Chapter

Activated Charcoal: A Novel Utility Product for Enhanced Animal Health and Production from Agricultural Wastes (Pig Dung and Palm Oil Wastes)

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Abstract

Feed remains the most important component of the cost of production in any poultry operations. Hence, the need to harness the potentials of numerous alternative ingredients such as activated charcoal (AC) produced from agricultural wastes. The objective of the present study was to evaluate the physic-chemical properties of AC produced from a blend of agro-wastes for use as feed additives. 120 day old broilers were distributed into four treatment groups (T1-T4) of thirty birds each and were maintained on a starter and finisher diet for 3 weeks each respectively with T1 (control) fed diet containing no AC. T2-T4 was fed diet which contained 0.5, 1.0 and 1.5% of AC respectively. Physical and chemical properties of the produced AC were determined while the blood and performance parameters were determined and all data subjected to statistical analysis. The AC significantly ($P > 0.05$) reduced feed intake, jejunum pH, FCR, serum cholesterol levels and increased ($P < 0.05$) live weight gain, intestinal lengths, carcass weight and some hematological indices especially in T3 when compared with broilers fed control diet. It was concluded that AC enhanced production and health by improving on the performance, hematology of young chicks and reduction in serum cholesterol level.

Keywords: agricultural wastes, activated charcoal, palm fruit fibre, palm kernel shell, pig dung

1. Introduction

Feed is the most important component in any intensive poultry operation, representing about 70% of the total cost of production [1]. Hence, there is a compelling need to harness the potential of numerous alternative ingredients such as activated charcoal (AC) produced from agricultural wastes as a replacement for expensive conventional ingredients. Agricultural wastes are defined as residues from the growing and processing of raw agricultural products such as fruits, vegetables,

meat, poultry, dairy products, and crops [2]. These are renewable resources whose utilization has received great attention due to environmental considerations and the increasing demand for energy worldwide [3]. Agricultural by-products are also being advocated for the production of adsorbents such as activated charcoal (AC) due to their carbon content and the possibility of mitigating environmental pollution through such a process [4]. They have also been found to be renewable and relatively less expensive when compared to other activated charcoal precursors of industrial and petroleum origin such as wood, coal, and lignite [5]. Recently, interests have focused on the use of agricultural wastes such as corn cob, groundnut shell, poultry litter, rice husk, palm kernel shell (PKS), coconut shell, and many others in the production of value-added products such activated charcoal, fertilizer, batteries, biofuel, bio-oil, and biogas [6].

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 waste will continue to increase globally as developed and developing countries continue to intensify their farming systems. Research in 2005 revealed 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 [7]. The annual production of agricultural wastes is this high because about 94% and 68% of household are engaged in crop and livestock farming, respectively [8]. The major agricultural crops biomass feedstocks with sustainable potential in Nigeria are millet, yam, cassava, sorghum, rice, groundnut, oil palm, sugar cane, and soybeans [9]. On livestock, the estimates made in 2001 gave the total number of cattle, sheep, goats, horses, pigs, and poultry in Nigeria as 245 million, which altogether produce 0.78 million tonnes of animal waste daily as reported by Akorede et al. [8].

Oil palm industry has been recognized for its contribution toward economic growth and development in Nigeria and Malaysia. That notwithstanding, it has also contributed to environmental pollution due to the production of large quantities of waste products during the product extraction. During the processing of palm oil, more than 70% (by weight) of the processed fresh fruit bunch was left over as oil palm waste consisting majorly of extracted fiber and palm kernel shell [10]. Palm kernel Shell (PKS) are the shell fractions left over after the nut has been removed after crushing in the oil palm mill. There is a surplus of these by-products in the palm oil value chain but their utilization is extremely very negligible. Apart from a few isolated cases where they serve as a source of fuel in cooking, the PKS, for example, are usually dumped in the open field and water ponds which impact negatively on the environment [10]. Therefore, the production of activated charcoal from palm kernel shells using the process of pyrolysis could be a value addition to palm oil processing which is a veritable economic activity in Nigeria and Malaysia [11].

Pyrolysis of agricultural waste is desirable as a large part of the crop body is non-edible and goes as waste. Straw makes up to 50% of the yield of cereal crops and has more potential for char production compared to wood [12]. Different varieties of agricultural wastes that have been tested for pyrolysis include cotton cocoon, groundnut shell, nutshell, palm kernel shell, corn stalk, bagasse, banana leaves, cotton seedcake, garlic stem, pepper stem, tobacco waste, sunflower bagasse, sorghum bagasse, and cassava peels (**Figure 1**) [12, 13].

AAFCO [14] defined activated charcoal as a dark-colored porous form of carbon made from organic parts of plant or animal substances by their incomplete combustion. They are processed carbon materials that are capable of adsorbing various

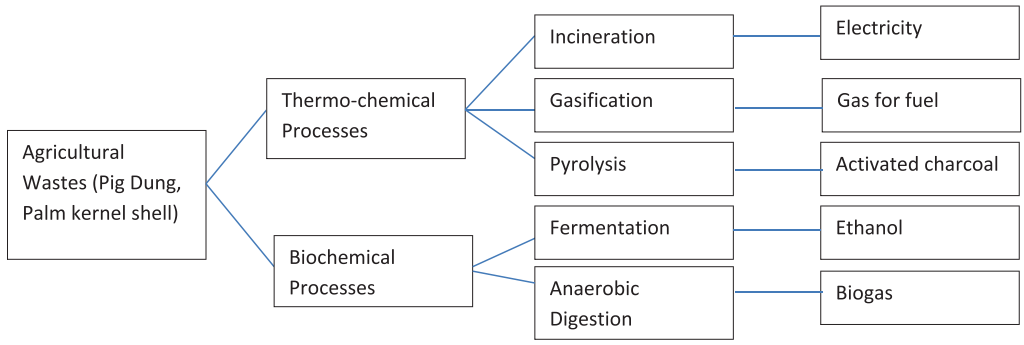

Figure 1.
Methods of conversion of agricultural waste to produce activated charcoal and other products using thermo-chemical and biochemical processes.

substances because of their highly developed pore structure and large internal specific surface area [15, 16]. It is differentiated from elemental carbon by its high surface area and the oxidation of the carbon atoms found at both its outer and inner surfaces [17]. The surface chemistry of activated charcoal confers on it the ability to absorb many gases, aqueous liquid, and poisons [16, 18, 19]. Several studies have shown that activated charcoal is harmless even when it is accidentally consumed, inhaled, or comes in contact with the skin. Although no allergic effects have been associated with its use, the American Academy of Clinical Toxicology, AACT [20] however recommended that activated charcoal should not be taken longer than 12 weeks without stopping. When mixed with water and swallowed to counteract poisoning, activated charcoal adsorbs the poison or drug, inactivating it, and then carries it inert through the entire length of the digestive tract out of the body [16, 19, 21].

