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# Energy manipulation of isonitrogenous diets for broiler chickens

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## Abstract

A total of 378 unsexed Anak broiler chicks were used to assess the effects of varying energy levels and manipulation on growth, haematology, and carcass traits. The experiment was conducted in two phases. First, one-day-old chicks were randomly assigned to one of three starter diets, which differed in their energy density (LSE: 2786.80 Kcal/kg; OSE: 3015.40 Kcal/kg; and HSE: 3252.20 Kcal/kg). The chicks were assigned to seven replicates per treatment with 18 chicks per replicate. When the chicks were 27 days old, they were randomly re-allocated to three finisher diets (LFE: 2770.66 Kcal/kg, OFE: 2961.74 Kcal/kg, and HFE: 3150.43 Kcal/kg). Thus, there were seven replicates of nine treatments with six chicks per replicate in the finishing phase. The starter and finisher diets were isonitrogenous. Birds fed the OSE and HSE starter diets gained more weight and were heavier at 27 days than birds fed LSE. Energy intake by birds fed HSE was greater than by birds fed OSE, and birds fed OSE had greater energy intake than birds fed LSE. Feed conversion ratio was improved for birds fed OSE and HSE. Birds fed LSE and then HFE consumed the least feed and gained as much or more weight during the finisher phase as any other group. Overall, FCR between days 27 and 50 tended to differ among the treatments ($P$ =0.06). Total protein intake increased with decreasing dietary energy in both phases. Varying dietary energy levels did not affect the haematological parameters, carcass traits and internal organ weights.

**Keywords:** carcass, compensatory growth, growth, haematology, lipogenesis, skeletal abnormalities
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## Introduction

In the last few decades, selection of and improvements in nutrition and management of broiler chickens have contributed to their increased growth performance. An increase in average growth rate of about 40 grams has been recorded annually, and the time required to attain market weight (1.8 kg) has decreased by 0.75 days per year in the past 30 years (Tumova *et al.*, 2002). Such improvement in THE growth rate usually coincides with increased breast muscles, carcass water and fat content (Havenstein *et al.*, 2003). However, the intensity of selection for high performance has resulted in health problems in broiler production (Nansuay *et al.*, 2015). Skeletal abnormalities, cardiovascular diseases, and low resistance to other metabolic diseases are commonly observed during commercial broiler production. Besides this susceptibility to diseases, ascites and sudden death syndrome are now recurring issues (Kalmar *et al.*, 2013, Wideman *et al.*, 2013). Also, the high nutrient density feed offered ad libitum to broilers allows them to consume more calories than are required for maintenance, leading to an accumulation of abdominal fat, which is often regarded as waste (Mushtaq *et al.*, 2014).

The response of the modern broiler chicken in growth rate, breast meat yield and feed conversion efficiency correlates strongly with both dietary energy and amino acid densities (Dozier *et al.*, 2010; Gous *et al.*, 2018). This emphasizes the importance of energy density when formulating diets for broiler chickens. However, improvements in feed efficiency, immune response and fat deposition require some form of dietary manipulation and planned periods of feed restriction (Eila *et al.*, 2011; Mirshansollahi, 2013). Birds have a tendency to accumulate fat after attaining maximum growth rate, usually by 39 days old, which is followed by a decrease in growth rate after 42 days. This implies that when the growth rate drops, protein deposition also drops, whereas deposition of fat continues, and is usually high (Kessler, 2000). Therefore, if FI is not

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properly controlled, available nutrients are utilized for lipogenesis and fat accretion. Feed manipulation programmes that are aimed at changing the pattern of growth and thereby reducing storage requirements have been duly considered. These strategies can take the form of ad libitum access to less energy-dense diets or time-dependent control of daily FI. Dietary manipulations have produced positive outcomes in areas such as health and reproduction (Urdaneta-Rincon & Leeson, 2000; Camacho *et al.*, 2004), and control of bodyweight, fatness, and metabolic disorders (Balog *et al.*, 2000; Rossi & Loerch, 2003). However, there is still controversy over optimal feeding strategies for controlling carcass fat deposition, final bodyweight (BW), and feed conversion ratio (FCR).

Many studies have focused on feed restriction and dietary manipulation strategies (Santoso, 2001; Yang *et al.*, 2013; Molapo & Webb, 2014) and at different energy density levels (Giachetto *et al.*, 2003). However, to the best of the authors' knowledge, no study has been conducted on changing the dietary energy density midway through the feeding period. Information on the effect of energy density in the finisher diet as a function of energy density in the starter diet is therefore unavailable. The present study aimed to investigate the effects of manipulating the energy density of the finisher diet on growth performance, haematology and carcass traits of broilers that had been fed low, optimum and high energy-density starter diets.

## Materials and Methods

The ethical clearance for this study was granted by the Animal Care and Ethics Committee of The Federal University of Technology Akure, Nigeria (Ref. ONI011NAKI01).

