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Genotypic differences in body weight and physiological response of local and exotic turkeys challenged with *Salmonella typhimurium*

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Abstract

To better understand susceptibility and/ or tolerance of locally adapted turkey to salmonellosis, we compared bodyweight, antibody titres and physiological traits based on genotype and sex of *salmonella*-infected turkeys. Three hundred poults from two genotypes (160 local and 140 exotic turkeys) were raised for twenty weeks. Bodyweight (BW), rectal temperature (RT), pulse rate (PR) and respiratory rate (RR) were measured weekly. Blood samples were collected from each turkey before inoculation as control and after inoculations at week 8 and 13 for serum antibody detection using an enzyme-linked immunosorbent assay. Exotic turkey had a higher weight ($p < 0.05$) than local while sexual dimorphism was in favour of toms despite the challenge with *Salmonella typhimurium*. The RT was significantly higher ($p < 0.05$) in exotic turkeys except at week 2, 6 and 8. In like manner, PR was higher ($p < 0.05$) in exotic turkey except at week 4 (204.3 ± 2.48 beats/minutes) and 8 (217.0 ± 1.46 beats/minutes) where it was higher in local turkey. RR also followed the same trend while Heat stress index (HSI) was higher ($p < 0.05$) in week 2 (1.5 ± 0.06 breaths/minutes) and 14 (1.2 ± 0.07 breaths/minutes) in exotic turkeys. Local turkeys had higher ($p < 0.05$) antibodies against Salmonella organisms before and after inoculation while the hens of both genotypes had higher ($p < 0.05$) antibody titres on the 7^{th} day after inoculations. The present results seemed not to be convincing enough to suggest differences in tolerance/susceptibility to Salmonella infection and therefore the two genotypes may be equally adapted.

Keywords: Antibody titre, genotypes, heat stress index, pulse rate, rectal temperature, respiratory rate

1 Introduction

The ability of an animal to survive and reproduce optimally within a given environment is called its adaptability (Barker, 2009). While tolerance may be defined as an organism's capacity to survive variation in extremes of environmental conditions such as temperature, humidity, cold and so on, adaptation on the other hand is the biological mechanism or evolutionary process by which organisms adjust to or better suited to the environment or changes in their current environment. This biological mechanism includes inherent genetic variations which are being shaped by selection and various demographic forces within an environment (Boothby, 2019; Gaughan *et al*., 2019). Adaptations are commonly defined as evolved solutions to recurrent environmental problems of survival and reproduction. The rate of adaptive evolution to changing environments depends on characteristics of the environment in terms of complexity, speed, and severity of environmental change and characteristics of the species of interest; population size and generation interval (Whitehead *et al*., 2017; Ho & Zhang, 2018). The ability of animals to adapt to their environment differs between and within species, breeds and strains, as a result of genetic variation through natural and artificial selections (Ilori *et al*., 2011). Thus, individual differences commonly arise through both heritable and non-heritable adaptive behaviour. Several physiological responses or heat tolerance traits including rectal temperature (RT), pulse rate (PR) and

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respiratory rate (RR) are some of the most important determinants of adaptation of poultry to tropical environments (Ilori *et al*., 2011; Ijadunola *et al*., 2020). This is probably because the relationship between PR and RR will give an index that will indicate whether an animal is heat stressed or not in its environment (Adedeji *et al*., 2015; Yakubu *et al*., 2018). Heat stress can exert negative effects on livability, production performance, immune functions and disease susceptibility in poultry. Animals generally and birds in particular need to be in homeostasis with their environment for optimum production through the maintenance of thermobalance (Zerjal *et al*., 2013; Ijadunola, 2020). This is because heat stress may result from exposure to high ambient temperature or from the inability to dissipate the metabolically generated heat (Adedeji *et al*., 2015). High ambient temperature and relative humidity have been reported to increase heat stress and are responsible for the increase in rectal/body temperature (RT) of animals (Sobolewski *et al*., 2021). Also, heat stress has been reported to affect both cell-mediated and humoral immunity in chickens and has been explored mostly through assaying phagocytic activities and serum antibody titers (Niu *et al*., 2009).

