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Research article

Effects of L-serine administration on meat quality, characteristics and mineral content of tibia bone in heat-stressed broiler

Ngozi Ejum Ogbuagu* and Joseph Olusegun Ayo

Department of Physiology, Faculty of Veterinary Medicine, Ahmadu Bello University, Zaria 810222, Nigeria

Abstract

The study evaluated the effects of L-serine administration on meat quality, characteristics and mineral content of tibia bone in heat-stressed broiler chickens. One hundred and twenty broiler chicks were allocated into four groups of 30 each. Group A (feed restriction), Group B (feed restriction + L-serine), Group C (*ad libitum*) and Group D (*ad libitum* + L-serine). Feed restriction (20%) was implemented on days 7–14, and L-serine (200 mg/kg) was provided orally from days 1–14. Seven broiler chickens were slaughtered from each group at 35 days old to determine meat drip loss, cooking loss and pH; and tibia bone weight, length, diameter, weight/length index, robusticity index, strength and proximate analysis. Serum samples were harvested for the determination of calcium and phosphorus concentrations. Temperature-humidity index in the pen (28.72 - 32.90) was above the thermoneutral zone indicating heat stress. The drip loss and cooking loss were lower in FR + L-serine and AL + L-serine groups compared to the controls. The tibia bone weight, length, weight/length index and breaking force were higher ($P < 0.05$) in FR + L-serine and AL + L-serine groups compared to the controls. The percentage composition of ash, calcium and phosphorus was relatively high in L-serine-administered groups. In conclusion, L-serine improved meat quality and tibia bone characteristics in broiler chickens exposed to heat stress.

Keywords: L-serine; meat quality; bone strength; heat stress; broiler chickens

Corresponding author: : Ngozi Ejum Ogbuagu, Department of Physiology, Faculty of Veterinary Medicine, Ahmadu Bello University, Zaria 810222, Nigeria. Tel: +2347038341598, E-mail: ogbuagungozi1989@gmail.com

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INTRODUCTION

The increase in the demand for broiler meat has led to the improvement in broiler genetics in the previous decades, which has resulted in significant welfare problems, including high mortality, leg disorders and cardiovascular diseases (Hartcher and Lum, 2020). Genetically improved hybrids have higher metabolic rates and production performance and, consequently, they generate more body heat increasing their susceptibility to heat stress (Hartcher and Lum, 2020). It is difficult for broiler chickens to dissipate heat from their body to the environment because they lack sweat glands. This inability causes broiler chickens to experience significant levels of the effects of heat stress (Hamdy, 2020). Heat stress is a significant environmental stressor, adversely affecting broiler chickens (Wasti et al., 2020). In the upcoming years, the impact of heat stress will be increased due to the rise in global temperature caused by climate change (Letcher, 2019). High relative humidity and ambient temperature, which are characteristics of the hot-dry season cause heat stress (Ayo and Ogbuagu, 2021) that increases the generation of reactive oxygen species (ROS) in skeletal muscles of broiler chickens (Kikusato and Toyomizu, 2019). The ROS damage membrane integrity, impair mitochondrial function, increase oxidation of lipid, protein and nucleic acid components and decrease the cellular antioxidant capacity (Humam et al., 2020). Protein denaturation affects water holding capacity, leading to increased drip loss, cooking loss and pale meat (Bowker and Zhuang, 2015). The pH is an important indicator that influences the quality of meat. Heat stress causes a decrease in meat pH due to increased anaerobic glycolysis (Gonzalez-Rivas et al., 2020). A rapid drop in meat pH is associated with increased drip loss and cooking loss in chicken breast muscle. These alterations decrease the quality of meat characteristics and lead to muscular chemical composition differences (Zaboli et al., 2019).

