Acta Scientiarum
http://periodicos.uem.br/ojs
ISSN on-line: 1807-8672
Doi: 10.4025/actascianimsci.v47i1.70924

Morphometric and thermo-physiological diversity in two chicken genotypes kept by rural farmers under tropical conditions

Elijah Akumbugu Faith[1], Danlami Moses Ogah[1], Abdulmojeed Yakubu[1,2*] and Oladeji Bamidele[3]

[1]Department of Animal Science, Faculty of Agriculture, Nasarawa State University, Keffi, Nasarawa State, Nigeria. [2]Centre for Sustainable Agriculture and Rural Development, Nasarawa State University, Keffi, Nasarawa State, Nigeria. [3]International Livestock Research Institute, Ibadan, Oyo State, Nigeria. *Author for correspondence. E-mail: abdulmojyak@gmail.com; abdulkubu@nsuk.edu.ng

ABSTRACT. This study investigated phenotypic diversity in indigenous normal feathered and Noiler chickens kept by rural farmers in Nasarawa State, Nigeria. A total of 180 birds at six weeks of age, comprising equal sexes were randomly sampled. Body weight, six primary biometric traits, four morphological indices and four thermo-physiological traits were measured on each bird for six months. The general linear model was used to test the fixed and interaction effects of genotype, sex and location on these traits. Noiler birds had higher ($p < 0.05$) morphometric traits and morphological indices than indigenous chickens, except for stockiness. Male birds outperformed their female counterparts in body traits and indices, while location effect was also significant. Heat tolerance traits were similar across genotypes, except for higher pulse rate in Noilers. Female birds appeared more stressed thermally while Nasarawa South birds exhibited higher thermal stress. There were significant ($p < 0.05$) effects of genotype*sex, genotype*location and sex*location interactions on most body parameters, morphological indices and heat tolerance traits. Optimal body weights for both Noiler male and female chickens were predicted at 25.83 and 27.25 weeks. The present findings would provide a basis for the conservation and genetic improvement of both chicken genotypes in Nigeria.

Keywords: Indigenous chickens; body conformation; heat tolerance; prediction; Nigeria.

Received on May 20, 2024.
Accepted on August 10, 2024.

Introduction

Chickens are a veritable animal genetic resource in Sub-Saharan Africa, and their genetic improvement has been identified as one of the sustainable ways of improving productivity with concomitant effect on household income and livelihoods of smallholder poultry farmers. Local African chicken ecotypes have high genetic diversity and have demonstrated the ability to survive persistent exposure to pathogens and harsh environmental conditions (Zidane et al., 2018; Mpenda et al., 2019). Some animals with desirable phenotypes and genotypes (Lozano-Jaramillo et al., 2019; Li et al., 2020) may be more useful than others in the changing environment and in new agro-ecological conditions (Sarker et al., 2014; Kantanen et al., 2015).

In Nigeria, there is an increasing demand for an in-depth evaluation of the natural genetic variation in the indigenous chickens as a criterion for policy formulation on conservation and improvement of livestock germplasm. This, therefore, calls for cost effective techniques to improve traits of interest in the indigenous chickens. An important step in improving the traits of interests for enhanced conservation, and utilisation of the indigenous chicken genetic resources is phenotypic characterization (Ajayi et al., 2012; Laenoi et al., 2015; Al-Atiyat et al., 2017). Phenotypic characterization of animal genetic resources is used to refer to the process of identifying distinct breed populations and describing their characteristics and those of their production environments. The phenotypic characteristics of distinctive breeds, therefore, provide a foundation for developing sustainable genetic improvement strategies (Assefa & Melesse, 2018). Body weight and body parts are phenotypic traits of economic importance (Malomane et al., 2014). Biometric traits have been widely reported to be good predictors of live weight and animal carcasses (Vargas et al., 2020). Chickens may also be characterized based on thermo-physiological characteristics. Among all, thermal/heat stress (HS) is the most concerning issue in the ever-changing climatic scenario, and is one of the most important stressors, especially in the tropical, sub-tropical, arid, and semi-arid regions of the world (Olfati et al., 2018; Al-Tamimi et al., 2019; Nawaz et al., 2021).

Modelling of growth (body weight) of birds is of paramount importance as it can be exploited in breeding and management (Yakubu & Madaki, 2017; Iqbal et al., 2020). Growth models, which are highly heritable, can be used in defining appropriate feeding regimens during the various growth phases (Selvaggi et al., 2015). They are also useful in the improvement of feed conversion achieved primarily by reduction in the growing period, and accomplished by selection for growth rate and feed conversion (Selvaggi et al., 2015; Okoro et al., 2017). All these have implications in the improvement of the profitability of the poultry enterprise.

The chickens native to Nigeria are of special interests due to their contribution to food security and livelihoods of rural households and smallholder farmers, especially women who are the primary keepers of the village chickens (Yakubu et al., 2020). Noiler is a newly developed, improved, dual-purpose breed of chicken in Nigeria (Bamidele et al., 2020). It is a tropically-adapted breed developed specifically for smallholders, to increase production, stimulate higher income, and improve the livelihoods of women and youth, especially within the rural setting. However, there is dearth of information on its phenotypic characterization which may aid future genetic improvement and conservation programmes to boost chicken production in flocks under the management of smallholder farmers. This study, therefore, aimed at characterizing both the normal feathered chickens, and Noiler chickens in Nasarawa State, Nigeria using body weight, biometric and thermo-physiological measurements.

Material and methods

Sampling sites and experimental birds

A total of 180 birds that were six weeks of age (growers) reared by smallholder farmers under similar scavenging management system were randomly sampled in the three senatorial zones (Nasarawa South, Nasarawa North and Nasarawa West) of Nasarawa State, Nigeria (Figure 1). This corresponded to thirty (15 males and 15 females) normal feathered and thirty (15 males and 15 females) Noiler chicken genotypes in each of the sampling sites of Nasarawa South, Nasarawa North and Nasarawa West. The sampling locations corresponded to those used under the African Chicken Genetic Gain (ACGG) project as described in an earlier study (Yakubu et al., 2018). The ethical guidelines approved under the ACGG project (www.africacgg.net) for on-farm study in Nigeria (Yakubu et al., 2020) were strictly adhered to.

