Journal of Sustainable Veterinary & Allied Sciences
P-ISSN-2695-2661 e-ISSN: 2811-1346
JOSVAS

JoSVAS 2022, Vol 3, Issue 1: 24-30
©2022 College of Veterinary Medicine,
Michael Okpara University of Agriculture, Umudike, Nigeria

Original Research Article

Physico-chemical properties of activated charcoal derived from a blend of agricultural waste material

***[1]Okey, S.N., [1]Ogbu, C.C., [2]Akomas, S.C., [3]Okoli, I.C. & [4]Okey, O.N.**

Department of Veterinary Biochemistry and Animal Production, Michael Okpara University of Agriculture Umudike, [2]Department of Veterinary Physiology and Pharmacology, , Michael Okpara University of Agriculture Umudike, [3]Department of Animal Science and Technology, Federal University of Technology, Owerri,[4]God's Gift Veterinary Services, Uyo, Akwa Ibom State, Nigeria.

*Corresponding author: nnamuokey@yahoo.com, +2347038932128

ABSTRACT

The wide differences in the densities, nature of the agricultural wastes or precursor materials and their carbon content means that activated charcoal (AC) yield, and physico-chemical properties could vary considerably among activated charcoals produced from different agricultural residues necessitating the evaluation of the physical and chemical properties of activated charcoals produced from different feedstocks. The objective of the present study was therefore to evaluate the physico-chemical properties of activated charcoal produced from a blend of pig dung, palm kernel shell, and palm fruit fibre for possible use as feed additives in poultry feed. The physical properties of the produced activated charcoal were activated charcoal yield, moisture content, pH, bulk density, water-holding capacity, specific gravity, oil adsorption capacity and surface area with values as 71.0%, 5.37%, 7.67, 0.72, 77.46%, 0.73, 118.47% and 587cm^2/g respectively. The chemical properties comprised of carbon content (79.43%), calcium (6185.11mg/kg), phosphorus (18603.29mg/kg), sodium (1722.47mg/kg), potassium (10275.48mg/kg), magnesium (3980.14mg/kg), manganese (721.00mg/kg), iron (996.35mg/kg), zinc (95.47mg/kg), copper (33.69mg/kg),arsenic (13.38mg/kg) and nitrogen (3008.04mg/kg). The values of the physical parameters obtained in this study were adjudged to be suitable for adsorption purposes in poultry and water treatment operations.

Keywords: Activated charcoal, agricultural waste, palm kernel shell, palm fruit fibre and pig dung

INTRODUCTION

Activated charcoal is defined as a dark-colored and porous form of carbon made from plant and/or animal substances by partial combustion followed by activation (AAFCO, 2012). They are processed carbon materials that are capable of adsorbing various substances because of their large pore structure and surface area (Abdul & Aberuagba, 2005). Activated charcoal is differentiated from the elemental carbon by its high surface area and the oxidation of the outer and inner carbon atoms(Al-Qodah & Shawabkah, 2009; Khan & Ansari, 2009).The surface chemistry of activated charcoal confers on it the ability to adsorb and bind gaseous elements, aqueous solutions, liquids and chemicals rendering them inert and unavailable for absorption in the body (Pradham & Sandle, 1999).Activated charcoal is therefore, one of the best antidotes to poisons such as those from mushrooms, insects and snakes (Maklad *et al*., 2012). Activated charcoal itself is not digested, absorbed, or metabolized in the body. It is the high adsorption capacity of AC that makes it suitable in water purification and in the removal of undesirable odours and impurities from foods (Burdock, 1997).

Activated charcoal can be produced by the incomplete combustion of agricultural residues. Agricultural residues are wastes from the growing, harvesting, and processing of agricultural products such as crops, fruits, vegetables, animal, and dairy products (Obi *et al.*, 2016). These are renewable resources whose utilization has received great attention due to environmental considerations and the increasing demand for energy worldwide (Tsai *et al.*, 2007; Balat *et al.*, 2009).The use of agricultural by-products and wastes for activated charcoal production is being advocated due to their carbon content, renewable nature, and the possibility of mitigating environmental pollution through such a process (Lima & Marshal, 2004). In addition, they are relatively less expensive when compared to other activated

http://doi.org/10.54328/covm.josvas.2022.073

charcoal precursors of industrial and petroleum origin (Ahmedna *et al.,* 2000). Recently, interests have focused on the use of agricultural residues such as maize cob, stalk, and stover, groundnut shell, poultry litter, pig and cow dung, rice husk, palm kernel shell (PKS), and coconut shell in the preparation of activated charcoal (Sugumuan *et al.,* 2012). The carbon content of these by-products though lower when compared with petroleum residues, wood, coal, peat and lignite, their low cost of production, and ready availability makes up for their lower carbon yield (Malik *et al.,* 2006).

