



Effects of Dietary Supplementation with Different Crop-Residue Biochars on Growth Performance, Carcass Characteristics and Internal Organ Proportions of Broiler Chickens

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Abstract

The increasing cost of conventional feed ingredients and the need for sustainable utilisation of agricultural residues have stimulated interest in alternative feed additives for poultry production. This study evaluated the effects of dietary supplementation with biochars produced from African breadfruit husk, soybean husk, Bambara nut husk and melon seed husk on growth performance, carcass characteristics and internal organ proportions of broiler chickens. A total of 150 day-old broiler chicks were randomly allocated to five dietary treatments in a completely randomised design, with three replicates of 10 birds per treatment. The control group received a basal diet without biochar, whereas the four experimental groups received the basal diet supplemented with 0.4% biochar derived from African breadfruit husk (ABHB), soybean husk (SBHB), Bambara nut husk (BNHB) or melon seed husk (MSHB), respectively. The feeding trial lasted eight weeks and was divided into starter and finisher phases. Body weight, body weight gain, average daily feed intake and feed conversion ratio were determined during each phase. At the end of the trial, carcass characteristics and relative weights of selected internal organs were evaluated. Treatment significantly affected initial and final body weight at some stages, whereas body weight gain, feed intake and feed conversion ratio were generally unaffected. At the finisher phase, birds fed the soybean husk biochar diet had the highest final body weight (2438.83 g), while birds receiving MSHB recorded the highest body weight gain (1011.90 g). Carcass weight differed among treatments, with MSHB producing the highest value (2342.66 g), while breast yield was highest in birds fed BNHB (30.43%). Abdominal fat was significantly higher in birds fed BNHB and MSHB than in the control group. Most internal organ proportions were not significantly affected by dietary treatment; however, relative spleen weight differed significantly, with the highest value recorded in MSHB-fed birds. Overall, dietary supplementation with 0.4% crop-residue biochars did not adversely affect growth performance or most carcass and organ characteristics. The findings indicate that low-level inclusion of crop-residue biochars may be feasible in broiler diets, although source-specific responses warrant further investigation. Future studies should characterise the physicochemical properties and contaminant profiles of the biochars and establish dose-response relationships before wider commercial application.

Keywords: biochar; crop residues; broiler chickens; growth performance; carcass characteristics; internal organs; sustainable feed additives.

Introduction

The poultry industry is an important contributor to global food and animal-protein supply because broiler chickens have a relatively short production cycle and high efficiency of converting feed nutrients into edible biomass. However, the sustainability and profitability of intensive broiler production

are increasingly constrained by high feed costs, dependence on conventional feed ingredients and the environmental consequences associated with agricultural production. Maize and soybean meal remain major components of poultry diets, and their production competes for land, water and other resources while also being subject to substantial price fluctuations.

The search for locally available and sustainable feed resources has therefore become increasingly important, particularly in developing countries. Agricultural production generates substantial quantities of crop residues, many of which are discarded, openly burned or otherwise poorly utilised. Their conversion into value-added products offers an opportunity to reduce waste while contributing to circular agricultural production systems.

Direct incorporation of many crop residues into poultry diets is constrained by their fibre content, variable nutrient composition and the presence of antinutritional factors. Processing technologies that modify the physicochemical characteristics of agricultural residues may improve their potential utilisation. One such technology is pyrolysis, which converts biomass into a carbon-rich material known as biochar.

Biochar is a porous carbonaceous material produced by thermochemical conversion of biomass under oxygen-limited conditions. Its physicochemical properties depend strongly on the original feedstock and pyrolysis conditions. Biochar has attracted increasing interest in poultry production because of its adsorption capacity, porous structure and potential effects on gastrointestinal conditions, nutrient utilisation, microbial populations and excreta management. A recent review specifically identified feedstock characteristics, production methods and inclusion levels as important determinants of the biological effects of biochar in poultry systems. (Onunkwo et al. (2021))

Evidence from recent broiler studies suggests that dietary biochar can influence production and physiological responses, but the effects are not necessarily consistent across biochar sources and inclusion levels. Emam et al. (2026), for example, reported improvements in growth performance and feed efficiency with 1.5–3.0% dietary biochar and observed changes in blood biochemical parameters and carcass characteristics. Similarly, Pervaiz et al. (2025) reported that 1% biochars produced from corn cob, wheat straw and sugarcane bagasse improved selected growth, bone, footpad and immune-related responses in broilers, demonstrating the importance of biochar source in determining biological responses.