Under heat stress conditions, leg weakness or lameness is a major challenge in broiler production (Khan et al., 2021), since bone resorption and mineral deposition are impaired, a factor that affects optimal bone strength (Yan et al., 2020; Khan et al., 2021). Consequently, heat stress decreases bone structural integrity and functions, adversely affecting the welfare and performance of broiler chickens (Hosseini-Vashan et al., 2016). The effects of heat stress could be ameliorated by management practices, including feed restriction and administration of antioxidants (Wasti et al., 2020; Ayo and Ogbuagu, 2021). Feed restriction programme increases the survival rate of heat-stressed broilers by lowering their high metabolic rate (Syafwan et al., 2011). It protects against metabolic disorders associated with broiler chickens fed *ad libitum* under stressful heat conditions (Julian et al., 1998). Early feed restriction decreases body weight without impairing performance and meat quality in broiler chickens (Butzen et al., 2013); but it increases the concentration of corticosterone, which reduces the antioxidant capacity in broiler chickens (Yan et al., 2021). Serine is an important component of protein and peptides and, like all amino acids, it is crucial for maintaining health and preventing disease (Metcalf et al., 2018). Recent research has demonstrated the antioxidant benefits of L-serine supplementation (Zhou et al., 2017). It decreases corticosterone concentration in mice (Wu et al., 2019) and scavenges

ROS (Zhou et al., 2017). L-serine, as an antioxidant, may alleviate the negative effects of ROS, and improve the immunity and meat quality of broilers.

The study aimed to evaluate the effects of L-serine administration on meat quality, characteristics and mineral content of tibia bone in heat-stressed broiler chickens..

MATERIALS AND METHODS

Study area

The study was carried out in the hot-dry season (March–April, 2021) in the Department of Veterinary Physiology, Ahmadu Bello University (ABU), Zaria ($11^0 10'$N, 07^0 38′E), which is located in the Northern Guinea Savannah region of Nigeria (Dzenda et al., 2013).

Compliance with ethical standards

The Ahmadu Bello University Committee on Animal Use and Care approved the experiment with this Reference Number: ABUCAUC/2021/028 .

Experimental birds

The subjects were 120 male and female day-old broiler chicks (Arbor Acre) housed in the Department of Veterinary Physiology poultry pen. Simple randomisation was used to allocate the chicks into four groups of 30 birds each, namely: Group A was subjected to feed restriction; Group B to feed restriction and administration of L-serine (200 mg/kg); Group C to *ad libitum*; and Group D to *ad libitum* and administration of L-serine (200 mg/kg). On days 7-14, the birds were subjected to 20% feed restriction (80% of the total feed consumed by the birds *ad libitum*), whereas on days 1-14 L-serine was administered through an oral route using a gavage. Starter (days 0-28) and finisher (days 29-35) commercial broiler feed, as well as unlimited access to drinking water, were provided for the broiler chickens. The experiment was conducted with strict adherence to biosecurity rules.

Thermal conditions in the poultry pen

A wet-and-dry-bulb thermometer (Brannan®, Cumbria, England) was used to measure the temperature inside the pen. The relative humidity (RH) was calculated using Osmon's hygrometric table (Narinda Scientific Industries®, Haryana, India). Using the following formula THI = 0.85 (Tdb) + 0.15Twb (for broilers), the temperature-humidity index (THI) was calculated. Where THI = temperature-humidity index, Tdb = dry-bulb temperature and Twb = wet-bulb temperature (Tao and Xin, 2003).

Diets analysis

The various ingredients contained in the broiler chicken diets are presented in Table 1. The crude protein, fat and fibre in the broiler starter diet were 22.00%, 4.5% and 5.00%, respectively; while in the finisher diet, the ingredients were 18.00%, 5.50% and 5.00%, respectively. The percentages of calcium, phosphorus and lysine were 1.10%, 0.50% and 1.33%, respectively

in the broiler starter; and 1.00%, 0.43% and 1.05%, respectively in the broiler finisher. The metabolisable energy contents were 3000.00 kCal/kg in the starter and 3200 kCal/kg in the finisher.

