Onionskin waste versus synthetic additives in broiler diet: influence on production indices, oxidative status, caecal bacteria, immune indices, blood chemistry and meat quality

Kazeem D. Adeyemi a, Ayishat I. Oseni a and Tobechukwu N. Asogwa b

aFaculty of Agriculture, Department of Animal Production, University of Ilorin, Ilorin, Nigeria; bCentral Research Laboratory and Diagnostics, Ilorin, Nigeria

ABSTRACT

This study evaluated the influence of dietary supplementation of onionskin waste (OW) and synthetic additives on growth, oxidative status, blood chemistry, caecal bacteria, immune indices and meat quality in broilers. One day old Ross 308 chicks (n = 280) were randomly allotted to basal diets containing either no additive, B-1; 0.5 g/kg oxytetracyline + 0.13 g/kg tert-butylhydroxyanisole, B-2; 10 g/kg OW, B-3; or 20 g/kg OW, B-4 for 42 days. Supplemented birds had higher (p < .05) body weight gain (BWG) and carcase weight compared to the B-1 birds. Diets had no effect (p > .05) on feed intake and feed efficiency, hematological indices, organ weight and serum immunoglobulin M. Onionskin supplementation repressed (p < .05) abdominal fat, serum total cholesterol, triglycerides, aspartate aminotransferase, muscle cholesterol and splenic interleukin-1β. The additives up-regulated (p < .05) splenic interleukin-10 and down-regulated tumour necrosis factor-α, and serum immunoglobulin A. Caecal Lactobacillus spp. was higher (p < .05) in B-1 and B-3 birds compared with the B-2 and B-4 birds. Supplemented birds had lower (p < .05) caecal Escherichia coli and Salmonella spp. counts than the B-1 birds. Antioxidant enzymes and total antioxidant capacity of breast muscle, liver and serum were higher (p < .05) in the supplemented birds compared with the B-1 birds. Dietary supplementation with 20 g/kg OW improved BWG and tissue antioxidant status, beneficially altered immune status, and caecal bacteria counts, and reduced abdominal fat, tissue cholesterol, and meat oxidative deterioration in broiler chickens.

HIGHLIGHTS

- Onionskin supplementation improved body and carcase weights and lowered serum and meat cholesterol in broilers.
- Onionskin enhanced tissue antioxidant enzymes and reduced oxidative deterioration in broilers.
- Onionskin supplementation altered caecal bacteria and immune status in broilers.

Introduction

The expanding demand for animal-derived foods is the primary driver for intensive livestock production (Moekti 2020), whose productivity and sustainability are hitherto premised on the usage of antimicrobials (Brown et al. 2017; Zhao et al. 2020). Nonetheless, in recent times, the attractiveness of antimicrobial usage in animal production is waning because the indiscriminate usage of antimicrobials has been implicated in the emergence of antimicrobial resistance, which is a global public health concern (Hofer 2019; Zhao et al. 2020) and the presence of antibiotic residues in the environment (Chen et al. 2019; Vidovic and Vidovic 2020). This situation has precipitated a ban or strict restriction on the usage of antimicrobials in livestock husbandry (FDA 2013; EFSA 2016; ESVAC 2017; NAFDAC 2017). Although antibiotic-free animal husbandry may be a rational strategy for limiting antimicrobial usage, the system is unsustainable due to the high morbidity and mortality and low productivity...
Against this backdrop, a suitable alternative to antimicrobials needs to be explored. The production practices associated with intensive broiler production could expose birds to myriad environmental stressors such as oxidative stress (Akbarian et al. 2016), which if not attenuated, could limit production performance, welfare, and product quality (Altan et al. 2003; Simitzis et al. 2012). Empirical evidence infers that dietary antioxidants could attenuate oxidative stress (Panda and Cherian 2014; Tawfeek et al. 2014; Arain et al. 2018) and oxidative deterioration in muscle-foods (Farahat et al. 2017; Yusuf et al. 2018; Adeyemi 2021). While synthetic antioxidants are effective in curbing oxidative stress (Fylaktakidou et al. 2004) and improving product quality (Olorunsanya et al. 2012; Farahat et al. 2017; Adeyemi 2021), their continuous usage could leave residues in animal products, which could hamper human health (Vandghanooni et al. 2013). The growing consumers’ aversion and strict regulation regarding the use of synthetic antioxidants have propelled the exploration of suitable alternatives (Farahat et al. 2017; Adeyemi 2021).

In recent times, the use of phytogenic additives has received increased attention as a possible alternative to synthetic additives in animal production (Farahat et al. 2017; Alagawany, Abd El-Hack, et al. 2017; Alagawany, Farag, et al. 2017; Abd El-Hack et al. 2019). Nonetheless, research outcomes are highly varied and inconsistent. In light of this, there is a need for additional studies in myriad production systems to give room for tailored decisions and informed choices in the use of phytogenic additives in poultry nutrition.

Onion is one of the most consumed vegetables in the world, with steady growth in production (FAO 2018). Consequently, a large quantity of onion wastes especially onionskin waste (OW) is generated thereby constituting environmental problems if not properly disposed of (González-Sáiz et al. 2008; Benítez et al. 2011). The utilisation of onionskin as livestock feed may be a pragmatic strategy for reducing the ecological impact of OW. Onionskin is rich in myriad phytochemicals especially quercetin, whose antimicrobial (Abdel-Raouf et al. 2011; Liu et al. 2014), immunomodulatory (Hager-Theodorides et al. 2014; Kim et al. 2015), and antioxidant (Liu et al. 2014; Sohaib et al. 2016) properties have been documented. Thus, the objectives of this study were to examine the influence of dietary supplementation of onionskin waste and synthetic additives on growth, immune indices, selected caecal bacteria, blood chemistry, carcass traits, antioxidant status, and meat quality in broiler chickens.

**Materials and methods**

**Source and phytochemical assessment of onionskin**

Red Onionskin waste (OW) was obtained from a local market. The OW was carefully sorted to remove foreign materials, air-dried for 48 h, pulverised, and stored in an air-tight container until needed. Quecetin in OW was determined spectrophotometrically as described by Pejic et al. (2004). Kaempferol in OW was determined by a spectrophotometric method described by Telange et al. (2014).

**Diets and bird management**

One-day-old male Ross 308 chicks (n = 280) were obtained from a commercial hatchery in Ibadan, Nigeria. The chicks were weighed and randomly distributed into 28-floor pens (1.50 m² each) consisting of wood shavings spread to a depth of 6 cm. The pens were randomly allotted to basal diets containing either no additive, B-1; 0.5 g/kg oxytetracycline + 0.13 g/kg tert-Butylhydroxyanisole (BHA), B-2; 10 g/kg OW, B-3; or 20 g/kg OW, B-4. Each dietary group had seven replicates with 10 chicks per pen. The basal diets were formulated according to the Ross Aviagen guidelines for starter (1–21 days) and finisher (22–42 days) broilers. Feed was offered as mash (milled to pass through 2 mm-screen for starter diet and 4 mm-screen for finisher diet) and was prepared weekly. Each additive was added to its respective basal diet by mixing with a small quantity of the basal diet prior to pooling with the remaining portion of the basal diet and mixed thoroughly. The proximate composition of the basal diets (Table 1) was determined according to the methods of AOAC (2000). The birds were vaccinated against infectious bursa disease on days 7 and 21, and Newcastle disease on days 14 and 28. For the first 7 days, birds were kept at 34 °C. Subsequently, the temperature was reduced by 3 °C per week until it reached 26 °C, which was maintained till the end of the trial. During the first week, 22 h of light was provided. Thereafter, light hours were progressively reduced by 2 h per week until a 18L:6D light program was reached, and was maintained until the end of the experiment. The birds had *ad libitum* access to water and feed throughout the trial.
Growth indices

Feed intake (FI) and body weight (BW) per pen were measured on a weekly basis. Average daily gain (ADG) and feed conversion ratio (FCR) were calculated.