Nigerian evidence is also emerging. Enyenihi et al. (2023) found that dietary coconut-shell charcoal produced relatively few changes in serum biochemical and haematological indices, although higher charcoal inclusion was associated with changes in intestinal microbial counts. In another Nigerian study, Onunkwo et al. (2021) evaluated graded dietary biochar inclusion in broilers over 56 days and reported effects on growth and haematological indices, further supporting the need to investigate biochar as a potential poultry-feed additive.

Despite these developments, limited information is available on the comparative feeding value of biochars produced specifically from African breadfruit husk, soybean husk, Bambara nut husk and melon seed husk. These materials are

locally available agricultural residues in southeastern Nigeria and could potentially be valorised through pyrolysis.

The present study therefore evaluated the effects of dietary supplementation with 0.4% biochars derived from these four crop residues on growth performance, carcass characteristics and internal organ proportions of broiler chickens. The hypothesis was that inclusion of these biochars at a low dietary concentration would not adversely affect broiler growth, carcass development or visceral organ characteristics.

Materials and Methods

Experimental location

The experiment was conducted at the Poultry Unit of the Teaching and Research Farm, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. The location lies within the humid rainforest agro-ecological zone of southeastern Nigeria and is characterised by a warm and humid tropical climate.

The poultry house was naturally ventilated and adequately illuminated. Concrete-floored pens were cleaned and disinfected before placement of the experimental birds, and wood shavings were used as litter material.

Collection and processing of crop residues

African breadfruit husk, soybean husk, Bambara nut husk and melon seed husk were obtained from Ngoro Market, Ikwo Local Government Area, Abia State, Nigeria. The residues were manually cleaned to remove extraneous materials and sun-dried before pyrolysis.

Production of biochars

The dried crop residues were converted into biochars using a simple drum-pyrolysis procedure. Each residue was loaded separately into a metallic drum and heated externally under oxygen-limited conditions. After carbonisation, the resulting material was quenched with water, sun-dried, milled into a fine powder and stored in airtight containers until incorporation into the experimental diets.

The four biochars were designated as follows:

- i. **ABHB:** African breadfruit husk biochar;
- ii. **SBHB:** soybean husk biochar;
- iii. **BNHB:** Bambara nut husk biochar; and
- iv. **MSHB:** melon seed husk biochar.

Experimental diets

The experimental diets were formulated to meet the nutrient requirements of broiler chickens. The starter diets contained approximately 2,883.75 kcal/kg metabolizable energy and 23.03% crude protein, while the finisher diets contained approximately 3,023.98 kcal/kg metabolizable energy and 20.48% crude protein.

Because all diets were formulated with the same basal ingredients and the biochars were incorporated at 0.4%, the principal experimental factor was biochar source.

Table 1. Experimental treatment structure

Treatment	Dietary treatment	Biochar inclusion
T1	Basal diet/control without biochar	0%
T2	African breadfruit husk biochar	0.4%
T3	Soybean husk biochar	0.4%
T4	Bambara nut husk biochar	0.4%
T5	Melon seed husk biochar	0.4%