The proximate analyses of the broiler chicken diets are presented in Table 1. Dry matter components were 93.60% in the broiler starter and 94.36% in the broiler finisher. The percentages of 24.00% and 5.10% were recorded for crude protein and fibre, respectively in the broiler starter. In the broiler finisher, crude protein and fibre contents were 20.15% and 5.23%, respectively. Crude fat comprised 3.60% in the starter and 3.10% in the finisher. The compositions of ash and nitrogen-free element in the broiler starter were 6.50% and 60.80%, respectively; and 5.00% and 66.52%, respectively in the broiler finisher. According to the proximate analysis, the broiler starter contained 0.97% calcium and 0.46% phosphorus, while the broiler finisher 0.86% calcium and 0.44% phosphorus.

Table 1 Composition and proximate analysis of broiler chicken diets

Feed Composition	Starter	Finisher
Ingredients (%)		
Crude protein	22.00	18.0
Crude fat	4.50	5.50
Crude fibre	5.00	5.00
Calcium	1.10	1.0
Phosphorus	0.50	0.43
Lysine	1.33	1.05
Metabolisable energy (kCal/kg)	3000.00	3200.00
Proximate analysis (%)		
Dry matter	93.60	94.36
Crude protein	24.00	20.15
Crude fibre	5.10	5.23
Oil	3.60	3.10
Ash	6.50	5.00
Nitrogen-free extract	60.80	66.52
Calcium	0.97	0.86
Phosphorus	0.46	0.44

Analysed in the Nutrition Laboratory, Ahmadu Bello University, Zaria, Nigeria

Measurement of feed intake

Daily feed intake of the broiler chickens was measured once a day at 07:00 hour (GMT + 1) during the period of the experiment. The weight of the feed before placement was measured using a Mettler Toledo® Digital Precision weighing balance (Model MT-500D, Columbus, Ohio, USA). The remaining feed was measured again 24 h later. Absolute feed intake per day was computed as the difference between the amount of feed provided to the broiler chickens and the amount that remained after 24 h (Aluwong et al., 2013; Sumanu et al., 2021).

Measurement of live weight gain

All the broiler chickens were weighed using a Mettler Toledo® Digital Precision weighing balance (Model MT-500D, Columbus, Ohio, USA) with a sensitivity of 0.01 g before and after each 7-day feeding and watering. The average of each week was considered as the live weight gain for that particular study period (Aluwong et al., 2013; Sumanu et al., 2021).

Collection of blood sample

In each group, 2 mL of blood was collected from the wing vein of seven broiler chickens. The blood samples were dispensed into plain tubes without anticoagulant and allowed to clot. The blood was transferred to the Research Laboratory of Veterinary Physiology, Ahmadu Bello University for analysis. Serum from the clotted blood samples was extracted by centrifuging at 3000 *g* for 10 minutes, and it was then kept at 4°C until further analyses.

Collection of meat and bone samples

Broiler chickens (n = 7) were selected from each group at 35 days and sacrificed via exsanguination. The breast fillets and tibia bones were harvested and transferred immediately with an ice pack to the Department of Veterinary Physiology Laboratory for analyses.

Measurement of meat pH

A portable surface pH meter (U-TECH, Delhi, India) was used to measure the fillets' surface pH. By inserting the electrode on the surface of each meat, two measurements were made, and the average pH value was recorded (Van Laack et al., 2000).

Measurement of drip loss

Drip loss of the breast fillets was measured after 24 and 192 hours of storage. Meat samples were wrapped in plastic bags and then hung from hooks through the thickest part of them for 24 hours in an incubator at 4°C. Prior to and following hanging, samples were weighed. Drip loss was expressed as a percentage of weight loss after adjusting for size as described by Albrecht et al. (2019):

$$D_L = \frac{m_1 - m_2}{m_1} \; x \; 100\%$$

Where D_L = drip loss (%), m_1 = mass before hanging, m_2 = mass after hanging

Measurement of cooking loss

The cooking loss was assessed 24 hours after slaughtering the broiler chickens. A sample of about 3 x 5 cm was cut off from the fillets' caudal end with a knife. The samples were individually weighed and placed in autoclave bags. A water bath (Memmert, Schwabach, Germany) at 80°C was used to cook the fillets until the core temperature reached 72°C. A food core thermometer (Testo, Lenzkirch, Germany) was used to measure the temperature. After cooking, a second weighing was performed, and the cooking loss was calculated as the weight loss, corrected for size, and reported as a percentage as described by Albrecht et al. (2019):