However, aside from heat stress, disease tolerance and resistance are strong determinants of survivability and productivity of any livestock species in the tropics characterised by a high rate of infectious diseases. Bacterial infections are the most common and abundant poultry diseases in the tropics. Bacterial diseases that affect poultry are apparent in turkey and they include *Eschericha coli*, Fowl cholera, Infectious coryza, Mycoplasms and Salmonellosis (Oboh & Igene, 2006). According to Ricardo (2011), Salmonellosis, a zoonotic disease is one of the most threatening bacterial diseases in the poultry industry, probably because it causes economic losses through mortality, morbidity and reduction in egg production while provoking food poisoning in human (Shivaprasad 2000; Ricardo 2011; Hesse *et al*., 2018). In poultry, exclusively two serotypes of Salmonella are recognised to produce clinical Salmonellosis: *Salmonella gallinarum* and *S. pullorum*, named 'Fowl Typhoid' and 'Pullorum Disease', respectively (Ricardo, 2011). Pullorum disease and fowl typhoid are infectious, acute or chronic bacterial diseases affecting primarily chickens and turkeys. They may cause food born disease in human resulting from infections from contaminated animal products and have become a global issue of public health concern. Intensive rearing and high-density flocks of commercial poultry have increased exposure to diseases (Adamu *et al*., 2013; Yakubu *et al*., 2018), whereas Nigerian indigenous turkey is known for its high potential adaptive superiority in terms of their tolerance to endemic diseases and other severe environmental conditions. The Nigerian indigenous turkey is adaptable to a wide range of climatic conditions and can be successfully raised almost anywhere provided they are well fed and protected against diseases, predators, and adverse weather conditions. This livestock species occupies an important position next to chicken, duck and guinea fowl in contributing to the protein needs of our growing population and is of considerable economic and social significance in the tradition of Nigerians (Peters *et al*., 1997; Ilori *et al*., 2011; 2018; Folorunsho *et al*., 2018; Ilori *et al*., 2019). Exotic turkeys have been selected for many production traits and are peculiar and commercially preferred for their body weight and early maturity, however, they are highly susceptible to diseases (Huff *et al*., 2005), and show poor adaptation to harsh and low input conditions of the tropical environment (Ilori *et al*., 2010; 2011; Adeyemi & Oseni, 2018; Folorunsho *et al*., 2018).

Several approaches are being used by farmers to prevent and ameliorate heat stress and disease infection in their flocks. The conventional method includes the use of temperature-controlled housing facilities and the use of antibiotics, vaccines and other drugs to salvage or prevent the flock from disease infection. However, these have been reported to be expensive and unaffordable for small scale farmers while the use of antibiotics causes residues in poultry products (Tirawattanawanich *et al*., 2011; Liu *et al*., 2016). Singh (1999) suggested that a potential countermeasure to adverse effects of heat stress is the genetic selection for heat-tolerant genes while both genetic improvement and better management practices have been suggested as an alternative approach to infectious diseases prevention in the tropics (Yakubu *et al*., 2013; Muhsinin *et al*., 2016). Diseases rarely occur in all members of animal populations exposed to pathogens majorly due to genetic differences among other factors which imply that some animals possess natural abilities to resist disease infection (Caron *et al*., 2013). Therefore, it becomes necessary to develop a genetic line of turkey that can adapt to the tropical environment with the least compromise in terms of meat production and immune performance. For optimum turkey production in Nigeria, in addition to a good management system, a turkey breed with genetic potential for early maturity, higher body weight and strong adaptability is required. Therefore, this study aimed to compare the adaptability of local and exotic turkey genotypes inoculated with the Salmonella disease vaccine.

2 Materials and methods

2.1 Description of the experimental site

This research work was carried out at the Turkey Breeding Unit of the Directorate of University Farms (DUFARMS),

Federal University of Agriculture, Abeokuta, Ogun state Nigeria. The farm location is 76 m above sea level and falls within latitude N 7°14'37" E 3°20'35" in Odeda Local Government area of Ogun State, Nigeria and experiences approximately eight months of rainfall (usually from March to October), with a mean annual precipitation of 1,037 mm. The monthly ambient temperature ranges from 25.1 °C in August to 29.1 °C in March with a mean relative humidity of 82 % (Google Earth, 2017; Ilori *et al*., 2018). The experiment was carried out between November 2017 and April 2018 and the prevailing environmental condition is as presented in Table S1 (annex).

2.2 Experimental birds and management

A total of three hundred (300) turkeys comprising one hundred and sixty Nigerian indigenous (74 males; 86 females) and one hundred and forty (67 males; 73 females) Nicholas white (exotic) turkeys were used for the study. A large foundation stock of Nigerian indigenous turkey was established at the Poultry Breeding Unit from which the poults used for the study were generated. The exotic turkeys, on the other hand, were sourced from Obasanjo Farm, the country representative of Nicholas white brand of Aviagen Turkey Ltd Lewisburg, West Virginia, USA. The poults were vaccinated against Marek's , Newcastle and infectious bronchitis diseases at day old from the hatchery. Subsequent vaccinations including, the Newcastle disease vaccine and the Fowlpox vaccine were given at the appropriate time. The poults were brooded for four weeks, during which adequate heat, ventilation, medication and feeding were provided. Commercial feeds were provided for the birds at the different stages of growth *ad libitum*. Starter mash of 28 % crude protein (CP), grower mash containing 24 % CP and finisher mash of 20 % CP were fed to the birds from 0 to 6, 7 to 16 and 17 to 20 weeks, respectively. Clean and cool water was also supplied *ad libitum* to the turkeys as described in Ilori *et al*. (2018) while antibiotics were administered as prophylactic as required. The two genotypes were reared separately in deep litter pens; wing tagged for proper identification and subjected to the same management practices throughout the experimental period of 20 weeks. The birds were tagged male or female at 8 weeks of age when distinct physical sexual characteristics were obvious. The design of the experiment is such that each turkey served as a replicate in the experiment while the two groups; local and exotic turkey were reared separately in different pens. Before the birds were inoculated with the Salmonella disease vaccine, blood samples from the two groups were taken for antibody titre and served as the control for antibody titres comparison. Growth traits and physiological responses were compared between the two challenged groups.