The experiment was conducted using 378 unsexed Anak broiler chickens (Zartech Farms, Ibadan, Nigeria) that were raised from one day old to 50 days old. The feeding programme was divided into two phases. First, one-day-old chicks were randomly assigned to the three starter diets, which varied in energy density (LSE: 2786.80 Kcal/kg, OSE: 3015.40 kcal/kg, and HSE: 3252.20 Kcal/kg) with seven replicates per treatment with 18 chicks per replicate. This first experiment was thus of a completely randomized design. At day 28, each of the 27-day-old chickens was randomly reassigned to one of three finisher diets, which also varied in energy density (LFE: 2770.66 Kcal.kg, OFE: 2961.74 Kcal/kg, and HFE: 3150.43 Kcal/kg) with seven replicates per treatment and six chicks per replicate. Both experimental diets were isonitrogenous.

A deep litter system of housing was used throughout the experiment, and an average of 13 hours of light was provided each day. Water and feed were offered ad libitum. The formulation of feed was done in accordance with the National Research Council (NRC, 1994) (Table 1). The feed ingredients that were used to formulate the experimental diets were analysed in triplicate for their dry matter (DM) (method 930.15), crude protein (CP) (method 988.05), ether extract (EE) (method 920.39) and crude fibre (CF) (method 978.10) (AOAC, 1990). The nitrogen content was analysed by the Kjeldahl procedure, and CP was calculated as N x 6.25. Nutrient recommendations for the Anak broiler strain were used to formulate the OSE and OFE diets.

During the experimental period, the broiler chickens were weighed weekly in the morning to determine average weight gain (WG), average FI (FI) and feed to gain ratio (FCR) from days 1 to 27 and from days 28 to 50. At the end of 50 days, three birds per replicate were selected at random, deprived of feed and water overnight, and euthanized. The birds were fully plucked, and the feet, head and wingtips removed. They were then dressed and eviscerated, and the carcass (without neck, head, lung, heart, feet, and liver) was dissected to obtain back, breast, thigh, back, wings, thighs, and drumsticks. Weighted parts, including the viscera (liver, heart, kidney, lungs, and abdominal fat) were expressed as a percentage of live weight. The thighs and drumsticks of each slaughtered bird were deboned and weighed, and the linear muscle was measured. Briefly, the thigh muscle was carefully separated into outer and inner portions and reweighed. Values were expressed as percentage of live weight. Linear measurements were also taken for the length and breadth of both portions of the thigh.

Blood samples for haematology parameters were collected from the jugular vein of each bird in heparinized bijou bottles and transported in an ice pack to the laboratory for further determination of haematological indices. The white blood cells (WBC), red blood cells (RBC), erythrocyte sedimentation rate (ESR), packed cell volume (PCV), haemoglobin (Hb) and leukogram parameters were determined on the same day of blood collection, following procedures described by Lamb (1981). The mean corpuscular haemoglobin concentration (MCHC), mean corpuscular haemoglobin (MCH), and mean corpuscular volume (MCV) were calculated as described by Sastry (2004).

Data were analysed using the GLM procedure of SAS (SAS Institute Inc., 2013). The model was a one-way analysis of variance fitting treatment effects. Thus, for the starter phase there were two degrees of freedom for treatment. For the finisher phase, treatment had eight degrees of freedom. Means were compared using Duncan's multiple range test where a significant difference existed. The statement of significance was declared at $P \leq 0.05$.

**Table 1** Ingredient and nutrient composition of experimental starter and finisher diets for broiler chicks (expressed in $gkg^{-1}$ of dry matter basis)

| Ingredients | Starter diet | | | Finisher diet | | |
|---|---|---|---|---|---|---|
| | Low energy | Optimum energy | High energy | Low energy | Optimum energy | High energy |
| Maize | 380.0 | 560.0 | 550.0 | 380.0 | 493.0 | 533.0 |
| Maize offal | 150.0 | - | - | 200.0 | 100.0 | 85.0 |
| Soybean meal | 120.0 | 140.0 | 140.0 | 120.0 | 130.0 | 140.0 |
| Groundnut cake | 145.0 | 148.5 | 170.0 | 130.0 | 140.0 | 150.0 |
| Brewers dried grain | 63.5 | 50.0 | | 78.0 | 60.0 | 15.0 |
| Fish meal | 50.0 | 50.0 | 50.0 | - | - | - |
| Oyster shell | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Rice bran | 50.0 | - | - | 50.0 | 20.0 | - |
| Palm oil | - | 10.0 | 48.5 | - | 15.0 | 35.0 |
| Monocalcium diphosphate | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Salt | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Lysine | 1.5 | 1.5 | 1.5 | 2.0 | 2.0 | 2.0 |
| Methionine | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Premixes[1] | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| *Calculated composition* | | | | | | |
| Crude protein | 224.7 | 224.5 | 224.2 | 190.8 | 190.8 | 190.7 |
| Metabolizable energy, kcal/kg | 2786.8 | 3015.4 | 3252.2 | 2770.4 | 2966.3 | 3151.6 |
| Crude fibre | 52.0 | 42.2 | 35.4 | 63.4 | 66.3 | 81.3 |
| Calcium | 14.9 | 11.8 | 14.8 | 56.2 | 66.2 | 81.3 |
| Phosphorus | 7.9 | 7.0 | 6.9 | 11.8 | 11.8 | 11.7 |
| Lysine | 11.7 | 11.9 | 11.9 | 6.5 | 5.9 | 5.6 |
| Methionine | 6.2 | 6.2 | 6.0 | 10.0 | 10.1 | 10.1 |
| *Proximate composition* | | | | | | |
| Dry matter | 927.4 | 934.3 | 930.0 | 910.9 | 915.1 | 914.7 |
| Crude protein | 214.8 | 214.8 | 215.3 | 186.1 | 186.1 | 187.2 |
| Ether extract | 43.6 | 60.6 | 60.6 | 60.6 | 87.2 | 100.3 |
| Crude fibre | 64.5 | 42.6 | 36.4 | 75.3 | 69.3 | 42.7 |
| Ash | 81.3 | 85.1 | 89.7 | 81.0 | 83.1 | 87.1 |
| Nitrogen free extract | 522.6 | 531.2 | 492.6 | 498.1 | 489.4 | 497.4 |