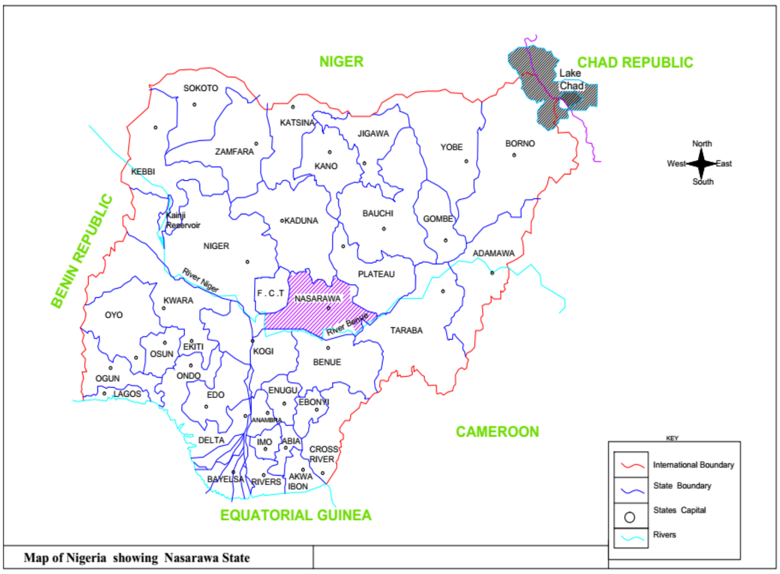

Figure 1. The map of Nigeria showing Nasarawa State.

Body size, biometric and thermo-physiological data collection

Body weight (BW), six primary biometric traits [body length (BL), breast circumference (BC), thigh circumference (TC), foot length (FL), total leg length (TLL) and wing length (WL)], four morphological indices [massiveness (MAS), stockiness (STK), long-leggedness (LL) and condition index (CI)] were measured on each bird every four-weeks for six (6) months (26 weeks) (from 3rd May, 2017 to 20th September, 2017). At the same time, the rectal temperature (RT), pulse rate (PR) and respiratory rate (RR) of birds were taken according to standard methods. The birds were six (6) weeks of age at the start of the 26-week experiment.

Body weight (BW):-10-kg digital measuring scale was used for the individual weight measurement. Body length (BL):-Body length was taken between the tip of the *Rostrum maxillare* (bill) and that of the Cauda (tail, without feathers). Breast circumference (BC):- This was measured under the wings of the birds at the edge of the sternum. Thigh circumference (TC):- It was measured as the circumference of the drumstick at the coxa region. Foot length (FL):- This was measured from the shank joint region to the extremity of the *Digitus pedis*. Total leg length (TLL):- This was measured as the length of the femur, shank and metatarsal. Wing length (WL):- It was measured from the shoulder joint region to the extremity of the terminal phalanx, digit 111. Massiveness (MAS):- The ratio of live body weight to body length × 100. Stockiness (STK):- The ratio of breast circumference to body length × 100. Long leggedness (LLN):- The ratio of total leg length to body length × 100 Condition index (CI):-The ratio of live body weight towing length × 100). The anatomical reference points were as earlier described (Fox et al., 1992; Oblakova, 2007; Teguia et al., 2008).

Rectal Temperature:- This was measured using a clean clinical thermometer inserted into the vent for one minute after which the readings were taken (t˚C). Respiration Rate:- This was recorded by counting for each bird the number of movements of the abdominal region or vent for one minute using a stopwatch as breaths/minute. Pulse Rate: This was recorded through the placement of the finger tips under the wing vein/counting the number of beats per minute using a stop watch as beats/minute (Yahav & McMurtry, 2001). Heat stress index:-The heat stress index (Yakubu et al., 2018) was derived from relationship between the pulse rate and respiratory rate and their normal average values as indicated below:

$$HSI=AR/AP\times(NP/NR)$$

HSI =Heat stress index value;
AR = Average value of respiratory rate;
AP = Average value of pulse rate;
NP = Normal pulse rate value;
NR = Normal respiratory rate value;

Statistical analysis

Using the pooled data of the six months of measurements, the General Linear Model (GLM) of SPSS version 22 (IBM Corporation, 2015) was employed to test the fixed/main effects of genotype (G_i), Sex (S_j) and Location (L_k) as well as their interactions on body traits (BL, BC, TC, FL, TLL and WL), morphological indices (MAS, STK, LL and CI) and thermo-physiological parameters (RT, PR and RR). The below linear model was used:

$$Y_{ijkl} = u + G_i + S_j + L_k + (GS)_{ij} + (GL)_{ik} + (SL)_{jk} + e_{ijkl}$$

where;
Y = individual mean observation;
μ = general mean of the population;
G_i = effect of genotype;
S_j = sex effect;
L_k = effect of location;
$(GS)_{ij}$ = genotype- sex interaction;
$(GL)_{ik}$ = genotype- location interaction;
$(SL)_{jk}$ = sex- location interaction;
e_{ijkl} = error term effect.

The relationships between body weight (kg) of the Noiler and Nigerian indigenous chickens (males and females, respectively) and age at 6, 10, 14, 18, 22 and 26 weeks were also established using linear and quadratic regression models. The linear and quadratic functions fitted were:
Linear model: $Y=bo + b1X + e$
Quadratic model: $Y= bo + b1X + b2X2 + e$
where;
Y = body weight of the birds
b_0 = the intercept
X = age of birds (6, 10, 14, 18, 22, 26 weeks)
b_1 and b_2 = regression coefficients
e = error term.