$$C_L = \frac{m_1 - m_2}{m_1} x\ 100\%$$

Where C_L= cooking loss (%), m_1 = mass before cooking, m_2 = mass after cooking

Measurement of tibia bones

Tibia bone was defleshed and weighed on a weighing scale (Model MT-500D, Columbus, Ohio, USA). The bone's length (mm) was measured from proximal to distal ends using a digital caliper. The diameter (mm) (proximal end, middle, and distal end) was measured from the posterior to the anterior surface of the bone. At -20 °C, the tibia bones were kept frozen until the strength was assessed. After the bones had been defrosted, the strength of the bones was assessed using a Mosanto Tensometer type "w" machine (Mosanto Tensometer, England, UK). The peak load at fracture, or the total load in N required for a fracture, was used to quantify bone strength halfway along the bone's length.

Proximate analysis of the tibia bone was performed after the strength assessment. The bones were dried (105°C) and ashed (600°C) overnight, and ash weight calculated. An atomic absorption spectrophotometer (Thermo Model ev-2800 Xuhui, China) was used to determine calcium and phosphorus content. The following formulae were used to calculate the robusticity index and the bone weight/length index, respectively (Kocabagli, 2001):

$$\text{Robusticity index} = \frac{\text{Bone length (mm)}}{\text{Cube root of bone weight (mg)}}$$

$$\text{Weight/length index} = \frac{\text{Weight (mg)}}{\text{Length (mm)}}$$

Data analyses

The data are presented as mean ± standard error of the mean (Mean ± SEM). Data were analysed using one-way analysis of variance (ANOVA) and Tukey's *post-hoc* test was used to examine the variations in group means. Data analysis was done using the Windows version of GraphPad Prism 8.02 (GraphPad Software, San Diego, California, USA). Values of $P < 0.05$ were considered significant.

RESULTS

Thermal conditions in the pen

At 7:00 h the DBT, RH and THI were 29.95 ± 0.38, 38.49 ± 2.64 and 28.40 ± 0.37, respectively. At 13:00 h the DBT, RH and THI were 34.83 ± 0.37, 34.12 ± 2.25 and 32.93 ± 0.33, respectively. At 18:00 h the DBT, RH and THI were 34.35 ± 0.37, 33.09 ± 2.31 and 32.43 ± 0.34, respectively (Figure 1).