The expansion of agricultural production has naturally resulted in increased quantities of livestock waste, agricultural crop residues and agro-industrial by-products. The generation of agricultural wastes will continue to increase globally as developing countries continue to intensify their farming systems. It was estimated that about 998 million tonnes of agricultural wastes are generated globally with organic wastes comprising 80% of the total solid wastes (BRECG, 1997; Agamuthu, 2009). More so, research revealed in 2005 that the biomass potential of Nigeria stood at 13 million hectares of fuel wood, 61 million tonnes per year of animal waste, and 83 million tonnes of crop residues (Agba *et al.,* 2010). The annual production of agricultural biomass is high because about 94% and 68% of households are respectively engaged in crop and livestock farming (Akorede *et al.,* 2017). The major agricultural crop residues with sustainable potential as feedstock for activated charcoal production in Nigeria are derived from cultivation, harvesting and processing of millet, yam, cassava, sorghum, rice, groundnut, oil palm, sugar cane and soya-beans (Mohammed *et al.,* 2013). For livestock, Akorede *et al.* (2017) reported the combined number of cattle, sheep, goats, horses, pigs and poultry in Nigeria as 245 million, which all together produce 0.78 million tonnes of animal waste daily. It is believed that the production and utilization of activated charcoal in commercial quantities in livestock and poultry production is an effective management strategy for agricultural wastes.

The wide differences between agricultural wastes in carbon content, and other physico-chemical properties means that activated charcoal yield, and physico-chemical properties could vary considerably among activated charcoals produced from different agricultural residues necessitating the evaluation of the physical and chemical properties of activated charcoals produced from different feedstocks. The objective of the present study was hence to evaluate the physico-chemical properties of activated charcoal produced from a blend of pig dung, palm kernel shell, and palm fruit fibre for possible use as feed additives in poultry ration.

MATERIALS AND METHODS

LOCATION OF THE STUDY

The study was carried out at the Teaching and Research Farm of Michael Okpara University of Agriculture Umudike, Umuahia, Abia State, located within the South East agro-ecological zone of Nigeria with geographical coordinates of 5.4801^o N and 7.5437^o E.

COLLECTION AND PREPARATION OF AGRICULTURAL WASTES

The palm kernel shell and palm fruit fibre were collected from a palm oil mill while freshly voided pig dung was collected from pig farms using plastic container. The materials were carefully collected to avoid contamination with sand or other objects. Each material was sun-dried to constant weight and crushed manually using a wooden pestle and mortar. The materials were then blended together at a ratio of 4:3:3 weight for weight for pig dung, palm kernel shell and palm fruit fibre, respectively and used to produce the activated charcoal.

PRODUCTION OF ACTIVATED CHARCOAL

The physical method of activated charcoal production described by Gunamartha & Widana (2018) was employed in the present study. The blended biomass materials were weighed using HN 289 digital scale (Omron Co., Ltd, Japan) and transferred to a clay pot of about 30 litres for carbonization. In addition to contributing to the carbon yield, palm kernel shell and palm fruit fibre also served as combustion accelerants enhancing the pyrolysis of pig dung (Nwokolo & Ogunyemi, 2008). The pot containing the precursors was sealed by covering with a metallic lid that had a small vent which limited the entry of oxygen into the mixture. The pot was placed on open fire for a combustion period of 5 hours at which no more smoke was produced from the vent. At this point, water was introduced quickly to stop the carbonization of the biomass and achieve activation. Thereafter, the pot was tightly closed and allowed to cool. The charcoal product was then harvested, rinsed with cold water to remove ash and other debris, dried, and weighed. The dried activated charcoal was transferred to a wooden mortar and ground with pestle into fine powder and stored in an air tight polythene container for characterization.

PHYSICO-CHEMICAL CHARACTERIZATION OF THE ACTIVATED CHARCOAL

The physical properties determined were bulk density, water holding capacity, specific gravity, moisture content, pH and oil adsorption capacity while the chemical properties were carbon, and mineral contents.