[1] Per kg of starter diet: vitamin A: 10,000 I, vitamin D: 2,800 IU, vitamin E, 35,000 IU, vitamin K: 1,900 mg, vitamin $B_{12}$: 19 mg, riboflavin 7,000 mg, pyridoxine: 3,800 mg, thiamine: 2,200 mg, d-pantothenic acid, 11,000 mg, nicotinic acid: 45,000 mg, folic acid: 1,400 mg, biotin: 113 mg, copper: 8,000 mg, manganese, 64,000 mg, zinc: 40,000 mg, iron: 32,000 mg, selenium: 0.06 mg, iodine: 800 mg, cobalt: 400 mg, choline: 475,000 mg, methionine: 50,000 mg, butylated hydroxytoluene: 5,000 mg, spiramycin: 5,000 mg; and per kg of finisher diet: vitamin A: 10000 IU, vitamin $D_3$: 2500 IU, vitamin K: 2.4 mg, vitamin E: 44 IU, biotin: 0.1 mg, folic acid: 2.0 mg. niacin: 25 mg, calcium pantothenate: 14.32 mg, pyridoxine: 3.10 mg, riboflavin: 5 mg, thiamine: 1.2 mg, vitamin $B_{12}$: 10.5 µg, iron: 85 mg, manganese: 125 mg, copper: 7.8 mg, selenium: 0.09 mg, zinc: 60 mg, choline chloride: 5.5 mg

## Results and Discussion

The live weight of the chicks at 27 days old increased (LSE<OSE<HSE) with dietary energy level ($P$ <0.05). During the starter phase, FI was not affected by the varying levels of dietary energy treatment ($P$ > 0.05). Thus, FCR was affected significantly by treatment during the starter phase, with FCR being lowest in the HSE group compared with the OSE and LSE groups. The effects of dietary energy level on growth performance during the starter phase are shown in Table 2.

When the chickens were redistributed to the finisher energy diets, the final live weight (LW) across the groups was again affected significantly (Table 3). Unlike the starter phase, FI was affected by energy density of the finisher diets ($P$ <0.05). Birds that were finished with LFE had higher FI compared with the other treatment groups. Generally, FI seemed to increase as the energy content of the feed decreased. The broiler chicks fed LSE during the starter phase and HFE at the finisher phase (LSE/HFE) had similar WG to those fed with OSE/HFE and HSE/HFE. The effect of varying dietary energy density on FCR was not significant in the finisher phase ($P$ >0.05). Total protein and energy intakes were affected in both phases ($P$ <0.05). Because the diets were isonitrogenous, protein intake increased as FI rose, whereas energy intake tended to follow the energy content of the feed.

No differences ($P$ >0.05) were observed in the ESR, PCV, RBC, Hb, MCHC, MCH, MCV, lymphocyte, neutrophil, monocyte, and eosinophil. Basophil was affected ($P$ <0.05) by dietary energy manipulation. However, the values were within the normal physiological range for healthy broiler chickens. The haematological indices of the broiler chickens fed the dietary finisher energy levels are shown in Table 4.

No differences were observed ($P$ >0.05) in the dressing percentage, eviscerated weight, thigh, drumstick, breast, back, head, neck, and abdominal fat. Similarly, the organ and muscle weight; heart, lungs, liver, spleen, pancreas, kidney, bursa gizzard and proventriculus, were not affected ($P$ >0.05) by the dietary finisher energy manipulation. The results of the carcass characteristics and organ weights are shown in Tables 5 and 6, respectively.