The slope of the quadratic regression plots ($y = dy\ dx^{-1} = 0$) was used to determine the optimum age in weeks for each production characteristic as described by Dağdemir, Demirand and Macit (2007).

Results and discussion

Effect of genotype on the body weight, biometric traits and morphological indices of chickens reared in the three senatorial zones of Nasarawa State, Nigeria is shown in Table I. Noiler birds recorded higher ($p < 0.05$) body parameters than their indigenous counterparts in terms of body weight and biometric parameters. Noiler birds were also superior ($p < 0.05$) to their normal feathered counterparts as regards massiveness (3.76) and condition index (5.46) with the exception of stockiness. Long-leggedness (78.80) was however higher in normal feathered birds. The higher body parameters of Noiler birds indicate that under similar production system, Noiler chickens are bigger in size. This could be attributed to genetic variation which tends to favour Noiler chickens, thereby making them more suitable for backyard poultry production. However, the relatively small body of the normal feathered birds may be an adaptive mechanism to survive under the resource-poor scavenging conditions in tropical environments. Similar assertion was made by Hassan et al. (2018) in a related study while comparing the brooding performance of five chicken genotypes reared in five Sub-National Zones in Nigeria. The superiority of Noiler birds to their normal feathered counterparts for massiveness and condition index further revealed potential genetic differences. The lower value of long-leggedness for Noiler birds is an indication that they exhibit a blockier appearance, which is a characteristic for meatiness. This is congruous to the submission of Yakubu (2011). The phenotypic diversity observed in this study may provide the basis for conservation and genetic improvement. More so, higher phenotypic variation of traits could be a pointer to a higher genetic difference (Maharani et al., 2019), guaranteeing a sufficient selection response. This is important as a result of human-directed selection on morphological traits (Kingsolver et al*.,* 2001, Bennett et al., 2018). According to Padhi (2016), breeding programmes through selection to improve the performance of backyard chickens is of paramount importance to help rural farmers increase their earnings from poultry and improve food security (Zidane et al., 2018; Zidane et al., 2023).

Table 1. Effect of genotype on the body weight, biometric traits and morphological indices of chickens reared in the three senatorial zones of Nasarawa State, Nigeria.

Parameters	Genotype			
	Normal feathered	CV	Noiler	CV
Body weight (kg)	0.85 ± 0.01^{b}	27.06	1.15 ± 0.01^{a}	20.11
Body length (cm)	24.64 ± 0.11^{b}	10.23	28.62 ± 0.10^{a}	8.08
Breast circumference (cm)	19.45 ± 0.12^{b}	14.13	22.69 ± 0.11^{a}	11.21
Thigh circumference (cm)	8.98 ± 0.07^{b}	17.86	10.79 ± 0.07^{a}	15.01
Foot length (cm)	6.38 ± 0.06^{b}	21.55	7.32 ± 0.06^{a}	18.96
Total leg length (cm)	18.58 ± 0.08^{b}	9.86	19.25 ± 0.08^{a}	9.61
Wing length (cm)	18.76 ± 0.07^{b}	8.55	19.88 ± 0.07^{a}	8.14
Massiveness	3.20 ± 0.04^{b}	28.64	3.76 ± 0.04^{a}	24.61
Stockiness	80.05 ± 0.40^{a}	11.45	80.65 ± 0.40^{a}	11.47
Long-leggedness	78.80 ± 0.27^{a}	7.85	69.81 ± 0.27^{b}	8.95
Condition index	4.20 ± 0.05^{b}	22.27	5.46 ± 0.05^{a}	21.18

[ab]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); CV = coefficient of variation (%).

Effect of sex on the body weight, biometric traits and morphological indices of chickens is presented in Table 2. Except for thigh circumference, which was similar in both sexes, male birds recorded higher ($p < 0.05$) values than their female counterparts in other body parameters. Male birds were superior ($p < 0.05$) to their female counterparts with respect to massiveness (3.65), stockiness (81.14) and condition index (5.03). However, female chickens had higher ($p < 0.05$) long-leggedness (74.90). The higher body size, linear body measurements and morphological indices (massiveness, stockiness and condition index) of male birds could be attributed to sexual dimorphism. It indicates that male birds are more muscular. This is consistent with the report that female chickens are most times significantly smaller than their male counterparts (Brown et al., 2017). The observation on body weight could have been amplified by selection pressure as reported by Maniatis et al. (2013). Growth regulation in chickens is affected by sex-specificity (Johnsson et al., 2018; Vargas et al., 2020). The higher long-leggedness of the female chickens indicates that they have narrower body which is characteristic of good layers. The significant differences in the total leg length and wing length in the present study is an indication that male birds have relatively longer legs and wing length than their female counterparts. The shorter legs of females were associated with small body size and could be exploited in minimizing the demand for work and power (Rose et al., 2016). The sexual dimorphism observed in the present study may aid sexual selection and facilitate understanding of eco-evolutionary dynamics (Fryxell et al., 2019) considering the selective adaptive advantage of sex in response to environmental stressors (Geffroy & Dou, 2019).

Table 2. Effect of sex on the body weight, biometric traits and morphological indices of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

Parameters	Sex			
	Male	CV	Female	CV
Body weight (kg)	$1.06±0.01^{a}$	21.59	$0.93±0.01^{b}$	24.89
Body length (cm)	$26.87±0.11^{a}$	9.37	$26.40±0.11^{b}$	9.65
Breast circumference (cm)	$21.58±0.12^{a}$	12.73	$20.56±0.11^{b}$	12.39
Thigh circumference (cm)	$9.96±0.07^{a}$	16.09	$9.81±0.07^{a}$	16.52
Foot length (cm)	$7.07±0.06^{a}$	19.43	$6.64±0.06^{b}$	20.92
Total leg length (cm)	$19.05±0.08^{a}$	9.61	$18.78±0.08^{b}$	9.86
Wing length (cm)	$19.50±0.07^{a}$	8.21	$19.14±0.07^{b}$	8.47
Massiveness	$3.65±0.04^{a}$	25.08	$3.311±0.04^{b}$	27.98
Stockiness	$81.14±0.40^{a}$	11.28	$79.56±0.40^{b}$	11.64
Long-leggedness	$73.71±0.27^{b}$	8.38	$74.90±0.27^{a}$	8.35
Condition index	$5.03±0.05^{a}$	22.75	$4.62±0.05^{b}$	25.05

^{ab}Means within same rows bearing different superscripts are significantly different ($p < 0.05$); CV = coefficient of variation (%).

