Polymorphism of the NRAMP1 gene association with haematological and physiological parameters of chickens inoculated with attenuated *Salmonella enteritidis*

Oluwatobi Elijah Ojua[1], Temitope Oyeyemi Adegboyega[2], Abdulrahmon Adedire Bamgbose[1], Tosin Ademola Adedeji[1] & Abimbola Deborah Matt-Obabu[2]

[1] Department of Animal Production and Health, P.M.B. 4000, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria

[2] Department of Animal Nutrition and Biotechnology, P.M.B. 4000, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria

Correspondence: Abimbola Deborah Matt-Obabu, Department of Animal Nutrition and Biotechnology, P.M.B. 4000, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria. E-mail: abimboladeborah3103@gmail.com

Received: November 12, 2025 DOI: 10.14295/bjs.v5i2.832

Accepted: January 05, 2026 URL: https://doi.org/10.14295/bjs.v5i2.832

Abstract

Poultry production is plagued by many severe diseases, one of which is salmonellosis. Treatment of this disease with antibiotics often leads to the development of bacteria-resistant strains and the accumulation of antibiotic residue in food, hence the need to use a safer method of treatment. NRAMP1 is a candidate gene for natural immune response associated with *Salmonella enteritidis*. One hundred and twenty pure-breed progenies generated from Naked Neck, Fulani ecotype, and Sasso chickens were reared together from day old to 8 weeks. At 7 weeks, 10 birds were randomly selected from each genotype, and 2 mL of blood sample was obtained from each bird for laboratory analysis. The selected birds were inoculated with attenuated S. enteritidis at week 8, and thereafter, 2 mL of blood was obtained from each bird's jugular vein for laboratory analysis. Data were collected on Packed Cell Volume (PCV), Haemoglobin (HB), Red Blood Cell (RBC), Mean Corpuscular Volume (MCV), Mean Corpuscular Haemoglobin (MCH), Mean Corpuscular Haemoglobin Concentration (MCHC), White Blood Cell (WBC), Neutrophils (N), Lymphocytes (L), Monocytes (M), Basophils (B), Eosinophils (E) and Platelet (PLT). The result revealed that genotype and inoculation of *Salmonella* had a significant ($p < 0.05$) effect on all the haematological parameters studied except for the Eosinophils ($p > 0.05$). Sasso chickens had Eosinophilis values before and after (0.00 ± 0.00 and 1.37 ± 0.65), NN (0.50 ± 0.50 and 1.50 ± 0.50), and FE (0.00 ± 0.00). The results of the analysis indicated that SNPs were positively associated with body weight, pulse rate, respiratory rate, rectal temperature, and heat stress index of Sasso chickens. SNPs 1G>C, 2G>T, 6G>C, and 84 C>T associated better with PR, RR, and W, while 84 C>T and 145 C>T associated better with RT and HSI, respectively. Conclusively, there was a significant effect of genotype on all haematological parameters except eosinophils before and after inoculation. Naked Neck had the highest values in all parameters except for mean corpuscular haemoglobin and lymphocytes. Also, there is a significant association between exon 11 of the NRAMP1 gene polymorphisms and physiological and haematological parameters.

Keywords: NRAMP1, *Salmonella* genus, salmonellosis, candidate gene.

Polimorfismo do gene NRAMP1 e sua associação com parâmetros hematológicos e fisiológicos de galinhas inoculadas com *Salmonella enteritidis* atenuada