**Table 2** Growth and nutrient intake of broiler chicks fed starter diets that varied in energy density until they reached 27 days old

| | Energy density of starter diet | | | | |
|---|---|---|---|---|---|
| Characteristic | LSE | OSE | HSE | SE | *P*-value |
| Initial live weight, g/bird | 55.00 | 55.00 | 57.50 | 2.27 | 0.066 |
| Final live weight, g/bird | 800.00[b] | 885.00[a] | 920.00[a] | 20.22 | 0.044 |
| Total weight gained, g/bird | 745.00[b] | 830.00[a] | 862.50[a] | 20.58 | 0.020 |
| Total food intake, g/bird | 1617.50 | 1580.00 | 1522.50 | 57.28 | 0.081 |
| Average weight gain, g/bird/day | 26.61[b] | 29.64[a] | 30.80[a] | 1.53 | 0.011 |
| Average feed intake, g/bird/day | 57.77 | 56.43 | 55.45 | 2.22 | 0.075 |
| Feed conversion ratio | 2.19[a] | 1.91[b] | 1.80[b] | 0.13 | 0.035 |
| Nutrient intake | | | | | |
| Protein intake, g | 363.45[a] | 354.71[a] | 341.34[b] | 5.25 | 0.021 |
| Protein/kg bodyweight | 454.31[a] | 400.00[b] | 371.02[b] | 20.34 | 0.018 |
| Energy intake, Kcal | 4507.65[c] | 4764.33[b] | 4951.47[a] | 51.47 | 0.031 |
| Energy/kg body weight | 5634.50[a] | 5383.42[b] | 5383.03[b] | 58.20 | 0.026 |

LSE: 2786.80 Kcal/kg; OSE: 3015.40 Kcal/kg; and HSE: 3252.20 Kcal/kg
[a,b,c] Mean values followed by a similar superscript do not differ with $P$ =0.05

**Table 3** Growth performance of broiler chicken fed starter and finisher diets that varied in energy density for days 1 to 27 and 28 to 50, respectively

| Traits | Diets | Dietary energy density treatments | | | | | | | | | SEM | *P*-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Starter[1] | LSE | | | OSE | | | HSE | | | | |
| | Finisher[2] | LFE | OFE | HFE | LFE | OFE | HFE | LFE | OFE | HFE | | |
| Initial LW, g | | 830.0$^{b}$ | 825.0$^{b}$ | 825.0$^{b}$ | 912.5$^{a}$ | 912.5$^{a}$ | 910.0$^{a}$ | 942.5$^{a}$ | 942.5$^{a}$ | 947.5$^{a}$ | 35.3 | 0.04 |
| Final LW, g | | 2220.0$^{e}$ | 2283.7$^{d}$ | 2382.5$^{c}$ | 2367.8$^{c}$ | 2457.5$^{ab}$ | 2448.7$^{b}$ | 2342.5$^{cd}$ | 2472.5$^{ab}$ | 2515.8$^{a}$ | 30.3 | 0.01 |
| Total WG, g | | 1390.0$^{d}$ | 1458.8$^{b}$ | 1557.5$^{a}$ | 1455.2$^{bc}$ | 1545.0$^{a}$ | 1548.8$^{a}$ | 1400.0$^{cd}$ | 1530.0$^{a}$ | 1568.2$^{a}$ | 28.5 | 0.04 |
| Total FI, g | | 5389.0$^{bc}$ | 5194.0$^{d}$ | 5118.0$^{d}$ | 5438.0$^{ab}$ | 5404.4$^{abc}$ | 5343.0$^{c}$ | 5475.0$^{a}$ | 5323.0$^{c}$ | 5191.0$^{d}$ | 42.8 | 0.03 |
| AFI, g/d | | 192.5 | 185.5 | 182.8 | 194.2 | 193.0 | 190.8 | 195.6 | 190.1 | 185.4 | 7.5 | 0.85 |
| AWG, g/d | | 49.6 | 52.1 | 55.6 | 52.0 | 55.2 | 56.0 | 50.0 | 54.6 | 56.0 | 4.6 | 0.06 |
| FCR | | 3.89 | 3.56 | 3.30 | 3.75 | 3.51 | 3.48 | 3.53 | 3.48 | 3.73 | 0.38 | 0.06 |
| Nutrient intake | | | | | | | | | | | | |
| Protein Intake, g | | 1028.22 | 991.02 | 976.00 | 1037.57 | 1031.08 | 1018.91 | 1044.08 | 1015.63 | 990.44 | 29.25 | 0.058 |
| Protein/kg BW | | 463.06$^{a}$ | 434.09$^{ab}$ | 405.96$^{bc}$ | 438.35$^{ab}$ | 419.65$^{bc}$ | 416.22$^{bc}$ | 445.817$^{ab}$ | 410.85$^{bc}$ | 393.81$^{c}$ | 20.23 | 0.037 |
| Energy intake, Mcal | | 149.30$^{bc}$ | 154.07$^{abc}$ | 161.30$^{abc}$ | 150.65$^{bc}$ | 160.30$^{abc}$ | 168.39$^{ab}$ | 143.81$^{c}$ | 157.90$^{abc}$ | 172.55$^{a}$ | 10.32 | 0.022 |
| Energy/kg BW | | 67.25 | 67.49 | 67.72 | 63.65 | 65.24 | 68.79 | 57.18 | 63.87 | 73.68 | 5.12 | 0.089 |