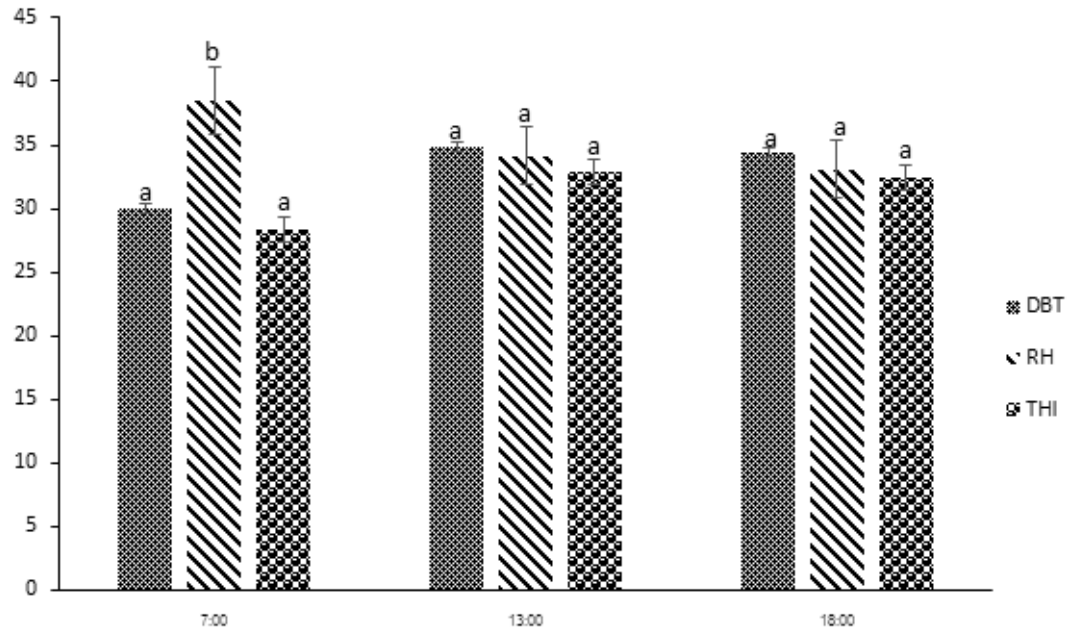

Figure 3 Diurnal variations in thermal environmental parameters during the hot-dry season. a, b =Bars with different superscript letters are significantly ($P < 0.05$) different. DBT, dry-bulb temperature; RH, relative humidity; THI, temperature-humidity index

Effect of L-serine administration on feed intake and body weight of heat-stressed broiler chickens.

Feed intake on days 7 and 14 did not differ ($P > 0.05$) among groups. Feed intake in group D was significantly ($P < 0.05$) higher than in other groups on days 21 and 28. However, on day 35, the feed intake in groups B and D broiler chickens did not differ ($P > 0.05$) but was significantly ($P < 0.05$)higher when compared with that recorded in groups A and C broiler chickens (Table 2).

Table 2 Effect of L-serine administration on feed intake (g) of heat-stressed broiler chickens

Days	A	B	C	D
7	371.00 ± 37.89	380.07 ± 38.14	352.26 ± 43.20	373.51 ± 43.63
14	577.81 ± 65.09	580.36 ± 75.37	633.25 ± 84.87	704.64 ± 75.04
21	697.09 ± 71.25^{a}	808.28 ± 66.74^{a,b}	694.76 ± 48.98^{a}	933.79 ± 56.34^{c}
28	641.39 ± 69.98^{a}	856.50 ± 83.59^{a}	559.62 ± 22.34^{b}	1093.80 ± 73.59^{c}
35	779.89 ± 51.85^{a}	1271.89 ± 87.46^{b}	989.35 ± 74.88^{c}	1222.05 ± 165.05^{b}

^{a,b,c} = Values in the same row with different superscript letters are significantly ($P < 0.05$) different.
A, feed restriction; B, feed restriction + L-serine; C, fed *ad libitum*; D, fed *ad libitum* + L-serine; n = 30.

The live weight of broiler chickens was highest ($P < 0.05$) in group D compared to other groups from days 7-35 of the recordings. The highest liveweight on day 35 was recorded in group D, followed by group B, while the least value was obtained in group A (Table 3).

Table 3 Effect of L-serine administration on live weight (g) of heat-stressed broiler chickens

Days	A	B	C	D
7	135.18 ± 1.68[a]	153.42 ± 1.34[b]	135.19 ± 1.85[a]	160.15 ± 2.19[c]
14	320.63 ± 7.40[a]	403.87 ± 5.88[b]	352.80 ± 6.87[c]	449.38 ± 5.38[d]
21	641.55 ± 8.76[a]	747.31 ± 13.84[b]	658.84 ± 10.07[a]	800.52 ± 15.95[c]
28	1022.14 ± 9.39[a]	1351.15 ± 9.89[b]	1220.46 ± 11.22[c]	1520.76 ± 10.19[d]
35	1207.95 ± 7.98[a]	1511.64 ± 13.67[b]	1327.30 ± 10.89[c]	1713.19 ± 10.88[d]

[a,b,c,d] = Values in the same row with different superscript letters are significantly ($P < 0.05$) different. A, feed restriction; B, feed restriction + L-serine; C, fed *ad libitum*; D, fed *ad libitum* + L-serine; n = 30.

Effect of L-serine administration on meat pH, drip loss and cooking loss of heat-stressed broiler chickens.

The pH values did not differ ($P > 0.05$) among all the groups throughout the hours of recordings (0, 24, 48 and 72 hours). The pH values decreased as the hour of recording increased in all the groups. The correlation coefficient between the hour of preservation and the pH was negative in all the groups: A (-0.994), B (-0.999), C (-0.991) and D (-0.998).