Majewska [22] carried out experiment to determine the effect of hardwood charcoal supplementation on the performance and carcass characteristics of broiler at varying inclusion level in the diet. The results showed that at 3% dietary supplementation, the birds were 5% and 3.5% heavier than the control and the dressing percentages and the relative weights of the muscles were also improved at 21 and 42 days, respectively. The author attributed the results to the detoxifying effects of charcoal, thereby lowering the surface tension of the intestinal digest to support liver function with respect to fat digestion. More so, the adsorption properties of charcoal act curatively on the gastrointestinal tract (GIT), adsorbing gases such as hydrogen sulphide and ammonia that are formed there, including bacterial toxins and mycotoxins produced by fungi [23]. Jiya [24] supplemented activated charcoal at 0.5% in broiler feeds and noted increased relative organ weights and reduced cholesterol level of carcass which he attributed to efficient mineral uptake and nutrient utilization.

Durunna et al. [25] reported improved growth rates and reduced flatulence, fly population, and litter odor at varied inclusion levels of wood charcoal in the feed of broiler birds. In another research by Dim et al. [26] to ascertain the effect of dietary supplementation of activated charcoal on growth, hematology, and serum lipid profiles of broilers, the final body weight, average daily weight, and FCR favored birds placed on 6% charcoal inclusion than other groups and the control after 56 days trial period.. More so, Dim et al. [26] noted that the white blood cell (WBC) count and the packed cell volume (PCV) were not affected at both the starter and finisher phases. However, the hemoglobin concentration (Hb) and the red blood cell count were significantly improved [27, 28], while the cholesterol and lipoprotein levels were significantly reduced with no effect on triglyceride at both phases [29].

2. Materials and methods

2.1 Ethical approval

The Animal Ethics Committee of the College of Veterinary Medicine, Michael Okpara University of Agriculture Umudike approved to this experiment.

2.2 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.

2.3 Study layout

The research was divided into two studies. Study 1 involved the production of activated charcoal from a blend of locally available agricultural residues such as pig dung, palm kernel shell, and palm fruit fiber and the evaluation of the physicochemical properties. Study 2 involved the evaluation of the effect of dietary inclusion of activated charcoal on growth, carcass yield, hematology, and serum biochemical indices of broiler chickens.

2.4 Collection, drying, and blending of agricultural residues

The palm kernel shell and palm fruit fiber were collected from a palm oil mill while freshly voided pig dung was collected from pig farms using a 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 pig dung, palm kernel shell, and palm fruit fiber, respectively, and used to produce the activated charcoal.

2.5 Study 1 (production of activated charcoal)

The physical method of activated charcoal production described by Gunamartha and Widana [30] 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 liters for carbonization. In addition to contributing to the carbon yield, palm kernel shell and palm fruit fiber also served as combustion accelerants enhancing the pyrolysis of pig dung [31]. 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

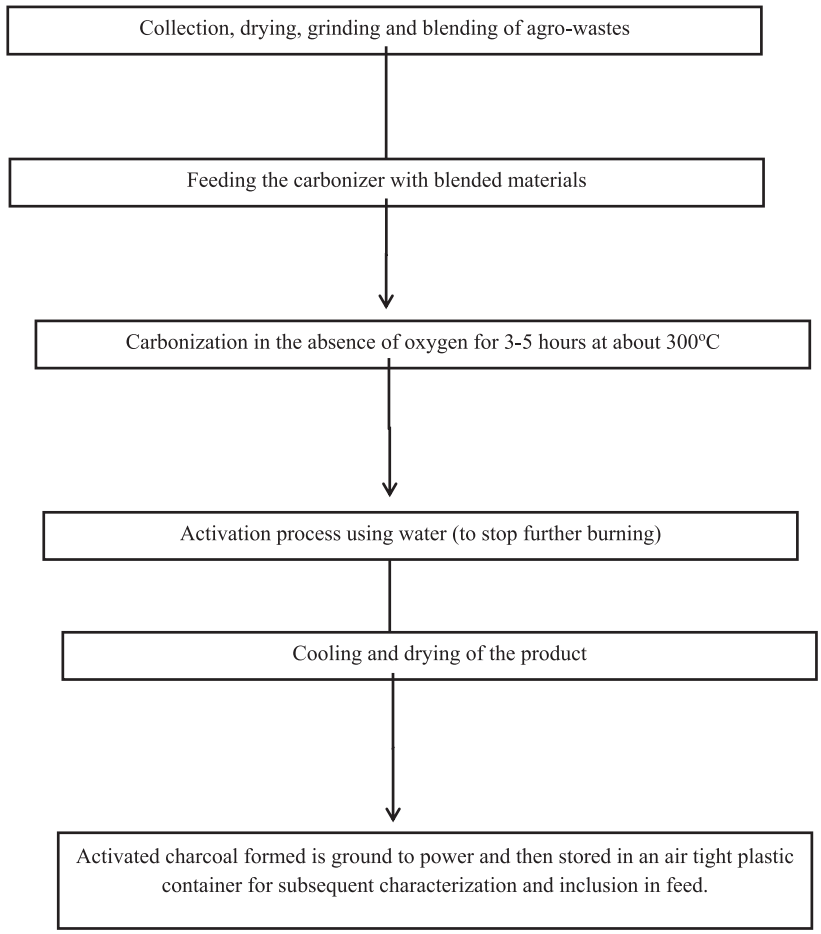

Figure 2.
Flow chat for producing activated charcoal.

characterization and subsequent supplementation in broiler feeds produced according NRC [32] recommendations (**Figure 2**).

2.6 Physicochemical 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.

2.6.1 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 and values were expressed in percentage. The bulk density, water holding capacity, and specific gravity of the activated charcoal were determined according to the procedure described by Makinde and Sonaiya [33] and modified by Omede [34]. The moisture content of the activated charcoal was determined using oven dry method as described by the American Society for Testing and Materials [35] and the percentage moisture content was calculated as recommended by AOAC [36]. 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 [37]. The test was performed at 23 ± 4°C with the oil absorbency measured three times and an average value taken according to [38]).

2.6.2 Determination of carbon and mineral contents

The concentration of macro minerals namely nitrogen (N_2), calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), 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.

3. Results

The physical properties of the produced activated charcoal are presented in **Table 1** while the chemical properties are presented in **Table 2**.