[1]LSE: 2786.80 Kcal/kg; OSE: 3015.40 Kcal/kg; and HSE: 3252.20 Kcal/kg
[2]LFE: 2770.66 Kcal/kg; OFE: 2961.74 Kcal/kg; and HFE: 3150.43 Kcal/kg
BW: bodyweight, FCR: feed conversion ratio, AWG: average weight gain, AFI: average feed intake, LW: live weight
[a,b,c,d,e] Within a row, means with a common superscript do not differ at P =0.05

**Table 4** Haematological indices of broiler chickens fed starter and finisher diets that varied in energy density for days 1 to 27 and 28 to 50, respectively

| Index | Diets | Dietary energy density treatments | | | | | | | | | SE | *P*-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Starter[1] | LSE | | | OSE | | | HSE | | | | |
| | Finisher[2] | LFE | OFE | HSE | LFE | OFE | HSE | LFE | OFE | HSE | | |
| ESR, Mm/hr | | 5.50 | 4.50 | 6.50 | 4.67 | 6.67 | 4.33 | 5.50 | 4.00 | 5.83 | 1.52 | 0.067 |
| PCV, % | | 23.67 | 25.67 | 24.33 | 25.33 | 24.00 | 24.00 | 25.33 | 24.00 | 24.33 | 2.58 | 0.083 |
| RBC, $10^6$/$mm^3$ | | 2.54 | 2.62 | 2.16 | 1.96 | 3.10 | 1.87 | 2.29 | 2.78 | 2.18 | 0.52 | 0.093 |
| Hb, g/dl | | 7.93 | 8.50 | 8.37 | 8.43 | 8.07 | 8.03 | 8.40 | 8.00 | 8.10 | 0.49 | 0.071 |
| MCHC, % | | 33.53 | 33.13 | 33.43 | 33.30 | 33.60 | 33.47 | 33.17 | 33.33 | 33.27 | 1.78 | 0.166 |
| MCH, pg | | 31.23 | 32.63 | 38.63 | 45.23 | 29.13 | 43.57 | 37.47 | 29.37 | 38.30 | 9.35 | 0.159 |
| MCV, $U^3$ | | 93.17 | 98.50 | 112.73 | 136.10 | 86.70 | 130.30 | 113.50 | 87.98 | 115.20 | 23.86 | 0.288 |
| Lymphocyte, % | | 59.33 | 59.33 | 60.00 | 58.67 | 62.67 | 60.33 | 57.67 | 61.67 | 61.67 | 3.25 | 0.069 |
| Neutrophil, % | | 27.67 | 28.00 | 30.33 | 27.67 | 26.67 | 27.00 | 30.67 | 28.33 | 29.33 | 1.89 | 0.079 |
| Monocyte, % | | 10.00 | 8.00 | 7.00 | 9.00 | 9.00 | 9.33 | 9.00 | 7.67 | 6.67 | 2.87 | 0.058 |
| Eosinophil, % | | 2.00 | 2.33 | 2.00 | 2.33 | 1.00 | 2.33 | 2.33 | 2.00 | 1.67 | 0.35 | 0.066 |
| Basophil, % | | $1.50^b$ | $2.23^a$ | $0.67^d$ | $2.33^a$ | $0.67^d$ | $1.00^c$ | $0.32^e$ | $0.33^e$ | $0.67^d$ | 0.15 | 0.009 |

[1]LSE: 2786.80 Kcal/kg; OSE: 3015.40 Kcal/kg; and HSE: 3252.20 Kcal/kg
[2]LFE: 2770.66 Kcal/kg; OFE: 2961.74 Kcal/kg; and HFE: 3150.43 Kcal/kg
ESR: erythrocyte sedimentation rate, PCV: packed cell volume, RBC: red blood cell, Hb: haemoglobin, MCV: mean cell volume, MCH: mean corpuscular haemoglobin, MCHC: mean corpuscular haemoglobin concentration
[a,b,c] Within a row, means with a common superscript do not differ at P =0.05

