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# Evaluation of *Piper guineense* (West African black pepper ) as a feed additive on carcass yield, meat colour and lipid profile of broiler chickens under two housing types

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**Abstract**

*To meet the rising demand for wholesome and healthy poultry products, broiler management practices should be designed to enhance both productivity and the welfare of the birds. This study was designed to evaluate the carcass yield, meat colour, and lipid profile of broiler chickens fed diets containing varying levels of* Piper guineense *leaf and seed meal, and reared in different housing systems. A total of 288 one-day-old Cobb-500 broiler chicks were brooded for two weeks and subsequently assigned to eight different treatment groups. Each treatment was replicated three times, with 12 birds per replicate. The diets contained a 2:1 combination of* Piper guineense *leaf and seed meal.Treatments 1, 2, 3, and 4 consisted of birds reared in battery cages and fed* Piper guineense *meal at 0, 0.5, 1.0, and 1.5% inclusion levels, respectively. Treatments 5, 6, 7, and 8 consisted of birds reared on deep litter and fed the same inclusion levels of* Piper guineense leaf and seed meal. *At the end of the study, birds were slaughtered and carcass and meat samples were collected for quality assessment. Data generated were analyzed using two-way Analysis of Variance as described in SAS (2012). Results showed that birds reared on deep litter had significantly higher ($p < 0.05$) live weight (3550.63 ± 64.55 g), plucked weight (3175.00 ± 64.53 g), dressed weight percentage (71.44 ± 0.69%), and breast muscle percentage (27.55 ± 0.76%) compared to birds reared in battery cages, which recorded corresponding values of 3365.00 ± 55.08 g, 2935.00 ± 63.23 g, 68.40 ± 1.23%, and 23.82 ± 0.52%, respectively. Conversely, drumstick, head, and lung weights were significantly higher ($p < 0.05$) in birds reared in battery cages. Dietary inclusion of* Piper guineense *significantly increased ($p < 0.05$) head and lung weights, while fat deposition decreased progressively with increasing inclusion levels In conclusion, broiler chickens reared in deep litter housing exhibited higher carcass yield and better meat quality. For optimal meat yield and quality the study recommends incorporating 1%* Piper guineense *leaf meal and seed (2:1) into diets of broiler chickens reared in deep litter housing system.*

**Keywords**: Battery cage, broiler, carcass quality, deep litter, *Piper guineense*

**Running Title:** *Piper guineense* as a feed additive for enhancing carcass characteristics

## Évaluation de *Piper guineense* (West African black pepper) comme additif alimentaire sur le rendement carcasse, la couleur de la viande et le profil lipidique de poulets de chair élevés sous deux types de logement

**Résumé**

*Pour répondre à la demande croissante de produits avicoles sains et de qualité, les pratiques d'élevage des poulets de chair doivent être conçues pour améliorer à la fois la productivité et le bien-être des oiseaux. Cette étude a été conçue pour évaluer le rendement carcasse, la couleur de la viande et le profil lipidique de poulets de chair nourris avec des régimes contenant des niveaux variables de farine de feuilles et de graines de Piper guineense, et élevés dans différents systèmes de logement. Un total de 288 poussins de chair Cobb-500 âgés d'un jour ont été élevés en démarrage pendant deux semaines, puis répartis en huit groupes de traitement différents. Chaque traitement a été répété trois fois, avec 12 oiseaux par répétition. Les régimes contenaient une combinaison 2:1 de farine de feuilles et de graines* *de Piper guineense. Les traitements 1, 2, 3 et 4 comprenaient des oiseaux élevés en batteries et nourris avec de la farine de Piper guineense à des niveaux d'incorporation de 0, 0,5, 1,0 et 1,5 %, respectivement. Les traitements 5, 6, 7 et 8 comprenaient des oiseaux élevés sur litière profonde et nourris avec les mêmes niveaux d'incorporation de farine de feuilles et de graines de Piper guineense. À la fin de l'étude, les oiseaux ont été abattus et des échantillons de carcasse et de viande ont été prélevés pour l'évaluation de la qualité. Les données générées ont été analysées à l'aide d'une analyse de variance à deux facteurs selon SAS (2012). Les résultats ont montré que les oiseaux élevés sur litière profonde avaient un poids vif (3550,63 ± 64,55 g), un poids plumé (3175,00 ± 64,53 g), un pourcentage de poids habillé (71,44 ± 0,69 %) et un pourcentage de muscle du bréchet (27,55 ± 0,76 %) significativement plus élevés (p < 0,05) par rapport aux oiseaux élevés en batteries, qui ont enregistré des valeurs correspondantes de 3365,00 ± 55,08 g, 2935,00 ± 63,23 g, 68,40 ± 1,23 % et 23,82 ± 0,52 %, respectivement. Inversement, les poids du pilon, de la tête et des poumons étaient significativement plus élevés (p < 0,05) chez les oiseaux élevés en batteries. L'incorporation alimentaire de Piper guineense a significativement augmenté (p < 0,05) les poids de la tête et des poumons, tandis que le dépôt de graisse diminuait progressivement avec l'augmentation des niveaux d'incorporation. En conclusion, les poulets de chair élevés en litière profonde ont présenté un rendement carcasse plus élevé et une meilleure qualité de viande. Pour un rendement et une qualité de viande optimaux, l'étude recommande d'incorporer 1 % de farine de feuilles et de graines de Piper guineense (2:1) dans l'alimentation des poulets de chair élevés en système de litière profonde.*

**Mots-clés** : Batterie, poulet de chair, qualité de la carcasse, litière profonde, *Piper guineense*

**Introduction**

Broiler production is one of the fastest growing sectors in the livestock industry, due to the high demand for poultry meat (Abhijit *et al*., 2025). To meet this demand, modern broiler farming adopts some management practices that promote and sustain maximum growth rate and feed efficiency. However, these management practices sometimes compromise the welfare of the broiler birds. One of the major factors with welfare concerns in broiler production has to do with the housing systems. Housing is a critical component in broiler production, where optimal growth performance and meat quality are key economics goals of commercial broiler industry in its quest of meeting the global high demand for animal protein. Housing components that promote welfare-friendly environment during rearing period of broilers have been recognized as essential for achieving desirable production outcomes (Goo *et al*., 2019). As the welfare of the birds directly influences various physiological and biochemical parameters that impacts positively on the quantity and quality of the products (meat) derived. Stress, movement restriction and poor environmental condition have been reported to have negative impact on growth rates, feed conversion and muscle development (Berri *et al*., 2005), which in turn affect physco-chemical quality traits of the meat.Nevertheless, the use of feed additives has become essential strategy in modern broiler production for enhancing productivity, maintaining the health and welfare of the birds.