Blood sampling and analysis

On day 40, blood samples were collected via brachial venipuncture into EDTA and plain bottles. Serum was obtained after centrifuging (3000 g, 10 °C, 15 min) the blood samples in the plain bottles. Haematology and serum biochemical indices were assessed as described by Adeyemi et al. (2020).

Serum immunoglobulins

Serum immunoglobulin M (IgM) and immunoglobulin A (IgA) were determined with the aid of double-antibody sandwich enzyme-linked immunosorbent assay (ELISA) kit following the manufacturer’s procedure. Serum IgM was determined with chicken IgM ELISA kit (CUSABIO® Cat # CSB-E11232Ch, CUSABIO Technology, Houston, USA). Serum IgA was determined with chicken IgA ELISA kit (CUSABIO® Cat # CSB-E11232Ch, CUSABIO Technology, Houston, USA).

Slaughter and carcase analysis

On day 42, the birds were deprived of feed but not water overnight. Five birds per pen, whose body weight was close to the mean body weight, were randomly selected and euthanized. Carcases were manually de-feathered and gutted. The weight of abdominal fat, carcase, and different carcase cuts was measured. The dressing percentage and relative weights of prime cuts were calculated.

Splenic cytokine expression

Spleen samples were excised from another set of three birds per pen that were euthanized. The expression of cytokines (interleukins) in the spleen of chickens was assayed using a double-antibody sandwich ELISA kit following the manufacturer’s procedure. Tumour necrosis factor (TNF-α) was determined using chicken TNF-α ELISA kit (Cusabio® Cat # CSB-E11231Ch, Cusabio Technology, Houston, USA). Interleukin 1β (IL-1β) was determined using a chicken IL-1β ELISA kit (Cusabio®, Cat # CSB-E11230Ch, Cusabio Technology, Houston, USA). Interleukin 10 (IL-10) was determined using a chicken IL-10 ELISA kit (Cusabio®, Cat # CSB-E12835C, Cusabio Technology, Houston, USA).

Caecal bacteria

Immediately after slaughter, digesta was obtained from the right and left caeca of three birds per pen that were used for spleen sampling. One gram of digesta sample was introduced aseptically into a test tube containing 9 mL of sterilised peptone water. The mixture was vortexed and dilution was made up to 1010. One mL of the mixture was taken from the test tube and introduced into Petri dishes and a sterile molten agar was introduced. Lactobacilli spp. was cultured on Man Rogosa Sharpe agar (Merck-1.10660.500, Merck KGaA, Darmstadt, Germany) and incubated at 37 °C for 48 h. Salmonella spp. was counted on Salmonella Shigella agar (Merck-107667, Merck KGaA, Darmstadt, Germany) and incubated at 37 °C for 48 h. Escherichia coli was cultured on eosin methylene blue agar (Merck-1.01347.0500, Merck KGaA, Darmstadt, Germany) and incubated at 37 °C for 24 h. The agars were prepared according to the manufacturer’s instructions. Bacterial units were counted with a colony counter (Stuart®; Burlington, VT, USA). Bacterial counts were expressed as log10 colony forming units (CFU) per gram of caecal digesta.

Table 1. Ingredients and chemical composition of basal diets.

| Item                  | Starter | Finisher |
|-----------------------|---------|----------|
| Feed ingredients (g/kg as fed) |         |          |
| Corn                  | 560.00  | 620.00   |
| Soybean meal          | 370.00  | 240.00   |
| Ground nut-cake       | 42.50   | 110.00   |
| Dicalcium phosphate   | 5.00    | 7.50     |
| Oyster shell          | 12.00   | 12.00    |
| Methionine            | 2.50    | 2.50     |
| Lysine                | 3.00    | 3.00     |
| Salt                  | 2.50    | 2.50     |
| Premix*               | 2.50    | 2.50     |
| Analyzed composition, g/kg |     |          |
| Dry matter            | 912.00  | 914.60   |
| Ether extract         | 54.00   | 52.20    |
| Crude protein         | 232.40  | 210.00   |
| Crude fibre           | 36.00   | 44.50    |
| Ash                   | 54.10   | 60.70    |
| Calculated analysis   |         |          |
| Metabolizable energy, kcal/kg | 2922  | 3150     |
| Calcium, %            | 1.05    | 1.34     |
| Available phosphorus, %| 0.52   | 0.75     |
| Methionine, %         | 0.65    | 0.53     |
| Lysine, %             | 1.48    | 1.22     |

*Supplied per kg diet: Retinol 3.45 mg; thiamine 1.43 mg; cholecalciferol 43.8 µg; Niacin 40.17 mg; α-tocopherol 26.8 mg; riboflavin 3.44 mg; pantothenic acid 6.46 mg; pyridoxine 2.29 mg; biotin 0.05 mg; folic acid 0.56 mg; cyanocobalamin 0.05 mg; menadione 2.29 mg; Iron 120 mg; Zinc 120 mg; copper 15 mg; manganese 150 mg; cobalt 0.4 mg; selenium 0.3 mg; iodine 1.5 mg.
**Meat quality analyses**

Breast muscles were excised from five birds per replicate that were used for carcase analysis. The breast muscles were deskin and trimmed free of external fat and epimysium connective tissue and assessed for meat quality analysis.

**Meat pH**

The pH reading was measured on a meat sample with a handheld digital pH metre (MW102 pH metre, MILWAUKEE® instruments, Inc. NC, USA) fitted with pH (MA920B/1) and temperature (MA830R) probes. The pH metre was calibrated before taking readings by dipping the pH probe into buffer solution of pH 7.0 followed by pH 4.0. A 5 g meat sample was homogenised with 25 mL of distilled water using an electric blender. The homogenate was transferred into a beaker and the pH was read. Three pH readings were taken from each sample.

**Colour coordinates**

Breast meat samples were exposed to the air to bloom for 30 min before taking colour readings. A handheld colorimeter (WR-10, Shenzhen, China) was used to measure meat colour coordinates namely, lightness \(L^*\), redness \(a^*\) and yellowness \(b^*\) following the International Commission on Illumination (Commission International De l’ Eclairage 1976) \(L^* a^* b^*\) classification system with the D65 illuminant. Three colour readings were taken at different points of each sample and the average was used for statistical analysis.