DETERMINATION OF PHYSICAL CHARACTERISTICS OF ACTIVATED CHARCOAL

Activated charcoal yield was determined as the ratio of the weight of dried activated charcoal to the weight of precursor carbonized. Value was expressed in percentage. The bulk density, water holding capacity and specific gravity of the activated charcoal was determined according to the procedure described by Makinde & Sonaiya (2007) and modified by Omede (2010). The moisture content of the activated charcoal was determined using oven dry method as described by American Society for Testing and Materials (ASTM Method D280-33, 2003) and the percentage moisture content calculated as recommended by AOAC (1990).The pH of the activated charcoal was determined with the aid of a pH meter (HANNA Combo PH Meter, Model: HI 98129, USA) while oil adsorption capacity was analyzed according to ASTM F 726-99 (1998). The test was performed at 23 ± 4°C with the oil absorbency measured three times and an average value taken according to Hussein *et al.* (2008).

DETERMINATION OF CARBON AND MINERAL CONTENTS

The concentration of macro minerals namely nitrogen (N_2), calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and sodium (Na) and micro minerals namely manganese (Mn), zinc (Zn), copper (Cu) and iron (Fe) in the activated charcoal were measured using the Atomic Absorption Spectrophotometer method (Bulk Scientific, 205, India). The procedure was based on the principle that metallic elements in a ground form absorb light of the same wavelength which they emit when excited, with the amount of radiation absorbed being directly proportional to the concentration of the element present.

RESULTS

The physical properties of the produced activated charcoal are presented in Table I. The Table shows that 7.1 kg activated charcoal was obtained from a total of 10 kg precursor material representing 71.0 % activated charcoal yield. Other physical properties were moisture content (5.3 %), pH (7.67), bulk density (0.72), water-holding capacity (77.46 %), specific gravity (0.73), oil adsorption capacity (118.47 %), and surface area (587 cm^2/g).

Table I: Physical properties of activated charcoal produced from a blend of agricultural waste materials

Parameter	Value
Activated charcoal yield (%)	71.0
Moisture (%)	5.37
pH	7.67
Bulk density (g/cm^3)	0.72
Water-holding capacity (%)	77.46
Specific gravity	0.73
Oil adsorption capacity (%)	118.47
Surface area (cm^2/g)	587.00

Table II: Chemical properties of activated charcoal produced from a blend of agricultural waste materials

Parameter	Value
Carbon content (%)	79.43
Calcium (mg/kg)	6185.11
Phosphorus (mg/kg)	18603.29
Sodium (mg/kg)	1722.47
Potassium (mg/kg)	10275.48
Magnesium (mg/kg)	3980.14
Manganese (mg/kg)	721.00
Iron (mg/kg)	996.35
Zinc (mg/kg)	95.47
Copper (mg/kg)	33.69
Arsenic (mg/kg)	13.38
Nitrogen (mg/kg)	3008.04

DISCUSSION

The observed activated charcoal yield of 71.0 % is less than the 74.19 % yield from palm kernel shell alone reported by Kong *et al.* (2013). The inclusion of pig dung and palm fruit fibre in the present study may have been responsible for the lower activated charcoal yield obtained. Pig dung and palm fruit fibre are lighter than palm kernel shell and may have lesser carbon contents. The moisture content of the activated charcoal obtained from this study (5.37%) was higher than the 3.43% and 3.50% reported by Okoroigwe *et al.* (2013) and Lima & Marshal (2004), respectively for AC derived from palm fruit fibre, and poultry litter, respectively. It was also higher than that of Nwankwo (2018) who recorded 3.50% as moisture content of AC from cow bone sourced from abattoirs. Kong *et al.* (2013) investigated the moisture content of activated charcoal derived from PKS and reported a lower moisture content of 1.47%. The lower moisture contents of the AC reported by these researchers could be attributed to higher carbonization and activation temperatures which were over 600°C in each case as against the 300°C (Prakash *et al.*, 2006) employed in the present study.

The AC exhibited a slightly alkaline pH value of 7.67 which was within the preferred range of 6.0-10.0 as reported for most agricultural residue-derived AC (Chen *et al*., 2002). It has also been noted that acidic and slightly alkaline activated charcoals exhibited greater adsorption capacity and are more effective adsorbents when compared to those with very high pH values (Madu & Ladije, 2013). The pH result obtain from this study was however higher than the 6.1, 6.64, and 6.60 reported by Okoroigwe *et al.* (2013), Evbuoman *et al.*