2.3 Inoculation with Salmonella disease vaccine

At 8 weeks of age, the turkeys were inoculated with Salmonella disease vaccine which was sourced from National Veterinary Research Institute, Vom, Plateau State, Nigeria, through subcutaneous injection of Salmonella disease vaccine at 0.5 ml (LD_{50}) per turkey as recommended by the manufacturer. This process was repeated after 5 weeks when the experimental turkeys were 13 week-old to compare pre and post inoculations antibody titres of the turkey to *Salmonella* infection.

2.4 Data collection

Data collected included:

Bodyweight: This was measured weekly using a weighing balance scale with a sensitivity of 0.01 g.

Measurement of physiological traits: Pulse rate, rectal temperature and respiratory rate of each bird were taken twice a day at 7.00 h in the morning and 17.00 h in the evening as described by Oladimeji *et al*. (1996) and Ilori *et al*. (2011). The measurement of rectal temperature took less than 10 seconds while respiratory rate and pulse rate were measured in 15 seconds each and multiplied by 4 to get the values of each trait in 1 minute. The total time of handling each bird was less than 60 seconds to avoid stress on the birds that might affect their well-being and growth. The duration of data collection was also put into consideration. The data were collected once every week for 20 weeks. Care was taken to minimize stress on birds while collecting the data while the procedures used were approved by the Animal Welfare and Use Committee of the Federal University of Agriculture, Abeokuta, Nigeria.

Pulse rate was measured by placing fingertips under wing vein and estimating the number of beats per minute using a stopwatch while the *rectal temperature* was measured using a clean clinical thermometer inserted about 3 cm deep into the rectum via the cloaca until an alarm sound indicated the end of the reading (T °C).

The *respiratory rate* was determined for each bird by estimating the number of movements of the abdominal region or vent for one minute using a stopwatch and recorded as breaths/minute.

Heat stress index was calculated from the relationship between observed pulse rate and respiratory rate together with their normal values using the formula according to Oladimeji *et al*. (1996) as follow:

$$H = AR/AP \times NP/NR$$

Where: H = Heat stress index; AR = Observed respiratory rate; AP = Observed pulse rate; NP = Normal pulse rate = 128 beats/minutes (Quizlet 2019); NR = Normal respiratory rate = 38.5 breaths/minutes (Quizlet, 2019).

2.5 Blood collection

Blood samples were collected once before inoculation (at 7^{th} week as baseline) and on the 2^{nd} and 7^{th} days after the first as well as the second inoculations. About 1 ml of blood was collected from each experimental bird, using a sterile needle and syringe into a well-labelled plain bottle and allowed to coagulate to obtain the serum for slide agglutination test (using Widal test indicator serum) and to determine the level of antibodies against Salmonella.

2.5.1 Slide agglutination test

On a slide containing blood sera of the experimental birds, 2 or 3 drops of saline were added and the test colony picked from the serum obtained from turkeys' blood was thoroughly mixed with the saline. To this mixture, 1 drop of Widal test-positive indicator serum was added. The formation of clumps confirmed the presence of Salmonella.

2.5.2 Detection of serum antibodies

Serum samples used to evaluate antibody response were obtained from each bird by collecting 1 ml whole blood before inoculation and at 2 and 7 days post-inoculations and were then stored at –20 °C until use. Antibody titre against Salmonella was determined by using commercially-available antibody test kits Salm Gp B BioChek following the manufacturer's instructions to detect antibodies against Lipopolysaccharides (LPS)-antigen of the Salmonella serogroup B (including serovar *Salmonella typhimurium*) according to the Kauffmann-White scheme (Grimont & Weil, 2007).

2.6 Statistical analysis

The General Linear Model (GLM) of the SAS 9.0 software (SAS Institute Inc., Cary, NC, USA) was used to determine the effect of genotype, sex and their interaction on body weight and physiological traits. Antibody titres against *Salmonella* were transformed using logarithmic transformation ($Log_{10}x+1$) and thereafter analysed for the effect of genotype, sex and their interaction using the same software. The model is as follow:

$$H_{ijk} = \mu + G_i + S_j + C_k + GS_{ij} + GC_{ik} + \epsilon_{ijk}$$

Where: Y_{ijk} is the traits measured (physiological, body weight, antibody titre); μ is the overall mean for the parameters of interest; G_i is the effect of ith genotype (i = local, exotic); S_j is the effect of j^{th} sex (j = male, female); C_k is the effect of pre and post-inoculation k^{th} period of measurement ($k = 1, 2, 3, 4, 5$); GS_{ij} is the effect of i^{th} genotype and j^{th} sex interaction; GC_{ik} is the effect of i^{th} genotypes and pre and post-inoculation k^{th} periods of measurement; and ϵ_{ijk} is the experimental error.

Means with significant differences were separated using the least significant difference ($p < 0.05$) of the same software. Preliminary analysis on mortality rate in the turkey flock was not significant and therefore not included in subsequent analysis.

3 Results

3.1 Effect of genotype on body weight (BW) and physiological traits of challenged turkey

Genotype had a significant ($p < 0.05$) effect on body weight and physiological traits of the challenged bird (Table 1). The body weight of turkeys increased as their age increased with exotic genotype consistently having the higher ($p < 0.05$) body weight throughout the experiment. The body weights of local and exotic turkeys ranged from 82.76 ± 1.73 g and 85.50 ± 1.75 g at week 1 to 3017.75 ± 64.07 g and 6565.20 ± 64.56 g at week 20 respectively.