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).

The carbon content and mineral composition of the activated charcoal produced in this study were as shown in **Table 2**.

Study 2: Evaluation of the effect of dietary inclusion of activated charcoal on growth, carcass yield, hematology, and serum biochemical indices of broiler chickens.

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 1.
Physical 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)	18,603.29
Sodium (mg/kg)	1722.47
Potassium (mg/kg)	10,275.48
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

Table 2.
Chemical properties of activated charcoal produced from a blend of agricultural waste materials.

3.1 Methodology, experimental birds, and design

One hundred and twenty unsexed day old arbor acre strain of broilers were used. On arrival, they were distributed into four treatment groups (T1–T4) of 30 birds each with each group further replicated three times comprising of 10 birds each in completely randomized design. They were maintained ad-libitum on a starter and finisher diet for 3 weeks each, respectively, with T1 (control) fed diet containing no activated charcoal. T2–T4 was fed diet which contained 0.5 g/kg, 1.0 g/kg and 1.5 g/kg of activated charcoal, respectively. Data collected were feed intake, live weight, carcass weight and organ weight. Live weight gain and feed intake were used to calculate the feed conversion ratio (FCR). Blood samples were collected at the end of 1st, 4th and 6th week of the experiment from the wing vein of the birds into EDTA (Ethylenediamine tetra-acetic acid) and plain bottles for hematological and serum biochemical analysis, respectively. The erythrocyte was counted using the hemocytometer method as describe by Schalm et al. [39] while the hemoglobin concentration was determined according to the techniques described by Cole [40]. In determining the packed cell volume (PCV), the Wintrob microheamatocrit tube method was used while other hematological indices were calculated according to the formula reported by Schalm et al. [39]. Serum biochemical tests were carried out using Randox commercial test kit specific for each biochemical parameter in accordance with standard procedures prescribed by the producer Randox Laboratories (UK). The serum parameters analyzed include the following included total serum protein, serum albumin and globulin, urea, serum creatinine concentration, alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase activity (ALP), total bilirubin content and total serum cholesterol. Weights of carcass and organ were determined by first slaughtering 12 birds (one per replicate) by severing of the neck with a sharp knife and removal of feathers [41]. Both the carcass and organ weights were expressed as percentage of live weight and data collected were subjected to statistical analyses using ANOVA.

Age	Parameters	Experimental groups			
		T1	T2	T3	T4
Day 1	Live w. (g)	37.80 ± 2.14	38.07 ± 2.41	37.73 ± 2.13	37.43 ± 2.46
Wk 1	Live w. (g)	180.00 ± 36.72	197.33 ± 18.77	219.33 ± 16.26	194.33 ± 11.15
	Weight gain	120.57 ± 1.30	118.63 ± 1.76	122.27 ± 3.25	199.97 ± 5.52
	Feed intake	30.33 ± 2.37^{b}	28.82 ± 2.74^{a}	29.19 ± 1.24^{ab}	28.33 ± 1.72^{a}
	FCR	1.74. ±0.01	1.68 ± 0.07	1.67 ± 0.03	1.65 ± 0.05
Wk 4	Live w (g)	933.00 ± 115.88	1059.67 ± 148.29	1070.67 ± 102.81	1053.33 ± 153.81
	Weight gain	817.37 ± 20.96^{a}	886.26 ± 18.63^{b}	924.87 ± 23.10^{c}	843.27 ± 3.27^{a}
	Feed intake	95.74 ± 8.12^{c}	92.70 ± 7.97^{bc}	89.28 ± 10.34^{ab}	85.93 ± 9.58^{a}
	FCR	1.83 ± 0.05^{d}	1.61 ± 0.03^{c}	1.47 ± 0.03^{a}	1.53 ± 0.02^{b}
Wk 6	Live w. (g)	1947.67 ± 55.08^{a}	2027.67 ± 26.41^{ab}	2114.33 ± 80.21^{b}	1988.33 ± 17.04^{a}
	Weight gain	959.83 ± 54.62	976.67 ± 17.89	1000.33 ± 44.58	964.37 ± 48.34
	Feed intake	156.49 ± 8.00^{b}	150.92 ± 6.72^{a}	150.96 ± 5.67^{a}	153.05 ± 8.00^{ab}
	FCR	2.07 ± 0.07	1.98 ± 0.07	1.94 ± 0.08	2.02 ± 0.11

Table 3.
Growth parameters of broiler chickens fed varying dietary levels activated charcoal.

Tables 3 present the growth performance of the experimental birds while **Table 4** shows the relative organ weights and intestinal parameters of the broiler chicken at 1, 4, and 6 weeks of age.

Results are presented as mean ± standard deviation (n = 3). The results with different letter superscripts are significantly different ($P < 0.05$) from any paired mean across the row.

Results are presented as mean ± standard deviation (n = 3). The results with different letter superscripts are significantly different ($P < 0.05$) from any paired mean across the row.

Tables 5–7 present the hematological indices of the experimental birds at 1, 4, and 6 weeks of age, respectively.

Results in **Table 5–7** are presented as mean ± standard deviation (n = 3). The results with different letter superscripts are significantly different ($P < 0.05$) from any paired mean across the row.

The serum biochemical indices of the experimental birds at week one, four and six are presented in **Tables 8–10**, respectively.

Results of **Tables 8–10** are presented as mean ± standard deviation (n = 30). The results with different letter superscripts are significantly different ($P < 0.05$) from any paired mean across the row.

4. Discussion

4.1 Study 1

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. [42]. The inclusion of pig dung and