(2013) and Nwankwo (2018), respectively using agricultural residues as precursors for pyrolysis. The observed bulk density of 0.72g/cm^3 was higher than 0.49g/cm^3 reported by Evbuoman *et al.,* (2013) for PKS derived-activated charcoal. The value of the bulk density is however within the preferred range of 0.06-1.03g/cm^3 as recommended by Bryne & Nagle (1997) for activated charcoal with high adsorption capacity and micro-porosity. The water-holding capacity of 77.46 % reported in this experiment was higher than the value of 47.4 % obtained by Kong *et al*. (2013) for PKS derived activated charcoal. Mollinedo *et al.* (2015) demonstrated the use of AC to improve the water-holding capacity of different soil samples and discovered that treatment of soil increased water retention capacity by 25% when compared with untreated control. The AC produced in this study is suitable for increasing the water retention capacity of soil considering its high water-holding capacity. Enhanced soil water retention will improve plant nutrient availability and uptake; thereby improving crop yield (Van Zwietan *et al.,* 2010; Zheng *et al.,* 2013). It will have additional fertilizer value because of its high concentration of important plant macro nutrients such as potassium and phosphorus (Steiner, 2008). The use of rice husk activated charcoal to fertilize rice fields had been a common practice in Asian countries (Steiner, 2008). The urban encroachments on poultry facilities have resulted in increased complaints from local residents (Okoli, 2004; Nwagwu *et al.,* 2012), due to bad odour and nuisance flies. In addition, farmers incure huge economic losses associated with poor litter in poultry farms resulting from foot and leg problems, respiratory diseases, poor weight gain and inferior feed conversion (Charles, 2005). The high water holding capacity of AC could be beneficial in minimizing problems associated with wet litter in livestock and poultry farms. Sashikala *et al.* (2012) compared the odour abatement of poultry litter using three odour control products (activated charcoal, silica gel and zeolite) under controlled environmental conditions and reported that activated charcoal and silica gel exhibited prominent adsorption or reduction in litter volatiles. Huwig *et al.* (2001) reported that activated charcoal is a very effective adsorbent for reducing the levels of mycotoxins in feed when compared with other minerals adsorbents such as aluminosilicates and bentonite while in broilers, Durunna *et al.* (2018) observed that daily weight gain was significantly higher in the groups fed diets supplemented with activated charcoal compared to the control group.

Specific gravity (SG) otherwise called relative density is the ratio of the density of substances to the density of water (Omede, 2010). This physical parameter plays a vital role in the transit of digesta through the gastrointestinal (GIT) tract of animals (Bhatti & Firkins, 1995). The value of the specific gravity obtained in this research 0.730 was lower than the 1.61 reported by Evbuoman *et al*. (2013) but higher than the 0.64 eported by Okoroigwe *et al*. (2013) for bamboo and palm kernel shell-derived activated charcoal, respectively. It should be recalled that particles with specific gravity of less than 1.20 were more likely to float in the gastrointestinal tract of animals thereby increasing their retention time while those greater than 1.50 sink leading to a reduced retention time (Kaske *et al.*, 1992; Bhatti & Firkins,1995). The specific gravity recorded in this study was far higher than the range of 0.33-0.46 reported by Omede (2010) for conventional feed ingredients produced in Nigeria and hence may enhance the specific gravity of feeds when supplemented in rations.

The oil adsorption capacity (OAC) and surface area (SA) obtained in this experiment were 118.47% and 587cm^2/g, respectively. The value for surface area is higher than the range of 248-253cm^2/g reported by Lima and Marshal (2004) for AC derived from poultry litter material. The high surface area coupled with the slightly alkaline pH of 7.67 could be responsible for the high oil adsorption capacity of 118.42% observed. It has been reported that low pH values and high surface area tend to increase the oil adsorption capacity of ACs (Madu & Ladije, 2013). With these outstanding properties, the activated charcoal derived from this study could be beneficial for gastrointestinal de-contamination when used as feed additive (Lartey *et al.*, 1999; Chyla *et al.*, 2005; Tumin *et al.*, 2008; Tabbakh & Barhoun, 2018). It has also been reported that low cost materials such as palm kernel shell, palm fruit fibre, and animal wastes are good precursors for producing AC for use as adsorbents because of well-developed pore structure and high surface area responsible for extensive adsorption capacity (Tsai, 2001). Therefore, the AC produced in this study could be suitable for use in water remediation in cases of oil spillage in oil producing communities (Tabbakh and Barhoun, 2018).Activated charcoal produced from readily available and renewable agricultural residues would be less expensive and serve as replacement for other more costly adsorbents imported for this and similar purposes, thereby transforming waste into wealth (Ahmedna, 2000; Malik, 2006). Furthermore, natural water sources available to most communities in developing countries like Nigeria are rivers, and natural ponds mostly contaminated with heavy metals and effluents discharged from industries (Tumin et *al.*, 2008). Studies by Etuk *et al.* (2014 & 2016) showed that such heavy metal contaminated water used in animal feeding have negative effects on performance. Activated charcoal such as produced in the present study could be suitable for purifying contaminated water for farm and domestic use by adsorption of metallic ions and bacterial toxins (Lartey *et al.*, 1999).