Also, the rectal temperature (RT) was significantly affected ($p < 0.05$) by turkey genotype except at week 4, 16 and 20. The rectal temperature range for exotic turkey was between 40.57 ± 0.14 °C at week 1 and 41.60 ± 0.05 °C at week 12 while that of local turkey ranged from 40.14 ± 0.14 °C at week 1 to 41.50 ± 0.05 °C at week 6. The RT was significantly higher ($p < 0.05$) in exotic turkeys at weeks 1 (40.57 ± 0.14 °C), 12 (41.60 ± 0.05 °C), 14 (41.43 ± 0.05 °C) and 18 (41.36 ± 0.06 °C). The local turkey significantly had higher PR of 204.28 ± 2.48 and 216.98 ± 1.46 at week 2 and 6 respectively while the exotic turkey had the highest PR of 203.25 ± 1.82, 207.87 ± 1.92 and 208.37 ± 1.03 beats/minute at week 16, 18 and 20 respectively. Genotype had a significant effect ($p < 0.05$) on the respiratory rate of turkey at weeks 1, 2, 10 and 14. At week 10, the RR of local turkey was significantly higher ($p < 0.05$) than that of exotic turkey (Table 2) whereas at week 14, the RR of exotic turkey was significantly higher ($p < 0.05$) than that of local turkey.

Similarly, the heat stress index (HSI) was significantly affected ($p < 0.05$) by the turkey genotype. The HSI for exotic turkey ranges from 0.71 ± 0.03 at week 10 to 1.53 ± 0.06 at week 2 whereas that of local turkey ranges from 0.78 ± 0.02 at week 6 to 1.57 ± 0.05 at week 1 (Table 2).

Table 1: *Effect of genotype on body weight and physiological traits of challenged turkeys (Least Squares Means (LSM) ± SE)*

Age (weeks)	*Genotype*	*Body weight (g)*	*Rectal temperature (°C)*	*Pulse rate (beats/mins)*	*Respiratory rate (breath/mins)*	*Heat stress (HSI)*
1	Local	82.76 ± 1.73	40.14 ± 0.14^{b}	181.13 ± 3.11	82.57 ± 1.78^{a}	1.57 ± 0.05^{a}
	Exotic	85.50 ± 1.75	40.57 ± 0.14^{a}	186.12 ± 3.14	70.07 ± 1.78^{b}	1.32 ± 0.04^{b}
2	Local	130.02 ± 3.06^{b}	41.35 ± 0.05^{a}	178.44 ± 4.39	62.32 ± 1.52^{b}	1.22 ± 0.05^{b}
	Exotic	142.56 ± 3.08^{a}	40.59 ± 0.05^{b}	171.67 ± 4.42	71.58 ± 1.53^{a}	1.53 ± 0.06^{a}
4	Local	269.89 ± 6.98^{b}	40.58 ± 0.42	204.28 ± 2.48^{a}	60.67 ± 1.66	1.01 ± 0.03
	Exotic	359.99 ± 7.04^{a}	41.22 ± 0.43	193.25 ± 2.50^{b}	57.66 ± 1.67	1.00 ± 0.03
6	Local	538.92 ± 14.07^{b}	41.50 ± 0.05^{a}	212.40 ± 1.81	50.43 ± 1.75	0.78 ± 0.02
	Exotic	727.92 ± 14.17^{a}	41.09 ± 0.05^{b}	207.84 ± 1.82	51.38 ± 1.77	0.82 ± 0.03
8	Local	798.44 ± 24.40^{b}	41.29 ± 0.06^{a}	216.98 ± 1.46^{a}	68.82 ± 2.85	1.04 ± 0.04
	Exotic	1209.71 ± 24.59^{a}	41.09 ± 0.06^{b}	211.46 ± 1.47^{b}	63.15 ± 2.87	0.98 ± 0.03
10	Local	1023.21 ± 34.21^{b}	41.09 ± 0.05	200.89 ± 3.33	67.72 ± 2.37^{a}	1.28 ± 0.16^{a}
	Exotic	1568.20 ± 34.46^{a}	41.14 ± 0.05	208.50 ± 3.36	45.14 ± 2.40^{b}	0.71 ± 0.03^{b}
12	Local	1018.79 ± 38.31^{b}	41.35 ± 0.05^{b}	224.17 ± 18.48	68.78 ± 3.49	1.12 ± 0.08
	Exotic	1993.80 ± 38.61^{a}	41.60 ± 0.05^{a}	194.91 ± 18.61	67.01 ± 3.52	1.14 ± 0.06
14	Local	1420.94 ± 52.77^{b}	41.17 ± 0.05^{b}	201.91 ± 1.81	48.74 ± 2.81^{b}	0.81 ± 0.03^{b}
	Exotic	2814.70 ± 53.18^{a}	41.43 ± 0.05^{a}	198.85 ± 1.82	71.22 ± 2.84^{a}	1.17 ± 0.07^{a}
16	Local	1853.67 ± 60.44^{b}	41.45 ± 0.05	196.24 ± 1.81^{b}	62.32 ± 2.86	1.06 ± 0.05
	Exotic	3877.76 ± 60.91^{a}	41.45 ± 0.05	203.25 ± 1.82^{a}	65.75 ± 2.88	1.07 ± 0.05
18	Local	2367.83 ± 65.46^{b}	41.18 ± 0.06^{b}	195.20 ± 1.91^{b}	58.10 ± 1.84	1.00 ± 0.04
	Exotic	5138.28 ± 65.96^{a}	41.36 ± 0.06^{a}	207.87 ± 1.92^{a}	62.21 ± 1.85	0.99 ± 0.03
20	Local	3017.75 ± 64.07^{b}	41.45 ± 0.06	201.50 ± 1.02^{b}	66.26 ± 1.35	1.09 ± 0.02^{a}
	Exotic	6565.20 ± 64.56^{a}	41.40 ± 0.06	208.37 ± 1.03^{a}	64.48 ± 1.36	1.02 ± 0.02^{b}