Age	Parameters	Experimental groups			
		T1	T2	T3	T4
Wk 1	Live weight (g)	180.00 ± 36.72	197.33 ± 18.77	219.33 ± 16.26	194.33 ± 11.15
	Gizzard+C (%)	7.30 ± 0.60	6.69 ± 0.62	6.82 ± 0.33	7.14 ± 0.41
	Gizzard (%)	4.85 ± 0.22^{b}	4.09 ± 0.19^{a}	4.41 ± 0.13^{a}	4.40 ± 0.27^{a}
	Proventri (%)	1.10 ± 0.18	0.99 ± 025	0.96 ± 0.03	1.08 ± 0.07
	Liver (%)	3.53 ± 0.17	3.37 ± 0.46	3.42 ± 0.11	3.87 ± 0.42
	Heart (%)	0.72 ± 0.10^{a}	0.88 ± 0.12^{ab}	0.91 ± 0.08^{b}	0.84 ± 0.06^{ab}
	Intest. L. (cm)	80.37 ± 3.89^{a}	112.33 ± 3.06^{b}	114.33 ± 9.29^{b}	124.00 ± 3.00^{b}
	Duodenal pH	5.16 ± 0.06	5.30 ± 0.02	5.20 ± 0.17	5.29 ± 0.02
	Jejunum pH	5.16 ± 0.14	5.29 ± 0.01	5.23 ± 0.12	5.29 ± 0.04
	Ileal pH	5.27 ± 0.02	5.30 ± 0.03	5.29 ± 0.03	5.26 ± 0.02
	Rectal pH	5.31 ± 0.02	5.30 ± 0.03	5.30 ± 0.02	5.28 ± 0.04
Wk 4	Live weight (g)	933.00 ± 155.88	1059.67 ± 148.29	1070.67 ± 102.81	1053.33 ± 153.81
	Gizzard+C (%)	3.53 ± 0.22^{a}	3.59 ± 0.27^{a}	4.28 ± 0.15^{b}	4.08 ± 0.14^{b}
	Gizzard (%)	2.47 ± 0.23^{ab}	2.30 ± 0.23^{a}	2.84 ± 0.04^{b}	2.68 ± 0.19^{ab}
	Proventri (%)	0.49 ± 0.06	0.44 ± 0.03	0.53 ± 0.12	0.55 ± 0.01
	Liver (%)	2.52 ± 0.18	2.67 ± 0.33	2.91 ± 0.15	2.84 ± 0.36
	Heart (%)	0.49 ± 0.03	0.53 ± 0.06	0.53 ± 0.10	0.50 ± 0.05
	Intest. L. (cm)	148.00 ± 19.08^{a}	165.00 ± 6.56^{ab}	185.00 ± 23.26^{b}	176.00 ± 13.08^{ab}
	Duodenal pH	6.02 ± 0.82	5.90 ± 0.36	5.93 ± 0.38	6.10 ± 0.26
	Jejunum pH	6.73 ± 0.25^{b}	6.43 ± 0.04^{ab}	6.17 ± 0.15^{ab}	5.29 ± 0.044^{a}
	Ileal pH	7.50 ± 0.50	8.00 ± 1.00	7.17 ± 0.15	7.83 ± 1.36
	Rectal pH	8.10 ± 1.39	8.53 ± 0.90	6.60 ± 0.53	8.50 ± 1.47
Wk 6	Live weight (g)	1947.67 ± 55.08^{a}	2027.67 ± 26.41^{ab}	2114.33 ± 80.21^{b}	1988.33 ± 17.04^{a}
	Carcass. w (g)	1359.64 ± 22.67^{a}	1473.67 ± 34.39^{ab}	1573.33 ± 104.64^{c}	1432.33 ± 22.68^{ab}
	Dressing %	69.81 ± 0.96^{a}	72.67 ± 0.90^{b}	74.38 ± 2.33^{b}	72.03 ± 0.76^{ab}
	Gizzard+C (%)	2.25 ± 0.12	2.30 ± 0.17	2.38 ± 0.11	2.20 ± 0.10
	Gizzard (%)	1.24 ± 0.09^{a}	1.56 ± 0.17^{b}	1.39 ± 0.15^{ab}	1.30 ± 0.06^{a}
	Proventri (%)	0.36 ± 0.02^{a}	0.41 ± 0.02^{b}	0.36 ± 0.01^{a}	0.37 ± 0.02^{a}
	Liver (%)	1.54 ± 0.06	1.67 ± 0.10	1.62 ± 0.11	1.68 ± 0.15
	Heart (%)	0.35 ± 0.02	0.38 ± 0.04	0.39 ± 0.02	0.35 ± 0.02
	Intest. L. (cm)	166.00 ± 17.06^{a}	188.67 ± 9.07^{ab}	207.67 ± 13.80^{b}	187.33 ± 6.51^{ab}
	Duodenal pH	5.93 ± 0.47	6.03 ± 0.64	5.93 ± 0.31	5.87 ± 0.25
	Jejunum pH	6.83 ± 0.12^{c}	6.17 ± 0.21^{b}	6.17 ± 035^{b}	5.97 ± 0.25^{ab}
	Ileal pH	7.60 ± 0.50	7.83 ± 0.55	7.93 ± 0.67	8.20 ± 0.30

Table 4.
Relative organ weight and intestinal parameters of broiler chickens fed varying dietary levels of activated charcoal.

Parameters	T1	T2	T3	T 4
RBC ($\times 10^6$/mm^3)	3.19 ± 0.06^a	3.67 ± 0.11^b	$3.43 \pm 0.32^{a,b}$	3.61 ± 0.17^b
PVC (%)	27.33 ± 0.58^a	31.33 ± 1.53^b	$29.33 \pm 2.08^{a,b}$	31.67 ± 1.53^b
HbC (g/dl)	9.63 ± 0.15^a	10.80 ± 0.40^b	$10.07 \pm 0.83^{a,b}$	10.87 ± 0.50^b
WBC ($\times 10^3$/mm^3)	36.50 ± 0.56^a	42.57 ± 3.19^b	$40.83 \pm 4.93^{a,b}$	42.97 ± 1.44^b
Platelet ($\times 10^3$/mm^3)	158.00 ± 5.29	161.00 ± 11.27	150.67 ± 8.02	160.67 ± 2.52
MCV(fL)	92.96 ± 7.70	90.24 ± 5.99	92.32 ± 5.91	93.07 ± 3.41
MCH (pg/cell)	30.24 ± 0.54	29.37 ± 0.47	29.42 ± 1.29	30.13 ± 0.04
MCHC (g/L)	35.25 ± 0.28	34.48 ± 0.48	33.95 ± 1.13	34.71 ± 1.04
Neutrophil (%)	30.33 ± 1.53	27.67 ± 2.31	29.00 ± 2.65	28.33 ± 0.58
Lymphocytes (%)	63.00 ± 2.00	64.67 ± 1.16	63.67 ± 1.16	65.00 ± 1.73
Monocytes (%)	4.67 ± 0.58	5.67 ± 0.58	5.33 ± 1.53	4.67 ± 1.16
Eosinophils (%)	2.00 ± 0.00	2.00 ± 1.00	2.00 ± 0.00	1.33 ± 0.58
Basophils (%)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table 5.
Hematological indices at 1 week of age for broiler chicks fed varying dietary levels of activated charcoal.