Resumo

A produção avícola é acometida por diversas doenças graves, dentre as quais se destaca a salmonelose. O tratamento dessa enfermidade com antibióticos frequentemente leva ao desenvolvimento de cepas bacterianas resistentes e ao acúmulo de resíduos de antibióticos nos alimentos, o que evidencia a necessidade do uso de métodos terapêuticos mais seguros. O NRAMP1 é um gene candidato associado à resposta imune natural contra Salmonella enteritidis. Cento e vinte progênies de raças puras, oriundas de galinhas Naked Neck, ecótipos Fulani e Sasso, foram criadas conjuntamente desde o primeiro dia de vida até as 8 semanas de idade. Na sétima semana, dez aves foram selecionadas aleatoriamente de cada genótipo, e 2 mL de amostra de sangue foram coletados de cada ave para análises laboratoriais. As aves selecionadas foram inoculadas com *Salmonella enteritidis* atenuada na oitava semana e, posteriormente, 2 mL de sangue foram coletados da veia jugular de cada ave para análises laboratoriais. Foram coletados dados de volume globular (VG), hemoglobina (HB), contagem de eritrócitos (RBC), volume corpuscular médio (VCM), hemoglobina corpuscular média (HCM), concentração de hemoglobina corpuscular média (CHCM), contagem de leucócitos (WBC), neutrófilos (N), linfócitos (L), monócitos (M), basófilos (B), eosinófilos (E) e plaquetas (PLT). Os resultados revelaram que o genótipo e a inoculação por Salmonella tiveram efeito significativo ($p < 0,05$) sobre todos os parâmetros hematológicos avaliados, exceto eosinófilos ($p > 0,05$). As galinhas Sasso apresentaram valores de eosinófilos antes e após a inoculação de 0,00 ± 0,00 e 1,37 ± 0,65; as Naked Neck (NN) apresentaram 0,50 ± 0,50 e 1,50 ± 0,50; enquanto o ecótipo Fulani (FE) apresentou 0,00 ± 0,00. Os resultados da análise indicaram que os SNPs apresentaram associação positiva com o peso corporal, a frequência cardíaca, a frequência respiratória, a temperatura retal e o índice de estresse térmico das galinhas Sasso. Os SNPs 1G>C, 2G>T, 6G>C e 84 C>T apresentaram melhor associação com frequência cardíaca (FC), frequência respiratória (FR) e peso corporal (P), enquanto os SNPs 84 C>T e 145 C>T mostraram melhor associação com temperatura retal (TR) e índice de estresse térmico (IET), respectivamente. Conclui-se que houve efeito significativo do genótipo sobre todos os parâmetros hematológicos, exceto os eosinófilos, antes e após a inoculação. As galinhas Naked Neck apresentaram os maiores valores para todos os parâmetros, exceto hemoglobina corpuscular média e linfócitos. Além disso, observou-se associação significativa entre os polimorfismos do exon 11 do gene NRAMP1 e os parâmetros fisiológicos e hematológicos.

Palavras-chave: NRAMP1, gênero *Salmonella*, salmonelose, gene candidato.

1. Introduction

Poultry production has played a significant role in the economy of Nigeria, and these roles are as follows: they are good sources of protein, high level of acceptability as they have no barriers (Heise et al., 2015). However, poultry production is faced with challenges of inefficient management, disease, and parasites (Alabi et al., 2000). Diseases have led to a reduction in the production of poultry-related products, and also the input costs, like labour and feed, have increased (Wongnaa et al., 2023; Nassar; Abbas, 2025).

Diseases have led to a reduction in the production of poultry-related products, and also the input costs, like labour and feed, have increased. The impact of these losses in the poultry industry is worse on the livelihood of poor people in developing countries, where up to 25% of monthly income may be lost due to poultry disease (Rist et al., 2015). Among the various diseases occurring in poultry, *Salmonella* has been found to cause serious economic losses to the poultry industry in terms of morbidity and mortality.

Salmonella is an enteric pathogen that can infect almost all animals, including humans. Salmonellosis in poultry is caused by Gram-negative bacteria from the genus *Salmonella* (Cobo-Simón et al., 2023; Sia et al., 2025). Most serotypes of *Salmonella* can infect several animal species, such as *Salmonella typhimurium* and *Salmonella enteritidis*. Chicken can get infected with *Salmonella enterica* at any time during their lifetime.

Prophylactic measures, vaccination, and the use of antibiotics are insufficient to eradicate salmonellosis in poultry stocks. However, some cases of antibiotic-resistant strains of *S. enteritidis* have been observed, leading to concerns about residual antibiotics in the bodies of treated poultry. The major problems associated with the widespread use of antibiotics are the development of bacteria resistant to antibiotics and the accumulation of antibiotic residues in food for human consumption (Baylis; Githeko, 2006).