**Table 5** Carcass characteristics of broiler chickens fed starter and finisher diets that varied in energy density for days 1 to 27 and 28 to 50, respectively

| Traits | Diets | Dietary energy density treatments | | | | | | | | | SE | *P*-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Starter[1] | LSE | | | OSE | | | HSE | | | | |
| | Finisher[2] | LFE | OFE | HFE | LFE | OFE | HFE | LFE | OFE | HFE | | |
| Dressing percentage | | 91.74 | 93.23 | 91.04 | 88.35 | 91.21 | 91.79 | 94.23 | 90.80 | 91.27 | 4.86 | 0.583 |
| Eviscerated weight | | 79.75 | 80.67 | 79.10 | 80.01 | 80.13 | 81.88 | 80.74 | 79.49 | 79.80 | 5.25 | 0.188 |
| Thigh, g/kg LW | | 114.66 | 113.62 | 111.56 | 119.35 | 121.55 | 119.36 | 108.12 | 111.71 | 113.00 | 9.83 | 0.192 |
| Drum stick, g/kg LW | | 102.0 | 104.18 | 100.18 | 109.18 | 105.86 | 98.29 | 108.47 | 98.85 | 87.52 | 8.85 | 0.081 |
| Shank, g/kg LW | | 49.93 | 44.40 | 43.56 | 50.18 | 50.18 | 42.39 | 47.47 | 42.91 | 39.07 | 8.03 | 0.367 |
| Wing, g/kg LW | | 87.74 | 97.90 | 87.34 | 90.71 | 90.55 | 85.18 | 92.86 | 89.64 | 84.16 | 6.05 | 0.059 |
| Breast, g/kg LW | | 156.10 | 184.13 | 180.46 | 156.10 | 161.80 | 188.86 | 169.90 | 170.70 | 177.50 | 24.62 | 0.263 |
| Back, g/kg LW | | 141.92 | 147.79 | 146.76 | 143.32 | 141.70 | 148.35 | 155.41 | 153.60 | 145.82 | 10.66 | 0.384 |
| Head, g/kg LW | | 26.23 | 26.27 | 24.49 | 26.02 | 25.48 | 24.33 | 28.88 | 25.77 | 24.91 | 4.29 | 0.072 |
| Neck, g/kg LW | | 54.52 | 46.29 | 54.51 | 55.03 | 52.56 | 58.96 | 52.03 | 55.63 | 58.80 | 6.07 | 0.086 |
| Abdominal fat, g/kg LW | | 16.90 | 18.53 | 23.38 | 19.28 | 25.56 | 20.62 | 19.40 | 24.87 | 24.27 | 5.71 | 0.091 |

[1]LSE: 2786.80 Kcal/kg; OSE: 3015.40 Kcal/kg; and HSE: 3252.20 Kcal/kg
[2]LFE: 2770.66 Kcal/kg; OFE: 2961.74 Kcal/kg; and HFE: 3150.43 Kcal/kg

**Table 6** Weights of internal organs (g) and linear measures of specific muscles from broiler chickens fed starter and finisher diets that varied in energy density for days 1 to 27 and 28 to 50, respectively

| Traits | Diets | Dietary energy density treatments | | | | | | | | | SE | *P*-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Starter[1] | LSE | | | OSE | | | HSE | | | | |
| | Finisher[2] | LFE | OFE | HFE | LFE | OFE | HFE | LFE | OFE | HFE | | |
| Heart | | 4.59 | 4.23 | 4.81 | 4.57 | 3.95 | 4.10 | 4.43 | 4.16 | 4.16 | 0.82 | 0.077 |
| Lungs | | 5.25 | 4.47 | 4.48 | 4.47 | 4.74 | 3.96 | 4.94 | 4.40 | 4.46 | 0.95 | 0.069 |
| Liver | | 16.41 | 14.53 | 14.12 | 15.17 | 13.88 | 14.43 | 15.18 | 17.17 | 12.71 | 2.42 | 0.096 |
| Spleen | | 0.73 | 0.72 | 0.96 | 0.75 | 0.71 | 0.57 | 0.55 | 0.93 | 0.77 | 0.28 | 0.785 |
| Pancreas | | 2.04 | 1.93 | 1.77 | 1.81 | 1.25 | 1.19 | 1.70 | 1.82 | 1.42 | 0.37 | 0.653 |
| Kidneys | | 4.97 | 5.03 | 5.72 | 6.18 | 5.24 | 4.05 | 4.57 | 6.25 | 5.44 | 1.52 | 0.229 |
| Bursa | | 0.84 | 0.77 | 0.90 | 0.71 | 0.86 | 0.97 | 1.19 | 1.12 | 0.79 | 0.22 | 0.328 |
| Gizzard | | 24.46 | 21.12 | 25.27 | 19.59 | 20.94 | 19.12 | 24.04 | 19.67 | 20.98 | 3.75 | 0.432 |
| Proventriculus | | 3.69 | 4.67 | 3.94 | 4.61 | 4.03 | 3.55 | 4.60 | 5.65 | 4.63 | 1.25 | 0.251 |
| Thigh, g/Kg LW | | 41.19 | 40.91 | 40.23 | 41.40 | 47.35 | 45.44 | 39.62 | 34.95 | 42.35 | 7.05 | 0.866 |
| Drumstick g/Kg LW | | 35.41 | 35.48 | 35.32 | 35.18 | 34.91 | 34.80 | 37.93 | 30.44 | 30.29 | 4.12 | 0.082 |
| OB, g/Kg LW | | 14.03 | 15.14 | 15.50 | 15.31 | 14.31 | 14.35 | 15.72 | 13.91 | 14.62 | 2.05 | 0.929 |
| IB, g/Kg LW | | 43.68 | 45.66 | 39.79 | 40.44 | 41.96 | 42.46 | 40.72 | 37.64 | 46.24 | 5.11 | 0.918 |
| IB length, cm/kg LW | | 7.17 | 7.62 | 7.51 | 7.52 | 8.04 | 6.99 | 7.92 | 7.66 | 7.18 | 1.82 | 0.176 |
| OB length, cm/kg LW | | 8.63 | 9.09 | 8.88 | 9.31 | 9.16 | 8.90 | 9.11 | 9.48 | 8.53 | 1.23 | 0.926 |
| IB breadth, cm/kg LW | | 1.52 | 1.78 | 1.88 | 1.78 | 1.77 | 1.98 | 1.86 | 1.84 | 2.06 | 0.52 | 0.267 |
| OB breadth, cm/kg LW | | 3.65 | 3.52 | 3.62 | 3.50 | 3.55 | 3.62 | 3.62 | 3.37 | 3.65 | 0.68 | 0.148 |