Effect of location on the body weight, biometric traits and morphological indices of chickens is shown in Table 3. The birds in Nasarawa West recorded the highest (1.03) body weight ($p < 0.05$) although they were not statistically different from those of Nasarawa South. The highest body length was recorded for birds in Nasarawa South and North whereas the lowest was recorded for Nasarawa West. The birds in Nasarawa South and West recorded the highest ($p < 0.05$) breast circumference. The highest ($p < 0.05$) thigh circumference was recorded for birds in Nasarawa South (10.09). Birds in Nasarawa Northand South recorded the highest ($p < 0.05$) result for foot length. The highest ($p < 0.05$) total leg length was observedfor birds in Nasarawa North. Birds in Nasarawa south recorded the highest ($p < 0.05$) wing length compared to the other senatorial zones. For morphological indices, the birds in Nasarawa West recorded higher ($p < 0.05$) values for massiveness (3.69) and condition index (5.14); the results for stockiness were higher ($p < 0.05$) in both Nasarawa South and West. The birds in Nasarawa South and *p* <West were also superior ($p < 0.05$) to those in NasarawaNorth in terms of long-leggedness. The differences observed in traits based on location could be due to the micro environmental variation. Such heterogeneity in the production environments had earlier been reported for birds in five agro-ecological zones of Nigeria (Yakubu et al., 2020). Although there were some linear body measurements and morphological indices more favourable to one location than the other, it is quite difficult to rate one environment as better than the other. This implies that both indigenous normal feathered and Noiler birds can adapt to the prevailing tropical environmental conditions in Nasarawa State, Nigeria.

Table 3. Effect of location on the body weight, biometric traits and morphological indices of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

Parameters	Location					
	NS	CV	NN	CV	NW	CV
Body weight (kg)	$0.99±0.02^{ab}$	37.31	$0.98±0.02^{b}$	38.67	$1.03±0.02^{a}$	36.83
Body length (cm)	$26.80±0.13^{a}$	8.96	$26.77±0.13^{a}$	9.20	$26.34±0.13^{b}$	9.36
Breast circumference (cm)	$21.55±0.14^{a}$	12.00	$19.82±0.14^{b}$	13.39	$21.83±0.14^{a}$	12.17
Thigh circumference (cm)	$10.09±0.09^{a}$	16.47	$9.75±0.08^{b}$	15.84	$9.83±0.82^{b}$	15.44
Foot length (cm)	$6.70±0.07^{b}$	19.30	$6.93±0.07^{a}$	21.88	$6.94±0.07^{a}$	19.13
Total leg length (cm)	$18.83±0.10^{b}$	9.80	$19.24±0.10^{a}$	9.85	$18.69±0.10^{b}$	10.15
Wing length (cm)	$19.83±0.09^{a}$	8.38	$19.34±0.08^{b}$	7.84	$18.80±0.08^{c}$	8.07
Massiveness	$3.39±0.05^{b}$	27.24	$3.36±0.04^{b}$	22.56	$3.69±0.04^{a}$	20.56
Stockiness	$82.41±0.50^{a}$	11.21	$76.31±0.49^{b}$	12.17	$82.34±0.48^{a}$	11.05
Long-leggedness	$73.427±0.34^{b}$	8.56	$75.59±0.33^{a}$	8.27	$73.90±0.33^{b}$	8.47
Condition index	$4.58±0.07^{c}$	28.23	$4.76±0.06^{b}$	23.89	$5.14±0 .06^{a}$	22.14

^{abc}Means within same rows bearing different superscripts are significantly different ($p < 0.05$); NS = Nasarawa South; NN = Nasarawa North; NW = Nasarawa West; CV = coefficient of variation (%).

Effect of genotype on the thermo-physiological traits of chickens is shown in Table 4. The values for rectal temperature, respiratory rate and heat stress index were not significant ($p > 0.05$) for both genotypes. However, the pulse rate was significantly ($p < 0.05$) higher (131.90) in Noiler birds compared to normal feathered birds. The increased pulse rate in Noiler birds is an indication that they have the tendency to be more stressed. It has been reported that elevated temperature and high relative humidity could result in heat stress which could lead to elevated pulse rate (Ayo et al., 2011). In the present study, the values of other thermo-physiological parameters other than pulse rate indicate the ability of the two genotypes to cope with the vagaries of weather in Nasarawa State found within the tropical guinea savanna zone of Nigeria. According to Isidahomen et al. (2012), the possession of genes for adaptability might have aided birds in withstanding harsh environmental conditions. The importance of thermo-physiological parameters in assessing stress has also been reported in chickens (Adedeji et al., 2015; Yakubu et al., 2018).

Table 4. Effect of genotype on the thermo-physiological traits of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

	Genotype			
Parameters	Normal feathered	CV	Noiler	CV
Rectal temperature (°C)	42.01±0.21[a]	1.09	42.06±0.21[a]	1.10
Pulse rate ([1]bpm)	131.90±0.29[a]	5.04	130.43±0.29[b]	5.14
Respiratory rate ([2]bpm)	29.92±0.05[a]	3.83	29.80±0.05[a]	3.88
Heat stress index	1.90±0.01[a]	12.06	1.91±0.01[a]	12.11

[ab]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); [1]bpm = beats per minute; [2]bpm = breaths per minute; CV = coefficient of variation (%).