Candidate genes are generally those with known biological functions that directly or indirectly regulate the developmental processes of the investigated traits, which can be confirmed by evaluating the effects of the causative gene variants in an association analysis (Tabor et al., 2002). The NRAMP 1 gene is a candidate gene associated with *S. enteritidis*-mediated immune response, and is related to the phagocytosis of *S. enteritidis*. Haemtological studies are useful in the diagnosis of many diseases as well as the investigation of the extent of damage to blood (Togun et al., 2007). Haematological parameters refer to those related to the blood and blood-forming organs (Waugh et al., 2001; Bamishaiye et al., 2009).

Haemtological studies are useful in the diagnosis of many diseases as well as the investigation of the extent of damage to blood (Togun et al., 2007). Haematological parameters are those parameters that are related to the blood and blood-forming organs (Bamishaiye et al. 2009).

Physiological responses help to reflect thermoregulation and the health status of the animals. The physiological parameters include: rectal temperature (RT), heart rate (HR), and Pulse Rate (PR). These parameters have been suggested as indicators of the level of heat stress in chickens. The understanding of the animal responses to thermal challenge is paramount to the successful implementation of breeding strategies to increase production and productivity of birds (Omodewu; Tiamiyu, 2021).

The objective is to study *NRAMP1*1 gene polymorphisms and their relationship with blood parameters and physiological responses of Nigerian indigenous and exotic chickens inoculated with attenuated *Salmonella*.

2. Materials and Methods

2.1 Experimental sites

The experiment was carried out at the Poultry Unit of the Teaching and Research Farm, Ladoke Akintola University of Technology, Ogbomoso (LAUTECH), Oyo State, Nigeria. It is located on longitude 4°15′ East and latitude 8°15′ North east of the Greenwich meridian. The altitude is between 300 and 600 m above sea level. The mean annual rainfall and temperature are 1247 mm and 27 °C respectively (BATC, 2004). Ogbomoso is located in a derived Savannah Zone. The laboratory analysis was carried out at the Central Research Laboratory, Ilorin, Kwara State, Nigeria.

2.2 Experimental birds and management

The experimental birds used consist of two Nigerian indigenous chickens (Naked Neck and Fulani ecotype) and an exotic chicken (Sasso). The Parent chickens were sourced from a pre-existing flock at the LAUTECH Teaching and Research farm at maturity. A total of fifteen (15) sires and sixty (60) dams were used as parent stocks and distributed as 5 cocks to 20 hens in each genotype. Birds were individually wing-tagged for identification purposes. Sires and dams were caged in an open-sided house of 1.161 m^2. Each bird was confined in a cell space of 15 × 15 inches for all the birds. Before stocking the cage, the whole pen and cages were washed and disinfected using Lysol® and were left for five days before stocking.

2.3 Experimental feeds and feeding

The cocks were fed *ad libitum* with commercial grower mash containing 15.0% Crude Protein and 2500 kcal kg^{-1} metabolizable energy, while the hens were fed with commercial layer mash containing 16.0% Crude Protein and 2800 kcal kg^{-1} metabolizable energy. Clean water was supplied *ad libitum.* Drugs and vaccines were administered as needed.

2.4 Brooding, chick rearing, and management

Before the arrival of the day-old chicks, the brooder pens were washed with Lysol® and disinfected. The dimension of each brooder pen was 8 × 10 m^2. Wood shavings were spread on the floor of each pen, and a heat source was placed at a corner in the brooder pen to provide warmth for the chicks. The heat was supplied for 4 weeks. The chicks were brooded for four weeks. Adequate heat, ventilation, medication, and feeding will be provided. The chicks were duly vaccinated, and antibiotics were administered as required. The three generated progenies were reared in a deep litter. All the experimental birds were wing-tagged for proper identification. At the arrival of the chicks, they were given multi-vitamin drugs which served as an anti-stress. Commercial chick mash containing 22.0% crude protein and 2900 Kcal kg^{-1} metabolizable energy was fed to the chicks from day old till eight weeks of age. Clean water was supplied *ad-libitum* to the birds. The litter was changed as at when due to prevent the accumulation of ammonia gas. Spillage of water on the litter was also prevented as much as possible. All chicks remained on deep-litter throughout the period of the experiment.