Parameters	T1	T 2	T3	T4
RBC ($\times 10^6$/mm^3)	4.12 ± 0.30^b	3.48 ± 0.25^a	$3.72 \pm 0.33^{a,b}$	3.37 ± 0.20^a
PVC (%)	35.67 ± 2.08^b	29.67 ± 2.52^a	$32.00 \pm 2.65^{a,b}$	30.67 ± 2.31^a
HbC (g/dl)	15.03 ± 0.67^b	12.87 ± 0.83^a	$13.40 \pm 1.40^{a,b}$	13.17 ± 0.38^a
WBC ($\times 10^3$/mm^3)	39.68 ± 2.18	37.43 ± 4.66	39.23 ± 1.36	44.25 ± 5.16
Platelet ($\times 10^3$/mm^3)	270.00 ± 54.53	302.67 ± 10.60	264.33 ± 53.31	295.00 ± 6.00
MCV(fL)	86.80 ± 5.19	85.12 ± 1.81	86.06 ± 0.91	86.74 ± 2.29
MCH (pg/cell)	36.59 ± 1.86	37.18 ± 5.15	35.99 ± 0.58	37.32 ± 1.78
MCHC (g/L)	42.17 ± 0.70	43.72 ± 6.43	41.83 ± 0.90	43.08 ± 3.10
Neutrophil (%)	61.67 ± 1.53	58.33 ± 1.53	61.67 ± 2.08	58.00 ± 3.61
Lymphocytes (%)	30.00 ± 2.00^a	36.00 ± 1.73^b	29.67 ± 2.52^a	$33.67 \pm 2.52^{a,b}$
Monocytes (%)	$5.00 \pm 1.00^{a,b}$	4.33 ± 0.58^a	5.67 ± 0.58^b	$5.00 \pm 0.00^{a,b}$
Eosinophils (%)	3.33 ± 0.58^b	1.33 ± 0.58^a	3.00 ± 0.00^b	3.33 ± 1.16^b
Basophils (%)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table 6.
Hematological indices at 4 weeks of age for broiler chickens fed varying dietary levels of activated charcoal.

palm fruit fiber in the present study may have been responsible for the lower activated charcoal yield obtained. Pig dung and palm fruit fiber 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. [11] and Lima and Marshal [4], respectively, for AC

Parameters	T1	T2	T3	T 4
RBC ($\times 10^6$/mm^3)	4.01 ± 0.17^{b}	$3.79 \pm 0.14^{a,b}$	$3.86 \pm 0.04^{a,b}$	3.68 ± 0.07^{a}
PVC (%)	38.00 ± 1.00^{c}	36.00 ± 1.00^{b}	36.33 ± 0.58^{b}	34.33 ± 0.58^{a}
HbC (g/dl)	14.57 ± 0.06^{c}	14.03 ± 0.06^{b}	14.00 ± 0.20^{b}	13.27 ± 0.25^{a}
WBC ($\times 10^3$/mm^3)	39.77 ± 1.46	38.50 ± 1.68	38.70 ± 2.55	37.57 ± 1.10
Platelet ($\times 10^3$/mm^3)	254.33 ± 39.72^{a}	303.00 ± 6.56^{b}	$281.00 \pm 11.14^{a,b}$	$265.67 \pm 5.51^{a,b}$
MCV(fL)	95.39 ± 2.50	95.02 ± 1.46	94.21 ± 0.68	93.39 ± 1.16
MCH (pg/cell)	36.33 ± 1.43	37.06 ± 1.31	36.30 ± 0.15	36.10 ± 1.37
MCHC (g/L)	3.83 ± 0.09	3.90 ± 0.10	3.85 ± 0.03	3.86 ± 0.14
Neutrophil (%)	53.33 ± 4.93	53.67 ± 3.22	54.67 ± 1.53	55.33 ± 2.08
Lymphocytes (%)	39.33 ± 4.73	39.33 ± 4.04	37.67 ± 2.08	37.33 ± 2.31
Monocytes (%)	4.67 ± 0.58	4.00 ± 0.00	4.67 ± 0.58	4.00 ± 0.00
Eosinophils (%)	2.67 ± 0.58	3.00 ± 1.00	3.00 ± 0.00	3.33 ± 0.58
Basophils (%)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table 7.
Hematological indices at 6 weeks of age for broiler chickens fed varying dietary levels of activated charcoal.

Parameters	T 1	T2	T3	T 4
Total protein (g/dl)	2.45 ± 0.15^{a}	3.03 ± 0.34^{c}	2.56 ± 0.22^{ab}	2.97 ± 0.13^{bc}
Albumin (g/dl)	1.36 ± 0.04^{a}	1.52 ± 0.05^{b}	1.28 ± 0.02^{a}	1.55 ± 0.14^{b}
Globulin (g/dl)	1.09 ± 0.15	1.44 ± 0.27	1.28 ± 0.20	1.42 ± 0.17
AST (m/l)	36.00 ± 6.00	40.00 ± 2.65	39.33 ± 5.13	33.33 ± 2.89
ALT (m/l)	23.33 ± 2.31^{ab}	27.33 ± 2.52^{b}	23.67 ± 2.31^{ab}	21.67 ± 2.52^{a}
ALP (m/l)	88.67 ± 5.51^{a}	90.00 ± 2.00^{ab}	97.67 ± 3.79^{bc}	99.00 ± 5.29^{c}
Bilirubin (mg/l)	0.45 ± 0.05	0.49 ± 0.05	0.43 ± 0.02	0.48 ± 0.07
Cholesterol (mg/dl)	83.03 ± 2.31^{a}	105.11 ± 1.12^{b}	90.42 ± 2.66^{a}	85.28 ± 6.67^{a}
Urea (mg/dl)	9.37 ± 0.66	9.93 ± 2.33	9.44 ± 0.73	9.03 ± 0.42
Creatinine (mg/dl)	0.88 ± 0.07	0.80 ± 0.08	0.87 ± 0.06	0.79 ± 0.05

Table 8.
Serum biochemical indices at 1 week of age for broiler chicks fed varying dietary levels of activated charcoal.

derived from palm fruit fiber, and poultry litter, respectively. It was also higher than that of Nwankwo [43] who recorded 3.50% as moisture content of AC from cow bone sourced from abattoirs. Kong et al. [42] 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 [44] 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 [45]. It has also been noted that acidic and slightly alkaline activated charcoals exhibited greater adsorption capacity and are