Broilers are genetically selected for rapid growth, which can predispose them to metabolic stress and oxidative damage due to increased oxygen consumption and reactive oxygen species (ROS) production. Oxidative stress can impair immune function, reduce feed efficiency and compromise meat quality (Surai, 2016). To mitigate these challenges, various feed additives containing antioxidants, phytogenic compounds, pre- or pro-biotics and organic acids are incorporated into broiler diets (Gadde *et al*., 2017). These additives have been reported to assist in neutralizing free radicals, strengthen the birds' antioxidant defense systems, and support gut health, thereby, enhancing nutrient absorption (Zhang *et al*., 2011). However, the use of natural feed additives with antioxidative properties, particularly, phytogenic feed additives (derivatives from herbs, spices and plant extracts) are preferable than synthetic compounds due to less risk of harmful residues in poultry products and the rising consumers' demand for organic and naturally raised poultry products (Fasseas *et a*l., 2007; Su *et al*., 2007; Valenzuela-Grijalva *et al*., 2017).

One such plant of growing interest is *Piper guineense* commonly known as West African black pepper. *Piper guineense* contains potent antioxidant and antimicrobial compounds like piperine, flavonoids and terpenoids (Akinyemi *et al*., 2005; Adebayo-Tayo *et al*., 2020). These phytochemicals have been reported to scavenge free radicals and enhance cellular defense mechanisms. Its inclusion in broiler ration could offer a sustainable, residue free strategy to reduce reliance on synthetic additives and improve bird resilience under stressful production conditions (Toghyani *et al*., 2010; Adedokun *et al*., 2021).

Therefore, this study was aimed at evaluating the carcass yield, meat colour and lipid profile of broiler chickens fed dietary inclusions of *Piper guineense* leaves and seeds, with the goal of mitigating the negative effects of producing broiler chickens in different housing types.

## Materials and Methods

### *Processing of test ingredients*

Dry *Piper guineense* seed and fresh leaves were purchased from reputable open food ingredient market. The leaves were air dried and constantly turned to avoid fungal growth, until it became crispy when touched while retaining its green colouration.The leaves and seeds were then ground to powder and stored in air tight containers until fully utilized.

### *Experimental animal and management*

A total of 288 one-day-old Cobb-500 strain of broiler chicks were bought from a reputable hatchery. The birds were brooded together for two weeks on deep litter pens. All vaccinations meant for broiler chickens were duly administered to the birds following the recommendations of the breeders. Clean water was adequately provided daily throughout the experimental period.

### *Experimental diets and design*

A commercial broiler starter feed was offered to the chicks from day one to the end of week four. After brooding, the chicks were given broiler finisher diet 5-8 weeks of the experiment. After two weeks of brooding, the chicks were assigned into eight treatment groups of 36 birds per treatment. Each treatment was balanced for weight and replicated thrice with 12 birds per replicate. Four experimental diets were assigned to each of the eight treatment groups while feeding was done *ad libitum*. The inclusion level of the *Piper guineense* leaves and seeds in the diets was done in ratio 2:1. The blends of *Piper guineense* were included in the diets at 0, 0.5, 1.0 and 1.5%, respectively. The rations were fed to the experimental birds for six weeks. Treatments 1, 2, 3 and 4 consist of birds in battery cage fed dietary inclusion of *Piper guineense* blend in the ratio of seed: leaf of 2:1, at 0, 0.5, 1.0, and 1.5%, respectively, while treatments 5, 6, 7 and 8 consisted of birds in deep litter fed dietary inclusion of *Piper guineense blend* at 0, 0.5, 1.0, and 1.5%, respectively. The equivalent amount of *Piper guineense* blend added to the diet was first deducted from the 100 kg commercial feed (quantity by quantity) before it was integrated and mixed properly. The nutrient composition of the commercial feed used is shown in Table 1 as provided on the brand label of the feed.

### *Carcass yield evaluation*

At the of the experiment (42 days of the study), two birds whose weights were within the weight of the replicate mean group were selected from each replicate group and used to assess the carcass yield, meat colour and lipid profile of the broiler chickens at the end of the feeding trial (56 days of age). The birds were denied feed for 12 hours, but sufficient water was supplied during the period. Thereafter, the fasted live weight was determined and recorded, using a weighing scale. The birds were slaughtered and bled by slitting the jugular vein, followed by scalding in hot water at $65^0$C.

Feathers were plucked and plucked carcass weights were recorded. Then, carcass was eviscerated through a slit made between the end of the kneel bone and the rectum. The eviscerated carcass was weighed and the value was recorded as the eviscerated weight for each of the birds in replicate group. Dressed weight of the eviscerated carcass was determined after head, shanks and eviscerated organs have been removed . Percentage dressed weight was calculated as outlined below

$$\text{Dressed weight (\%)} = \frac{\text{Eviscerated carcass weight (g)}}{\text{Live weight (g)}} x \frac{100}{1}$$

The weights of the internal organs were taken using the sensitive scale and was expressed as the percentage of the final live weight of the birds.

$$\text{Organ weight (\%)} = \frac{\text{organ weight (g)}}{\text{Live weight (g)}} x \frac{100}{1}$$

The fats around the cloaca, bursa of fabriculous, proventriculus, and muscles adjacent to the abdomen were extracted, weighed, and considered as abdominal fat deposits according to the method of Cahaner *et al.*, 1986.

***Determination of meat colour***

The colour of breast muscle was determined by taken a sample of sliced meat from the posterior part of the slaughtered broiler chickens' breast using a Colorimeter (CHROMA METER CR-410, JAPAN). The values of L*, a* and b* colorimetric coordinates was determined on scale (Riegel *et al.,* 2003): L*= corresponds to Lightness, a*= corresponds to Redness, b*= corresponds to yellowness, On the basis of a* and b* values were calculated as follows:

Chroma (Ñ) = $(a^{*2}+b^{*2})^{0.5}$

***Determination of meat lipid profile***

Composite paste of the right thigh muscle was prepared with a known amount of chloroform and methanol mixture in the ratio of 1:1 (v/v) for each replicate. The resulting paste solvent mixture was filtered and rinsed with an additional volume of the combined homogenate and allowed to stand for five minutes. The filtered homogenate was equilibrated to remove non-lipid material, and 2 % (0.32M) w/v KCL solution was added to the aqueous layer (Folch *et al*., 1957). The filtrate was centrifuged and the lipid extract was decanted. The decanted mixture gotten was used to obtain the meat lipid profile following the method described by Christie (1982).

***Statistical analysis***

Data generated were subjected to 2–way Analysis of Variance in a 2 x 4 factorial layout, involving 2 housing types (battery cage and deep litter) and four inclusion levels of *Piper guineense* (0, 0.5, 1, 1.5%) using SAS (2012). Significantly different means ($P < 0.05$) among the variables were separated using New Ducan Multiple Range Test as contained in SAS (2012) statistical package.

**Results**

**Main effects of housing types and dietary inclusion level of *Piper guineense* on carcass yield of broiler chickens**

The effects of housing types and dietary inclusion of *Piper guineense* blends on carcass yield of broilers is presented in Table 2. Birds raised on deep litter housing types were significantly ($p<0.05$) higher in live weight ( 3550..63± 64.55 g), plucked weight (3175.00 ± 64.53 g), dressed percentage (71.44 ±0.69%) and breast muscle (27.55 ± 0.76 %) when compared to 3365.00 ± 55.08 g, 2935.00 ± 63.23 g, 68.40 ±1.23% and 23.82 ± 0.52% values obtained for birds managed on battery cage, respectively.