Effect of sex on the thermo-physiological traits of chickens is shown in Table 5. The pulse rate (130.15) and the respiratory rate (30.18) were significantly ($p < 0.05$) higher in female birds compared to their male counterparts. The female birds also recorded higher ($p < 0.05$) heat stress index value (1.93) compared to their male counterparts. However, rectal temperature was not influenced ($p < 0.05$) by sex. Increase in respiratory rate could be as a result of greater demand for oxygen as well as evaporative cooling requirements. The observation on pulse rate is congruous with the findings of Espinha et al. (2014) where higher pulse rate was recorded in females than males. In contrast, Mutibvu et al. (2017) reported higher pulse rate in male free-range chickens. The high heat stress index in female birds indicates that they are more prone to stress and may therefore elicit different homeostatic responses compared to their male counterparts. The heat stress index values observed generally in this study are congruous with those reported by El-Gendy et al. (2007) and Adedeji et al. (2015).

Table 5. Effect of sex on the thermo-physiological traits of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

	Sex			
Parameters	Male	CV	Female	CV
Rectal temperature (°C)	42.06±0.02[a]	1.09	42.01±0.02[a]	1.10
Pulse rate ([1]bpm)	129.16±0.29[b]	5.14	130.15±0.29[a]	5.16
Respiratory rate ([2]bpm)	29.54±0.05[b]	3.87	30.18±0.05[a]	3.84
Heat stress index	1.91±0.01[b]	11.98	1.93±0.01[a]	11.99

[ab]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); [1]bpm = beats per minute; [2]bpm = breaths per minute; CV = coefficient of variation (%).

Effect of location on the thermo-physiological traits of chickens was significant ($p < 0.05$) (Table 6). Birds in Nasarawa North and West recorded higher ($p < 0.05$) rectaltemperature compared to those of Nasarawa South. Pulse rate was higher ($p < 0.05$) for birds in Nasarawa West and South compared to those in Nasarawa North. The highest ($p < 0.05$) respiratory rate (30.39) and heat stress index (1.93) were recorded for birds in Nasarawa South. In locations of higher stress, there is a need for the adoption of modern managerial and environmental strategies to mitigate thermal discomfort (Nawal et al., 2021).

Table 6. Effect of location on the thermo-physiological traits of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

	Location					
Parameters	NS	CV	NN	CV	NW	CV
Rectal temperature (°C)	41.94±0.03[b]	1.32	42.11±0.03[a]	1.34	42.05±0.03[a]	1.35
Pulse rate ([1]bpm)	131.60±0.36[a]	5.05	130.43±0.35[b]	5.08	131.46±0.36[a]	5.19
Respiratory rate ([2]bpm)	30.39±0.07[a]	4.25	29.34±0.06[c]	3.87	29.85±0.06[b]	3.81
Heat stress index	1.93±0.01[a]	9.57	1.88±0.01[c]	10.07	1.90±0.01[b]	9.98

[abc]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); [1]bpm = beats per minute; [2]bpm = breaths per minute; NS = Nasarawa South; NN = Nasarawa North; NW = Nasarawa West; CV = coefficient of variation (%).

Genotype and Sex interaction effect on body parameters (except body weight, body length andfoot length) and morphological indices (except massiveness) of chickens was significant ($p < 0.05$) (Table 7). In terms of breast circumference, male birds in both Normal feathered and Noiler chickens recorded higher values. Interaction effect on thigh circumference was only evident in normal feathered birds with higher value (9.20) recorded for the males. However, only Noiler males had higher values thantheir female counterparts with regard to total leg length (19.67), wing length (20.17) and stockiness (82.18). With respect to long-leggedness, the value was higher (80.69) in female Normal feathered but lower (69.10) in female Noiler chickens. Male birds in both Normal feathered and Noiler chickens recorded higher values (4.49 and 5.58, respectively) with respect to condition index. The present findings are in consonance with the report of Yakubu and Ari (2018) where genotype * sex interaction indicated that strains performed differently in both sexes as regards those characteristics that were significantly influenced. In another study, the interaction between genotype and sex was observed for body weight at weeks 4 and 10 of age (El-Henfnawy et al., 2022)

Table 7. Genotype and Sex interaction effect on body weight, biometric traits and morphological indices of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

	Normal feathered			Noiler		
Parameters	Male	Female	CV	Male	Female	CV
Body weight (kg)	0.93±0.02[a]	0.77±0.02[a]	2.43	1.200±0.02[a]	1.09±0.02[a]	2.41
Body length (cm)	24.89±0.15[a]	24.41±0.15[a]	33.26	28.84±0.15[a]	28.40±0.15[a]	32.94
Breast circumference (cm)	19.76±0.17[a]	19.13±0.16[b]	24.27	23.39±0.16[a]	21.99±0.16[b]	24.04
Thigh circumference (cm)	9.20±0.10[a]	8.76±0.10[b]	12.05	10.72±0.10[a]	10.86±0.10[a]	11.93
Foot length (cm)	6.60±0.08[a]	6.16±0.08[a]	8.25	7.55±0.08[a]	7.10±0.08[a]	8.17
Total leg length (cm)	18.44±0.12[a]	18.73±0.12[a]	15.06	19.67±0.12[a]	18.84±0.12[b]	14.92
Wing length (cm)	18.84±0.10[a]	18.69±0.10[a]	16.41	20.17±0.10[a]	19.59±0.10[b]	16.26
Massiveness	3.40±0.05[a]	3.00±0.05[a]	5.11	3.90±0.05[a]	3.62±0.05[a]	5.06
Stockiness	80.10±0.58[a]	80.01±056[a]	50.50	82.18±0.56[a]	79.13±0.56[b]	50.02
Long-leggedness	76.90±0.39[b]	80.69±0.38[a]	51.51	70.52±0.38[a]	69.10±0.38[b]	51.02
Condition index	4.49±0.08[a]	3.91±0.07[b]	8.64	5.58±0.07[a]	5.33±0.07[b]	8.56

[ab]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); CV = coefficient of variation (%).