The value of the carbon content was 79.43% which is higher than the 65.4 % reported by Kong *et al.* (2013).It is also higher than that of wood-derived activated charcoal (AC) (71.40%) and coconut shell-derived AC (60.07%) as reported by Widowati & Asnah (2014) but lower than the 85.0, and 88.4 % reported by Hidayu & Muda (2016), and Okoroigwe *et al*. (2013), respectively using palm kernel shell and oil palm fibre as precursor materials. Lima & Marshal (2004) pyrolysed poultry litter and recorded a carbon content of 29% which was far below the carbon content obtained in this study. The value obtained in the present experiment was however within the preferred range of 62.20 - 92.40% recommended by Domingues *et al*. (2017) for activated charcoal with high degree of micro-porosity and adsorption capacity. More so, the carbon content value obtained in this study can be adjudged to be high when compared to the International Biochar Initiative (IBI) standard which requires 10% minimum organic carbon in activated charcoal (European Biochar Certificate, 2012). The European Biochar Foundation also recommended that for any residue left after pyrolysis to qualify as activated charcoal, the carbon content should not be less than 10% (International Biochar Initiative, 2017). Several studies have shown that the most important factors that affect carbon yield and carbon content of AC are density and nature of the carbonized material or precursor (Verheijen *et al*., 2010). This could be the reason why different agricultural residues exhibit different physico-chemical characteristics even with the same method of treatment or activation. Martinez *et al*. (2006) observed that the texture, carbon yield and carbon content as well as development of pores of AC were strongly affected by the physical and chemical characteristics of the starting material or precursor. The concentration of minerals evaluated in the present study were calcium (6185.11mg/kg), phosphorus (18603.29mg/kg),sodium (1722.47mg/kg), potassium (10275.48mg/kg), magnesium (3980.14mg/kg), manganese (721.00mg/kg), iron (996.35mg/kg), zinc (95.47mg/kg), copper (33.69mg/kg), arsenic (13.38mg/kg), and nitrogen (3008.04mg/kg). These mineral concentrations were much higher than the values reported by Okoroigwe *et al.* (2013) and that of Gunamartha & Widana (2018) for PKS and cow dung-derived activated charcoals, respectively. These variations could be attributed to the nature of the starting material (precursor) which influences the mineral composition and concentration of the resulting activated charcoal (Cagnon *et al.*, 2009, Camphell *et al.*, 2012, Abechi *et al.*, 2013). More so, the properties of the AC and its elemental composition can be influenced by the method of activation, duration of activation, and carbonization temperature (Centinkaya *et al.*, 2003; Hirupraditkoon *et al.*, 2011). The high concentration of potassium in the activated charcoal produced in this experiment could be attributed to the inclusion of palm fruit fibre as one of the precursors. Activated charcoal rich in potassium could serve as fertilizers to enrich soils for enhanced crop yield (Udoetok, 2012). The heavy metals for example arsenic and the micro mineral (zinc) were within the allowable threshold for these elements in activated charcoals namely lead < 150mg/kg, copper < 30mg/kg, zinc < 400mg/kg and arsenic < 30mg/kg(European Biochar Certificate, 2012).

CONCLUSION

The study showed that the activated charcoal produced using these agricultural residues (pig dung, palm fruit fibre and PKS) was of high physico-chemical properties within the range of most activated charcoals produced for gastrointestinal decontamination, water treatment and environmental remediation.

REFERENCES

AAFCO (2012). Official publication. Association of American Feed Control Officials. USA.

Abechi, S.E., Gimba, C.E., Uzairu, A. & Dalltu, Y.A. (2013). Preparation and characterization of activated carbon from palm kernel shell by chemical activation. *Resource Journal of Chemical Science*, 3(7): 54-61.

Addul, A. & Aberuagba, F. (2005). Comparative study of the adsorption of phosphate by activated carbon from corncobs, groundnut shell and rice husk. *AUJ Journal*, 9(1), 59-63.

Agamuthu, P. (2009). Challenges and opportunities in agro-waste management: An Asian perspective. *Inaugural Meeting of First Regional (3R) Forum in Asia*, 11-12th November, Tokyo, Japan.

Agba, M. M., Ushie, E. F., Abam, I., Agba, M.S. & Okoro, J. (2010). Developing the biofuel industry for effective rural transportation. *European Journal of Scientific Research*, 40, 441-449.