The drip loss was least ($P < 0.05$) in groups B and D, compared to any other group. Similarly cooking loss had also its lowest ($P < 0.05$) value in groups B and D compared to groups A and C (Table 4).

Table 3 Effect of L-serine administration on meat pH, drip loss and cooking loss of heat-stressed broiler chickens

Parameters	Hour	A	B	C	D
pH	0	6.67 ± 0.03	6.87 ± 0.03	6.40 ± 0.10	6.70 ± 0.06
	24	6.33 ± 0.18	6.53 ± 0.03	6.13 ± 0.09	6.40 ± 0.06
	48	5.70 ± 0.25	6.27 ± 0.12	5.53 ± 0.27	6.13 ± 0.07
	72	5.63 ± 0.03	6.10 ± 0.03	5.48 ± 0.06	6.09 ± 0.06
Overall mean ± SEM		6.08 ± 0.32	6.44 ± 0.19	5.89 ± 0.29	6.33 ± 0.17
Drip loss (g)		2.21 ± 0.10[a]	1.06 ± 0.00[b]	2.27 ± 0.00[a]	1.08 ± 0.01[b]
Cooking loss (g)		32.58 ± 0.27[a]	30.11 ± 0.00[b]	32.94 ± 0.72[a]	30.33 ± 0.00[b]

Group A, feed restriction; Group B, feed restricted + L-serine; Group C, *ad libitum*; Group D, *ad libitum* + L-serine; n = 7; $P < 0.05$.

Effect of L-serine administration on serum calcium and phosphorus of heat-stressed broiler chickens.

The calcium concentration in groups B and D did not differ significantly ($P > 0.05$) when compared to groups A and C. The phosphorus concentration in groups B and D did not differ significantly ($P > 0.05$) when compared to group A or C (Table 5).

Table 5 Effect of L-serine administration on serum calcium and phosphorus of heat-stressed broiler chickens

Groups	Calcium (mg/dL)	Phosphorus (mg/dL)
A	10.68 ± 0.45	4.98 ± 0.13
B	11.08 ± 0.26	5.26 ± 0.11
C	10.83 ± 0.40	5.04 ± 0.12
D	11.17 ± 0.30	5.27 ± 0.11

Group A, feed restriction; Group B, feed restriction + L-serine; Group C, *ad libitum*; Group D, *ad libitum* + L-serine; n =7; $P < 0.05$.

Effect of L-serine administration on tibia bone parameters of heat-stressed broiler chickens.

The highest ($P < 0.05$) weight, length, diameter and force were recorded in groups B and D, compared to any other group. The weight/length index was higher ($P < 0.05$) in groups B and D than in groups A and C. The robusticity index did not differ significantly ($P > 0.05$) among all the groups (Table 6).

Table 6 Effect of L-serine administration on tibia bone morphometry of heat-stressed broiler chickens

Parameter	A	B	C	D
Weight (g)	7.00 ± 0.52^{a}	11.32 ± 0.42^{c}	8.62 ± 0.44^{b}	13.73 ± 0.19^{d}
Length (mm)	75.43 ± 2.33^{a}	87.47 ± 0.74^{c}	82.5 ± 0.45^{b}	90.87 ± 0.89^{c}
Diameter (mm)	5.97 ± 0.38	7.89 ± 0.48	6.17 ± 0.57	7.46 ± 0.56
Breaking force (N)	203.70 ± 25.09^{a}	269.70 ± 8.01^{c}	221.70 ± 14^{b}	265.00 ± 14.48^{c}
W/L index	92.89 ± 6.24^{a}	129.50 ± 5.54^{b}	104.50 ± 5.35^{a}	151.30 ± 3.47^{c}
Robusticity index	3.96 ± 0.13	4.03 ± 0.07	3.90 ± 0.07	3.80 ± 0.05

^{a,b,c} = Values with different superscript letters are significantly ($P < 0.05$) different. A, feed restriction; B, feed restriction + L-serine; C, *ad libitum*; D, *ad libitum* + L-serine; n =7; $P < 0.05$.