Table 2. Broiler Starter Experimental Diets

Ingredient (%)	T1 Control	T2 ABH Biochar	T3 SBH Biochar	T4 BNH Biochar	T5 MSH Biochar
Maize	50.00	50.00	50.00	50.00	50.00
Soybean meal	28.00	28.00	28.00	28.00	28.00
Wheat bran	8.00	8.00	7.00	7.00	7.00
Fish meal	3.00	3.00	3.00	3.00	3.00
Bone meal	3.00	2.60	2.60	2.60	2.60
Palm oil	2.50	2.50	2.50	2.50	2.50
Limestone	1.60	1.60	1.60	1.60	1.60
Blood meal	1.50	1.50	1.50	1.50	1.50
Brewer's dried grain	1.50	1.50	1.50	1.50	1.50
Biochar	—	0.40 ABH	0.40 SBH	0.40 BNH	0.40 MSH
Salt	0.30	0.30	0.30	0.30	0.30
Vitamin-mineral premix	0.25	0.25	0.25	0.25	0.25
DL-Methionine	0.20	0.20	0.20	0.20	0.20
Lysine	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100

Table 3. Broiler Finisher Experimental Diets

Ingredient (%)	T1 Control	T2 ABH Biochar	T3 SBH Biochar	T4 BNH Biochar	T5 MSH Biochar
Maize	55.00	55.00	55.00	55.00	55.00
Soybean meal	23.00	23.00	23.00	23.00	23.00
Wheat bran	8.00	8.00	8.00	8.00	8.00
Fish meal	2.50	2.50	2.50	2.50	2.50
Bone meal	3.00	2.60	2.60	2.60	2.60
Palm oil	3.00	3.00	3.00	3.00	3.00
Limestone	1.50	1.50	1.50	1.50	1.50
Blood meal	1.60	2.00	2.00	2.00	2.00
Brewer's dried grain	1.50	1.50	1.50	1.50	1.50
Biochar	—	0.40 ABH	0.40 SBH	0.40 BNH	0.40 MSH

Ingredient (%)	T1 Control	T2 ABH Biochar	T3 SBH Biochar	T4 BNH Biochar	T5 MSH Biochar
Salt	0.30	0.30	0.30	0.30	0.30
Vitamin-mineral premix	0.25	0.25	0.25	0.25	0.25
DL-Methionine	0.20	0.20	0.20	0.20	0.20
Lysine	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100

Experimental birds and management

A total of 150 day-old broiler chicks obtained from a commercial hatchery were randomly assigned to five dietary treatments. Each treatment comprised three replicate pens containing 10 birds each.

The birds were reared on deep litter and brooded during the early stage of production. Feed and drinking water were provided ad libitum throughout the eight-week experimental period. Routine vaccination and health-management practices were implemented according to the farm's standard programme. Birds were monitored daily for signs of disease and mortality.

Experimental design

The experiment followed a completely randomised design consisting of five dietary treatments and three replicates per treatment.

The statistical model was:

$$Y_{ij} = \mu + T_i + \epsilon_{ij} \quad \{ij\} = \mu + T_i + \epsilon_{ij}$$

Growth performance measurements

Individual body weights were recorded at the beginning of the experiment and subsequently at weekly intervals. The following parameters were determined:

Body weight gain (BWG):

$$BWG = \frac{\text{Final body weight} - \text{Initial body weight}}{\text{body weight} - \text{Initial body weight}}$$

Feed intake: calculated from feed offered minus feed refused and expressed on a per-bird basis.

Feed conversion ratio (FCR):

$$FCR = \frac{\text{Feed intake}}{\text{Body weight gain}}$$

Mortality was recorded daily and expressed as a percentage of the initial number of birds.

Carcass evaluation

At the end of the eight-week feeding trial, birds were selected for carcass evaluation. The birds were fasted for approximately 12 h with access to water before slaughter. They were weighed before slaughter and subsequently bled, scalded, defeathered and eviscerated.

Measurements included live weight, carcass weight and dressed weight. Breast, thigh, drumstick, wing, shank, neck, head and back were weighed and expressed as proportions of the appropriate carcass weight.

Internal organ measurements

The liver, heart, gizzard, spleen, intestine, proventriculus and gall bladder were excised, cleaned and weighed. Relative organ weights were expressed as a percentage of live body weight.

Statistical analysis

Data were analysed using one-way analysis of variance appropriate for the completely randomised design. Treatment means were separated using Duncan's multiple range test at $P < 0.05$. Results are presented as means with the standard error of the mean (SEM).