Ahmedna, M., Marshal, W. E. & Rao, R. M. (2000). Production of granular activated carbons from selected agriculture by products and evaluation of their physicochemical and adsorption properties. *Bio-Resource Technology*, 71: 113-123.

Akorede, M. F., Ibrahim, O., Amuda, S. A., Otuoze, A. O. & Olufeagba, B. J. (2017). Current status and outlook of renewable energy development in Nigeria. *Nigeria Journal of Technology*, 36(6), 196-212.

Al-Qodah, Z. & Shawabkah, R. (2009). Production and characterization of granular activated carbon from activated sludge. *Brazilian Journal of Chemical Engineering*, 26(1), 127-136.

AOAC (1990). The official methods of analysis. Association of Official Analytical Chemists, 13th Edition, Washington DC.

ASTM D 280-33 (2003). Standard Test Methods for the hydroscopic moisture content of activated carbon. ASTM, West Conshohocken, PA.

ASTM F 726-99 (1998). Standard Test Methods for oil adsorption capacity of activated carbon, ASTM, International West Conshohocken, PA.

Balat, M., Kirtary, E. & Balat, H. (2009). Main routes for the thermo-conversion of biomass into fuels and chemical. Part 1: Pyrolysis Systems. *Energy Conversion and Management*, 50, 3147-3157.

Bhatti, S.A. & Firkins, J.T. (1995). Kinetics of hydration and functional specific gravity of fibrous feed by-products. *Animal Science Research and Reviews*, Special circle, 156.

BRECG (1997). Environmental review of national solid waste management plan. Brown and Root Environmental Consultancy Group. Interim report submitted to the Government of Mauritius.

Burdock, G.A. (1997). Encyclopedia of food and color additives. CRC Press, Boca Raton, USA.

Byrne, C.E & Nagle, D.C. (1997). Carbonization of wood for advanced materials applications. *Carbon,* 35(2), 259-266.

Cagnon, B., Py, X., Guillot, A., Stoecidi, F. & Chambar, G. (2009). Contribution of hemicelluloses and lignin to the mass and the porous properties of chars and steam activated carbons from various lignocellulosic precursors. *Bioresource Technology*, 100(1), 292-298.

Camphell, Q.P., Bunt, J.R., Kasaini, H. & Kruger, D.J. (2012). The preparation of activated carbon from South Africa coal. *Journal of Science African Institute Min. Metal,* 112, 37-44.

Centinkaya, S., Sakintuna, B. & Yuyun, Y. (2003). Formation of crystal structure during activated carbon production from Turkish Elbistan lignite. *Fuel and Chemical Division and Preparation*, 48(1), 67-69.

Charles, E.B. (2005). Litter management for confined turkeys. Poultry Science and Technical Guide, No. 41, *The North Carolina Agricultural Extension Service Bulletin.* Pp. 3-7.

Chen, X., Jeyaseelam, S. & Graham, N. (2002). Physical and chemical properties of activated carbon made from sewage sludge. *Journal of Waste Management*, 22, 755- 760.

Chyla P. A., Seger, D., Krenzelok, E. P. & Vale, J. A. (2005). Single-dose activated charcoal. *Clinical Toxicology,* 43 (2), 61-87.

Domingues, R.R.,Trugilho, P.F., Silva, C.A.,DeMelo, I.C.N.A., Melo, L.C.A.,Magriotis, Z.M & Sanchez-Monedero, M.A. (2017). Properties of biochar derived from wood and high-nutrient biomasses with the aim of agronomic and environmental benefits. *PLoSONE,* 12,e0176884.

Durunna, C.S., Abatai, U.G & Uchegbu, C. (2018). Performance evaluation of broiler chickens fed varying levels of raw african velvet tamarind, *Icheku* (*Dialiumguineense*) wood charcoal as feed additive. *Proceedings of 43rdAnnual Conference of the Nigerian Society for Animal Production*, March 18th - 22nd 2018 Owerri, Imo State, Nigeria. Pp: 514 -516.

Etuk, I. F., Ogbuewu, I. P., Iwuji, T. C., Okoli, I. C., Aladi, N. O., Williams, E. & Unamba-Opara, C. I. (2016). Physiological responses of broilers to drinking water from different sources in eastern Nigeria. *International Journal of Agriculture and Rural Development,* 19(1), 2422-2426.

Etuk, I. F., Ogbuewu, I. P., Okoli, I. C., Etuk, E. B., Iwuji, T. C., Obikoonu, H. O., Opara, M. N. & Odoemelam, V. U. (2014). Quality of different water sources used in poultry and piggery farms in southeastern Nigeria. *International Journal of Agriculture and Rural Development*, 17(2), 1847-1852.

