCAS), bentonite, montmorillonite, sepiolite, and cholestyramines observed high levels of activated carbon are not beneficial as these materials are not very specific to mycotoxins only and can bind to nutrients too. Even though in *vitro* studies have shown promising results, the amount supplemented in *vivo* is critical to obtain desirable results. There are however few exceptional findings such as the one done whereby high doses of biochar were beneficial to goats that were exposed to higher aflatoxin poisoning (Hatch et al., 1982). It is important to understand that, so far, no single adsorbent is capable of alleviating all types of mycotoxins uniformly as from summary shown whereby even for some non-charcoal binders like HSCAS which are considered very effective can bind nearly completely for all AFB_1, in small extent on ZEN and OCHRA while they are almost not effective against trichothecenes (Huwig et al., 2001).

4.3 Potential Contaminations

Usually, the heavy metals are not generated during pyrolysis, even though they may be present in biomass sources mostly from industrial byproducts as well as sewages. At the optimum pyrolysis temperature, these metals are not volatile and hence remained as an ash component of the biochar. However, some hazardous organic contaminants including dioxins and polycyclic aromatic hydrocarbons are often produced during pyrolysis. For instance, reported the favorable conditions for the formation of dioxins are the presence of chlorine, the open burning of the biomass materials and also temperatures around 450 - 850 ^{0}C (Shibamoto and Yasuhara, 2007). The impact of these compounds can range from being completely not toxic to carcinogenic and mutagenic, and often associated with the factors such as shorter residence time and low pyrolysis temperature. Therefore, it is important to carefully evaluate the biomass sources and applying optimum conditions during pyrolysis to minimize the risks.

4.4 Farmers' Awareness

Even though there have been promising findings on its diverse application globally, there is still existing a knowledge gap of farmers who are end-users of biochar. There is a contrasting practical application as well as the level of interest by farmers and other stakeholders such as environmental managers and policymakers on the global scale. While nearly 90% produced biochar in regions like Europe plays an important role in agro-environmental activities including livestock husbandry, crop production and modulation of the environment, the case is different in most of developing countries. The woody-based biomass is heavily utilized in charcoal production as a source of fuel while the agri-industrial byproducts from processing industries are less recycled to produce value-added materials including biochar. There is misapprehension by farmers that all biochars are of the same physicochemical characteristics while meanwhile, the inquiries such appropriate rates how often biochar can be applied are yet to be clearly understood. This hence calls for necessary practical initiatives such as an establishment of best-use biochar application protocols and programs in educating farmers through extension and livestock field officers. Additionally, the use of media, initiatives on biochar projects and markets will contribute more of its adoption.

4.5 The Affordability

Most of the currently used biochar are commercially produced and they are associated with higher prices and limited available markets. For example, the average cost of biochar in the United States by 2014 is 2.87 US dollars per kilogram (Guo et al., 2016). For resource-constrained farmers, the production of low cost and desirable biochar using locally available biomass resources is restricted due to higher production costs while in most countries this technology is nonexistent. Since there are abundant and inexpensive raw materials, governments need to attract investments in commercial biochar production by the local industries where the availability and affordability will be enhanced while meanwhile, job creation is enabled. Supported with research findings, economical analysis, and improved awareness, it is then possible for decision-making bodies to be interested in supporting the biochar through regulations and safety standards.

5. Conclusion

The current literature highlight how the biochar and activated charcoal can be useful in promoting farm animals' health and performance. These carbonaceous materials are potentially safe and promising feed additives in improving the animal performance and hence can be an alternative for substances such as antibiotics. Their role in regulating mycotoxins in feed, the plant-derived toxins from the plant materials, potent pollutants such as heavy metals, organic pollutants and residues from pesticides and herbicides as well as pathogenic activities of *E.coli* and the *Salmonella* is crucial for the safety of animal feed. This in return has been directly linked to the enhancement of health and performances indicators to farm animals specifically weight gain, immunity response, feed intake, feed conversion rates, carcass characteristics and the overall quality of animal products.

There is, therefore, a need to emphasize the establishment of local-based protocols and recommendations for farmers to improve the utilization of biochar for different purposes such as agronomical practices, animal husbandry, and environmental modulation. Furthermore, the collaborations among researchers, extension workers, policymakers and farmers are important in the dissemination of basic knowledge and information that aims at capitalizing the utilization of biochar. Even though studies have indicated the improved animal performance with biochar supplementation, very few studies have been able to vividly verify the underlined mechanisms. With the current advances in technology, there is, therefore, a need for more investigation to explain mechanisms as well as the existing high variations on biochar and activated charcoal effectiveness.

Conflict of Interest

The authors of this review article declare no conflict of interest.

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