Results

Growth performance during the starter phase

The effects of dietary crop-residue biochars on starter-phase performance are presented in Table 1.

Table 1. Growth performance of broiler chickens fed diets supplemented with different crop-residue biochars during the starter phase

Parameter	T1 Control	T2 ABHB	T3 SBHB	T4 BNHB	T5 MSHB	SEM
Initial body weight (g)	43.46 ^a	43.12 ^a	40.30 ^b	40.83 ^b	40.76 ^b	0.42
Final body weight (g)	959.03	1013.73	966.63	991.96	937.93	12.12
Body weight gain (g)	915.56	970.60	926.50	951.13	897.16	12.09
Average daily feed intake (g/bird/day)	497.33	502.64	506.48	499.96	499.77	10.38
FCR	0.54	0.51	0.54	0.52	0.55	0.007

Means within a row with different superscripts differ significantly at $P < 0.05$. SEM = standard error of the mean; ABHB = African breadfruit husk biochar; SBHB = soybean

husk biochar; BNHB = Bambara nut husk biochar; MSHB = melon seed husk biochar.

Initial body weight differed among treatments, whereas final body weight, body weight gain, average daily feed intake and FCR did not show statistically significant treatment effects according to the numerical results supplied. Numerically,

birds fed ABHB had the highest final body weight and body weight gain, whereas MSHB produced the lowest values. Feed intake varied only modestly among treatments.

Growth performance during the finisher phase

Table 2. Growth performance of broiler chickens fed diets supplemented with different crop-residue biochars during the finisher phase

Parameter	T1 Control	T2 ABHB	T3 SBHB	T4 BNHB	T5 MSHB	SEM
Initial body weight (g)	1324.30 ^b	1411.00 ^{ab}	1487.73 ^a	1399.06 ^{ab}	1418.26 ^{ab}	19.55
Final body weight (g)	2216.73 ^b	2421.86 ^a	2438.83 ^a	2288.46 ^{ab}	2430.16 ^a	32.57
Body weight gain (g)	892.43	1010.86	951.10	889.40	1011.90	26.95
Average daily feed intake (g/bird/day)	1347.07	1368.75	1368.04	1367.26	1365.07	4.28
FCR	1.34	1.54	1.43	1.54	1.37	0.04

At the finisher phase, initial and final body weights differed among treatments, whereas body weight gain, feed intake and FCR were not significantly affected. Birds receiving SBHB had the highest final body weight (2438.83 g), statistically comparable with T2 and T5. MSHB produced the highest numerical body weight gain (1011.90 g), closely followed by ABHB (1010.86 g).

The absence of significant treatment effects on feed intake and FCR suggests that the low biochar inclusion level did not substantially alter voluntary feed consumption or overall feed conversion during the finisher phase.

Carcass characteristics

Table 3. Carcass characteristics of broiler chickens fed diets supplemented with different crop-residue biochars

Parameter	T1 Control	T2 ABHB	T3 SBHB	T4 BNHB	T5 MSHB	SEM
Live weight (g)	2325.00	2460.16	2332.00	2364.50	2420.50	27.49
Carcass weight (g)	2164.50 ^{ab}	2334.33 ^{ab}	2136.00 ^b	2206.50 ^{ab}	2342.66 ^a	31.44
Dressed weight (g)	2120.00	2259.83	2135.00	2099.50	2291.50	30.63
Breast (%)	26.95 ^{ab}	27.43 ^{ab}	29.40 ^{ab}	30.43 ^a	25.44 ^b	0.68
Drumstick (%)	12.29	12.72	12.13	12.53	12.72	0.17
Thigh (%)	12.19	12.03	12.80	12.16	12.05	0.13
Shank (%)	4.62	4.41	4.67	4.69	4.58	0.19
Neck (%)	4.93	4.22	4.42	4.27	4.88	0.12
Wing (%)	9.19	10.28	9.41	9.60	9.53	0.48
Head (%)	2.81	2.83	2.73	2.58	2.69	0.07
Back (%)	15.97	16.05	15.57	14.98	15.90	0.18
Abdominal fat (%)	0.25 ^b	0.29 ^{ab}	0.30 ^{ab}	0.42 ^a	0.41 ^a	0.02

Carcass weight differed significantly among treatments, with MSHB producing the highest value (2342.66 g) and SBHB the lowest (2136.00 g). Breast yield was highest in BNHB-fed birds (30.43%) and lowest in MSHB-fed birds (25.44%). The proportions of drumstick, thigh, shank, neck, wing, head and back did not differ significantly among treatments.