2.5 Duration of the experiment

The experiment was carried out for twenty-four (24) weeks.

2.6 Pre-inoculation

The following data were collected before inoculating the birds with *Salmonella enteritidis* (PT4 strain).

2.6.1 Physiological response

The physiological response was determined by measuring the following parameters: Rectal Temperature (RT), Respiratory Rate (RR), and Pulse Rate (PR).

2.6.2 Rectal temperature (t°c)

Rectal temperature was measured using a digital thermometer. This was done by inserting the digital thermometer into the cloaca of the birds about 5 cm deep for a minute.

2.6.3 Respiratory rate

This was measured by observing and counting the number of flank movements per minute and recording them as breadths/minute.

2.6.4 Pulse rate

This was determined using a stethoscope, which was placed on the femoral artery at the inner part of the thigh, or by placing the stethoscope at the left chest of each chicken, and the number of heartbeats was counted per minute and recorded as beats/minute.

2.6.5 Heat stress index

This was derived from the relationship between observed pulse and respiratory rate, together with their normal values (Adedeji et al., 2015).

The formula is as follows:

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

Where: H = Heat stress index, AR = Observed respiratory rate, AP = Observed pulse rate, NP = Normal pulse rate, and NR = Normal respiratory rate

2.7 Blood collection

Two (2 mL) of blood were collected from the wing veins of randomly selected birds for the determination of both haematological and DNA analysis.

2.7.1 Haematological Parameters

A sample of blood (1 mL) was collected from twenty healthy birds randomly selected in each genotype at the 7th week of age from both sexes, before the inoculation with attenuated *salmonella* and served as a baseline study. The samples of blood were collected by the use of sterile syringes and needles from the wing veins and stored in the EDTA bottles (ethylene diamine tetraacetic acid). Erythrocyte concentration (RBC), haemoglobin (Hb), packed cell volume (PCV), and leucocyte concentration (WBC) counts were measured using an automated cell counter within 24 h after collection of blood (Hu et al., 2011; Opoola et al., 2020). Haemoglobin (Hb) concentration was estimated using a hemoglobinometer, and Packed Cell Volume (PCV) was determined using the micro haematocrit method. Differential leukocyte count and RBC, WBC counting were carried out using a compound microscope. The Mean Corpuscular Volume (MCV), Mean Corpuscular Haemoglobin (MCH), and Mean Corpuscular Haemoglobin Concentration (MCHC) were also determined (Sunmola et al., 2019).

The following formulas were used: MCV in femtolitre (fL) = 10 × PCV (%)/RBC counts (millions μ^{-1}), MCH in pg/cell = haemoglobin (g 100 mL)/RBC counts (millions/μ), MCHC in g dL = haemoglobin (g 100 mL) × 100/PCV (%)

2.7.2 Inoculation with attenuated *Salmonella*

The *Salmonella* to be used was sourced from the Central Research Laboratory, Ilorin Kwara State. At 8 weeks, the selected 20 experimental birds were inoculated subcutaneously with 0.5mL/bird of the attenuated *Salmonella* (Opoola et al., 2020).

2.8 Post-inoculation

A sample of blood (1 mL) was collected from twenty healthy birds randomly selected in each genotype at the 7th week of age from both sexes, before the inoculation with attenuated *salmonella* and served as a baseline study. The samples of blood were collected by the use of sterile syringes and needles from the wing veins and stored in the EDTA bottles (ethylene diamine tetraacetic acid). Erythrocyte concentration (RBC), haemoglobin (Hb), packed cell volume (PCV), and leucocyte concentration (WBC) counts were measured using an automated cell counter within 24 h after collection of blood (Hu et al., 2011; Opoola et al., 2020). Haemoglobin (Hb) concentration was estimated using a hemoglobinometer, and Packed Cell Volume (PCV) was determined using the micro haematocrit method. Differential leukocyte count and RBC, WBC counting were carried out using a compound microscope. The Mean Corpuscular Volume (MCV), Mean Corpuscular Haemoglobin (MCH), and Mean Corpuscular Haemoglobin Concentration (MCHC) were also determined (Sunmola et al., 2019).