Europeab Biochar Certificate (2012). European Biochar Certificate-Guideline for a sustainable production of Biochar. European Biochar Foundation (EBC), Arbaz, Switzeerland. http://www.european-biochar.org/en/download.

Evbuoman, B. O., Abutu, A. S. & Ezeh, C. P. (2013). The effects of carbonization temperature on some physicochemical properties of bamboo based activated carbon by potassium hydroxide (KOH) activation. *Greener Journal of Physical Science,* 3(5), 187-191.

Gunamantha, I.M. & Widana, G.A.B. (2018). Characterization of the potential of biochar from cow and pig manure for genecology application. *Conference Series: Earth Environmental Science*, 131, 12-55.

Hidayu, A. R. & Muda, N. (2016). Preparation of impregnated activated carbon from palm kernel shell and coconut shell for Co_2 capture. *Procedia Engineering*, 148, 106-113.

Hirupraditkoon, S., Tunthong, N., Ruangchai, A. & Nuithitku, K. (2011). Adsoption capacities of activated carbons prepared from bamboo by KOH activation. *World Academy of Science, Engineering and Technology*, 78, 711-715.

Hussein, M., Amer, A. A. & Sawsan, I. I. (2008). Oil spill adsorption using carbonized pith bagasse: Trial for practical application. *International Journal of Environmental Science Technology*, (5), 233-242.

Huwig, A., Freimund, S., Kappeli, O. & Dutler, H. (2001). Mycotoxin detoxification of animal feeds by different adsorptions. *Toxicologty Letters*, 122, 179-188.

International Biochar Initiative. (2017). Standardized product definition and product testing guidelines for biochar that is used in soil. *International Biochar Initiative*, IBI-STD-1.1.

Kaske, M., Hatiboglu, S. & Engelhadt, W.V. (1992). The influence of density and size of particles on rumination and passage from the reticulo-rumen of sheep. *British Journal of Nutrition*, 67, 235-244.

Khan, A.M. & Ansari, R. (2009). Activated carbon preparation, characterization and applications: A review article. *International Journal of Chemical Technology Resource,* 1(4), 859-864.

Kong, S.H., Loh, S.K., Bachmann, R.J., Choo, Y.M. & Abdu Rahim, S. (2013). Production and physico-chemical characterization of biochar from palm kernel shell. *Food Science and Technology Postgraduate Colloquium, AIP Conference Proceeding,* 1571, 749 – 752.

Lartey, R.B., Acquanh, F. & Nketia, K. S. (1999). Developing national capacity for manufacture of activated carbon from agricultural waste. *Ghana Engineering,* 3, 45-50.

Lima, I. M. & Marshal, W. E. (2004). Granular activated carbons from broiler manure: physical, chemical and adsorptive properties. *Journal of Bioresource Technology*, 96, 699-709.

Madu, P.C. & Lajide, l. (2013). Physicochemical characteristics of activated charcoal derived from melon seed husk. *Journal of Chemical and Pharmaceutical Research*, 5(5), 94-98

Makinde, O. A. & Sonaiya, E. B (2007). Determination of water holding capacity, blood and rumen fluid adsorbance of some fibrous feed stuff. In: A. Giang*et al*., (eds). *Sustainability of Livestock Industry in Oil Economy.Proceedings of the 32nd Annual Conference of the Nigeria Society for Animal Production*, 28: 84-87.

Maklad, A .I., Ashraf, M. E., Enas, I. E. & Mennat-Allah, A. M. E. (2012). Pediatric poisoning in Egypt. *Journal of Poultry Applied Pharmaceutical Science,* 2 (2), 1-6.

Malik, R., Ramtake, D.S. & Water, S.R. (2006). Physico-chemical and surface characterization of adsorbent prepared from groundnut shell by $ZnCl_2$ activation and its ability to adsorb

Martinez, M.L., Torres, M.M., Guzman, C.A. & Maestri, D.M. (2006). Preparation and characterization of activated carbon from olive stones and walnut shells. *Industrial Crops Production*, 23, 23-28.

Mohammed, Y. S., Mustafa, M.W., Bashir, N. & Mokhatar A. S. (2013). Renewable energy resources for distributed power generation in Nigeria: A review of the potential. *Renewable and Sustainable Energy Reviews,* 22, 257-268.

Mollinedo, J., Schumacher, J.E. & Chintala, R. (2015). Influence of feedstocks and pyrolysis on bichoar’s capacity to modify soil water retention characteristics. *Journal of Analytical and Applied Pyrolysis,* 114, 100-108.