Genotype and location interaction effect on body parameters and morphological indices was significant ($p < 0.05$) (Table 8). In normal feathered birds, body weight was higher in NS (1.50), followed by NW and NN. However, body weight was higher in both NW (1.50) and NN (1.47) as regards Noiler birds. Body length followed a similar trendwith body weight with respect to normal feathered chickenswhile in Noiler, it was longer in NN followed by NW andNS. Breast circumference was higher (26.66) in NS (normal feathered) while in Noiler, birds in NW recorded the highest value (27.99). Thigh circumference followed a similar trend with body length (normal feathered) while in Noiler, the trend was similar to body weight. With respect to footlength, the highest value (8.09) was recorded in NS (normal feathered) while the least (5.30) was observed in NS (Noiler).Total leg length was also higher (22.47) in NS among the normal feathered chickens while in Noiler, the highest value (21.63) was obtained in NN. For normal feathered, NS birds recorded the highest value (24.03) in wing length, whereas, in Noiler chickens, the least value (15.65) was observed inNS. Massiveness was higher in NS (4.24) (normal feathered)and NW (4.54) (Noiler). However, the same pattern was observed in both stockiness and long-leggedness with the highest values recorded for NN followed by NW and NS in male chickens. However, in their female counterparts, the highest values were recorded for NS followed by NW and NN, respectively. The highest condition index was observed in NS (6.14) in normal feathered birds; whereas, NS was least (3.03) in Noiler chickens. According to de Kinderen et al. (2023), different strains may be best suited for different agro-ecologies. The present information on Nigerian indigenous chickens may be useful in breeding and selection decisions with respect to the genotype that is best suited to a particular location. However, such decisions should equally take into account other performance indices and farmers' trait preferences (Terfa et al., 2019; Yakubu et al., 2020).

There was significant ($p < 0.05$) sex and location interaction effect on body weight, biometric traits (except body length and breast circumference) and morphological indices (except stockiness) of chickens (Table 9). Among the males, body weight was highest in NS (1.11) whereas in females, the highest value (1.00) was recorded in NW. As regards thigh circumference, its effect was only evident among females where highest value (10.21) was observed in NS. Foot length was highest in NW (7.38, Males) and NN (6.90, females). The effect of total leg length was also evident in female chickens found in NN. Wing length was highest in NS (19.98, males) and NS (19.69) and NN (19.48) (females). The value for massiveness was highest in both NS (3.70) and NW (3.77) in males while in females, massiveness was highest in NW (3.62) and stockiness highest in both NS and NW. Long-leggedness was found to be highest in NW (75.11) in males and NN (78.33) in females. The interaction effect on condition index was only evident in females with highest value recorded in NW (5.15). The present findings are in agreement with the report of Markos et al. (2024), where sex-by-chicken ecotype interaction affected the measured morphometric traits. In a related study, Bamidele et al. (2023) ported that the interaction effect of location and sex was evident on body weight.

Table 8. Genotype and Location interaction effect on body weight (kg), biometric traits (cm) and morphological indices of chicken reared in the three senatorial zones of Nasarawa State, Nigeria

	Normal feathered				Noiler			
Parameters	NS	NN	NW	CV	NS	NN	NW	CV
Body weight	1.50±0.02[a]	0.48±0.02[c]	0.56±0.02[b]	1.35	0.47±0.02[b]	1.47±0.02[a]	1.50±0.02[a]	1.34
Body length	35.10±0.19[a]	19.09±0.18[c]	19.75±0.18[b]	10.49	18.49±0.18[c]	34.44±0.18[a]	32.93±0.1[b]	10.39
Breast circumference	26.66±0.21[a]	16.00±0.20[b]	15.678±0.20[b]	11.83	16.43±0.20[c]	23.65±0.20[a]	27.99±0.20[b]	11.72
Thigh circumference	12.39±0.12[a]	7.03±0.12[c]	7.52±0.12[b]	6.94	7.78±0.12[b]	12.45±0.12[a]	12.13±0.12[a]	6.87
Foot length	8.09±0.11[a]	5.50±0.10[b]	5.54±0.10[b]	5.98	5.30±0.10[b]	8.35±0.10[a]	8.33±0.10[a]	5.92
Total leg length	22.47±0.15[a]	16.84±0.14[b]	16.43±0.14[c]	9.01	15.19±0.15[c]	21.63±0.14[a]	20.94±0.14[b]	8.92
Wing length	24.03±0.13[a]	16.77±0.12[b]	15.50±0.12[c]	7.51	15.65±0.12[b]	21.90±0.12[a]	22.08±0.12[a]	7.44
Massiveness	4.24±0.07[a]	2.51±0.06[c]	2.85±0.06[b]	3.77	2.53±0.06[c]	4.21±0.06[b]	4.54±0.06[a]	3.74
Stockiness	75.95±0.72[c]	84.40±0.68[a]	79.81±0.68[b]	40.94	88.87±0.69[a]	68.22±0.68[c]	84.86±0.68[b]	40.55
Long-leggedness	64.56±0.48[c]	88.29±0.46[a]	83.55±0.46[b]	30.88	82.30±0.47[a]	62.89±0.46[c]	64.25±0.46[b]	30.59
Condition index	6.14±0.09[a]	2.89±0.09[c]	3.56±0.09[b]	5.41	3.03±0.09[b]	6.62±0.09[a]	6.72±0.09[a]	5.36

[abc]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); NS = Nasarawa South; NN = Nasarawa North; NW = Nasarawa West; CV = coefficient of variation (%).