**Drip loss**

Breast meat samples were weighed and the weight was designated as initial weight \((Iw)\). The weighed samples were placed in Ziploc bags (Quart, \(7 \times 8 \text{ inch}^2\)), and stored in a refrigerator (Haier Thermocool, HR-170T) at 5 ± 1 °C. After 24 and 72 h post-mortem, the samples were removed from the Ziploc bags, blotted dry and weighed and the weight was designated as final weight \((Fw)\). Drip loss was calculated using the formula below:

\[
\text{Drip loss} \, (\%) = \left( \frac{(Iw - Fw)}{Iw} \right) \times 100
\]

**Cooking loss**

Breast meat samples were weighed and the weight was designated as initial weight \((Iw)\). The samples were placed in Ziploc bags (Quart, \(7 \times 8 \text{ inch}^2\)) and cooked in pre-heated water bath at 80 °C until the internal temperature of the samples reached 78 °C as monitored by a stabbing temperature probe that was inserted into the centre of the meat sample. The cooked meat samples were cooled with running tap water for 10 min, removed from the Ziploc bags, blotted dry without squeezing, and reweighed \((Fw)\). Cooking loss was calculated using the equation below:

\[
\text{Cooking loss} \, (\%) = \left( \frac{(Iw - Fw)}{Iw} \right) \times 100
\]

**Lipid oxidation**

Lipid oxidation in meat was measured by thiobarbituric acid reactive substance (TBARS) assay based on the reaction between thiobarbituric acid (TBA) (Sigma-Adrich, St. Louis, MO, USA) and malondialdehyde (MDA) according to the method of Buege and Aust (1978). A 1 g meat sample was mixed with 5 mL of 20% (v/v) trichloroacetic acid (TCA) (Sigma-Adrich, St. Louis, MO, USA) and centrifuged at 3000 \(\times g\) for 10 min. Then, 6 mL of 0.2 g/dL TBA was added to the supernatant. The mixture was heated in boiling water for 30 min. After cooling on ice, the resulting chromogen was extracted with 8 mL of n-butyl alcohol. The organic phase was separated by centrifugation at 3000 \(\times g\) for 10 min and the absorbance was read at a wavelength of 530 nm on a spectrophotometer (Spectronic 21 D, Milton Roy, 18974 PA, USA). The MDA solution that was made freshly by the hydrolysis of 1,1,3,3-tetramethoxypropane (Sigma-Adrich, St. Louis, MO, USA) was used as the standard. The TBARS value was expressed as nmol MDA/mg protein.

**Protein oxidation**

Protein oxidation was measured by the quantification of carbonyl groups based on their reaction with 2,4-dinitrophenylhydrazine (DNPH) (Sigma-Adrich, St. Louis, MO, USA) to form hydrazones following the method of Levine et al. (1990). Briefly, 0.1 g of meat sample was incubated with 1.0 mL of 20 mM DNPH solution for 60 min. Proteins were precipitated by the addition of 20% (v/v) trichloroacetic acid (Sigma-Adrich, St. Louis, MO, USA) and re-dissolved in DNPH. Thereafter, the proteins were precipitated from the solution using 20% (v/v) trichloroacetic acid; the protein pellet was washed three times with ethanol and ethyl acetate, and re-suspended in 1 mL of 6 M guanidine (Sigma-Adrich, St. Louis, MO, USA). The absorbance was read at 370 nm on a spectrophotometer (Spectronic 21 D, Milton Roy, 18974 PA, USA). Results were presented as \(\mu\)mol carbonyl/mg protein.

**Tissue antioxidant status and meat cholesterol**

Total antioxidant capacity (TAC) was determined as described by Baydar et al. (2007). Glutathione
Peroxidase (GPx) was assessed by measuring the disappearance of NADPH at 35°C (Paglia and Valentine 1967). Superoxide dismutase (SOD) activity was assayed by measuring the inhibition of autoxidation of epinephrine at pH 10.2 and 30°C (Misra 1985). Catalase (CAT) activity was assayed using H2O2 as substrate (Claiborne 1985). Muscle cholesterol was determined enzymatically as described by Salé et al. (1984).

**Statistical analysis**

The experiment followed a completely randomised design with seven replicates per treatment. Data were checked for normality and homogeneity of variance. The growth performance, blood and immune indices, carcase traits, caecal microbiota, and muscle antioxidant enzymes data were subjected to the generalised linear model (GLM) procedures of SAS (SAS Institute Inc., Cary, NC, USA). Significance was declared at \( p < .05 \). Following a significant F-test, differences between means were separated using Tukey’s HSD test. Data on time-dependent meat physicochemical traits and oxidative stability were analysed using the repeated statement of the MIXED procedure of SAS in which diet, chill storage, and interaction between diet and chill storage were fitted as fixed effects in a repeated measure analysis. Significance was declared at \( p < .05 \). Least-square means were separated using the PDIFF option of SAS and were adjusted with Tukey’s HSD test.

**Results and discussion**

**Onionskin phytochemicals**

The drawbacks related to the usage of synthetic additives have scaled up the quest for natural additives in broiler production (Aji et al. 2011; Khadem et al. 2014; Farahat et al. 2017; Adeyemi 2021). In this study, we explored the potential of onionskin waste in this context. The onionskin utilised in this study contained quercetin (21.38 mg/g DW), kaempferol (2.76 mg/g DW), total phenolic (56.75 mg GAE/g DW), and total flavonoids (15.28 mg QE/g DW). Our results are somewhat comparable to the values reported earlier (Burri et al. 2017, Sagar et al. 2020). Previous investigations have affirmed the antioxidant (Liu et al. 2014; Sohaib et al. 2016), antimicrobial (Abdel-Raouf et al. 2011; Liu et al. 2014), and immunomodulatory (Hager-Theodorides et al. 2014; Kim et al. 2015) properties of phytochemicals in onionskin. Thus, the active constituents in onionskin waste are expected to induce changes in growth performance, gut microbiota, immune indices, and antioxidant status in broiler chickens.

**Production indices of broilers**

The supplemented birds had heavier body weights (Table 2) compared to the B-1 birds at the starter (\( p = .038 \)) and finisher phases (\( p = .041 \)). Feed intake and feed conversion ratio, and percentage mortality were not affected (\( p > .05 \)) by dietary treatments. The alterations in immune indices and caecal microbiota

| Table 2. Production indices in broiler chickens fed diet supplemented with different additives. |
|---|
| **Dietary treatments** |
| **Item** | B-1 | B-2 | B-3 | B-4 | SEM | \( p \)-Value |
| Body weight, g/bird | | | | | | |
| Day 1 | 44.43 | 44.14 | 44.00 | 44.29 | 0.52 | .944 |
| Day 21 | 803.29<sup>b</sup> | 859.57<sup>a</sup> | 848.29<sup>a</sup> | 855.29<sup>a</sup> | 10.32 | .038 |
| Day 42 | 2139.14<sup>b</sup> | 2273.86<sup>a</sup> | 2264.86<sup>a</sup> | 2283.14<sup>a</sup> | 25.85 | .041 |
| Body weight gain, g/bird/day | | | | | | |
| Day 1–21 | 36.12<sup>b</sup> | 38.83<sup>a</sup> | 38.30<sup>a</sup> | 38.62<sup>a</sup> | 0.69 | .000 |
| Day 22–42 | 63.61 | 67.31 | 67.46 | 67.99 | 2.08 | .439 |
| Day 1–42 | 49.87<sup>b</sup> | 53.10<sup>a</sup> | 52.87<sup>a</sup> | 53.30<sup>a</sup> | 0.93 | .037 |
| Feed intake, g/bird/day | | | | | | |
| Day 1–21 | 54.00 | 57.30 | 57.49 | 57.99 | 1.66 | .332 |
| Day 22–42 | 150.13 | 153.56 | 153.99 | 152.65 | 2.86 | .781 |
| Day 1–42 | 102.07 | 108.93 | 105.74 | 105.32 | 2.46 | .299 |
| Feed conversion ratio | | | | | | |
| Day 1–21 | 1.49 | 1.47 | 1.50 | 1.50 | 0.04 | .990 |
| Day 22–42 | 2.36 | 2.27 | 2.28 | 2.24 | 0.05 | .632 |
| Day 1–42 | 2.04 | 2.05 | 2.00 | 1.98 | 0.05 | .669 |
| Mortality, % | | | | | | |
| Day 1–21 | 2.18 | 2.01 | 2.01 | 2.00 | 0.05 | .063 |

<sup>a,b</sup>Means with different superscript in a row differ significantly (\( p < .05 \)).