^{ab}: means in the same column of the same age group with different superscripts (a, b) are significantly different ($p < 0.05$).
Exotic: Nicholas white turkey genotype; Local: Nigerian indigenous turkey genotype.

3.2 Effect of sex on body weight and physiological response of challenged turkey

Table 2 shows the results of the effect of the sex of turkey on body weight (BW) and physiological responses. Sexual dimorphism in the current study favoured males (toms) of both genotypes. The toms had higher ($p < 0.05$) body weight than their female (hens) counterparts throughout the experimental period. The average body weight at the 20th week was 5450.46 ± 67.91 g for male and 4132.49 ± 60.50 g for female turkey.

Rectal temperature was only significantly affected at week 1 and 8 (Table 2). The rectal temperature for both sexes ranges from 40.12 ± 0.13 °C at week 1 in female to 41.49 ± 0.05 °C at week 12 in male. Except at week 10, sex had no significant effect ($p > 0.05$) on the PR of turkey. Furthermore, the RR was significantly influenced ($p < 0.05$ by turkey sex only at week 2 and 8 with the female having the higher RR of 68.95 ± 1.44 (breath/mins) at week 2 while male had higher value (70.00 ± 3.02 (breath/mins) at week 8.

3.3 Bodyweight and physiological response as affected by genotype by sex interaction of challenged turkeys

The weights of turkeys in the current study were significantly affected ($p < 0.05$) by the interaction of genotype and sex of the turkeys as shown in Table S2. Males of both local and exotic turkey genotypes had consistently higher ($p < 0.05$) weights. However, exotic tom had the highest weight followed by its hen, local male while the least was observed in the local hen turkey (Table S2).

Except at week 18, the rectal temperature (RT) was not significantly affected ($p > 0.05$) by genotype and sex interaction of turkeys. The mean RT values for male and female of both genotypes at 18th week was 41.45 ± 0.08 °C for female exotic turkey, 41.31 ± 0.08 °C for male local turkey, 41.27 ± 0.09 °C for male exotic turkey and 41.05 ± 0.08 °C for female local turkey. Except at the 20^{th} week, the heat stress index (HIS) of turkey was not significantly affected ($p > 0.05$) by genotype and sex interaction. In the 20^{th} week, the female local genotype had the highest HSI mean value (1.13 ± 0.03) and the female exotic turkey the least value (1.00 ± 0.03).

Table 2: *Effect of sex on body weight, rectal temperature, pulse rate and respiratory rate of challenged turkeys (LSM ± SE)*

Age (weeks)	*Sex*	*Body weight (g)*	*Rectal temperature (°C)*	*Pulse rate (beats/mins)*	*Respiratory rate (breath/mins)*	*Heat stress (HSI)*
1	M	90.34 ± 1.84^{a}	40.58 ± 0.15^{a}	180.77 ± 3.30	74.05 ± 1.88	1.39 ± 0.04
	F	77.92 ± 1.64^{b}	40.12 ± 0.13^{b}	186.48 ± 2.94	78.59 ± 1.68	1.43 ± 0.04
2	M	147.33 ± 3.24^{a}	40.97 ± 0.06	172.27 ± 4.65	64.95 ± 1.61^{b}	1.34 ± 0.07
	F	125.25 ± 2.89^{b}	40.97 ± 0.05	177.84 ± 4.14	68.95 ± 1.44^{a}	1.36 ± 0.05
4	M	338.42 ± 7.40^{a}	40.55 ± 0.45	199.58 ± 2.63	59.90 ± 1.76	1.00 ± 0.03
	F	291.55 ± 6.60^{b}	41.25 ± 0.40	197.95 ± 2.34	58.42 ± 1.56	1.00 ± 0.03
6	M	695.13 ± 14.91^{a}	41.24 ± 0.05	208.74 ± 1.92	49.63 ± 1.86	0.79 ± 0.03
	F	571.71 ± 13.29^{b}	41.34 ± 0.04	211.50 ± 1.71	52.18 ± 1.65	0.82 ± 0.02
8	M	1127.04 ± 25.87^{a}	41.08 ± 0.06^{b}	214.98 ± 1.55	70.00 ± 3.02^{a}	1.08 ± 0.06
	F	881.10 ± 23.05^{b}	41.30 ± 0.06^{a}	213.47 ± 1.38	61.97 ± 2.69^{b}	0.96 ± 0.03
10	M	1467.88 ± 36.26^{a}	41.06 ± 0.05	209.66 ± 3.53^{a}	57.97 ± 2.51	0.93 ± 0.05
	F	1123.53 ± 32.30^{b}	41.17 ± 0.05	199.72 ± 3.15^{b}	54.89 ± 2.25	1.05 ± 0.17
12	M	1685.98 ± 40.61^{a}	41.49 ± 0.05	195.15 ± 19.58	72.51 ± 3.70	1.28 ± 0.10^{a}
	F	1326.61 ± 36.18^{b}	41.46 ± 0.05	223.92 ± 17.45	63.28 ± 3.29	1.04 ± 0.51^{b}
14	M	2419.63 ± 55.94^{a}	41.28 ± 0.05	200.21 ± 1.91	64.08 ± 2.98	1.08 ± 0.07^{a}
	F	1816.01 ± 49.84^{b}	41.31 ± 0.05	200.55 ± 1.71	55.88 ± 2.66	1.94 ± 0.05^{b}
16	M	3253.13 ± 64.07^{a}	41.48 ± 0.05	199.52 ± 1.92	66.53 ± 3.03	1.12 ± 0.06
	F	2478.31 ± 57.08^{b}	41.48 ± 0.05	199.97 ± 1.71	61.54 ± 2.70	1.03 ± 0.04
18	M	4268.54 ± 69.38^{a}	41.29 ± 0.06	203.46 ± 2.02	61.30 ± 1.95	1.01 ± 0.04
	F	3237.56 ± 61.82^{b}	41.25 ± 0.05	199.61 ± 1.80	59.01 ± 1.74	0.99 ± 0.03
20	M	5450.46 ± 67.91^{a}	41.43 ± 0.06	206.05 ± 1.09	65.43 ± 1.43	1.06 ± 0.03
	F	4132.49 ± 60.50^{b}	41.43 ± 0.06	203.82 ± 0.97	65.31 ± 1.28	1.07 ± 0.02