Parameters	T1	T2	T3	T 4
Total protein (g/dl)	3.27 ± 0.24	3.26 ± 0.21	3.18 ± 0.28	3.14 ± 0.13
Albumin (g/dl)	1.90 ± 0.06	2.09 ± 0.17	2.02 ± 0.35	1.90 ± 0.06
Globulin (g/dl)	1.37 ± 0.27	1.17 ± 0.06	1.16 ± 0.10	1.23 ± 0.08
AST (m/l)	36.33 ± 3.21	38.67 ± 5.13	38.67 ± 2.08	35.33 ± 5.03
ALT (m/l)	30.67 ± 1.15	28.00 ± 3.00	25.33 ± 2.52	26.00 ± 6.25
ALP (m/l)	91.07 ± 5.00	91.60 ± 4.44	92.80 ± 3.22	93.13 ± 3.07
Bilirubin (mg/l)	0.53 ± 0.06	0.52 ± 0.09	0.57 ± 0.04	0.46 ± 0.15
Cholesterol (mg/dl)	103.37 ± 3.84^{c}	$96.27 \pm 0.71^{b,c}$	$92.03 \pm 2.37^{a,b}$	84.43 ± 9.04^{a}
Urea (mg/dl)	12.20 ± 1.87	14.80 ± 0.53	14.60 ± 2.23	13.33 ± 1.59
Creatinine (mg/dl)	0.79 ± 0.08	0.79 ± 0.09	0.87 ± 0.15	0.87 ± 0.17

Table 9.
Serum biochemical indices at 4 weeks of age for broiler chicks fed varying dietary levels of activated charcoal.

Parameters	T1	T2	T3	T4
Total protein (g/dl)	3.46 ± 0.03^{c}	3.21 ± 0.03^{b}	$3.12 \pm 0.08^{a,b}$	3.06 ± 0.07^{a}
Albumin (g/dl)	2.18 ± 0.08^{c}	1.92 ± 0.04^{b}	1.80 ± 0.01^{a}	1.80 ± 0.04^{a}
Globulin (g/dl)	1.28 ± 0.10	1.29 ± 0.03	1.32 ± 0.08	1.26 ± 0.03
AST (m/l)	40.33 ± 0.58^{b}	$36.67 \pm 2.89^{a,b}$	34.33 ± 2.08^{a}	40.33 ± 1.53^{b}
ALT (m/l)	29.67 ± 1.53	27.33 ± 2.52	27.00 ± 2.65	28.67 ± 1.15
ALP (m/l)	85.67 ± 4.04	89.00 ± 3.61	83.33 ± 3.06	84.67 ± 2.52
Bilirubin (mg/l)	0.56 ± 0.04	0.60 ± 0.03	0.58 ± 0.02	0.57 ± 0.03
Cholesterol (mg/dl)	97.17 ± 0.95^{c}	90.87 ± 1.32^{b}	$86.33 \pm 5.05^{a,b}$	81.50 ± 0.92^{a}
Urea (mg/dl)	9.50 ± 0.28	9.57 ± 0.99	9.17 ± 0.13	9.07 ± 0.21
Creatinine (mg/dl)	0.84 ± 0.02	0.81 ± 0.04	0.83 ± 0.02	0.86 ± 0.06

Table 10.
Serum biochemical indices at 6 weeks of age for broiler chicks fed varying dietary levels of activated charcoal.

more effective adsorbents when compared to those with very high pH values [46]. The pH result obtain from this study was however higher than the 6.1, 6.64, and 6.60 reported by Okoroigwe et al. [11], Evbuoman et al. [47] and Nwankwo [43], respectively, using agricultural residues as precursors for pyrolysis. The observed bulk density of 0.72 g/cm^3 was higher than 0.49 g/cm^3 reported by Evbuoman et al., [47] for PKS derived-activated charcoal. The value of the bulk density is however within the preferred range of 0.06–1.03 g/cm^3 as recommended by Bryne and Nagle [48] 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. [42] for PKS derived activated charcoal. Mollinedo et al. [49] 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 [50, 51]). It will have additional fertilizer value because of its high concentration of important plant macro nutrients such as potassium and phosphorus [52]. The use of rice husk-activated charcoal to fertilize rice fields had been a common practice in Asian countries [52]. The urban encroachments on poultry facilities have resulted in increased complaints from local residents [53, 54], due to bad odor 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 [55]. 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. [56] compared the odor abatement of poultry litter using three odor 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. Specific gravity (SG) otherwise called relative density is the ratio of the density of substances to the density of water [34]. This physical parameter plays a vital role in the transit of digesta through the gastrointestinal (GIT) tract of animals [57]. The value of the specific gravity obtained in this research 0.730 was lower than the 1.61 reported by Evbuoman et al. [47] but higher than the 0.64 reported by Okoroigwe et al. [11] 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 [57, 58]. The specific gravity recorded in this study was far higher than the range of 0.33–0.46 reported by Omede [34] 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 248–253 cm^2/g reported by Lima and Marshal [4] 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 [46]. With these outstanding properties, the activated charcoal derived from this study could be beneficial for gastrointestinal de-contamination when used as feed additive [55, 59–61]. It has also been reported that low-cost materials such as palm kernel shell, palm fruit fiber, 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 [62, 63]. Therefore, the AC produced in this study could be suitable for use in water remediation in cases of oil spillage in oil producing communities [60]. 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 [5, 64]. 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 [61]. Studies by [65, 66]) 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 [59].

The value of the carbon content was 79.43% which is higher than the 65.4% reported by [42]). 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 and Asnah [67] but lower than the 85.0, and 88.4% reported by Hidayu and Musa [68], and Okoroigwe et al. [11], respectively, using palm kernel shell and oil palm fiber as precursor materials. Lima and Marshal [4] 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. [69] 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 [70]. 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% [71]. 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 [72]. This could be the reason why different agricultural residues exhibit different physicochemical characteristics even with the same method of treatment or activation. Martinez et al. [73] 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 (6185.11 mg/kg), phosphorus (18,603.29 mg/kg), sodium (1722.47 mg/kg), potassium (10,275.48 mg/kg), magnesium (3980.14 mg/kg), manganese (721.00 mg/kg), iron (996.35 mg/kg), zinc (95.47 mg/kg), copper (33.69 mg/kg), arsenic (13.38 mg/kg), and nitrogen (3008.04 mg/kg). These mineral concentrations were much higher than the values reported by Okoroigwe et al. [11] and that of Gunamartha and Widana [30] 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 [74–76]. 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 [77, 78]. The high concentration of potassium in the activated charcoal produced in this experiment could be attributed to the inclusion of palm fruit fiber as one of the precursors. Activated charcoal rich in potassium could serve as fertilizers to enrich soils for enhanced crop yield [79]. The heavy metals, for example, arsenic and the micro mineral (zinc) were within the allowable threshold for these elements in activated charcoals namely lead <150 mg/kg, copper <30 mg/kg, zinc <400 mg/kg, and arsenic <30 mg/kg [70].