However, birds managed in battery cages had significantly ($p<0.05$) higher drumstick (10.84 ± 0.30 %), head (2.75 ± 0.11 %) and lungs (0.32± 0.03%) compared to 10.00 ± 0.21%, 1.90 ± 0.04%, and 0.23 ± 0.01%, respectively, obtained for birds on deep litter housing type. Other parameters considered were not significantly ($p >0.05$) influenced by housing type.

Dietary inclusion levels of *Piper guineense* significantly ($p< 0.05$) impacted the head, fat and lungs weights of broiler chickens. The comparable weightier head of 2.59±0.24% was noted for broiler chickens fed control diets, those fed ration with 1.5% *Piper guineense* supplemental diets recorded the least head weight of 2.12 ± 0.17%. Comparable mean values were observed in fat levels of birds on *Piper guineense* blends ration, irrespective of the levels, but differed significantly (p<0.05) from the values (2.01± 0.27%) documented for birds on control diet.

Lungs weight of broilers were significantly (p<0.05) influenced by dietary inclusion of *Piper guineense* with range values of 0.24± 0.01% noted in birds on diet with 0.5% *Piper guineense* inclusion diet to 0.34 ± 0.04% documented for broiler chicken on 1.0% supplemental level of *Piper guineense* diet. Other carcass parameters considered in this study were not statistically (p>0.05) different.

**Interactive effects of housing type and dietary inclusion level of *Piper guineense on* carcass yield of broiler chickens**

The interactive effects of housing type and dietary inclusion of *Piper guineense* is presented in Table 3. All the carcass yield parameters considered were significantly (p<0.05) influenced, except neck, heart, kidney and spleen weights. Broiler chickens reared on deep litter housing system and fed control diet had higher live weight, plucked weight, eviscerated weight and dressed weights values (3750.00 g, 3415.00 g, 2995.00 g and 2739.80 g, respectively) and least in battery cage reared chickens fed ration that do not contain *Piper guineense* (3175.00 g, 2875.00 g, 2513.20 g and 2233.00 g, respectively). However, The highest percentage dressed weight and breast muscle percent of 73.18 ±1.86% and 28.79 ±2.17% were documented for broilers managed under the deep litter and fed control diets, respectively, while, lowest values of 65.22±3.75% and 22.61±1.62%, respectively, were recorded for broilers raised in battery cages and fed 1.5 % dietary inclusion level of *Piper guineense*.. The back and drumstick percentages had higher mean values of 12.84 ±0.60% and 11.48±0.45% recorded for birds reared on battery cages and fed ration with 0.5 % *Piper guineense* whereas the least mean values of 10.66±0.53% and 9.61±0.60% were documented for birds raised in battery cage and fed ration that contained 1.5% of *Piper guineense* and those on deep litter housing type, fed ration with 0.5% inclusion level of *Piper guineense*. The highest mean values (7.33±0.41 %, 4.85±0.09 % and 3.18±0.15 %) of wings, shank and head weight respectively were noted for broilers managed under battery cage and fed control diet. Liver weight was impacted (p<0.05) by dietary inclusion of *Piper guineense* with mean values that ranges from 1.53±0.09% recorded in birds fed control diet and reared under the deep litter to 1.92 ±0.09% documented for broiler chickens reared in deep litter housing system fed diet containing 1.0% supplemental level of *Piper guineense*. Comparable mean values were observed in fat levels which differed significantly (p<0.05) from the value of 2.61± 0.24%noted for broilers managed under deep litter housing system and fed ration containing supplemental level of 0.5% *Piper guineense*. The Lung had the highest significant (p<0.05) value of 0.46±0.04% noted for birds raised on battery cages, fed ration containing 1.0% of *Piper guineense* and the least comparable value of 0.22± 0.01% documented for birds raised under deep litter and fed supplemental diet containing 1.0% *Piper guineens*e blend. The gizzard and proventriculus had a comparable mean values with range of 1.93 ±0.10% and 0.39±0.02% noted for broilers raised on battery cages and fed diet containing 0.5% inclusion level of *Piper guineense* to 1.48±0.08 % and 0.29±0.01%, respectively, recorded for broiler birds managed under deep litter and fed ration containing 1.0% of *Piper guineense* blend.

**Main effects of housing type and dietary inclusion levels of *Piper guineense* on meat colour of broiler chickens**

The effects of housing type and dietary inclusion levels of *Piper guineens*e on meat colour of broiler chickens is depicted on Table 4. Meat colour from the outer view were not significantly (p>0.05) influenced by housing types. Lightness (46.06±0.57, 45.96±0.66) , yellowness (6.96±0.17, 6.78±0.18) and light intensity (53.15±0.57, 51.31±1.59) were numerically higher in birds managed in battery cages while the values of redness (6.59±0.27, 6.81±0.27), red intensity (7.91±0.30, 8.17±0.33) and yellow intensity (9.30±0.24, 10.50±1.39) were higher numerically in broilers managed in deep litter, moreover chroma value was higher in broiler chickens raised in battery cage (12.31±0.25) compared to lower value ( 13.65±1.31) noted for birds in deep litter housing type.

The inner views of meat colour were not significantly ($p>0.05$) impacted by housing type, lightness ( 42.18±0.49, 43.39±0.42), redness (9.29±0.36, 9.64±0.29), yellowness (6.82±0.22, 7.40±0.26 ), Light intensity (49.11±0.49, 50.85±0.56), red intensity (11.32±0.41, 11.64±0.34) and yellow intensity (9.47±0.32, 10.28±0.39) were numerically higher in broilers managed in deep litter housing type compared to their corresponding values recorded for broilers reared on battery cage system, however chroma value was higher in battery cage system compared to lower value noted in birds reared in deep litter housing type.

Most of the meat colour parameters considered for the outer view in this present study were not impacted positively ($p>0.05$) by dietary inclusion of *Piper guineense* except meat yellowness which differed significantly ($p<0.05$) with a comparable higher mean value of 7.51±0.16% obtained for birds fed ration containing 1.5% *Piper guineense* blend.

The inner view revealed that dietary inclusion level of *Piper guineense* significantly ($p<0.05$) influenced redness, yellowness, red intensity and yellow intensity. The highest mean value of redness (10.41±0.25) was noted for broilers fed ration with 1.0% *Piper guineense* while those fed ration with 0.5% *Piper guineense* supplemental diet recorded the least redness value of 8.71±0.41.

Comparable mean values were observed in yellowness and yellow intensity of meat from broilers fed ration with different inclusion levels of *Piper guineense* which differed significantly ($p<0.05$) from the values (5.8±0.30) and (8.02±0.46) obtained for birds on control diet, respectively . The intensity of redness of broilers meat was significantly ($p<0.05$) influenced by dietary inclusion of *Piper guineense* with mean values ranging from 10.62±0.46 obtained for broiler chickens fed 0.5% of *Piper guineense* to 12.51±0.27 obtained for broiler chickens on 1.0% supplemental level of *Piper guineense*. The highest significant ($p<0.05$) chroma value of 16.15±0.37 was obtained for birds fed 1.0% supplemental diet of *Piper guineense* while the least significant value of 13.71±0.53 was obtained for broiler chickens fed control diet. Other meat colour parameters considered, were not statistically ($p>0.05$) different.