^{ab}: means in the same column of the same age group with different superscripts (a, b) are significantly different ($p < 0.05$).
Exotic: Nicholas white turkey genotype; Local: Nigerian indigenous turkey genotype.

Table 3: *Effect of genotype on antibody titres of turkey before and after inoculated with Salmonella disease vaccine.*

	*1**	*2*	*3*	*4*	*5*
Local	0.36 $\pm 0.02^{a}$	0.38 $\pm 0.02^{a}$	0.45 $\pm 0.03^{a}$	0.41 $\pm 0.03^{a}$	0.43 $\pm 0.03^{a}$
Exotic	0.24 $\pm 0.01^{b}$	0.26 $\pm 0.01^{b}$	0.26 $\pm 0.01^{b}$	0.28 $\pm 0.01^{b}$	0.29 $\pm 0.01^{b}$

*1: Antibody titres of turkeys before inoculation; 2: Antibody titres of turkeys 2^{nd} day after the first inoculation; 3: Antibody titres of turkeys 7^{th} day after the first inoculation; 4: Antibody titres of turkeys 2^{nd} day after second inoculation and 5: Antibody titres of turkeys 7^{th} day after the second inoculation.
Means in the same row with different superscripts (a,b) are significantly different ($p < 0.05$).

Table 4: *Effect of sex on antibody titres of turkey before and after inoculated with Salmonella disease vaccine.*

Sex	*1**	*2*	*3*	*4*	*5*
Male	0.32 ± 0.03	0.34 ± 0.03	0.35 ± 0.02	0.36 ± 0.03	0.36 ± 0.03
Female	0.28 ± 0.02	0.31 ± 0.02	0.35 ± 0.03	0.33 ± 0.02	0.35 ± 0.02

*1: Antibody titres of turkeys before inoculation; 2: Antibody titres of turkeys 2^{nd} day after the first inoculation; 3: Antibody titres of turkeys 7^{th} day after the first inoculation; 4: Antibody titres of turkeys 2^{nd} day after second inoculation and 5: Antibody titres of turkeys 7^{th} day after the second inoculation.

3.4 Antibody titres of turkey as affected by genotype, sex and their interactions: before and after inoculation with Salmonella disease vaccine

The effects of genotype on antibody titres of turkey inoculated with Salmonella disease vaccine as presented in Table 3 shows that antibodies of turkeys were significantly affected ($p < 0.05$) by turkey genotype both before and after inoculation. The local turkey consistently had a higher antibody titre than the exotic turkey genotype, both before and after inoculations.

Table 4 revealed no significant effect ($p > 0.05$) of sex on antibody titres of turkey. Genotype by sex interaction had no significant ($p > 0.05$) effect on antibodies of turkey inoculated with Salmonella disease vaccine as shown in Table S3 except on the 2^{nd} day after the second inoculation, with local

Table 5: *Effect of sex on antibody titres of turkey before and after inoculated with Salmonella disease vaccine.*

Genotype	*Sex*	*1**	*2*	*3*	*4*	*5*
Local	Male	0.38 ± 0.04^{a}	0.40 ± 0.04^{a}	0.43 ± 0.03^{a}	0.45 ± 0.04^{a}	0.43 ± 0.04^{a}
	Female	0.34 ± 0.02^{b}	0.37 ± 0.03^{ab}	0.47 ± 0.04^{a}	0.38 ± 0.03^{ab}	0.43 ± 0.04^{ab}
Exotic	Male	0.25 ± 0.01^{a}	0.26 ± 0.02^{a}	0.25 ± 0.01^{a}	0.26 ± 0.01^{a}	0.27 ± 0.02^{a}
	Female	0.24 ± 0.01^{b}	0.26 ± 0.01^{ab}	0.26 ± 0.02^{ab}	0.29 ± 0.01^{a}	0.30 ± 0.01^{a}