4.2 Study 2

The feed intakes of broilers as seen in **Table 3** were higher in the control when compared with the supplemented groups except in week 5 and in week 3 where that of the control did not vary significantly with group 2 probably because of its lowest inclusion rate. This trend of reduction in feed intake in the supplemented groups (T2–T4) was in agreement with the report of Kutlu et al. [80] who observed that

activated charcoal reduced feed intake which was attributed to higher bulk density of activated charcoal supplemented feeds [81]. More so, the blackening of feeds by charcoal might cause reduction in palatability [81, 82] which could be responsible for the significant reduction in feed intakes for the supplemented broiler groups. The implication is that feedstuffs with high bulk density exhibit high water-holding capacity and absorb excess water in the gastrointestinal tract (GIT) capable of triggering satiety resulting to low feed intakes [34]. Satiety signal such as cholecystokinin (CCK) provides information about feed intake to the brain which thereby suppress appetite [83–86]. As for the control group, there was a decreased expression of the satiety receptor (CCKR) that was responsible for the increased feed intakes [87]. These reductions in feed intake in the supplemented groups is expected in view of the fact that activated charcoal is a prebiotic which improve the nutrient status of animal by enabling more and efficient use of the nutrient present in the diet and not by stimulating appetite [88]. The non-significant variation in feed intake between broilers in group 1 and group 2 at 3 weeks of age may be attributed to the lowest inclusion of activated charcoal (0.5 kg/100 kg of feed) in diet of broilers in group T2 which may not have adversely affected feed intake. More so, the blackening of the feeds by charcoal at this lowest inclusion was also not too noticeable.

According to the results in **Table 3**, the live weight of broilers in the supplemented groups (T2–T4) was significantly higher than the control group (T1) at 6 weeks of age with the exception of group 4 that did not vary significantly with group 1. This non-significant variation between the live weights of broilers in groups T1 and T4 can be attributed to the highest inclusion level of activated charcoal in the diet of broilers in group 4 which was 1.5 kg/100 kg of feed which maximally reduced feed intake. The increment in the live weights and weight gains in group T2 and T3 as shown in **Table 3** and the FCR that favored the supplemented groups were in agreement with the findings of Dim et al. [26] who reported that the final body weight, average daily weights and FCR favored birds placed on diet supplemented with activated charcoal than the control after 56 days trial period. The results were also in conformity with the report of Jiya et al. [24] whose results showed improved performance on inclusion of activated charcoal in broiler diets. The effect on live weights and weight gains were significantly better in group 3 with 10% charcoal inclusion than in group T2 and T4. These results were exactly similar with the findings of Durunna et al. [25] who recommended 1.0 kg/100 kg of the feed as the best inclusion level for broilers as against 0.6 kg/100 kg of feed by Dim et al. [26]. The live weights of broilers in group T4 were comparable to those in group T1 probably due to the high bulk density and the blackening of the broiler diets of G4 at 1.5 kg/100 kg inclusion that resulted to the lower feed intakes [80–82]. According to the results in **Table 3**, the feed conversion ratio (FCR) were better in group T3 than other groups especially at week 4 where it showed significant difference. The improvement in the feed conversion efficiency in the supplemented groups especially in group T3 could be attributed to the ability of the birds fed AC to maximally utilize the vitamin-mineral premix especially iron and B-complex vitamins in the diet probably due to the binding of AC with toxins and anti-nutritional factors in the gut [26].

More so, the higher intestinal length of the supplemented groups as seen in **Table 4** could be responsible for their high performance due to increased area available for adsorption of nutrients coupled with the significant reductions in the pH of their jejunum at 4 and 6 weeks of age. The weight of the gizzard with content and gizzard were significantly higher in group T3 and T2, respectively, at 4th and 6th week in each case which resulted to their increased dressing percentages. The weight

of the proventriculus and heart were significantly higher in groups T2 and T3, respectively, which together with gizzard are the major organs determining performance of birds and the economics of production [89]. Weight of internal organs expressed as percentage of live weight were significantly higher with respect to gizzard and gizzard with content in groups T3 and T4 at 4 weeks of age than group 2 while the gizzard of group T2 and T3 were significantly higher than the control at 6 weeks of age as shown in **Table 4** as against the gizzard of the control group that was relatively higher at first week of age. More so, the weight of the heart expressed as percentage of live weight was significantly greater in the supplemented groups than the control group T1. These significant variations in weights are expected as the gut (gizzard) and heart are the major organs determining performance of birds and the economics of production [89]. The significant differences noticed in the weights of the heart in relation to live weight of the supplemented group can be attributed to the lowering effect of AC on serum cholesterol levels which may be responsible for the increased activity and weights of the heart. Activated charcoal interferes with the entero-hepatic circulation of bile acid and cholesterol, thereby lowering serum cholesterol in cases of hypercholesterolemia [90, 91]. In a related development, Shabani et al. [92] and Dim et al. [26] reported that plasma cholesterol levels were reduced in birds whose diets were supplemented with activated charcoal.

According to **Table 4**, there were no significant difference in the liver and proventricular weights relative to live weight between the broilers in the supplemented group and the control except at 6th week where the relative weights of the proventriculus to live weight was significantly higher in T2 than other groups. This was in agreement with the findings of Majewska and Zaborowski [93] that liver weights did not show any significant variations between the groups whose diets were supplemented with AC and control. There were no significant difference in the weights of the gizzard + contents relative to live weight between the groups at first and 6 weeks of age except at 4 weeks of age when groups T3 and T4 were significantly higher than group T1 and group T2. At 4 weeks of age, the relative weight of the gizzard to live weight was significantly higher in group 3 than other groups and at 6 weeks of age by group T3 and group T2. This higher relative weight of the gizzards to live weights in group T3 in the 4th and 6th week could be responsible for its higher performance since weight is an index of growth and performance.

At 1 week of age, hematological values (RBC, PCV, HbC, and WBC) were significantly higher in the supplemented treatment groups (T2 and T4) than the control (T1). These results were in conformity with the report of Dim et al. [26] who reported that AC inclusion in broiler feeds improved significantly the hematological indices such as hemoglobin concentration (Hb) and red blood cells counts (RBC). This trend was not the case at 4 and 6 weeks of age where T1 recorded RBC, PCV, and Hb that were significantly higher than T4. At 1 week of age, the broilers in the supplemented treatment groups (T2–T4) had better hematological picture than the control but with the continuous supplementation of activated charcoal till 6th week, it turned in favor of T1 followed by T3 signifying a negative correlation.