**Interactive effects of housing type and dietary inclusion level of *Piper guineense* on meat colour of broiler chickens**

Table 5 shows the interactive effects of housing type and dietary inclusion of *Piper guineense* on meat colour of broiler chickens. The result obtained revealed that the interactive effects of housing type and dietary inclusion of *Piper guineense* (outer view) had no significant ($p>0.05$) effects on meat light intensity and yellow intensity. However, the interaction between housing type and dietary inclusion of *Piper guineense* significantly ($p<0.05$) influenced the lightness, redness, redness intensity and yellowness of the meat. The highest mean values of these parameters (47.75±0.82), (7.80±0.40), (7.52±0.19) and (9.19±0.47) were noted for meat from broilers managed in battery cages and fed ration that contained 1.5% *Piper guineense*. The least chroma values (11.08±0.20) were obtained for birds raised on deep litter system and fed dietary inclusion of 1.0% of *Piper guineense* whereas the highest comparable mean value (17.66±5.19) was recorded in broiler chickens managed under the deep litter housing system and fed diet not containing *Piper guineense* blend.

All the meat colour parameters were significantly ($p<0.05$) influenced by the interaction between housing type and dietary inclusion of *Piper guineense* (inner view). The highest lightness and light intensity values of 45.19±0.74 and 51.72±0.72 were obtained in meat from broiler chickens managed under battery cage and fed ration with 1.0% *Piper* *guineense* while their least values of 40.42±0.83 and 47.39±0.88 were obtained for broilers reared on battery cage and fed ration with 0.5% *Piper guineense*. The least yellowness value of 5.73±0.47 was noted in broilers managed under battery cage and fed diet that do not contain *Piper guineense* whereas the highest value of 8.24±0.55 was recorded for birds reared under the deep litter housing system and fed dietary inclusion of *Piper guineense* at 0.5%. Redness, red intensity and yellow intensity recorded the highest mean values (10.80±0.29), (13.03±0.30) and (11.44±0.52) for broilers reared on deep litter housing system and fed ration containing 1.5% inclusion level of *Piper guineense* while the least mean values of 8.31±0.45 and 10.09±0.59 were documented for birds reared in deep litter housing system and fed ration not containing *Piper guineense* for redness and red intensity respectively. Birds managed in battery cage and fed ration not containing *Piper guineense* recorded the least value of 7.84±0.66 for yellow intensity. The highest chroma value of 17.62±1.27 was noted for birds managed in deep litter and fed dietary inclusion of 1.5% of *Piper guineense* and 13.13±0.55 was the least chroma value documented for broiler chickens raised in deep litter and fed control diet.

**Main effects of housing type and dietary inclusion of *Piper guineense* on meat lipid profile of broiler chickens**

The effect of housing type on meat lipid profile of broiler chicken is represented in Table 6. All lipid profile measured were not significantly (p>0.05) different. Cholesterol (69.45±2.23 mg/dL)), triglyceride (116.85±5.23 mg/dL), high density lipoprotein (12.14±0.50 mg/dL), and low density lipoprotein (17.28±1.71 mg/dL) were numerically higher in deep liter housing type compared to their corresponding values (66.98±1.64 mg/dL), (114.45±8.88 mg/dL), (12.01±0.72 mg/dL) and (16.68±1.33 mg/dL) obtained from meat of birds reared on battery cages respectively. The very low density lipoprotein values of 31.60±1.65 mg/dL noted for birds managed in battery cage compared to 28.88±1.58 mg/dL documented for deep litter reared birds.

All parameters considered were not significantly (p>0.05) influenced by dietary inclusion of *Piper guineense*. The highest numerical values for cholesterol (71.08±2.32 mg/dL), low density lipoprotein (18.75±2.43 mg/dL) and very low density lipoprotein (32.10±0.27 mg/dL) were observed in birds on dietary inclusion level of *Piper guineense* at rate of 0.5% whereas, the highest numerical triglyceride value of 130.23±12.27 mg/dL and high density lipoprotein value of 13.00±1.24 mg/dL were noted in broiler chickens on control diet. Triglyceride values decreased numerically with increasing inclusion levels of *Piper guineense*.

**Interactive effects of housing type and dietary inclusion of *Piper guineense* on meat lipid profile of broiler chickens**

All the lipid profile parameters considered in this present study were not significantly (P >0.05) impacted by the interactive effects of housing type and dietary inclusion of *Piper guineense* (Table 7). All the lipid profile parameters increased numerically with increasing quantity of *Piper guineense* at 0.5% and 1.0% levels of inclusion and mostly decreased at 1.5% inclusion level of *Piper guineense* for broiler managed under battery cage. For birds raised under deep litter, all the meat lipid profile parameters decreased numerically with increasing quantity of *Piper guineense* and slightly increased numerically at 1.5% inclusion level for high density lipoprotein, low density lipoprotein and very low density lipoprotein.

**Discussion**

The higher significant value observed in live weight, plucked weight, dressed weight and percentage dressed weight of broiler chickens reared in the deep litter over their counterparts in battery cage could be as a result of the better welfare experienced by the birds since they were able to exercise their innate behaviours like dust bathing, nesting, locomotive activities, scratching and flapping of their wings that cannot be done by those managed under battery cage system. The present study does not agree with the observation of Abdel- Azeem *et al.* (2019) that reported higher live body weight in cage system compared to the value gotten for birds on deep litter system at the end of 35 days of experiment and also reported no significant difference between cage and floor system at the end of 1, 14 and 28 days of age. The reason for the variation in both studies may be due to genotype, environmental and age differences of the experimental birds. This observation is in line with the assertion of Fanatico *et al.* (2005) that outlined some factors that influenced carcass quality of poultry birds to include genotype, age, sex, diet, stocking density, environment, exercise and pasture intake. The difference observed in the weight of breast muscle meat with higher value observed in birds reared in deep litter over their counterparts on battery cage system agrees with Sogunle *et al.* (2008) who revealed that the floor system showed a higher significant value in the weight of breast muscle meat when compared to cage system. The reason for the higher value could be linked to the variation in live weight as reported by Njoku *et al*. (2015) that carcass weight increased with increasing slaughtering weight. Higher significant values of head and drumsticks were observed in the battery cage system when compared with the deep litter system and this agrees with the report of Sogunle *et al.* (2016) that observed higher significant differences in some cut-parts of exotic breeds of turkey reared in wooden cages over their counterparts reared in deep litter housing system. The significant differences in head and drumstick weights could be linked to docile behaviour and better muscle metabolism in these set of birds confined in battery cage over those in deep litter as reported by Castellini *et al*. (2002). The non significant effect of housing system in the internal organs except for lungs in which cage system had a higher percentage over deep litter system agrees with the study of Sogunle *et al.* *(*2008) who reported that housing system did not influence internal organs except lungs which also had a better significant value in cage system. The enlarged lungs of birds in battery cage over the value obtained for birds reared in deep litter could be as a result of compromised comfort and welfare due to physiological stress which concurs with the observation of Silva (2001) that reported that changes in environmental condition imposes stressful conditions and decreases the selection of resistant strains that may deteriorate birds comfort, welfare and performance.