*1: Antibody titres of turkeys before inoculation; 2: Antibody titres of turkeys 2^{nd} day after the first inoculation; 3: Antibody titres of turkeys 7^{th} day after the first inoculation; 4: Antibody titres of turkeys 2^{nd} day after second inoculation and 5: Antibody titres of turkeys 7^{th} day after the second inoculation.
Means in the same row with different superscripts (a,b) are significantly different ($p < 0.05$)

tom having the highest titre followed by the local hen, exotic hen while the least was observed in the exotic tom.

3.5 Antibody titres of local and exotic turkeys as affected by sampling time

The antibody levels of toms of both genotypes were not significantly affected ($p > 0.05$) by sampling time (before and after inoculation) (Table 5). However, antibody levels of hens of both genotype were significantly influenced ($p < 0.05$). The antibody level of the local hen significantly increased from 0.34 ± 0.02 before inoculation to 0.47 ± 0.04 on the 7^{th} day after the first inoculation. Also, the antibody levels of hen of exotic turkey consistently increased from 0.24 ± 0.01 before inoculation to 0.30 ± 0.01 on the 7^{th} day after the second inoculation.

4 Discussion

Adaptation of turkey to the tropical environment depends among other factors on the environmental conditions and physiological response of the birds. This is because the physiological function of any livestock is dependent on environmental and genetic factors.

The significant effect of genotype on bodyweight is in line with previous findings (Ilori *et al*., 2010; Adeoye *et al*., 2017; Folorunsho *et al*., 2018) that the bodyweight of exotic turkey was significantly higher than that of local and crossbred genotypes and this despite challenge with *Salmonella*. However, body weights of both local and exotic turkeys at 20 weeks (after inoculation) were generally higher than those earlier reported by Ilori *et al*. (2010) where local turkey weighed 2.869 ± 46.08 kg, and exotic turkey 4.485 ± 52.07 kg at 20 weeks of age. These are a bit lower than the ones reported at 24 weeks of age (3.29 ± 0.61 kg and 8.37 ± 1.72 kg) for indigenous and exotic turkey respectively in southwest Nigeria (Adeoye *et al*., 2017). These higher body weights as reported at 20 week in our study might not directly indicate that the turkey was immune to Salmonella but rather may be attributed to improvement in these turkeys, better management practices or differences in stock used. Despite the inoculation with the *Salmonella* vaccine, there still existed the occurrence of sexual dimorphism for body weight as it always the case for poultry. This has earlier been reported in poultry in favour of males being attributed to the differences in hormonal profile (Burke, 1994; Hancock *et al*., 1995; Deeb & Cahaner, 2001; Ilori *et al*., 2010). Dudusola *et al*. (2020) also reported occurrence of sexual dimorphism in favour of male turkey of both indigenous and exotic turkey compared to their female counterparts. However, hens of the exotic turkey genotype had higher body weight than the local toms right from the 4th week of age despite the hormonal differences (Baeza *et al*., 2001). This is owed to the fact that the exotic turkey had generally been selected for improved growth potential while the local turkey had only undergone natural selection for survival (Ilori *et al*., 2010, 2011; Dudusola *et al*., 2020).

Both local and exotic turkey genotypes had a rectal temperature (RT) within the normal range (40.05 °C - 41.5 °C) reported by Ngongeh (2017) on chicken and 40.2 °C to 41.3 °C reported in locally adapted turkey in Nigeria (Ilori *et al*., 2011; Nosike *et al*., 2018). The higher RT recorded from the 12^{th} week to the 18th week in the exotic turkey genotype may be a result of metabolic heat generated due to improved body weight compared to the local counterpart. High ambient temperature and relative humidity are responsible for the increase in rectal/body temperature (RT) of animals. The local turkey, however, had a higher RT post-inoculation compared to the earlier reported (Ilori *et al*., 2011; Nosike *et al*., 2018) in turkey without any disease challenge. Variation in RT among these genetic groups of Salmonella-infected turkeys with other immune response traits can be exploited in the selection of locally adapted turkey for Salmonella disease.

The pulse rate (PR) was higher in both genotypes in those weeks where there were corresponding higher RT. This might be due to birds panting to dissipate heat as the RT increases. PR for both local and exotic turkey genotypes

fluctuated weekly post-inoculation, which could be attributed to the effect of external factors such as temperature and/or Salmonella challenge. However, the PRs of exotic turkeys were higher than that of local turkeys as their body weight geometrically increased especially post-inoculation from the 16th week of age. This is expected because the metabolic activities of an animal have a direct relationship with its body size and residual heat produced in the body, suggesting that, as the body size of the exotic turkey more distinctly increases, metabolic activities also increase which could also bring about an increase in body temperature and hence, the increase in pulse rates.