Proximate analysis of tibia bone of heat-stressed broiler chickens administered L-serine

The proximate analyses of the tibia bone of the broiler chickens are presented in Table 7. The dry matter, crude protein and crude fibre of the tibia bone present in the groups were: A (41.80%, 26.37% and 13.81%, respectively), B (45.35%, 29.23% and 15.10%, respectively), C (42.92%, 27.75% and 14.16%, respectively) and D (46.36%, 30.38% and 14.70%, respectively). The crude fat, ash and nitrogen-free element of the tibia bone present in the groups were: A (3.76%, 31.50% and 17.31%, respectively), B (4.00%, 34.00% and 22.03%, respectively), C (3.85%, 32.50% and 19.89%, respectively) and D (4.00%, 34.50% and 23.19%, respectively). The calcium and phosphorus of the tibia bone present in the groups were: A (15.63% and 7.52%), B (19.00% and 9.05%), C (16.01% and 7.97%) and D (18.72% and 8.97%).

Table 7 Effect of L-serine administration on proximate analysis of tibia bone of heat-stressed broiler chickens

Group	DM (%)	CP (%)	CF (%)	Oil (%)	Ash (%)	NFE (%)	Calcium (%)	Phosphorus (%)
A	41.80	26.37	13.81	3.76	31.50	17.31	15.63	7.52
B	45.35	29.23	15.10	4.00	34.00	22.03	19.00	9.05
C	42.92	27.75	14.16	3.85	32.50	19.89	16.01	7.97
D	46.36	30.38	14.70	4.00	34.50	23.19	18.72	8.97

DM, dry matter; CP, crude protein; CF, crude fibre; NFE, nitrogen free element
A, feed restriction; B, feed restriction + L-serine; C, *ad libitum*; D, *ad libitum* + L-serine; n =7; $P < 0.05$.

DISCUSSION

The findings of the study demonstrate that the broiler chickens were affected by the hot-dry conditions, which are characterized by high ambient temperature and low relative humidity (Ayo et al., 2022). The high ambient temperature obtained throughout the study period was above the thermoneutral range (18-24 °C) for broiler chickens established by Vinoth et al. (2015). The temperature-humidity index, an indicator of heat stress, was also above the thermoneutral zone (20.8°C) throughout the study, indicating that the broiler chickens were constantly under heat stress conditions (Tao and Xin, 2013). The meteorological data indicated that rearing broiler chickens during the hot-dry season was thermally stressful and may have a negative impact on broiler chickens. The results of the present study are in accordance with those of Sumanu et al. (2021) and Ayo et al. (2021), who stated that broiler chickens and guinea fowls, respectively, are thermally stressed during the hot-dry season. Ameliorative measures such as administration of antioxidants are required in the rearing of broiler chickens under heat-stressed conditions.

The finding demonstrates that L-serine as a potent antioxidant enhanced feed consumption, apparently by stimulating the appetite of the chickens. Enhanced feed intake increased weight gain of the broiler chickens. The finding is similar to that of Omar et al. (2020) who reported increased feed intake and weight gain in broiler chickens administered with antioxidants.

The meat pH did not differ significantly among the groups. The result is similar to the findings of Shakeri et al. (2019) who reported that antioxidants and consistent and short-term heat stress have no effects on meat pH. The result disagrees with the findings of Albrecht et al. (2019), who reported significantly increased meat pH in broiler chickens supplemented with methionine. This may be due to the fact that the broiler chickens were not subjected to heat stress. Furthermore, the reduction in pH value as the hour of recording increased agrees with the finding of Shakeri et al. (2019) on heat-stressed broiler chickens administered antioxidants. The relative increase in meat pH in L-serine-supplemented groups may explain the antioxidant effects against oxidative stress (Zhou et al., 2017). L-serine may prolong the shelf-life of broiler chicken meat subjected to heat stress.