Live weight, plucked weight, eviscerated weight and dressed weight, were not significantly influenced by *Piper guineense* supplementation in the diets of broiler chickens. This agrees with Amouzmehr *et al*. (2012) that showed that supplementation of garlic extracts in diet at rates of 3.0% and 6.0% did not affect carcass characteristics including carcass yield, breast muscle, thigh and abdominal fat. This present study also agrees with the observation of Abbza *et al*. (2008) that reported non significant effect of integrating 0.1% essential oil of black pepper in the ration of ducks. The result of the present study is in contrast with the report of Tazi *et al*. (2014) that noted higher significant ($p<0.05$) values in body weight gain, and commercial cuts percentages such as breast muscle, drumstick and thigh. in broiler chicks fed diets containing different levels of black pepper as natural feed additive. The present study also disagreed with Mushtag (2007) whose study showed that there was higher dressed percentage by incorporating plant extract in diets of broiler chickens and Ndelekwute *et al*. (2016) who reported significant increase in dressed weight of birds on dietary supplementation of *Piper nigrum.* The non significant values observed in this present study indicate that *Piper guineense* did not have any detrimental or toxic effects that may impede the performance of the broiler chickens. The abdominal fat was significantly reduced by dietary inclusion of *Piper guineense.* This shows that inclusion of *Piper guineense* into the diet of broiler chickens could enhance the production of a better meat quality that may be low in cholesterol. The above assertion agrees with Manta *et al.* (2013) that reported that *Piper guineense* have a cholesterol lowering ability. The result of this present study agrees with the study of Ndelekwute *et al.* (2016) that reported that abdominal fat reduced when black pepper was incorporated into the diet of broiler chicken, likewise, Abbza *et al*. (2008) reported that abdominal fat reduced significantly with increase of 0.1 % of black oil in the diet of broiler chickens. From this present study, the lungs were significantly reduced at 0.5 % inclusion level of *Piper guineense.* This partially agrees with the study of Ndelekwute *et al*. (2016) who reported that lungs was significantly higher in birds on control diet. The similarities in values of kidney and spleen indicates that *Piper guineense* was not toxic to the birds at all the levels of inclusion in this present study.

According to Henderson *et al.* (1999), that reported that cell proliferation in lymphatic organs is accelerated as an immediate response to pathogenic invasion, resulting in enlarged organs. This study revealed that birds raised in battery cage system and fed diet supplemented with 0.5 % of *Piper guineense* had heavier gizzard and proventriculus compared to their corresponding values noted for those managed in battery cage and fed diets containing different inclusion levels of *Piper guineense*. This implies that more feed will be ingested by the organs as the function denotes, and ground by the grits for better digestion and utilization of the birds. This reason is in agreement with the report of Santos *et al* (2006) that stated that the difference in gizzard and proventriculus weight could be linked to enhanced gizzard function and improved digestion of feed in this set of birds.

The significant improvement in meat colour in this present study is in line with the earlier reports that revealed natural antioxidants could delay loss of meat colour by extending the red colour (a*) and delaying metamyoglobin formation (Velasco and Williams, 2011; Etim *et al*. 2013). The yellowness (b*) could be as a result of the presence of Beta- carotenoid in *Piper guineense* (Nwankwo *et al*., 2014). This is in support of Bonsu *et al.* (2012) that reported that variation in skin and meat colour could be attributed to the carotene s in neem- based diets fed to broiler chickens. Also, Barbut (1993) reported that addition of garlic, black pepper and hot red pepper had an influence on broiler chicken meat colour. *Piper guineense* influenced chroma but this does not agree with Ponsano *et al.* (2002) who observed no significant effect on chroma value of broiler chickens fed *Rhodocyclus gelatinosus biomass*. The higher significant chroma value obtained in 1.0 % inclusion level indicates that the colour of the broiler chicken was more vivid, saturated and intense, and these improvement could be attributed to the presence of the phyto-chemicals in *Piper guineense* that possesses colour-stabilizing antioxidative properties (Etim *et al*., 2013).

Neither housing types nor dietary inclusion of *Piper guineense* affected the lipid profile of broiler chicken in this study. However, *Piper guineense* reduced triglyceride numerically in a consistent manner. This could be as a result of cardiac glycosides, which is one of the bio active compound present in *Piper guineense* known to be important in the management of cardiovascular diseases (Pal and Verma., 2013) . This present study concurs with Attia *et al.* (2017) who reported that dietary supplementation of herbal blend extracts (thyme, pepper mint, green tea and licorice) into the diet of broiler chickens (cobb-500 strain) had no significant impact in lipid profile of broiler chickens. Moreover, this study disagrees with the investigation of Daneshyar *et al*. (2011) where dietary supplementation of turmeric in production of broiler chickens (Ross 308) impacted the meat lipoprotein, triglyceride and cholesterol concentration. Likewise, Sanwo *et al. (*2019) reported significant reduction in cholesterol fractions of meat obtained from FUNAAB-Alpha meat type chickens on diets supplemented with turmeric and clove.

**Conclusion**

Housing type influenced live weight, pluck weight, dressed percentage, some cut up parts like breast muscle, drumstick, head weights and improved lung weight, Likewise, dietary inclusion of *Piper guineense* had positive impact on head weight, abdominal fat content, and lung weight of broiler chickens. Interaction between housing type and dietary inclusion of *Piper guineense* influenced most carcass yields of broiler chickens. Therefore, it can be recommended that broiler chickens are better reared on deep litter housing system and fed diet that contained 1% *Piper guineense* for improved carcass yield and meat quality.

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**Table 1: Nutritional composition of the experimental diets given to the birds as declared by the producer**

| Nutrients (%) | Starter Ration | Finisher Ration |
|---|---|---|
| Metabolizable Energy (Kcal/kg) | 2998 | 2990 |
| Crude protein | 23.21 | 20.37 |
| Crude fibre | 4.57 | 4.39 |
| Ether extract | 4.85 | 4.63 |
| Calcium | 1.18 | 1.35 |
| Phosphorus | 0.66 | 0.75 |
| Methionine | 0.86 | 0.77 |
| Lysine | 1.27 | 1.12 |
| Salt | 0.30 | 0.30 |