The following formulars was used: MCV in femtolitre (fL) = 10 × PCV (%)/RBC counts (millions/μ), MCH in pg/cell = haemoglobin (g 100 mL)/RBC counts (millions μ^{-1}), and MCHC in g dL = haemoglobin (g 100 mL) × 100/PCV (%).

2.9 Statistical analysis

Data collected on blood were arcsine transformed to normalize the data and subsequently corrected for sex effect. After the correction, the data were subjected to One-Way Analysis of Variance using the procedure of SAS (2003). Significant mean differences were separated by *Duncan's* Multiple Range Test using the same software.

The model adopted is as specified below:

Haematological parameters

$$Y_{ij} = \mu + \beta_i + e_{ij}$$

Where: Y_{ij} = response variable μ = Overall mean, β_i = Fixed effect of the i^{th} breed (i =1, 2, 3), and e_{ij} = Experimental error which is evenly distributed

Physiological parameters

$$Y_{ij} = \mu + \alpha_i + e_{ij}$$

Where: Y_{ij} = response variable *(RT, PR*, and *HR)*, μ = Overall mean, α_i = Fixed effect of the i^{th} breed (i = *NN*, *FE SA*), and e_{ij} = Experimental error, which is evenly distributed

Association analysis

The association model used is as follows:

$$Y_{ij} = \mu + B_i + e_{ij}$$

Where: Y_{ij} = individual observations, μ = population mean, B_i = effect of the i^{th} SNPs, and e_{ij} = residual error.

3. Results

3.1 Physiological parameters of chickens

The mean values of genotype effect on body weight, rectal temperature, pulse rate, respiratory rate, and heat stress index of chickens before inoculation with *Salmonella enteritidis* at 7 weeks of age are shown in Table 1. The results indicated that genotype had a significant effect on body weight, pulse rate, respiratory rate, and heat stress index. Sasso had the highest value of body weight, pulse rate, and respiratory rate, while the lowest values were recorded in Naked Neck chickens. However, the highest and the lowest heat stress index were observed in the Naked Neck chickens and the Sasso breed of chickens, respectively.

Table 1. Mean Values of body weight and physiological parameters of chickens before inoculation at 7 weeks of age as Affected by Genotype.

Genotype	OBS	BW(g)	RT(^{0}C)	PR (beats/min)	RR (breath/min)	HIS
SA	22	673.38± 137.12^a	42.29±0.29	45.38 ± 3.34^a	56.63 ±10.21^a	3.10±0.87^c
NN	18	389.00±46.57^c	41.95±0.27	34.00±4.55^c	47.00±3.46^c	3.69± 1.40^a
FE	15	477.50±15.73^b	42.23±0.26	40.50±8.23^b	50.50±5.36^b	3.13±1.30^b

Note: ^{abc} = Mean occupying the same column having different superscripts are significantly different ($p < 0.05$). BW: Body Weight, RT: Rectal Temperature, PR: Pulse Rate, RR: Respiratory Rate, HSI: Heat Stress Index, SA: Sasso, NN: Naked Neck, FE: Fulani Ecotype. Source: Authors, 2025.

The mean values of genotype effect on body weight, rectal temperature, pulse rate, respiratory rate, and heat stress index of chickens after inoculation at 9 weeks of age are revealed in (Table 2). The results showed that genotype had a significant ($p < 0.05$) effect on body weight, pulse rate, respiratory rate, and heat stress index. Sasso had the highest value of body weight, pulse rate, and respiratory rate, while Naked Neck had the lowest values. However, Naked Neck had the highest value for the heat stress index, while Sasso had the lowest value.

Table 2. Mean values of genotype effect on body weight and physiological parameters of chickens after inoculation at 9 weeks of age.

Genotype	OBS	BW(g)	RT(ºC)	PR (beats/min)	RR (breath/min)	HIS
SA	22	752.38±50.34^a	42.88±0.71	51.00±15.60^a	64.25±46.25^a	4.16±0.80^b
NN	15	421.00±46.56^c	41.95±0.57	39.50±4.51^c	50.25±5.36^c	4.64±1.30^a
FE	18	558.00±9.67^b	42.45±0.25	49.25± 2.50^b	54.00±12.00^b	4.12±1.10^c

Note: ^{abc} = Mean occupying the same column having different superscripts are significantly different ($p < 0.05$). BW: Body Weight, RT: Rectal Temperature, PR: Pulse Rate, RR: Respiratory Rate, HSI: Heat Stress Index, SA: Sasso, NN: Naked Neck, FE: Fulani Ecotype. Source: Authors, 2025.