Furthermore, drip loss was lower in groups B and D broiler chickens provided with L-serine. Similar results were recorded for cooking loss in L-serine-administered groups. The result is in accordance with the effect of L-serine on the elevation of meat pH. High meat pH is linked to the high water-binding capacity of muscle proteins (Zaboli et al., 2019). There have been

reports that diet can affect the amount of water that meat can hold (Young et al., 2004). L-serine supplementation improved the water-binding capacity by reducing drip loss and cooking loss; thus, reducing the possible nutrient loss in water during preservation, melting and cooking. L-serine administration to broiler chickens facilitated the retention of the nutritive value of the meat even after slaughter and cooking. Although, a palatability test was not conducted in the present study, L-serine by decreasing drip and cooking loss and, consequently, retaining the nutrients in the meat may improve the palatability and organoleptic qualities of the meat. The results of the current study are consistent with that of Shakeri et al. (2019), who observed low drip loss and cooking loss in broiler chicks provided with the antioxidant betaine.

The result of the percentage composition of ash, calcium and phosphorus agrees with the findings of Hosseini-Vashan et al. (2016) who reported decreased tibia content of ash, Ca and P in heat-stressed broiler chickens. L-serine being an antioxidant relatively increased the ash, Ca and P in the present study, which agrees with the findings of Rehman et al. (2018) that *Moringa oleifera* as an antioxidant increases tibia bone ash of broiler chickens. L-serine scavenges the excess ROS produced during heat stress by increasing the antioxidant capacity of the body. It is involved in the synthesis of glutathione peroxidase (Zhou et al., 2017), which decreases the effect of heat stress on the body systems. Heat stress results in leg problems, bone breakage, deformities, infections and osteoporosis, causing poor performance and welfare of broiler chickens (Kierończyk et al., 2017). Heat stress increases corticosterone release in circulation which adversely affects calcium metabolism and bone formation (Hosseini-Vashan et al., 2016). The excretion of minerals (Ca, P, Na, K, Mg and Mn) increases in birds exposed to temperature above the thermoneutral zone , which decreases the quantity present in the bones (Hosseini-Vashan et al., 2016).

The result shows a decrease in tibia weight and length in group A and an increase in these parameters in both groups B and D. The findings of the present study show the beneficial role of L-serine in increasing tibia bone weight and length in both feed-restricted and *ad libitum* broiler chickens subjected to heat stress conditions. The results show that the administration of L-serine to broiler chickens under heat stress ameliorated the negative effects associated with it. This result agrees with that of Yan et al. (2020), who observed increased values of bone parameters in broiler chickens administered antioxidant *Bacillus subtilis*–based probiotic.

The breaking force of the tibia bone increased in broiler chickens administered L-serine. This was evidenced by the increased contents of the tibia bone ash, calcium and phosphorus in L-serine-administered broiler chickens, associated with the formation and metabolism of bone.. Calcium as the major component of bone is present as calcium-phosphate complexes, which increase bone strength. Increased tibia bone ash indicates an improvement in bone mineralisation. Thus, the broiler chickens administered L-serine had higher bone strength than the controls. The weight/length index is an index of density (Salaam et al., 2016), which increased in L-serine-administered groups. The result shows that the tibia bones of L-serine administered groups had higher mineral contents that made the bones denser than those of the controls, indicating stronger bones. The findings agree with that of Yan et al. (2019), who showed the effect of synbiotic as an antioxidant in bone mineral density.

Overall, L-serine improved the bone composition in the treated groups and may improve the overall weight of the broiler chickens.

CONCLUSIONS

In conclusion, L-serine mitigated the negative effects of heat stress in broiler chickens, reared under hot-dry conditions by increasing breast fillet pH, tibia bone weight, length, diameter, breaking force and bone weight/bone length index. It decreased drip loss and cooking loss of meat. L-serine may improve meat quality and bone strength and enhance productivity in broiler chickens.

AUTHOR CONTRIBUTIONS

Ngozi Ejum Ogbuagu: Conceptualization; Resources; Data curation; Formal analysis & Writing - original draft.

Joseph Olusegun Ayo: Conceptualization; Methodology; Supervision; Investigation & Writing - review & editing.

CONFLICT OF INTEREST

The authors reported no conflict of interest.

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