Generally, the RR for both local and exotic turkey genotypes in the current study was in the range reported by Ilori *et al*. (2011) in turkey. One of the factors that could be responsible for the disturbance of the thermal balance of birds for example high RR is a change in RT and an increase in ambient temperature. This is because birds pant more to lose heat as the ambient temperature increases which are accompanied by an increase in RRs (Lin *et al*. 2005; Ilori *et al*. 2011). This invariably can result in a stressor on an animal which in turn affect the adaptability and productivity of such animal.

Despite the challenge with the Salmonella organism, HSI in this study falls within the range reported in turkey in our previous study (Ilori *et al*., 2011; Yakubu *et al*., 2012). The HSI of exotic turkey genotype was almost at the same range as that of local turkey genotype pre and post-inoculations. White feather colour as seen in the exotic turkey has been reported to radiate and dissipate heat better than the black or lavender colour of the local turkey genotype (Lucas & Marcos 2013; Ilori *et al*., 2019). Variation in physiological traits in the two genotypes in response to *Salmonella* could be exploited in the development of appropriate genotype for improved turkey production in Nigeria.

Despite Salmonella challenge to the turkey, there was still evidence of sexual dimorphism for physiological traits. The higher, RT, PR and RR in males may be attributed to higher body weights and increased activities of males than in females (Lucas & Marcos, 2013). In the same vein, the HSI between male and female turkeys as observed in this study was almost within the same range as reported in previous studies without disease challenge (Ilori *et al*., 2011; Yakubu *et al*., 2012). Higher HSI at week 12 and 14 in male turkeys is expected due to high PR and RR experienced in male turkeys at this period.

The consistently higher antibody titre in local compared to exotic turkey is expected because local turkeys had only been naturally selected to adapt to the tropical environments (Ilori *et al*., 2010) that are characterized by a high rate of infectious diseases, low input and harsh weather conditions and are therefore able to mount a stronger innate and cell-mediated immune response against *Salmonella* infection. Since the immunity is inversely related to production, therefore, the exotic turkeys are not as adapted as local turkeys in terms of immunity against tropical infections. The antibodies of both genotypes increased rapidly after inoculation with the Salmonella disease vaccine. The increase in antibody response to Salmonella organisms after inoculations suggests that rapid antibody response to infection might be an important component in protection against Salmonella (Lee *et al*., 1981; Brito *et al*., 1993). The existence of differences is an indication that the two breeds can be ranked differently in response to a challenge from Salmonella. However, this might not be enough basis for classifying the breeds as tolerant or susceptible to Salmonella infection.

The non-significant effect of sex on antibody titre against *Salmonella* infection is similar to the report of Ahmed (2015) that the sex of chicken had no significant effect on their antibody titre against Newcastle disease. Kaiser *et al*. (1998) reported that the main effect of sex was not significant on the antibodies against Salmonella in broiler breeder chicks. However, the higher antibody titres among the toms than the hens suggest the better ability of turkey tom to respond to invasion by Salmonella organisms by generating a larger number of antibodies against Salmonella. This may be attributed to hormonal differences in the two sexes especially reproductive hormone in the female that is capable of suppressing immunity. Likewise, the non-significant effect of genotype by sex interaction on antibody titre against Salmonella may also imply that either the tom or hen of local and exotic turkeys before inoculation and early post-inoculation have the potential to generate antibodies against infectious diseases such as Salmonella. However, as infection persists, the local turkey was able to mount a better immune response suggesting local turkeys can adapt and survive better than both sexes of exotic turkeys in a disease prevailing environment such as we have in the tropics.

Although sampling times (before and after inoculation with Salmonella vaccine) had no significant effect on the toms of both genotypes, the antibody levels of the toms of both genotypes began to rise from the second day after inoculation with the Salmonella vaccine. This implies that the toms of both genotypes are seroprotected from the second day of inoculation and this persists throughout the periods examined after inoculations. This result agreed with the report of Ambrosch *et al*. (2004) that ELISA antibody titres showed a rapid increase after vaccination with a virosomal hepatitis vaccine and suggested that rapid antibody response might be an important component of protection against Salmonella (Brito *et al*., 1993). The significant ef-

fect of sampling time on the hens of both genotypes may be attributed to genetic differences between the hens. However, this is not enough to ascertain that the differences in the response of both genotypes is due to genetic differences but can form part of the facts which can be used to separate the two hens into different immune lines.

5 Conclusion and recommendation

The exotic turkey had a higher body weight than the local turkey however, the physiological traits varied between local and exotic turkey with local turkey showing better adaptability in terms of RT, PR and RR than exotic turkeys. Antibody levels against Salmonella were raised quicker and were higher in local turkey than in exotic turkey, which confirmed the better ability of local turkey to mount a quick response against *Salmonella* and resist infectious diseases. The present information may guide appropriate management practices to ameliorate the detrimental effect of infectious disease challenge and heat stress in the tropics. Variations observed in this study therefore could provide good insights and genetic basis for turkey breed development in terms of growth performance and better adaptation to the tropical environment.

Supplement

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Compliance with ethical standards

The manuscript does not contain clinical studies or patient data.

Statement of animal rights

All the protocols for this research were approved by the Animal Care and Use Committee of the Federal University of Agriculture, Abeokuta, Nigeria.

Conflict of interest

The authors declare that they have no conflict of interests.

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