The mean values of genotype effect on body weight, rectal temperature, pulse rate, respiratory rate, and heat stress index of chickens before and after inoculation at 7 and 9 weeks of age, respectively, are shown in (Table 3). The results indicated that genotype had a significant ($p < 0.05$) effect on the body weight, pulse rate, respiratory rate, and heat stress index. The values for body weight, pulse rate, respiratory rate, and heat stress index within each of the genotypes were higher after inoculation when compared to before inoculation.

Table 3. Mean values of genotype effect on the haematological parameters of chickens before inoculation at 7 weeks of age.

	Genotype		
Parameters (n = 17)	Sasso	Naked Neck	Fulani Ecotype
PCV (%)	16.33±8.35^c	32.50±5.69^a	20.33±7.64^b
HB (g/dL)	7.60±4.16^c	15.53±2.58^a	9.13±3.62^b
RBC (x10^6/µL)	1.43±0.80^c	2.65±0.45^a	1.70±0.67^b
MCV (fl)	120.14±18.26^b	122.40±2.47^a	119.20±3.64^c
MCH (pg)	53.66±1.80^c	58.73±2.69^a	54.07±0.67^b
MCHC (g/dL)	453.88±56.52^b	479.50±14.27^a	452.33±9.02^b

WBC (x10^3/µL)	81.79±51.66^c	152.35±14.19^a	86.93±40.84^b
N (x10^3/µL)	9.50±5.32^b	12.00±2.12^a	6.67±1.15^c
L (x10^3/µL)	84.75±7.81^b	69.25±7.80^c	88.00±1.00^a
M (x10^3/µL)	2.50±1.67^c	4.25±2.06^a	2.67±0.29^b
B (x10^3/µL)	3.00±2.43^b	4.00±4.83^a	2.67±0.29^c
E (x10^3/µL)	0.00±0.00	0.50±0.00	0.00±0.00
PLT (x10^3/µL)	24.00±12.14^c	83.25±44.92^a	29.33±18.88^b

Note: ^{abc} = Mean occupying the same row having different superscripts are significantly different ($p < 0.05$). PCV = Packed Cell Volume, HB = Haemoglobin, RBC = Red Blood Cell, MCV = Mean Corpuscular Volume, MCH = Mean Corpuscular Haemoglobin, MCHC = Mean Corpuscular Haemoglobin Concentration, WBC = White Blood Cell, N = Neutrophils, L = Lymphocytes, M = Monocytes, B = Basophils, E = Eosinophils, PLT = Platelet. Source: Authors, 2025.

The mean values of genotype effect on the heamatological parameters of chickens before inoculation at 7 weeks of age are presented in (Table 4). The results showed that genotype had significant ($p < 0.05$) effect on packed cell volume (PCV), haemoglobin (HB), red blood cell (RBC), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC), white blood cell (WBC), neutrophils (N), lymphocytes (L), monocytes (M), basophils (B) and platelet (PLT) except for eosinophills. Naked Neck had the highest values of PCV, HB, RBC, MCV, MCH, MCHC, WBC, N, M, B, and PLT, while the highest value of L was observed in Fulani ecotype chickens.

Table 4. Mean Values of genotype effect on the Haematological parameters of chickens after inoculation at 9 weeks of age.