Table 9. Sex and Location interaction effect on body weight (kg), biometric traits (cm) and morphological indices of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

	Male				Female			
Parameters	NS	NN	NW	CV	NS	NN	NW	CV
Body weight	1.11±0.02[a]	1.02±0.02[b]	1.06±0.02[ab]	2.53	0.87±0.02[b]	0.93±0.02[b]	1.00±0.02[a]	2.51
Body length	27.11±0.19[a]	26.88±0.18[a]	26.60±0.18[a]	34.64	26.49±0.18[a]	26.65±0.18[a]	26.08±0.18[a]	34.25
Breast circumference	22.16±0.21[a]	20.09±0.20[a]	22.48±0.20[a]	25.21	20.94±0.20[a]	19.56±0.20[a]	21.19±0.20[a]	24.92
Thigh circumference	9.97±0.12[a]	10.03±0.12[a]	9.88±0.12[a]	12.71	10.21±0.12[a]	9.46±0.12[b]	9.77±0.12[b]	12.57
Foot length	6.88±0.11[b]	6.95±0.10[b]	7.38±0.10[a]	8.52	6.51±0.10[b]	6.90±0.10[a]	6.50±0.10[b]	8.42
Total leg length	19.11±0.15[a]	18.96±0.14[a]	19.09±0.14[a]	15.20	18.55±0.14[b]	19.51±0.14[a]	18.29±0.14[b]	15.03
Wing length	19.98±0.13[a]	19.19±0.12[b]	19.34±0.12[b]	16.56	19.69±0.12[a]	19.48±0.12[a]	18.25±0.12[b]	16.37
Massiveness	3.70±0.07[a]	3.48±0.06[b]	3.77±0.06[a]	5.22	3.07±0.06[b]	3.24±0.06[b]	3.62±0.06[a]	5.16
Stockiness	83.40±0.72[a]	76.21±0.68[a]	83.82±0.68[a]	48.93	81.42±0.69[a]	76.42±0.69[a]	80.86±0.68[a]	48.38
Long-leggedness	73.19±0.48[b]	72.84±0.46[b]	75.11±0.46[a]	55.18	73.67±0.46[b]	78.33±0.46[a]	72.69±0.46[b]	54.16
Condition index	4.95±0.09[a]	4.95±0.09[a]	5.13±0.09[a]	9.00	4.14±0.09[c]	4.57±0.09[b]	5.15±0.09[a]	8.90

[abc]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); NS = Nasarawa South; NN = Nasarawa North; NW = Nasarawa West; CV = coefficient of variation (%).

Genotype and Sex interaction effect on thermo-physiological traits of chickens was significant ($p < 0.05$) except for rectal temperature (Table 10). Pulse rate and respiratory rate were higher in females than males. Also, heat stress index was higher in female Noiler chickens whereas the sexes were statistically the same ($p > 0.05$) in their normal feathered counterparts. The differential responses of the sexes in the two genotypes of the current study may be attributed to inherent sex differences as a result of evolutionary causes while another possible reason could be the different stress related selection pressures the birds were subjected to (Elfwing et al., 2015). In a related study, Adedeji et al. (2015) reported significant genotype and sex interaction with respect to rectal temperature, pulse rate, respiratory rate and heat stress index. In the study of Adedeji et al. (2015), the female birds were also found to more stressed.

Table 10. Genotype and Sex interaction effect on thermo-physiological traits of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

	Normal feathered			Noiler		
Parameters	Male	Female	CV	Male	Female	CV
Rectal temperature(°C)	42.06±0.03[a]	41.97±0.03[a]	2.14	42.06±0.03[a]	42.05±0.03[a]	2.12
Pulse rate ([1]bpm)	130.72±0.41[b]	132.79±0.40[a]	33.48	127.33±0.40[b]	133.62±0.4[a]	32.12
Respiratory rate ([2]bpm)	29.66±0.08[b]	30.15±0.07[a]	5.89	29.40±0.07[b]	30.21±0.07[a]	5.84
Heat stress index	1.89±0.01[a]	1.89±0.08[a]	0.57	1.92±0.01[a]	1.88±0.01[b]	0.56

[ab]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); [1]bpm = beats per minute; [2]bpm = breaths per minute; CV = coefficient of variation (%).

Effect of genotype and location interaction on thermo-physiological traits of chickens was significant with the exception of rectal temperature ($p < 0.05$) (Table 11). Pulse rate was highest in NW (135.29, Normal feathered) and NS (134.75, Noiler). Respiratory rate was also highest in NW (30.29, Normal feathered) as well as in NS (30.84, Noiler). However, the highest heat stress index was recorded in NS (1.95) for Normal feathered birds and NW (1.92) and NS (1.90) for Noiler chickens. These results indicate the genetic potential of the indigenous stock as tropically adapted birds. This is in consonance with earlier reports on genetic basis of thermal stress response (Felver-Gant et al., 2012; Rojas-Downing et al., 2017; Menchetti et al., 2024) including single genes of major effect as well as complex multigenic control (Lamont et al., 2014).

Table 11. Genotype and Location interaction effect on thermo-physiological traits of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

	Normal feathered				Noiler			
Parameters	NS	NN	NW	CV	NS	NN	NW	CV
Rectal temperature (°C)	41.90±0.21[a]	42.12±0.21[a]	42.02±0.21[a]	2.12	41.97±0.03[a]	42.10±0.03[a]	42.08±0.03[a]	2.10
Pulse rate ([1]bpm)	128.07±0.29[c]	131.89±0.29[b]	135.29±0.29[a]	31.38	134.75±0.36[a]	129.03±0.35[b]	127.63±0.36[c]	31.09
Respiratory rate([2]bpm)	29.89±0.05[b]	29.54±0.05[c]	30.29±0.05[a]	5.54	30.84±0.07[a]	29.15±0.06[c]	29.41±0.06[b]	5.49
Heat stress index	1.95±0.01[a]	1.86±0.01[b]	1.87±0.01[b]	0.55	1.90±0.01[ab]	1.89±0.01[b]	1.92±0.01[a]	0.54

[abc]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); NS = Nasarawa South; NN = Nasarawa North; NW = Nasarawa West; [1]bpm = beats per minute; [2]bpm = breaths per minute; CV = coefficient of variation (%).