SEM: standard error of mean.

<sup>AB</sup>-1, basal diet (BD) without additive; B-2, BD + 0.5 g/kg oxytetracycline + 0.13 g/kg tert-Butylhydroxyanisole; B-3, BD + 10 g/kg Onionskin waste (OW); and B-4, BD + 20 g/kg OW.
by the supplements may possibly be responsible for the improved body weight gain (BWG) in the supplemented birds. Although empirical evidence remains ambivalent, enhancing intestinal absorption of nutrients, and repealing subclinical populations of pathogenic microorganisms may be the plausible mechanisms via which the supplements promote BWG in birds (Khadem et al. 2014; Brown et al. 2017). Our observations are akin to those of Khadem et al. (2014), who found improved BWG in birds supplemented with *Macleaya cordata* extract and oxytetracycline. Moreover, the supplementation of onion bulbs (Aji et al. 2011; Goodarzi et al. 2014) and herb residues (Lokaewmane et al. 2020) improved BWG in broiler chickens. On the contrary, supplementation of *Mentha cordifolia* leaf (Khempaka et al. 2013) and *Crassocephalum crepidioides* leaf (Adeyemi et al. 2021) did not affect BWG in broiler chickens.

In spite of the changes in BWG, feed intake and feed efficiency were not influenced by dietary treatments. This result aligns with those of Lokaewmane et al. (2020) who reported that the dietary supplementation of herb residues did not affect feed intake in broilers. Contrarily, feed intake and efficiency were improved following the supplementation of an onion bulb (Aji et al. 2011; Goodarzi et al. 2014). The mortality rate did not differ between diets and was within the range recommended by Ross Aviagen. Thus, the birds in this study seemed healthy. Similarly, the supplementation of herb residues (Lokaewmane et al. 2020) and *Crassocephalum crepidioides* leaf (Adeyemi et al. 2021) did not affect the percentage mortality in broiler chickens. Contrarily, *Mentha cordifolia* leaf supplementation reduced mortality in broiler chickens (Abdel-Wareth et al. 2019).

### Carcase traits

The supplemented birds had heavier (*p* = .039) carcase weight compared to the non-supplemented birds (Table 3). Dietary additives did not affect (*p* > .05) the dressing percentage and the relative weight of breast, thigh, drumstick, back and wings in broiler chickens. Further, the relative weight of internal organs was not affected (*p* > .05) by dietary treatments. Onionskin waste supplementation lowered (*p* = .045) abdominal fat in broiler chickens. The heavier body weight in the supplemented birds may account for the heavier carcase weight. Likewise, the supplementation of residues of *Curcuma aromatic* and *Kaempferial galangal* improved carcase weight in broiler chickens (Lokaewmane et al. 2020). The similarity in the dressing percentage and relative weight of carcase cuts and internal organs may suggest that the supplements did not affect carcase partitioning and organ development in broiler chickens. Correspondingly, the supplementation of *Mentha cordifolia* leaf (Abdel-Wareth et al. 2019), herb residues (Lokaewmane et al. 2020), and *Crassocephalum crepidioides* leaf (Adeyemi et al. 2021) did not affect dressing percentage, relative

### Table 3. Carcase attributes and organ weight in broiler chickens fed diet supplemented with different additives.

| Item                      | Diet \( ^a \) | B-1         | B-2         | B-3         | B-4         | SEM     | \( p \)-Value |
|---------------------------|---------------|-------------|-------------|-------------|-------------|---------|--------------|
| Carcase traits            |               |             |             |             |             |         |              |
| Carcase weight, CW, g     | 1524.57 \( ^b \) | 1601.56\( ^a \) | 1627.98\( ^a \) | 1638.84\( ^a \) | 33.56 \( .039 \) |         |              |
| Dressing %                | 70.91         | 70.46       | 71.88       | 71.78       | 1.68 \( .065 \) |         |              |
| Abdominal fat, % BW       | 0.88\( ^a \)  | 0.92\( ^a \) | 0.72\( ^b \) | 0.67\( ^b \) | 0.06 \( .045 \) |         |              |
| Carcase cuts, % CW        |               |             |             |             |             |         |              |
| Breast                    | 31.06         | 32.32       | 32.58       | 31.89       | 3.21 \( .395 \) |         |              |
| Thigh                     | 15.90         | 16.06       | 17.86       | 16.23       | 1.96 \( .123 \) |         |              |
| Drumstick                 | 16.14         | 15.25       | 14.99       | 15.27       | 1.56 \( .118 \) |         |              |
| Back                      | 24.85         | 24.57       | 23.16       | 25.22       | 4.16 \( .102 \) |         |              |
| Wing                      | 12.06         | 11.59       | 11.41       | 11.38       | 2.14 \( .069 \) |         |              |
| Organ weight, % BW        |               |             |             |             |             |         |              |
| Duodenum                  | 0.77          | 0.63        | 0.62        | 0.82        | 0.10 \( .111 \) |         |              |
| Ileum                     | 0.77          | 0.93        | 0.63        | 0.66        | 0.02 \( .734 \) |         |              |
| Jejunum                   | 0.89          | 0.93        | 0.84        | 0.99        | 0.08 \( .115 \) |         |              |
| Colon                     | 1.33          | 1.66        | 1.68        | 1.44        | 0.10 \( .092 \) |         |              |
| Liver                     | 1.94          | 1.92        | 1.84        | 1.81        | 0.05 \( .090 \) |         |              |
| Heart                     | 0.54          | 0.45        | 0.49        | 0.74        | 0.03 \( .144 \) |         |              |
| Gizzard                   | 2.05          | 2.11        | 1.98        | 2.17        | 0.14 \( .816 \) |         |              |
| Proventriculus            | 0.38          | 0.39        | 0.35        | 0.40        | 0.03 \( .062 \) |         |              |
| Caecum                    | 0.60          | 0.48        | 0.51        | 0.59        | 0.04 \( .129 \) |         |              |

\( ^a \)Means with different superscript in a row differ significantly \( p < .05 \).

SEM: standard error of mean; CW: carcase weight; BW: body weight.