**Table 2: Main effects of housing type and dietary inclusion levels of *Piper guineense* on carcass yield of broiler chickens**

| **Parameters** | **Battery cage** | **Deep litter system** | **Control** | **0.5 %** | **1.0 %** | **1.5 %** |
|---|---|---|---|---|---|---|
| Live weight (g) | 3365.63±55.08$^{b}$ | 3550.00±64.55$^{a}$ | 3462.50±167.90 | 3511.30±57.09 | 3445.00±55.00 | 3412.50±22.66 |
| Plucked weight(g) | 2935.00±63.23$^{b}$ | 3175.00±64.53$^{a}$ | 3145.00±148.74 | 3135.00±56.41 | 3015.00±89.26 | 2925.00±72.28 |
| Eviscerated weight (g) | 2542.79±59.16 | 2721.96±70.45 | 2754.10±129.58 | 2599.40±96.19 | 2647.50±84.12 | 2528.50±62.40 |
| Dressed weight (g) | 2300.80±53.67$^{b}$ | 2535.86±51.57$^{a}$ | 2486.40±127.07 | 2465.70±48.86 | 2392.20±81.51 | 2329.00±65.08 |
| Dressed (%) | 68.40±1.23$^{b}$ | 71.44±0.69$^{a}$ | 71.82±1.13 | 70.23±0.87 | 69.33±1.52 | 68.31±2.12 |
| **Cut- up parts (% of live weight)** | | | | | | |
| Breast muscle muscles | 23.82±0.52$^{b}$ | 27.55±0.76$^{a}$ | 26.78±1.30 | 25.38±0.75 | 25.30±1.15 | 25.29±1.35 |
| Back | 11.91±0.34 | 11.94±0.30 | 12.40±0.40 | 12.28±0.49 | 11.98±0.34 | 11.07±0.45 |
| Drumstick | 10.84±0.30$^{a}$ | 10.00±0.21$^{b}$ | 10.64±0.35 | 10.54±0.49 | 10.42±0.42 | 10.10±0.37 |
| Thigh | 10.92±0.55 | 11.64±0.29 | 11.45±0.38 | 10.70±1.03 | 11.52±0.35 | 11.44±0.54 |
| Wings | 6.78±0.64 | 6.65±0.41 | 6.93±0.25 | 6.57±0.10 | 6.70±0.23 | 6.68±0.15 |
| Shank | 4.46±0.14 | 3.87±0.13 | 4.35±0.23 | 3.87±0.23 | 4.44±0.08 | 4.01±0.28 |
| Neck | 3.16±0.16 | 3.23±0.13 | 3.40±0.22 | 3.27±0.23 | 2.98±0.16 | 3.12±0.23 |
| Head | 2.75±0.11$^{a}$ | 1.90±0.04$^{b}$ | 2.59±0.24$^{a}$ | 2.21±0.17$^{b}$ | 2.38±0.16$^{a}$ | 2.12±0.17$^{b}$ |
| **Internal organs (% of live weight)** | | | | | | |
| Fat | 1.30±0.14 | 1.58±0.21 | 2.01±0.27$^{a}$ | 1.24±0.19$^{b}$ | 1.18±0.19$^{b}$ | 1.23±0.27$^{b}$ |
| Liver | 1.60±0.04 | 1.70±0.05 | 1.58±0.07 | 1.65±0.05 | 1.74±0.09 | 1.64±0.07 |
| Gizzard | 1.74±0.07 | 1.60±0.07 | 1.64±0.11 | 1.71±0.10 | 1.60±0.07 | 1.74±0.11 |
| Lungs | 0.32±0.03$^{a}$ | 0.23±0.01$^{b}$ | 0.27±0.02$^{ab}$ | 0.24±0.01$^{b}$ | 0.34±0.04$^{a}$ | 0.26±0.03$^{ab}$ |
| Heart | 0.48±0.02 | 0.45±0.01 | 0.48±0.03 | 0.46±0.02 | 0.47±0.02 | 0.45±0.02 |
| Kidney | 0.21±0.01 | 0.20±0.01 | 0.22±0.01 | 0.21±0.01 | 0.21±0.01 | 0.18±0.02 |
| Spleen | 0.08±0.01 | 0.08±0.01 | O.09±0.01 | 0.08±0.01 | 0.09±0.01 | 0.09±0.01 |
| Proventiculum | 0.34±0.01 | 0.32±0.01 | 0.35±0.02 | 0.35±0.02 | 0.31±0.01 | 0.31±0.02 |

$^{ab}$Means along the same row with different superscripts are significantly ($p<0.05$) different.

$^{abcd}$ Means along the same row with different superscripts are significantly ($p<0.05$) different.

**Table 3: Interactive effects of housing type and dietary inclusion of *Piper guineense on* carcass yield of broiler chickens**

| | **Batter cage** | | | | **Deep litter** | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameters (g)** | **0** % | **0.5** % | **1.0** % | **1.5** % | **0** % | **0.5** % | **1.0** % | **1.5** % |
| Live weight | 3175.00±179.70[b] | 3472.50±58.08[ab] | 3390.00±84.26[ab] | 3425.00±25.00[ab] | 3750.00±210.16[a] | 3550.00±104.08[ab] | 3500.00±70.71[ab] | 3400.00±40.82[ab] |
| Plucked weight | 2875.00±126.06[b] | 3160.00±100.33[ab] | 2875.00±116.44[b] | 2830.00±132.29[b] | 3415.00±196.87[a] | 3110.00±66.08[ab] | 3155.00±102.75[ab] | 3020.00±29.43[b] |
| Eviscerated weight | 2513.20±113.01[b] | 2681.90±147.37[ab] | 2514.30±109.01[b] | 2461.80±120.10[b] | 2995.00±163.99[a] | 2516.90±130.07[b] | 2780.70±96.51[ab] | 2595.30±27.89[b] |
| Dressed weight | 2233.00±107.34[b] | 2483.70±88.85[ab] | 2255.20±99.56[b] | 2231.40±115.33[b] | 2739.80±145.00[a] | 2447.80±55.08[ab] | 2529.20±92.63[ab] | 2426.70±10.37[ab] |
| Dressed weight (%) | 70.46±1.11[abc] | 71.45±1.43[ab] | 66.47±1.91[bc] | 65.22±3.75[c] | 73.18±1.86[a] | 69.00±0.70[abc] | 72.20±1.31[ab] | 71.40±0.74[ab] |
| **Cut- up parts (% of Live weight)** | | | | | | | | |
| Breast muscle | 24.77±0.66[abc] | 24.69±0.45[abc] | 23.23±1.00[bc] | 22.61±1.62[c] | 28.79±2.17[a] | 26.10±1.44[abc] | 27.37±1.51[ab] | 27.96±1.03[a] |
| Back | 12.38±0.75[ab] | 12.84±0.60[a] | 11.79±0.38[ab] | 10.66±0.53[b] | 12.42±0.44[ab] | 11.71±0.73[ab] | 12.18±0.59[ab] | 11.48±0.74[b] |
| Drumstick | 11.22±0.40[ab] | 11.48±0.45[a] | 10.18±0.85[ab] | 10.48±0.64[ab] | 10.05±0.42[ab] | 9.61±0.60[b] | 10.66±0.26[ab] | 9.72±0.34[b] |
| Thigh | 11.12±0.68 | 10.41±2.13 | 10.95±0.38 | 11.19±0.83 | 11.78±0.39 | 10.98±0.63 | 12.09±0.47 | 11.69±0.80 |
| Wings | 7.33±0.41[a] | 6.66±0.14[ab] | 6.38±0.35[b] | 6.76±0.22[ab] | 6.54±0.17[ab] | 6.48±0.14[b] | 7.01±0.24[ab] | 6.59±0.23a[b] |
| shank | 4.85±0.09[a] | 4.21±0.30[abc] | 4.47±0.15[ab] | 4.32±0.44[abc] | 3.85±0.25[ac] | 3.54±0.28[c] | 4.40±0.07[abc] | 3.70±0.32[bc] |
| Neck | 3.65±0.27 | 3.12±0.35 | 2.72±0.12 | 3.14±0.42 | 3.15±0.33 | 3.42±0.33 | 3.24±0.25 | 3.10±0.25 |
| Head | 3.18±0.15[a] | 2.61±0.17[b] | 2.79±0.07[ab] | 2.42±0.28[bc] | 2.00±0.09[cd] | 1.81±0.08[d] | 1.98±0.08[cd] | 1.82±0.08[d] |
| liver | 1.62±0.10[b] | 1.59±0.07[b] | 1.56±0.07[b] | 1.64±0.12[b] | 1.53±0.09[b] | 1.72±0.05[ab] | 1.92±0.09[a] | 1.63±0.07[b] |
| **Internal organs ( % of live Weight)** | | | | | | | | |
| Fat | 1.17±0.25[b] | 1.43±0.22[b] | 1.27±0.29[b] | 1.16±0.43[b] | 2.61±0.24[a] | 1.31±0.31 | 1.09±0.30[b] | 1.03±0.40[b] |
| gizzard | 1.74±0.15[ab] | 1.93±0.10[a] | 1.71±0.10[ab] | 1.60±0.15[ab] | 1.53±0.15[ab] | 1.49±0.07[b] | 1.48±0.08[b] | 1.89±0.15[ab] |
| Lungs | 0.27±0.03[b] | 0.25±0.02[b] | 0.46±0.04[a] | 0.30±0.06[b] | 0.27±0.01[b] | 0.23±0.02[b] | 0.22±0.01[b] | 0.23±0.02[b] |
| Heart | 0.46±0.06 | 0.46±0.04 | 0.46±0.04 | 0.40±0.02 | 0.50±0.02 | 0.46±0.03 | 0.48±0.03 | 0.49±0.03 |
| Kidney | 0.23±0.02 | 0.20±0.02 | 0.20±0.02 | 0.20±0.01 | 0.21±0.01 | 0.21±0.01 | 0.23±0.02 | 0.16±0.03 |
| Spleen | 0.09±0.00 | 0.09±0.01 | 0.09±0.01 | 0.88±0.01 | 0.09±0.01 | 0.08±0.01 | 0.09±0.01 | 0.10±0.01 |
| Proventiculum | 0.33±0.04[ab] | 0.39±0.02[a] | O.33±0.02[ab] | 0.32±0.03[ab] | 0.36±0.02[ab] | 0.31±0.03[ab] | 0.29±0.01[b] | 0.31±0.03[ab] |