Sex and location interaction effect on thermo-physiological traits of chickens was significant ($p < 0.05$) (Table 12). The lowest value of rectal temperature was recorded among males in NS (41.92) while among Noilers, lowest values were observed in NS (41.97) and NW (41.96). As regards pulse rate, it was highest in NS (130.05) and NN (129.28) (Males) and in NW (135.18) (Females). Respiratory rate was lowest in NN (29.14, Males) and NN (29.55, Females). However, the highest heat stress index was recorded in NW among males and in NS among female birds. It was not possible to compare our findings with others due to dearth of information in literature.

Table 12. Sex and Location interaction effect on thermo-physiological traits of chicken reared in the three senatorial zones of Nasarawa State, Nigeria.

	Male				Female			
Parameters	NS	NN	NW	CV	NS	NN	NW	CV
Rectal temperature (°C)	41.92±0.38[b]	42.11±0.38[a]	42.14±0.38[a]	2.11	41.97±0.38[b]	42.11±0.38[a]	41.96±0.38[b]	2.09
Pulse rate ([1]bpm)	130.05±0.52[a]	129.28±0.49[a]	127.74±0.49[b]	32.46	132.78±0.50[b]	131.65±0.49[b]	135.18±0.49[a]	32.10
Respiratory rate ([2]bpm)	29.77±0.10[a]	29.14±0.09[b]	29.67±0.09[a]	5.55	30.97±0.09[a]	29.55±0.09[a]	30.03±0.09[b]	5.49
Heat stress index	1.91±0.01[b]	1.88±0.01[c]	1.94±0.01[a]	0.55	1.94±0.01[a]	1.87±0.01[b]	1.85±0.01[b]	0.55

[abc]Means within same rows bearing different superscripts are significantly different ($p < 0.05$); [1]bpm = beats per minute, [2]bpm = breaths per minute; NS = Nasarawa South; NN = Nasarawa North; NW = Nasarawa West; CV= coefficient of variation (%).

Regression models for the prediction of body weight from the age of Noiler and Nigerian indigenous normal feathered chicken are presented in Table 13. The predictions were for both linear and quadratic functions. However, the quadratic function appeared to predict better body weight from age. This is due to the higher coefficient of determination ($R^{2)}$ and its Adjusted ($R^{2)}$ as well as lower root mean square error (RMSE) values (Table 13). The body weight of both Noiler male and Female chickens from the quadratic functions were predicted at optimal ages of 25.83 and 27.25 weeks, respectively while the optimal age for the body weight for Normal feathered male and female chickens investigated were not available (NA) and this could be as a result of the zero level of Age^2 (Table 13). Modelling body weight from age provides an insight in the understanding of growth status of the birds. In order to authenticate a regression function, the coefficient of determination (R^2) is often taken (Olaniyan et al., 2017). It is a reflection of the amount of variation in the Y-values that is explained by the regression line. In this wise, R^2 as depicted in the quadratic model of the present study indicated that 76.6, 79.2, 64.0 and 60.9% of the variability between body weight and age have been accounted for. The current values especially those of the Noiler birds appear high enough and reliable in predicting the body weight from age. However, they are lower than the values reported by Yakubu and Madaki (2017) where the prediction of body weight from age (weeks) using quadratic model gave R^2 and adjusted R^2 values of 0.852 and 0.852, respectively. The present information on body weight prediction is useful especially under the management conditions of smallholder farmers, where weighing scale is not readily available (Negash, 2021).

Table 13. Regression models for the prediction of body weight from the age of Noiler and Nigerian indigenous normal feathered chicken.

Equation	Optimal age	R^2	Adj. R^2	RMSE	P-value
Body weight (Noiler male)					
BW=0.773+0.052Age		0.676	0.675	0.247	0.001
BW=0.096+0.155Age-0.003Age^2	25.83	0.766	0.764	0.210	0.001
Body weight (Noiler female)					
BW=0.620+0.048Age		0.751	0.750	0.188	0.001
BW=0.221+0.109Age-0.002Age^2	27.25	0.792	0.791	0.172	0.001
Body weight (Normal feathered male)					
BW=0.224+0.019Age		0.639	0.638	0.098	0.001
BW=0.195+0.023Age-0.000Age^2	NA	0.640	0.637	0.098	0.001
Body weight (Normal feathered female)					
BW=0.221+0.017Age		0.608	0.607	0.096	0.001
BW=0.201+0.020Age-0.000Age^2	NA	0.609	0.606	0.096	0.001

NA, not available due to zero level of Age^2; R^2, coefficient of determination; Adj, adjusted; RMSE, root mean square error.

Conclusion

Noiler birds recorded higher values than their indigenous normal feathered counterparts in terms of body weight, biometric parameters and morphological indices such as massiveness, long-leggedness and condition index. There were marked sexual differences in the morphological measurements with male birds being superior to their female counterparts. Despite the fact that there were some morphometric traits and morphological indices more favourable to one location than the other, it was quite difficult to arrive at the best zone for chicken rearing in Nasarawa State. Increased pulse rate in Noiler birds compared to their normal feathered counterpart is an indication that the former had the tendency to be more stressed. Female birds appeared to be more stressed considering the pulse rate, respiratory rate and heat stress index. The genotype and sex, genotype and location and sex and location interactions influenced most body parameters, indices and thermo-physiological traits. The body weight of both Noiler male and female chickens from the quadratic functions were predicted at optimal ages of 25.83 and 27.25 weeks. Phenotypic variations of Nigerian indigenous normal feathered and Noiler chicken resources indicate diversity that may provide opportunity for better understanding of the ecology, selection, improvement and conservation of the chicken populations.

Acknowledgements

This study was supported by the MSc. postgraduate study fellowship (2017-2019) awarded to the first author by the African Chicken Genetic Gains-Nigeria (ACGG-NG) project (Grant Agreement OPP1112198). We are grateful to Prof. E.B. Sonaiya, Principal Investigator (PI) and the Co-PI, Prof. Mrs O.A. Adebambo of ACGG-NG project including Dr. Tadelle Dessie (ACGG International Program Leader).

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