\( ^b \)B-1, basal diet (BD) without additive; B-2, BD + 0.5 g/kg oxytetracycline + 0.13 g/kg tert-Butylhydroxyanisole; B-3, BD + 10 g/kg Onionskin waste (OW); and B-4, BD + 20 g/kg OW.
weights of carcase cuts, and internal organs in broiler chickens. The lower abdominal fat in the onionskin-supplemented birds suggests that onionskin repressed hepatic lipogenesis as reflected in the reduction in serum triglyceride and cholesterol in the birds. Similarly, the supplementation of Mentha cordifolia leaf (Abdel-Wareth et al. 2019), and onion and garlic mix (Al-Ramamne 2018) reduced abdominal fat in broilers.

**Blood chemistry**

Hematological indices were not affected ($p > .05$) by dietary treatments (Table 4). The onionskin-supplemented birds had lower serum total cholesterol ($p = .039$), triglycerides ($p = .001$), VLDL-cholesterol ($p = .001$) and aspartate aminotransferase (AST) ($p < .001$) and higher HDL-cholesterol ($p < .0001$) in broiler chickens. The concentration of alanine transferase was not affected ($p > .05$) by dietary treatments. The similarity in the hematological indices between the treatments may indicate that the supplements did not exert deleterious effects on the health and physiological status of the birds. The reduction in serum total cholesterol, triglycerides, and LDL-cholesterol in the OW birds may suggest that the onion phytochemicals inhibited the activity of 3-hydroxy-3-methyl glutaryl-CoA reductase, which is a crucial enzyme in cholesterol synthesis (Elson and Qureshi 1995). The major protein that makes up the HDL is apolipoprotein A (Murray et al. 2012). The reduction in the activity of 3-hydroxy-3-methyl glutaryl-CoA reductase lowers the LDL receptor activity, and consequently LDL concentrations, and increases apolipoprotein A activity binding to HDL (Slowing et al. 2001). Consistently, serum cholesterol, triglycerides, and LDL-cholesterol reduced while HDL-cholesterol increased following the supplementation of onion and garlic mix in broilers (Al-Ramamne 2018). Alanine transferase and aspartate aminotransferase can indicate hepatic health and function (Annongu et al. 2014). The reduction in the concentration of serum AST in the onionskin-supplemented birds reflected the hepatoprotective effect of onionskin phytochemicals. Likewise, the supplementation of quercetin (Kim et al. 2015) and a blend of bitter leaf and Moringa oleifera leaf (Daramola 2019) reduced serum AST in broilers.

**Caecal bacteria**

The supplementation of oxytetracycline, and 20 g/kg onionskin reduced ($p = .044$) caecal Lactobacillus spp. counts in broiler chickens (Table 5). Further, onionskin waste and oxytetracycline lowered caeca E. coli ($p = .009$) and Salmonella spp. ($p < .0001$) counts in broilers. Oxytetracycline exhibits an antimicrobial effect by inhibiting microbial protein synthesis by precluding aminoacyl-tRNA attachment to the ribosomal acceptor site (Chopra and Roberts 2001). Our finding aligns with that of Danzeisen et al. (2011) who reported a reduction in Lactobacillus count following antibiotic supplementation. Phytochemicals could

![Table 4. Blood and serum biochemical indices in broiler chickens fed diet supplemented with different additives.](image-url)
exert their antimicrobial potential by disrupting the cellular membranes of pathogenic microbes, promoting the proliferation of beneficial microbes, releasing immunostimulatory substances, and consequently affecting the surface properties and the pathogenicity of microbes (Vidanarachchi et al. 2005; Hashemi and Davoodi 2012). A noteworthy observation in this study was that the antimicrobial potential of onionskin waste against *E. coli* was dose-dependent. Likewise, onion extract reduced *E. coli* and *Salmonella* counts in vitro (Kabrah et al. 2016). Further, the supplementation of green coffee powder lowered *E. coli* and *Salmonella* counts in broilers (Ashour et al. 2020), while onion supplementation reduced ileal *E. coli* count and improved *Lactobacillus* count in broilers (Goodarzi et al. 2014).

**Immune indices**

In this study, we assessed the expression of TNF-α and IL-1β that exert pro-inflammatory effects and IL-10, which exerts anti-inflammatory effects (Kaiser and Stäheli 2014). Dietary supplements up-regulated (*p* = .001) splenic IL-10 and down-regulated (*p* = .016) splenic TNF-α in broilers (Table 5). Onionskin waste supplementation down-regulated (*p* = .001) splenic IL-1β in a dose-dependent manner. Serum IgM concentration was not influenced (*p* = .106) by dietary treatments. Nonetheless, dietary supplements repressed serum IgA (*p* = .011) in birds. It seems that the additives mediated immunomodulation via their antimicrobial and antioxidant properties as reflected in the changes in caecal bacteria population and tissue antioxidant status. Our findings align with those of Lee et al. (2017), who reported that *Allium hookeri* supplementation down-regulated the expression of IL-1β and TNF-α and up-regulated IL-10 in lipopolysaccharide-challenged broilers. Likewise, antibiotic and quercetin supplementation lowered serum IgA in broiler chickens (Kim et al. 2015).

**Tissue antioxidant status and muscle cholesterol**

Dietary supplements altered the antioxidant enzyme activities in the serum, liver and muscle of broiler chickens though the results vary among tissues (Table 6). Serum catalase (*p* = .003) and SOD (*p* < .001), hepatic GPx (*p* = .032) and catalase (*p* < .001), and muscle catalase (*p* = .003) and GPx (*p* = .001) and the TAC of serum, liver and muscle were higher in the supplemented birds compared with the non-supplemented birds (Table 6). Moreover, the 20 g/kg onionskin waste had higher hepatic catalase and TAC and higher serum SOD than did other supplements. It appears that the BHA and onionskin phytochemicals activate and/or complement the activity of antioxidant enzymes. Likewise, dietary grape seed extract enhanced hepatic glutathione reductase in broilers (Farahat et al. 2017). Moreover, the supplementation of 0.5–2% stalk residue of *Pleurotus eryngii* improved the hepatic, serum and muscle antioxidant enzymes in broiler chickens (Lee et al. 2012). However, green coffee supplementation did not affect serum antioxidant enzymes in broiler chickens (Ashour et al. 2020). Onionskin waste supplementation reduced muscle cholesterol (*p* = .030) in a similar to the observation in serum cholesterol and this could be attributed to the onionskin phytochemicals. Phytochemicals can lower tissue cholesterol by inhibiting the absorption of cholesterol from the intestinal lumen (Slowing et al. 2001), enhancing cholesterol turnover to bile acids, and

### Table 5. Caecal bacteria population and immune indices in broiler chickens fed diet supplemented with different additives.