**Table 4: Main effects of housing and dietary inclusion level of *Piper guineense* on meat colour of broiler chickens**

| | Housing Type | | Inclusion Levels of Piper guineense | | | |
|---|---|---|---|---|---|---|
| **Parameters** | **Battery cage** | **Deep litter** | **0 %** | **0.5 %** | **1.0 %** | **1.5 %** |
| Outer | | | | | | |
| L | 46.06±0.57 | 45.96±0.66 | 46.72±0.85 | 44.62±1.09 | 45.88±0.77 | 46.81±0.61 |
| A | 6.59±0.27 | 6.81±0.27 | 6.86±0.49 | 6.41±0.36 | 6.26±0.25 | 7.29±0.35 |
| B | 6.96±0.17 | 6.78±0.18 | 6.31±0.29$^{b}$ | 6.87±0.22$^{ab}$ | 6.78±0.22$^{b}$ | 7.51±0.16$^{a}$ |
| L* | 53.15±0.57 | 51.31±1.59 | 50.69±3.04 | 51.65±1.10 | 52.66±0.92 | 53.92±0.61 |
| A* | 7.91±0.30 | 8.17±0.33 | 8.24±0.61 | 7.78±0.42 | 7.49±0.26 | 8.65±0.39 |
| B* | 9.30±0.24 | 10.50±1.39 | 11.25±2.80 | 9.29±0.28 | 9.03±0.30 | 10.03±0.23 |
| Chroma | 12.31±0.25 | 13.65±1.31 | 14.59±2.64 | 12.22±0.26 | 11.80±0.22 | 13.30±0.34 |
| Inner | | | | | | |
| L | 42.18±0.49 | 43.39±0.42 | 42.77±0.71 | 42.23±0.69 | 43.93±0.63 | 42.20±0.56 |
| A | 9.29±0.36 | 9.64±0.29 | 8.96±0.49$^{b}$ | 8.71±0.41$^{b}$ | 10.41±0.25$^{a}$ | 9.78±0.53$^{ab}$ |
| B | 6.82±0.22 | 7.40±0.26 | 5.81±0.30$^{b}$ | 7.54±0.36$^{a}$ | 7.42±0.25$^{a}$ | 7.68±0.27$^{a}$ |
| L* | 49.11±0.49 | 50.85±0.56 | 49.92±0.75 | 49.39±0.74 | 51.39±0.93 | 49.24±0.57 |
| A* | 11.52±0.41 | 11.64±0.34 | 10.91±0.61$^{b}$ | 10.62±0.46$^{b}$ | 12.51±0.27$^{a}$ | 11.88±0.61$^{ab}$ |
| B* | 9.47±0.32 | 10.28±0.39 | 8.02±0.46$^{b}$ | 10.54±0.53$^{a}$ | 10.18±0.35$^{a}$ | 10.77±0.42$^{a}$ |
| Chroma | 14.91±0.36 | 15.64±0.39 | 13.71±0.53$^{b}$ | 15.11±0.43$^{a}$ | 16.15±0.37$^{a}$ | 16.14±0.57$^{a}$ |

$^{ab}$Means along the same row with different superscripts are significantly ($p<0.05$) different.

L-Lightness, A-Redness, B-Yellowness, L*, A* and B* are colour directions, where A* is the red axis, A is the green axis, B* is the yellow axis and B is the blue axis. N/B: Area around the center represents achromatic colours and moving outwards, colour saturation increases

**Table 5*: Interactive effects of housing type and* *dietary inclusion level of Piper guineense* on meat colour of broiler chickens**