Nwagwu, C., Ede, P .N., Okoli, I. C., Chukwuka, O. K., Okoli, C. G. and Moreki, J. (2012). Effect of environmental factors and structural dimension of aerial pollution gas concentrations in tropical poultry pen in Nigeria. *International Journal of Applied Poultry Research,* 1(1), 15-20.

Nwankwo, I.H. (2018). Production and characterization of activated carbon from animal bone. *American Journal of Engineering Research,* 7(7), 335-341.

Nwokolo, C. O. & Ogunyemi, S. (2008). Empirical study on optimizing recovery from oil palm waste in Nigeria. *International Conference on Renewable and Alternative Energy*, Owerri, Nigeria. March 29-April 2, 2009. Books of Abstracts. Pp:24.

Obi, F.O., Ugwuishiwu, B.O. & Nwakaire, J.N. (2016). Agricultural waste concept, generation, utilization and management. *Nigerian Journal of Technology,* 35 (4), 957-964.

Okoli, I. C. (2004). Frequency of isolation of Salmonella from commercial poultry feeds and their anti-microbial resistance profile. Phd Thesis, Federal University of Technology Owerri, Imo State, Nigeria.

Okoroigwe, E. C., Ofomatah, A.C., Oparaku, N.F. & Unachukwu G. O. (2013). Production and evaluation of activated carbon from palm kernel shell for economic and environmental sustainability. *International Journal of Physical Science, 8* (19), 1036-1041.

Omede, A. A. (2010). The use of physical characteristics in the quality evaluation of commercial feeds and feedstuffs. MSc Thesis, Federal university of Technology Owerri, Nigeria.

Pradham, B.K. & Sandle, N.K. (1999). Effect of different oxidizing agent treatments on the surface properties of carbon. *Carbon,* 4, 391-400.

Prakash Kumar, B.G., Shivakamy, K., Miranda, L.R. & Velan, M. (2006). Preparation of steam activated carbon from rubber and wood sawdust *(Heveabrailienis)* and its adsorption kinetics. *Journal of Hazardous Materials,* B l36, 922 - 929.

Sashikala, M., Pillai, G. P., Xinguang, R. & Stuetz, M. (2012). Odour abatement of poultry litter using odour control products. *A publication of Italian Association of Chemical Engineering,* Vol. 30, Onlinewww.acidic.it.cet

Steiner, C. (2008). Biochar carbon sequestration: Biorefinig Carbon Cycle Program University of Georgia, Athens, GA.

Sugumuan, P., Susan V.P., Ravichandran, P. & Seshadri, S. (2012). Production and characterization of activated carbon from banana empty fruit bunch and *Delonixregina* fruit production. *Journal of Sustainable Energy and Environment,* 3, 125-132.

Tabbakh, T. & Barhoun, R. (2018). Cleanup oil spills by activated carbons prepared from agricultural wastes. *Indian Journal of Material Sciences*, 16(1), 1-9.

Tsai, W.T., Lee, M.K. & Chang, Y.M. (2007). Fast pyrolysis of rice husk: Product yields and compositions. *Bio-resource Technology,* 98, 22-28.

Tumin, N.D., Luqman, A.C., Zawani, Z. & Suraya, A.R. (2008). Adsorption of copper from aqueous solution by *Elaisguineensis* kernel activated carbon. *Journal of Engineering Science and Technology,* 3(2), 180 – 189

Udoetok, I.A. (2012). Characterization of ash made from oil palm empty fruit bunches. *International Journal of Environmental Sciences,* 3(1), 518 -524.

Van Zwietan, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S. & Cowie, A. (2010). Effect of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and Soil*, 327, 235-246.

Verheijen, F., Diafas, I., Jeffery, S., Bastos, A. & Valde, M. V. D. (2010). Biochar application to soils: A critical scientific review of effects on soil properties and functions. European Commission Joint Research Centre, Brussels.

Widowati, W. & Asnah, A. (2014). Biochars effect on potassium fertilizer and leaching potassium dosage for two corn-planting seasons. *Agrivita,* 36, 165-71.

Zheng, Z., Song-da, Z., Ting-giang, L., Feng-Liang, Z., Zhen-Li, H., He-ping, Zi, Zia-e, Y., Hai-long, W., Jing, Z. & Muhammad, T.R. (2013). Adsorption of ammonium phosphate from aqueous solution by biochar derived from phytoremediation of plants. *Journal of Zhejiang University Science B,* 14 (912), 1152-1161.