| Item | Diet | SEM | p-Value |
|------|------|-----|---------|
| Caecal bacteria (log<sub>10</sub>CFU) | | | |
| *Lactobacillus* spp. | B-1 | 4.36<sup>a</sup> | 3.76<sup>b</sup> | 4.47<sup>a</sup> | 3.52<sup>b</sup> | 0.27 | .044 |
| *Escherichia coli* | B-2 | 3.38<sup>b</sup> | 1.78<sup>b</sup> | 1.85<sup>b</sup> | 0.73<sup>c</sup> | 0.48 | .009 |
| *Salmonella* spp. | B-3 | 3.40<sup>a</sup> | 1.50<sup>b</sup> | 1.49<sup>b</sup> | 1.44<sup>b</sup> | 0.04 | <.0001 |
| Immune indices | | | |
| Interleukin-10, pg/mL | B-4 | 6.30<sup>b</sup> | 13.67<sup>a</sup> | 15.09<sup>a</sup> | 19.43<sup>a</sup> | 2.90 | .001 |
| Interleukin-1β, pg/mL | B-1 | 232.11<sup>a</sup> | 250.00<sup>a</sup> | 142.78<sup>b</sup> | 51.11<sup>c</sup> | 24.41 | .001 |
| Tumour necrosis factor-α, pg/mL | B-2 | 77.00<sup>a</sup> | 39.00<sup>b</sup> | 41.58<sup>b</sup> | 53.09<sup>b</sup> | 8.32 | .016 |
| Immunoglobulin M, ng/mL | B-3 | 17.44<sup>a</sup> | 11.20<sup>b</sup> | 13.86<sup>b</sup> | 9.86<sup>c</sup> | 3.56 | .106 |
| Immunoglobulin A, pg/mL | B-4 | 604.92<sup>a</sup> | 344.23<sup>b</sup> | 387.3<sup>b</sup> | 322.5<sup>b</sup> | 88.89 | .011 |

<sup>a,b</sup>Means with different superscript in a row differ significantly (*p* < .05). SEM: standard error of mean; CFU: colony forming units.

<sup>a</sup>B-1, basal diet (BD) without additive; B-2, BD + 0.5 g/kg oxytetracycline + 0.13 g/kg tert-Butylhydroxyanisole; B-3, BD + 10 g/kg Onionskin waste (OW); and B-4, BD + 20 g/kg OW. 

<sup>b</sup>
inhibiting the biosynthesis of hepatic cholesterol (Srinivasan and Sambaiah 1991). Relative to the oxytetracycline-BHA meat, the supplementation of 10 g and 20 g OW induced about 38% and 53% reduction in muscle cholesterol respectively. Likewise, dietary supplementation of lycopene lowered meat cholesterol in broiler chickens (Englmaierova et al. 2011).

### Breast meat quality

Diet-chill storage interaction was not significant for the physicochemical properties (p > .05), carbonyl content (p = .428) and malondialdehyde content (p = .218) of breast meat (Table 7). Muscle pH was not affected by diets (p = .639). The uniform rearing conditions and dietary energy may partly explain this observation.

### Table 6. Tissue antioxidant enzymes and breast meat cholesterol in broiler chickens fed diet supplemented with different additives.

| Item                          | B-1       | B-2       | B-3       | B-4       | SEM   | p-Value |
|-------------------------------|-----------|-----------|-----------|-----------|-------|---------|
| Serum Glutathione peroxidase, U/mg protein | 70.00     | 78.67     | 70.33     | 75.67     | 4.52  | .596    |
| Superoxide dismutase, U/mg protein | 114.33d   | 153.00c   | 177.67b   | 206.00a   | 5.25  | <.0001  |
| Catalase, U/mg protein        | 669.06b   | 846.67a   | 810.29a   | 891.40a   | 28.99 | .003    |
| Total antioxidant capacity, mg/dL | 41.67b    | 65.00a    | 58.00a    | 59.00a    | 3.36  | .006    |
| Liver Glutathione peroxidase, U/mg protein | 192.00b   | 378.22a   | 410.90a   | 396.10a   | 78.36 | .032    |
| Superoxide dismutase, U/mg protein | 1084.2   | 1213.5    | 1370.9    | 1519.8    | 151.80| .267    |
| Catalase, U/mg protein        | 2340.6d   | 5212.6c   | 19690.1b  | 39208.1a  | 663.0 | <.0001  |
| Total antioxidant capacity, mg/dL | 49.78b    | 57.56b    | 61.17b    | 79.50a    | 4.56  | .038    |
| Breast muscle Glutathione peroxidase, U/mg protein | 102.33b   | 169.00a   | 142.33a   | 174.33a   | 8.45  | .001    |
| Superoxide dismutase, U/mg protein | 236.00    | 252.33    | 265.33    | 293.67    | 20.54 | .309    |
| Catalase, U/mg protein        | 1675.0c   | 2868.0b   | 3741.0b   | 3860.0b   | 303.19| .003    |
| Total antioxidant capacity, mg/dL | 74.11b    | 90.88a    | 55.59b    | 62.34a    | 4.53  | .005    |
| Cholesterol, mg/100 g wet tissue | 74.11a    | 90.88a    | 55.59b    | 62.34a    | 4.53  | .005    |

a,b,c,dMeans with different superscript in a row differ significantly (p < .05).

SEM: standard error of mean.

AB-1, basal diet (BD) without additive; B-2, BD + 0.5 g/kg oxytetracycline + 0.13 g/kg tert-Butylhydroxyanisole; B-3, BD + 10 g/kg Onionskin waste (OW); and B-4, BD + 20 g/kg OW.

### Table 7. Breast meat quality and oxidative stability in broiler chickens fed diet supplemented with different additives.

| Item                          | B-1       | B-2       | B-3       | B-4       | SEM   | p-Value |
|-------------------------------|-----------|-----------|-----------|-----------|-------|---------|
| pH 0 h, 15 min                | 6.13a     | 6.23a     | 6.18a     | 6.13a     | 0.05  | .639    |
| 24 h                          | 5.84a     | 5.87y     | 5.82a     | 5.79y     | .705  | -.0001  |
| Drip loss, %                  | 2.71b     | 2.34a     | 2.16a     | 2.16a     | 0.27  | .357    |
| 3 day                         | 7.48y     | 7.60y     | 6.48y     | 7.35y     | .705  | -.0001  |
| Cooking loss, %               | 10.88     | 10.71     | 11.21     | 11.53     | 2.86  | .229    |
| 3 day                         | 10.31     | 8.47      | 9.23      | 10.56     | .449  | .230    |
| Lightness (L*)                | 45.43a    | 45.56a    | 46.45a    | 47.11a    | 1.59  | .315    |
| 3 day                         | 49.799    | 50.20y    | 50.55y    | 51.13y    | .102  | .008    |
| Redness (a*)                  | 4.45a     | 4.27x     | 5.45x     | 4.85x     | 1.28  | .927    |
| 3 day                         | 3.25a     | 3.23y     | 3.81y     | 3.68y     | .933  | .006    |
| Yellowness (b*)               | 11.00     | 11.48     | 11.66     | 11.76     | 2.29  | .171    |
| 3 day                         | 12.40     | 11.43     | 11.73     | 12.24     | .868  | .061    |
| Carboxyl, umol/mg protein     | 0.63hx    | 0.30bx    | 0.50ax    | 0.20bx    | 0.26  | <.0001  |
| 3 day                         | 2.23y     | 2.06y     | 2.07y     | 2.04y     | .021  | .428    |
| Malondialdehyde, nmol/mg protein | 0.15°x    | 0.08°bx   | 0.08°bx   | 0.07°bx   | 0.02  | <.0001  |
| 3 day                         | 0.54°y    | 0.46y     | 0.45y     | 0.42y     | .034  | .214    |

a,bMeans bearing different superscript in a row differ significantly (p < .05).

x,yMeans bearing different superscript in a column differ significantly (p < .05).

SEM: standard error of mean.