Abdominal fat was significantly affected by treatment, with the highest values observed in BNHB- and MSHB-fed birds, while the control had the lowest value.

The data therefore indicate that biochar supplementation produced selective rather than uniform effects on carcass traits.

Internal organ characteristics

Table 4. Relative internal organ weights of broiler chickens fed diets supplemented with different crop-residue biochars

Parameter (%)	T1 Control	T2 ABHB	T3 SBHB	T4 BNHB	T5 MSHB	SEM
Gizzard	1.98	2.03	2.12	2.02	2.12	0.04
Liver	2.31	1.91	1.90	1.98	2.27	0.10
Spleen	0.19 ^{bc}	0.13 ^c	0.25 ^{abc}	0.34 ^{ab}	0.36 ^a	0.02
Intestine	3.59	2.63	2.95	2.99	3.33	0.15
Proventriculus	0.46	0.50	0.63	0.47	0.47	0.33
Gall bladder	0.25	0.21	0.31	0.28	0.30	0.02
Heart	0.48	0.54	0.51	0.48	0.54	0.01

Most relative organ weights were not significantly affected by dietary treatment. The exception was spleen weight, which differed significantly among treatments. MSHB produced the highest relative spleen weight (0.36%), whereas ABHB produced the lowest value (0.13%).

The absence of significant differences in liver, gizzard, heart, intestine, proventriculus and gall bladder weights provides no evidence from these gross anatomical measures of a major adverse effect of 0.4% dietary biochar supplementation.

However, the difference in spleen weight should not automatically be interpreted as improved immunity because no antibody titres, lymphocyte functional assays, cytokine measurements or other direct immune-response indicators were determined.

Discussion

Growth performance

The present study demonstrated that low-level supplementation with biochars produced from four different crop residues generally did not adversely affect broiler growth performance. Although some differences in initial and final body weights were observed, body weight gain, feed intake and FCR were largely comparable among treatments.

The lack of a pronounced response may partly reflect the relatively low inclusion level of 0.4% used in the present study. Recent studies have used substantially higher inclusion rates. Emam et al. (2026), for example, evaluated 1.5 and 3.0% dietary biochar and reported improvements in growth and feed efficiency. Pervaiz et al. (2025) similarly reported positive effects at 1% inclusion of biochars derived from different agricultural residues. These findings indicate that biochar responses may be dose-dependent.

The absence of adverse performance responses at 0.4% is nevertheless important from a feed-safety perspective. The result suggests that inclusion at this low level did not impose a sufficiently large nutritional penalty to compromise growth.

The numerical superiority of some treatments should, however, be interpreted cautiously. For example, ABHB produced the highest numerical starter-phase body weight gain, while MSHB produced the highest numerical finisher-phase gain. Because these differences were not statistically

significant for BWG, they should not be described as demonstrable growth-promoting effects.

The findings are broadly consistent with the Nigerian study of Onunkwo et al. (2021), in which dietary biochar was evaluated in broilers over a 56-day period. They are also consistent with the broader literature indicating that biochar responses depend on source, processing characteristics and inclusion level. Al-Khalaifah and Al-Nasser (2023) emphasised this variability in their review of biochar applications in poultry production.

Carcass characteristics

Dietary treatment significantly influenced carcass weight, breast yield and abdominal fat, whereas most other carcass components were unaffected.

The highest carcass weight was recorded in birds receiving MSHB, whereas the highest breast yield occurred in BNHB-fed birds. These responses suggest that the source of biochar may influence selected aspects of carcass deposition, although the mechanism cannot be established from the present data.