1LSE: 2786.80 Kcal/kg; OSE: 3015.40 Kcal/kg; and HSE: 3252.20 Kcal/kg
2LFE: 2770.66 Kcal/kg; OFE: 2961.74 Kcal/kg; and HFE: 3150.43 Kcal/kg
LW: live weight; OB: outer breast, IB: inner breast

Grains provide the main source of dietary energy for broilers. However, the energy required for birds to achieve maximum performance (NRC, 1994) necessitates the inclusion of lipids in their diets. Palm oil was added to the diets to obtain the dietary concentrations used in this study. Throughout the experimental period, no illness was observed, and the mortality rate was zero for all groups. The observed increase in weight gain with increasing dietary energy during the starter period agrees with other documented reports (Dozier *et al*., 2007; Ghazalah *et al*., 2008; Akinmoladun *et al*., 2016). The varying dietary energy levels affected FI in both phases. This differs from the report of Leeson *et al.* (1996), who fed birds diets that differed in energy level (2700 to 3000 Kcal/kg) and observed no difference in FI. Generally, modern-day broilers control FI based on the energy content of the diet. However, the low FI, especially of birds fed with dietary energy levels above the required or optimum levels in this study, could be a result of having included oil in the diet. Mateos and Sell (1982) posited that high inclusion levels of oil in broiler diets can lower FI by reducing the rate of passage through the gastrointestinal tract. However, in broilers the results on the rate of passage as affected by diets that contain oil are conflicting. The FCR during the growing phase for birds fed the low-energy starter diet was poor compared with birds fed more energy-dense diets, in agreement with Leeson *et al*. (1996) and Dozier *et al*. (2007).

Growth and FI during the finisher period were affected by the energy density of the diet that was provided. These findings disagree with results from other studies (Summers *et al.*, 1992; Infante-Rodriguez, 2016). However, heavier weights have been reported for broilers fed low energy diets compared with a standard diet (Houshmand *et al.*, 2011). In this study, heavier final weights were attained by birds fed more energy-dense diets. Birds fed LSE and HFE displayed more compensatory growth by showing a similar weight gain compared with the other dietary regimes. Some authors reported full weight gain recovery in the form of compensatory growth at slaughter age after feed manipulation or restriction (Demir *et al.*, 2004; Jahanpour *et al.*, 2015). The significant effect of dietary energy levels on FI during the finishing phase in this study disagrees with Tancharoenrat and Ravindran (2014), who reported that at higher dietary energy levels, FI was not affected. However, they reported improved feed conversion and weight gain with higher dietary energy. The report of Kim *et al.* (2012) on the reduction of the FI at higher dietary energy levels agrees with the current study. When diets were compared, weight gain was found to rise linearly with an elevation in dietary energy levels in both phases. According to Leeson *et al.* (1996), a rise in dietary energy consumption usually results in an improvement in weight gain. There are controversies, however, as to whether or not broiler chickens can adjust their intake of calories when fed diets with different energy levels (Leeson *et al.*, 1996; Dozier *et al.*, 2017; Saleh *et al.*, 2004; Hildago *et al.*, 2004). The redistribution of dietary finisher energy affects energy intake. This disagrees with the report of Leeson *et al.* (1996), who observed that energy intake was essentially the same between birds fed 3300, 3100 and 2700 kcal/kg dietary metabolizable energy (ME) levels.