AB-1, basal diet (BD) without additive; B-2, BD + 0.5 g/kg oxytetracycline + 0.13 g/kg tert-Butylhydroxyanisole; B-3, BD + 10 g/kg Onionskin waste (OW); and B-4, BD + 20 g/kg OW.
The conversion of muscle glycogen to lactate may account for the reduction in pH \( (p = .002) \) over ageing. Muscle pH is an imperative quality indicator and it is largely dependent upon the amount of muscle glycogen at slaughter and the rate of glycolysis post-mortem (Salwani et al. 2015).

The drip loss \( (p = .705) \), cook loss \( (p = .449) \), and colour coordinates \( (p > .05) \) were not influenced by diets. The uniform muscle pH may possibly account for these observations. Moreover, the non-significant changes in colour coordinates may suggest that the concentration and forms of myoglobin in the muscle were not influenced by dietary treatments. Contrarily, the dietary inclusion of green coffee powder enhanced muscle pH, redness, and lightness, and reduced yellowness of broiler meat (Ashour et al. 2020). The increase \( (p < .0001) \) in drip loss over ageing may reflect rigor-induced decrease in the water holding capacity of myofibrillar proteins (Adeyemi 2021). The lightness increased \( (p = .008) \) while the redness decreased \( (p = .006) \) over ageing. The observation may indicate the reduction in myoglobin concentration resulting from increased drip loss or the conversion of myoglobin to metmyoglobin over ageing (Adeyemi et al. 2017).

The B-2 and B-4 meats presented lower carbonyl content \( (p = .021) \) compared with other meats on day 1 post-mortem. Further, supplemented meats had lower malondialdehyde content \( (p = .034) \) compared with the un-supplemented meat on day 1 post-mortem. These observations may reflect the improvement in muscle antioxidant enzymes induced by the supplements. Plant phytochemicals can promote tissue oxidative status by inhibiting signalling pathways, activating host antioxidant enzymes, and scavenging free radicals (Arain et al. 2018). This observation is akin to those of previous works in which dietary supplementation of butylated hydroxytoluene and grape seed extract lowered malondialdehyde content (Farahat et al. 2017), while the supplementation of butylated hydroxyanisole and Morinda lucida leaf (Adeyemi 2021) reduced malondialdehyde and carbonyl contents in broiler meat. Carbonyl \( (p < .0001) \) and malondialdehyde \( (p < .0001) \) contents increased during chill storage indicating a loss of antioxidant defense system.

**Conclusions**

Dietary supplementation of onionskin waste enhanced body weight gain, carcase weight and tissue antioxidant status, altered caecal microbial population and immune indices, and lowered oxidative deterioration of breast meat in broiler chickens as did the oxytetracycline-BHA supplemented diet. Dietary supplementation of onionskin waste lowered abdominal fat, serum total cholesterol, triglycerides, aspartate transaminase, and meat cholesterol in broiler chickens. The immunomodulatory, antimicrobial, and antioxidant potentials of onionskin waste were dose-dependent. The supplementation of 20 g OW per kg diet may be a potential alternative to oxytetracycline and tert-Butylhydroxyanisole in the broiler diet. Further studies to examine the potential of onionskin waste on stressed or diseased broilers and the impact of onionskin supplementation on the sensory attributes of broiler meat are suggested.

**Ethical approval**

The experiment was conducted according to the guidelines approved (FERC/ASN/2019/069) by the Animal Ethics Committee, University of Ilorin, Ilorin, Nigeria.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

**ORCID**

Kazeem D. Adeyemi http://orcid.org/0000-0002-6719-2081

**Data availability statement**

The data analysed during the current study are available from the corresponding author on a reasonable request.

**References**

Abd El-Hack ME, Alagawany M, Abdelnour S. 2019. Responses of growing rabbits to supplementing diet with a mixture of black and red pepper oils as a natural growth promoter. J Anim Physiol Anim Nutr. 103(2): 509–517.

Abdel-Raouf N, Ibraheem IB, Abdel-Tawab S, Naser YA. 2011. Antimicrobial and antihyperlipidemic activities of isolated quercetin from Anabaena aequalis. J Phycol. 47(4): 955–962.

Abdel-Wareth AAA, Kehraus S, Südekum K. 2019. Peppermint and its respective active component in diets of broiler chickens: growth performance, viability, economics, meat physicochemical properties, and carcass characteristics. Poult Sci. 98(9):3850–3859.

Adeyemi KD. 2021. Comparative effect of dietary Morinda lucida leaf and Butylated hydroxyanisole (BHA) on carcass traits, meat quality, and oxidative stability of broiler...
FAO. 2018. Food and agriculture data. [cited 2020 September 18]. Available from: http://faostat3.fao.org/Q/ QC/E

Farahat MH, Abdallah FM, Ali HA, Hernandez-Santana A. 2017. Effect of dietary supplementation of grape seed extract on the growth performance, lipid profile, antioxidant status and immune response of broiler chickens. Animal. 11(5):771–777.

FDA. 2013. Phasing out certain antibiotic use in farm animals [Internet]. Silver Spring (MD): Food and Drug Administration; 2013 [cited 2020 October]. Available from: http://www.fda.gov/ForConsumers/ConsumerUpdates/ucm378100.htm

Fylaktakidou KC, Hadjipavlou-Litina DJ, Litinas KE, Nicolaides DN. 2004. Natural and synthetic coumarin derivatives with anti-inflammatory/antioxidant activities. Curr Pharm Des. 10(30):3813–3833.

González-Sáiz JM, Esteban-Diez I, Rodríguez-Tecedor S, Pizarro C. 2008. Valorization of onion waste and by-products: MCR-ALS applied to reveal the compositional profiles of alcoholic fermentations of onion juice monitored by near-infrared spectroscopy. Biotechnol Bioeng. 101(4):776–787.

Goodarzi M, Nanekarani S, Landy N. 2014. Effect of dietary supplementation with onion (Allium cepa L.) on performance, carcass traits and intestinal microflora composition in broiler chickens. Asian Pac J Trop Dis. 4:S297–S301.

Hager-Theodorides AL, Goliomytis M, Delis S, Deligeorgis SG. 2014. Effects of dietary supplementation with quercetin on broiler immunological characteristics. Anim Feed Sci Technol. 198:224–230.

Hashemi SR, Davoodi H. 2012. Herbal plants as new immuno-stimulator in poultry industry: a review. Asian J Anim Vet Adv. 7(2):105–116.

Hofer U. 2019. The cost of antimicrobial resistance. Nat Rev Microbiol. 17(1):3.

Kabrah MAM, Faidah HS, Ashshi AM, Turkistani MSA. 2016. Antibacterial effect of onion. Sch J App Med Sci. 4:4128–4133.

Kaiser P, Stäheli P. 2014. Avian cytokines and chemokines. In: Avian immunology. Waltham (MA): Academic Press; p. 189–204.

Khadem A, Soler L, Everaert N, Niewold TA. 2014. Growth promotion in broilers by both oxytetracycline and Macleaya cordata extract is based on their anti-inflammatory properties. Br J Nutr. 112(7):1110–1118.

Khempaka S, Pudpila U, Molee W. 2013. Effect of dried Kim DW, Hong EC, Kim JH, Bang HT, Choi JY, Ji SY, Lee WS, Kim SH. 2015. Effects of dietary quercetin on growth performance, blood biochemical parameter, immunoglobulin and ammonia production in broilers. J Appl Poult Res. 22(4):904–912.