| | **Battery cage** | | | | **Deep Litter** | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameters** | **0 %** | **0.5 %** | **1.0 %** | **1.5 %** | **0 %** | **0.5 %** | **1.0 %** | **1.5 %** |
| Outer | | | | | | | | |
| L | 46.98±0.94$^{a}$ | 41.80±0.65$^{b}$ | 47.70±0.82$^{a}$ | 47.75±0.38$^{a}$ | 46.46±1.48$^{a}$ | 47.45±1.57$^{a}$ | 44.43±1.21$^{ab}$ | 45.29±0.96$^{a}$ |
| A | 6.48±0.59$^{ab}$ | 5.53±0.51$^{b}$ | 6.58±0.33$^{ab}$ | 7.80±0.40$^{a}$ | 7.24±0.80$^{a}$ | 7.30±0.28$^{a}$ | 6.20±0.42$^{ab}$ | 6.45±0.48$^{ab}$ |
| B | 6.27±0.38$^{bc}$ | 6.67±0.27$^{abc}$ | 7.38±0.31$^{a}$ | 7.52±0.19$^{a}$ | 6.35±0.47$^{bc}$ | 7.08±0.35$^{ab}$ | 6.03±0.09$^{c}$ | 7.33±0.25$^{a}$ |
| L* | 54.80±0.94 | 48.84±0.68 | 54.80±0.82 | 54.86±0.38 | 47.29±5.94 | 54.46±1.57 | 51.52±1.23 | 51.88±1.24 |
| A* | 7.82±0.72$^{ab}$ | 6.87±0.59$^{b}$ | 7.75±0.36$^{ab}$ | 9.19±0.47$^{a}$ | 8.65±1.02$^{ab}$ | 8.69±0.39$^{ab}$ | 7.52±0.43$^{ab}$ | 7.77±0.53$^{ab}$ |
| B* | 8.26±0.55 | 9.26±0.43 | 9.72±0.45 | 9.95±0.26 | 14.24±5.55 | 9.32±0.38 | 8.07±0.12 | 9.91±0.35 |
| Chroma | 11.53±0.56$^{b}$ | 11.63±0.42$^{b}$ | 12.52±0.11$^{ab}$ | 13.56±0.48$^{ab}$ | 17.66±5.19$^{a}$ | 12.82±0.15$^{ab}$ | 11.08±0.20$^{b}$ | 13.04±0.48$^{ab}$ |
| Inner | | | | | | | | |
| L | 41.69±0.80$^{bc}$ | 40.42±0.83$^{c}$ | 45.19±0.74$^{a}$ | 41.40±0.75$^{bc}$ | 43.86±1.11$^{ab}$ | 44.08±0.67$^{ab}$ | 43.04±1.10$^{ab}$ | 42.71±0.64$^{abc}$ |
| A | 9.60±0.84$^{abcd}$ | 8.48±0.52$^{cd}$ | 10.29±0.41$^{abc}$ | 8.78±0.90$^{bcd}$ | 8.31±0.45$^{d}$ | 8.94±0.66$^{abcd}$ | 10.42±0.43$^{ab}$ | 10.80±0.29$^{a}$ |
| B | 5.73±0.47$^{c}$ | 6.83±0.35$^{cde}$ | 7.76±0.39$^{abc}$ | 9.97±0.22$^{bcd}$ | 5.89±0.42$^{de}$ | 8.24±0.55$^{a}$ | 7.05±0.38$^{abcd}$ | 8.14±-.32$^{ab}$ |
| L* | 48.92±0.93$^{abc}$ | 47.39±0.88$^{c}$ | 51.72±0.74$^{a}$ | 48.42±0.78$^{bc}$ | 50.92±1.12$^{ab}$ | 51.40±0.68$^{ab}$ | 51.70±0.32$^{a}$ | 49.86±0.65$^{abc}$ |
| A* | 11.74±1.03$^{abc}$ | 10.49±0.57$^{bc}$ | 12.29±0.44$^{abc}$ | 10.76±1.06$^{bc}$ | 10.09±0.59$^{c}$ | 10.74±0.75$^{bc}$ | 12.57±0.41$^{ab}$ | 13.03±0.30$^{a}$ |
| B* | 7.84±0.66$^{b}$ | 9.70±0.63$^{ab}$ | 10.61±0.58$^{a}$ | 9.73±0.34$^{ab}$ | 8.19±0.68$^{b}$ | 11.38±0.77$^{a}$ | 9.68±0.49$^{ab}$ | 11.44±0.52$^{a}$ |
| Chroma | 14.29±0.90$^{bc}$ | 14.44±0.33$^{bc}$ | 16.27±0.60$^{ab}$ | 14.66±0.79$^{bc}$ | 13.13±0.55$^{c}$ | 15.78±0.75$^{ab}$ | 16.03±0.47$^{ab}$ | 17.62±1.27$^{a}$ |

$^{abcd}$Means along the same row with different superscripts are significantly ($p<0.05$) different. Lightness, A-Redness, B-Yellowness, L*, A* and B* are colour directions, where A* is the red axis, A is the green axis, B* is the yellow axis and B is the blue axis. N/B: Area around the center represents achromatic colours and moving outwards, colour saturation increases

**Table 6: Main effects of housing and dietary inclusion level of *Piper guineense* on meat lipid profile of broiler chickens**

| **Parameters** | **Battery cage** | **Deep litter** | **0 %** | **0.5 %** | **1.0 %** | **1.5 %** |
|---|---|---|---|---|---|---|
| Cholesterol(mg/dL) | 66.98±1.64 | 69.45±2.23 | 68.35±2.53 | 71.08±2.32 | 69. 15±3.2 | 64.28±2.70 |
| Triglyceride(mg/dL) | 114.45±8.88 | 116.85±5.23 | 130.23±12.27 | 116.10±12.45 | 112.95±7.87 | 103.33±2.50 |
| HDL (mg/dL) | 12.01±0.72 | 12.14±0.50 | 13.00±1.24 | 12.60±0.83 | 11.33±0.50 | 11.38±0.60 |
| LDL (mg/dL) | 16.68±1.33 | 17.28±1.71 | 18.58±2.47 | 18.75±2.43 | 14.93±1.86 | 15.65±1.65 |
| VLDL (mg/dL) | 31.60±1.65 | 28.88±1.58 | 30.70±3.52 | 32.10±0.27 | 28.98±1.64 | 29.20±3.09 |

HDL- High density lipoprotein, LDL- low density lipoprotein, VLDL-Very low Density Lipoprotein

**Table 7: Interactive effects of housing type and dietary inclusion level of *Piper guineense* on meat lipid profile of broiler chickens**

| | Battery Cage | | | | Deep Litter | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameters** | **0 %** | **0.5 %** | **1.0 %** | **1.5 %** | **0 %** | **0.5 %** | **1.0 %** | **1.5 %** |
| Cholesterol(mg/dL) | 64.25±1.45 | 68.05±3.35 | 71.80±3.30 | 63.80±3.00 | 72.45±1.65 | 74.10±1.70 | 66.50±6.10 | 64.75±5.85 |
| Triglyceride(mg/dL | 129.05±28.25 | 99.90±1.50 | 124.40±27.70 | 104.45±4.25 | 131.40±10.10 | 126.00±5.40 | 107.80±5.00 | 102.20±4.10 |
| HDL (mg/dL) | 13.35±2.95 | 11.05±1.30 | 11.70±0.90 | 11.50±0.90 | 12.65±0.55 | 13.70±0.10 | 10.95±0.65 | 11.25±1.15 |
| LDL (mg/dL) | 18.95±2.65 | 14.75±1.85 | 16.40±4.00 | 16.60±3.80 | 18.20±5.40 | 22.75±0.05 | 13.45±0.65 | 14.45±0.01 |
| VLDL (mg/dL) | 33.75±2.95 | 31.65±0.05 | 31.75±0.65 | 29.25±7.55 | 27.65±6.85 | 32.55±0.15 | 26.20±0.60 | 29.15±0.55 |

HDL- high density lipoprotein, LDL- low density lipoprotein, VLDL-very low density lipoprotein