Consumption of dietary energy is directly related to weight gain and carcass traits. However, dietary energy manipulation did not affect the carcass traits. Values recorded for birds fed under the LSE/OFE regime group seemed to have slightly more wing, breast, back, head and neck and less abdominal fat relative to their LW than those fed under the OSE/OFE and HSE/HFE regimes. Mohebodini *et al.* (2009) and Onbasilar *et al.* (2009) found that feed manipulation did not affect the carcass traits of broiler chickens. In addition, Rosa *et al.* (2007) and Kim *et al.* (2012) reported that at slaughter age, carcass yield of broilers was not influenced under elevated dietary energy. However, an increase in yield of breast and thigh muscle, and reductions in the weight of wings, head, neck, back and legs and drumstick for birds fed high energy and protein diets have also been reported (Marcu *et al.*, 2012, 2013). Contrarily, supplementation of extra energy and protein to broiler's diet reportedly improve carcass yield in female broilers. About 8.6%, 9.5% and 9% increase in the starter (3026 Kcal/kg), grower (3142 Kcal/kg) and finisher (3196 Kcal/kg) dietary ME, respectively, improved breast and drumstick for both genders of broiler chickens (Marcu, 2013). However, Lee and Leeson (2001) noted that when there was a compensatory growth in birds following a period of under-nutrition, the additive effect on the carcass characteristics of economic importance was not significant. Fat deposition in broilers has been reported to positively correlate with elevated dietary energy levels (Leeson *et al.*, 1996). However, the values obtained in this study were not affected by dietary finisher energy manipulation. This result agrees with Giachetto *et al.* (2003), who failed to show a significant effect of the interaction between feed manipulation and energy levels on carcass fat. Most studies have reported the absence of abdominal fat response to dietary manipulation (Saleh *et al.*, 2005; Mohebodini *et al.*, 2009). Conversely, others have reported a reduction (Boostani *et al.*, 2009) or even an increase (Zhan *et al.*, 2007) in abdominal fat percentage. When supplemented with lysine, Zhao *et al.* (2008) noted that higher dietary energy increases breast, carcass, abdominal fat, and thigh. Feeding broiler chickens with extra energy and amino-acid levels has been reported to increase abdominal fat deposition, while the weight of carcass cuts remained unaffected (Wang *et al.*, 2014). However, carcass fat deposition was found to be confounded with protein and amino acids intake (Jackson *et al.*, 1982; Leeson *et al.*, 1996). When FI increases, naturally the

crude protein intake will increase, and this may reduce carcass fat deposition. Summer *et al.* (1992) affirmed that deposition of excess dietary energy is confined to the abdomen and can slow processing procedures because carcass evisceration is slower for birds with excessive abdominal fat.

Values obtained for the internal organs concur with the report of Rabie *et al.* (2017), who observed insignificant effects of various energy levels (2900, 3000, and 3100 kcal/kg ME) on weights of gizzard, liver, and heart in 14-week-old cockerels. Carcass traits of broiler chicks were not influenced by elevated dietary energy levels (Rabie *et al.*, 2010). Carcass cuts and yield were not affected by dietary ME levels in starter (12.55 - 13.39 MJ/kg) and finisher (12.79 - 13.8 MJ/kg) phases in a study by Corduk *et al.* (2007). In the report of Araujo (1982), the effect of energy levels (3200 vs 3600 kcal ME/kg) did not influence the liver, heart, and gizzards.

Muscle and connective tissues are the most abundant tissues in meat, and their properties and relative proportions are responsible for the leanness and quality of meat (Listrat *et al.*, 2016). Muscle fibre, and biochemical and structural characteristics can be manipulated independently by intrinsic and extrinsic factors to improve meat quality (Joo *et al.*, 2013; Listrat *et al.*, 2016). However, the findings in this study did not reveal any particular trend in terms of linear muscle dimensions or morphometrics with dietary finisher energy manipulation.

Analysis of blood samples can be used to probe for particular metabolites in an animal's body (Doyle, 2006). The haematological values that were obtained in this study were not affected by the dietary energy levels. This implies that protein digestion had not been interfered with. These results agree with those of Jahanpour *et al.* (2013), who investigated the effect of quantitative feed restriction on the blood metabolites of broiler chickens. However, the blood indices obtained in this study differ from the report of Dairo *et al.* (2010), who observed a significant effect on the haematology of birds fed a high-energy–low-protein diet. Similarly, the PCV and Hb of slow-growing chicks fed various levels of dietary energy have been shown to be affected during exposure to heat stress (Attia *et al.*, 2011). The leukogram parameters (lymphocytes, neutrophils, eosinophils) reported in this study were not affected either, implying that phagocytosis, the ability to fight disease invasions, was not impaired by the diets. All haematological indices that were recorded in this study were within the recommended range for normal and healthy chickens (Mitruka & Rawnsley, 1977; Olorode *et al.*, 1996).

## Conclusions

Broiler chickens would still be able to attain market weight when fed with a less dense nutrient diet in the starter phase, followed by a high energy diet in the finisher phase. Further, dietary finisher energy manipulation did not compromise the health status of the chicken. However, given the mixed reports regarding body composition, an increase in fatness is possible after feeding a less energy dense diet in the starter phase.

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**Authors' Contributions**

OFA: conceptualization, methodology, writing and original draft preparation; ABF: analysis, writing, review and editing; OFA and ABF: funding acquisition

**Conflicts of Interest Declaration**

The authors declare no conflict of interest.

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