Kim DW, Hong EC, Kim JH, Bang HT, Choi JY, Ji SY, Lee WS, Kim SH. 2015. Effects of dietary quercetin on growth performance, blood biochemical parameter, immunoglobulin and blood antioxidant activity in broiler chicks. Kor J Poult Sci. 42(1):33–40.

Lee TT, Ciou JV, Chiang CJ, Chao YP, Yu B. 2012. Effect of Pleurotus eryngii stalk residue on the oxidative status and meat quality of broiler chickens. J Agric Food Chem. 60(44):11157–11163.

Lee Y, Lee SH, Gaddde UD, Oh ST, Lee SJ, Lillehøj HS. 2017. Dietary Allium hookeri reduces inflammatory response and increases expression of intestinal tight junction proteins in LPS-induced young broiler chicken. Res Vet Sci. 112:149–155.

Levine RL, Garland D, Oliver CN. 1990. Determination of carbonyl content in oxidatively modified proteins. In: Methods in enzymology. Vol. 186. Waltham (MA): Academic Press; p. 464–478.

Liu HNY, Liu LL, Hu YL, Suo L, Zhang F, Jin XA, Feng A, Teng N, Li Y. 2014. Effects of dietary supplementation of quercetin on performance, egg quality, cecal microflora populations, and antioxidant status in laying hens. Poult Sci. 93(2):347–353.

Lokaewkane M, Phakdeeekul W, Kanyacome S, Kedthongma W, Sirival R, Doydee P, Kullawong A, Juntanam T, Khejornsar P. 2020. Effects of herb residue supplementation on growth performance, economic return, carcass quality and ammonia nitrogen of broiler chickens. Int J Poultry Sci. 19(10):486–492.

Millet S, Maertens L. 2011. The European ban on antibiotic growth promoters in animal feed: from challenges to opportunities. Vet J. 187(2):143–144.

Misra HP. 1985. Adrenochrome assay. In: Greenwald R, editor. CRC handbook of methods for oxygen radical research. Boca Raton (FL): CRC; p. 237–241.

Moekti GR. 2020. Industrial livestock production: a review on advantages and disadvantages. IOP Conf Ser: Earth Environ Sci. 492:012094.

Murray RK, Bender DA, Bothan KM, Kennelly PJ, Weil PA, Rodwell WW. 2012. Harper’s illustrated biochemistry. New York (NY): The Mc Graw-Hill Companies, Inc.

NAPDAC. 2017. Antimicrobial use and resistance in Nigeria. Situation analysis and recommendations. Abuja (Nigeria): Federal Ministries of Agriculture and Rural Development. Environment and Health Report.

Oluronsanya AO, Adeyemi KD, Babatunde IA. 2012. Effect of bamboo (Bambusa vulgaris) and elephant grass (Pennisetum purpureum) leaf extracts on oxidative stability of cooked and raw broiler meat. J Agr Res Dev. 10:381–386.

Paglia DE, Valentine WN. 1967. Studies on the quantitative and qualitative characterization of erythrocyte glutathione peroxidase. The J Lab Clin Med. 70:158–169.

Panda AK, Cherian G. 2014. Role of vitamin E in counteracting oxidative stress in poultry. The J Poult Sci. 51(2):130134.

Pejic N, Kuntic V, Vujic Z, Micic S. 2004. Direct spectrophotometric determination of quercetin in the presence of ascorbic acid. Farmaco. 59(1):21–24.

Sagar NA, Pareek S, Gonzalez-Aguilar GA. 2020. Quantification of flavonoids, total phenols and antioxidant properties of onion skin: a comparative study of fifteen Indian cultivars. J Food Sci Technol. 57(7):2423–2432.

Sale FO, Marchesini S, Fishman PH, Berra B. 1984. A sensitive enzymatic assay for determination of cholesterol in lipid extracts. Anal Biochem. 142(2):347–350.

Salwani MS, Adeyemi KD, Sarah SA, Vejayan J, Zulkifli I, Sazili AQ. 2015. Skeletal muscle proteome and meat quality of broiler chickens subjected to gas stunning prior slaughter or slaughtered without stunning. CyTA-J Food. 14:1–381.

Simitzis PE, Kalogeraki E, Goliomytis M, Charismiadou MA, Triantaphyllopoulos K, Ayoutanti A, Niforou K, Hager-Theodorides AL, Deligeorgis SG. 2012. Impact of stocking density on broiler growth performance, meat
characteristics, behavioural components and indicators of physiological and oxidative stress. Br Poult Sci. 53(6): 721–730.

Slowing K, Ganado P, Sanz M, Ruiz E, Tejerina T. 2001. Study of garlic extracts and fractions on cholesterol plasma levels and vascular reactivity in cholesterol-fed rats. J Nutr. 131(3):994S–999S.

Sohaib M, Butt MS, Anjum FM, Khan MI, Shahid M. 2016. Augmentation of oxidative stability, descriptive sensory attributes and quality of meat nuggets from broilers by dietary quercetin and ALPAH-tocopherol regimens. J Food Proc Preserv. 40(3):373–385.

Srinivasan K, Sambaiah K. 1991. The effect of spices on cholesterol 7 alpha-hydroxylase activity and on serum and hepatic cholesterol levels in the rat. Int J Vitamin Nutr Res. 61:364–369.

Tawfeek SS, Hassanin KMA, Youssef IMI. 2014. The effect of dietary supplementation of some antioxidants on performance, oxidative stress, and blood parameters in broilers under natural summer conditions. J World Poult Res. 4:10–19.

Telange DR, Patil AT, Tatode A, Bhoyar B. 2014. Development and validation of UV spectrophotometric method for the estimation of kaempferol in kaempferol: hydrogenated soy phosphatidylcholine (HSPC) complex. Pharma Meth. 5(1):34–38.

Vandghanooni S, Forouharmehr A, Eskandani M, Barzegari A, Kafil V, Kashanian S, Ezzati Nazhad Dolatabadi J. 2013. Cytotoxicity and DNA fragmentation properties of butylated hydroxyanisole. DNA Cell Biol. 32(3):98–103.

Vidanarachchi JK, Mikkelsen LL, Sims I, Iji PA, Choc M. 2005. Phytobiotics: alternatives to antibiotic growth promoters in monogastric animal feeds. Recent Adv Anim Nutr Austr. 15:31–144.

Vidovic N, Vidovic S. 2020. Antimicrobial resistance and food animals: influence of livestock environment on the emergence and dissemination of antimicrobial resistance. Antibiotic. 9(2):52.

Yusuf AL, Adeyemi KD, Roselina K, Alimon AR, Goh YM, Samsudin AA, Sazili AQ. 2018. Dietary supplementation of different parts of Andrographis paniculata affects the fatty acids, lipid oxidation, microbiota, and quality attributes of longissimus muscle in goats. Food Res Int. 111:699–707.

Zhao Y, Yang QE, Zhou X, Wang FH, Muurinen J, Virta MP, Brandt KK, Zhu YG. 2020. Antibiotic resistome in the livestock and aquaculture industries: status and solutions. Critical Rev Environ Sci Technol. 1–38. https://doi.org/10.1080/10643389.2020.1777815