Importantly, the higher carcass weight in MSHB-fed birds cannot simply be attributed to improved feed utilisation because the MSHB treatment did not have a statistically superior FCR. Likewise, the higher breast yield in BNHB-fed birds should not be interpreted as evidence of enhanced protein deposition without supporting measurements such as nitrogen retention, carcass protein content or tissue composition.

Recent evidence supports the possibility of biochar-associated changes in carcass characteristics. Emam et al. (2026) reported significant effects of dietary biochar on selected carcass traits in broilers. Pervaiz et al. (2025) also reported effects of different biochars on broiler production-related traits, although responses differed according to biochar source.

The increase in abdominal fat observed particularly with BNHB and MSHB warrants further investigation. Because dietary treatments were formulated to be broadly similar in nutrient concentration, this response may reflect source-specific effects of the biochars or small differences in their mineral and physicochemical characteristics. However,

mechanistic conclusions cannot be drawn from the present experiment.

Internal organ characteristics

Most relative internal organ weights were not significantly affected by dietary biochar supplementation. This is an important observation because marked changes in visceral organ size can sometimes indicate altered metabolic activity, nutritional imbalance or physiological stress.

The relative spleen weight was significantly higher in MSHB-fed birds than in the control and ABHB groups. However, increased spleen weight should not automatically be equated with improved immune status. Functional immune measurements were not included in the study.

The absence of significant differences in liver and heart weights is particularly relevant when evaluating the general tolerance of a feed additive. Nevertheless, gross organ weights alone cannot establish the absence of toxicity. Histopathological examination, serum biochemical indices and contaminant analyses would provide stronger evidence of safety.

Interestingly, the recent study by Pervaiz et al. (2025) found that biochar supplementation influenced lymphoid-organ-related traits and immune responses in broilers, indicating that biochar may interact with physiological and immune systems in a source-dependent manner.

Implications for sustainable poultry production

The conversion of agricultural residues into biochar potentially provides a dual benefit: valorisation of otherwise underutilised biomass and development of alternative feed additives. The approach is consistent with circular-economy principles because agricultural residues are transformed into a potentially useful product rather than being discarded or openly burned.

However, the sustainability argument should not be interpreted as evidence that all crop-residue biochars are automatically safe or nutritionally beneficial. Biochar composition depends strongly on feedstock and pyrolysis conditions. Al-Khalaifah and Al-Nasser (2023) highlighted the importance of feedstock and processing characteristics in determining the properties and applications of poultry biochar.

Consequently, future research should evaluate biochar physicochemical characteristics, mineral composition, heavy metals, polycyclic aromatic hydrocarbons and other potential contaminants before recommending routine inclusion in commercial poultry diets.

Conclusion

Dietary supplementation with 0.4% biochars produced from African breadfruit husk, soybean husk, Bambara nut husk and melon seed husk did not adversely affect the general growth performance of broiler chickens. Although treatment effects were observed for selected body-weight and carcass variables, body weight gain, feed intake and feed conversion ratio were generally comparable among treatments.

Carcass weight, breast yield and abdominal fat were influenced by biochar source, whereas most other carcass components were unaffected. Similarly, most internal organ proportions remained comparable among treatments, although relative spleen weight differed significantly.

Overall, the results indicate that 0.4% inclusion of the evaluated crop-residue biochars was tolerated by broiler chickens under the conditions of this experiment. However, the results do not establish that any of the biochars improved nutrient utilisation, immunity or overall health. Further studies involving dose-response evaluation, digestibility, nutrient retention, gut microbiota, meat quality, histopathology and comprehensive biochar safety characterisation are warranted before commercial recommendations are made.

Recommendation

Based on the present findings, inclusion of 0.4% crop-residue biochar in broiler diets can be considered a promising experimental approach for valorising locally available agricultural residues. However, routine commercial use should be preceded by chemical and toxicological characterisation of each biochar and validation under larger-scale production conditions.

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