In accordance with Jindal et al. [82] and Evans et al. [81], the inclusion of AC in poultry feeds increased the bulk density and caused blackening of the feeds which caused some degree of unpalatability responsible for low feed intakes and subsequent reduction RBC counts, PCV and Hb especially in T4 with the highest inclusion level of AC as witnessed in the 4th and 6th week of age. The hematological components which consist of PCV, RBC, Hb, MCV, MCH and MCHC all fell within the normal range for broilers as reported by previous researchers with MCV, MCH and MCHC showing no

significant differences between the supplemented treatment groups (T2–T4) and the control (T1) as shown in **Tables 1** and **3**. Iyaode et al. [94] reported normal hematological range for broilers as 25.60–32.50% for PCV, 8.93–10.45 g/dl for Hb and 3.53–3.80 x 10^6/μL for RBC count in broilers. Marcos et al. [95] reported broiler hematological references range to be 22–35% for PCV, 2.5–3.5 x 10^6 / μL for RBC, 7–13 g/dl for Hb and 12–30 × 10^3/μL for WBC. Hidayat et al. [96] recorded normal range for Hb in broilers as 6.65–7.4 g/dl while Salam et al. [97] and Sugiharto et al. [98] both reported range of hemoglobin concentration (Hb) in broilers to be between 5.18 and 9.30 g/dl.

The results were in agreement with the report of Dim et al. [26] noted that the hemoglobin concentration (Hb) and the red blood cell (RBC) count were significantly improved, while the cholesterol levels were significantly reduced in broilers whose diets were supplemented with activated charcoal. The authors attributed the ability of the birds fed activated charcoal to maximally utilize the vitamin-mineral premix in the diet especially iron and B-complex vitamins probably due to the binding of activated charcoal with toxins and anti-nutritional factors in the gut of bird. At 4 and 6 weeks of age, there were dose-dependent reductions in the serum cholesterol levels in the supplemented treatment groups (T2–T4) which were significantly lower when compared with T1 as shown in **Tables 8–10**. This was in agreement with the results of previous researchers that confirmed that serum cholesterol levels were reduced in birds whose diets were supplemented with activated charcoal [26, 92].

These reductions in serum cholesterol levels have elucidated the fact that activated charcoal could be useful in the treatment of hypercholesterolemia [90, 91]. This is achieved by its interference on entero-hepatic circulation by binding to cholesterol and cholesterol-containing bile acids in the gut, thus preventing them from being absorbed [99]. When bile acids are excreted, plasma cholesterol is converted to bile acids to normalize bile acids levels which eventually lowers plasma and serum cholesterol levels [90, 91]. It should be recalled that approximately 2/3 of intestinal cholesterol is derived from bile while just about 1/3 comes from diet [91, 99]. Hence the serum cholesterol is determined by the balance of its synthesis, catabolism and intestinal absorption [90]. The most common statin based therapy for hypercholesterolemia acts by inhibiting the HMG-CoA reductase enzyme to reduce cholesterol synthesis while activated charcoals are useful in reducing the intestinal absorption [90, 91]. Therefore, blocking intestinal absorption is a key point in hypercholesterolemia therapy. Activated charcoal used in this study was able to absorb excess of cholesterol in the intestine before it entered the blood circulation as corroborated by the reports of Joseph et al. [99] and Roosdiana et al. [91]. This is in agreement with the findings of Boonanuntansarn [100] that activated charcoal had a significant reduction on the blood cholesterol levels in 4-week old Nile Tilapia.

Ugbogo et al. [101] stated that although cholesterol plays central role in many biochemical processes where it helps to digest fats, strengthen cell membranes and make hormones, it is majorly known for its association with cardiovascular diseases. Hypercholesterolemia is a metabolic disease which is caused by an elevated total cholesterol level in blood circulation. This may result to its build up on arterial walls, hence narrowing the lumen and increasing risk of blood clots, heart attack and stroke often associated with disease like diabetes mellitus, hypertension and some form of thyroid, liver and kidney disease [91, 101]. About 40–70% of the world's population suffers from hypercholesterolemia [102] and it had also been reported in cats and dogs [103]. A long-term treatment of this condition using a synthetic drug known as statin was associated with side effect including joint pains and liver damage [91]. It became

imperative to explore alternative medication derived from natural products such as AC to overcome this problem.

At 1 week of age, the ALP, albumin, and total proteins were significantly higher in broiler groups whose diets were supplemented with activated charcoal (T2–T4). This was unlike at 6 weeks of age where the total protein and albumin level were significantly higher in T1 than in T2, T3 and T4 with its AST significantly higher than T3. According to Ugboho et al. [101], total protein and ALP levels present in the blood can be used to evaluate unexplained weight loss and symptoms of liver damage. The ALP, albumin and total protein were significantly higher in the supplemented treatment groups but the trend was not maintained at 6 weeks of age. The significant increase in the albumin and total protein levels in the control (T1) at 6 weeks of age when compared to the supplemented treatment groups (T2–T4) can be due to the metabolic demand from the liver resulting from the high feed intake [94]. Most of the biochemical parameters were within the patterns often found in avian species as reported by Marcos et al. [95]. The total proteins recorded in this study were in the range of 2.5–4.5 g/dl as cited by Thrall [104] while the ALT were in range of 19–50 μ/L as reported by Lumeji [105]. Globulin also was within the normal range for Gallus gallus specie (0.5–1.8 g/dl) as reported by Thrall [104].

5. Conclusion and recommendation

The study showed that the activated charcoal produced using these agricultural residues (pig dung, palm fruit fiber, and PKS) was of high physicochemical properties within the range of most activated charcoals produced for gastrointestinal decontamination, water treatment and environmental remediation. Its inclusion in broiler feed improved performance and carcass yield and could serve as alternative feed additive in view of the ban placed on sub-therapeutic inclusion of antibiotics for growth promotion due to antimicrobial resistance. The hematological and biochemical parameters examined were within the patterns often found in avian species signifying that activated charcoal is non-toxic and safe to be used in oral administration at best inclusion level of 1 kg/100 kg of feed. Therefore, the agricultural waste-derived activated charcoal used in this study is suitable for improvement of hematological parameters in young chicks and in cases of hypercholesterolemia to bind cholesterol and cholesterol-containing bile acids in the gut. It could also serve as a replacement for the synthetic drug used for this condition which is currently very expensive coupled with their long standing side effects which have generated a lot of complaints from patients.

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Conflict of interest

The authors wish to declare that there is no conflict of interest whatsoever in this chapter contribution.

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