	Genotype		
Parameters (n = 17)	Sasso	Naked Neck	Fulani Ecotype
PCV (%)	26.25±1.72^b	34.50±2.84^a	23.63±4.41^c
HB (g/dL)	12.76±0.74^b	20.35±1.29^a	10.99±0.43^c
RBC (x10^6/µL)	2.24±0.15^b	3.59±0.23^a	1.99±0.39^c
MCV (fL)	117.49±1.12^c	126.35±1.24^a	122.59±2.10^b
MCH (pg)	56.93±0.89^b	61.50±1.34^a	55.89±0.38^c
MCHC (g/dL)	483.75±5.70^a	480.08±7.14^b	469.70±5.21^c
WBC (x10^3/µL)	112.88±3.90^b	154.35±7.10^a	107.51±23.56^c
N (x10^3/µL)	11.50±2.11^b	16.85±2.12^a	9.14±0.67^c
L (x10^3/µL)	71.25±3.90^b	70.52±3.90^c	92.08±0.58^a
M (x10^3/µL)	2.13±0.48^c	5.52±1.31^a	4.73±1.67^b
B (x10^3/µL)	13.75±2.62^b	16.07±2.42^a	11.52±0.07^c
E (x10^3/µL)	1.38±0.65	1.00±0.00	0.00±0.00
PLT (x10^3/µL)	43.75±6.04^b	85.43±22.46^a	31.29±10.90^c

Note: ^{abc} = Mean occupying the same row having different superscripts are significantly different ($p < 0.05$). OBS, PCV = Packed Cell Volume, HB = Haemoglobin, RBC = Red Blood Cell, MCV = Mean Corpuscular Volume, MCH = Mean Corpuscular Haemoglobin, MCHC= Mean Corpuscular Haemoglobin Concentration, WBC = White Blood Cell, N = Neutrophils, L = Lymphocytes, M = Monocytes, B = Basophils, E = Eosinophils, PLT = Platelet. Source: Authors, 2025.

The mean values of genotype effect on the haematological parameters of chickens after inoculation at 9 weeks of age are presented in (Table 5). The results showed that genotype had significant ($p < 0.05$) effect on packed cell volume (PCV), haemoglobin (HB), red blood cell (RBC), Mean Corpuscular Volume (MCV), mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC), white blood cell (WBC), neutrophils (N), lymphocytes (L), monocytes (M), basophils (B) and platelet (PLT) except for eosinophils. Naked Neck had the highest value of PCV, HB, RBC, MCV, MCH, WBC, N, M, and PLT. However, Sasso and Fulani ecotype chickens had the highest values for MCHC and L, respectively.

Table 5. Mean Values of genotype effect on body weight and physiological parameters of chickens before and after inoculation.

		Genotype		
Parameters (n = 55)		Sasso	Naked Neck	Fulani Ecotype
Body weight (g)	Before	673.38 ± 137.12^b	389.00 ± 46.57^b	477.50 ± 15.73^b
	After	752.38 ± 50.34^a	421.00 ± 46.56^a	558.00 ± 9.67^a
Rectal Temperature (^{0}c)	Before	42.29±0.29	41.95±0.27	42.23±0.26
	After	42.88±0.71	41.95±0.57	42.45±0.25
Pulse Rate (beats/min)	Before	45.38 ± 3.34^b	34.00 ± 4.55^b	40.50 ± 8.23^b
	After	51.00 ± 15.60^a	39.50 ± 4.51^a	49.25 ± 2.50^a
Respiratory rates (breath/min)	Before	56.63 ± 10.21^b	47.00 ± 3.46^b	50.50 ± 9.40^b
	After	64.25 ± 46.25^a	50.25 ± 5.36^a	54.00 ± 12.00^a
Heat Stress Index	Before	3.10 ± 0.87^b	3.69 ± 1.40^b	3.13 ± 1.30^b
	After	4.16 ± 0.80^a	4.64 ± 1.30^a	4.12 ± 1.10^a

Note: ^{ab} = Mean occupying the same column with each parameter having different superscripts are significantly ($p < 0.05$) different. BW: Body Weight, RT: Rectal Temperature, PR: Pulse Rate, RR: Respiratory Rate, HSI: Heat Stress Index. Source: Authors, 2025.

The mean values of haematological parameters of Sasso, Naked Neck, and Fulani ecotype chickens before and after inoculation are presented in (Table 6). The result revealed that genotype had significant ($p < 0.05$) effect, on packed cell volume (PCV), haemoglobin (HB), red blood cell (RBC), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC), white blood cell (WBC), lymphocytes (L), basophils (B) and platelet (PLT) except for eosinphils at both before and after. The values for PCV, HB, RBC, MCV, MCH, MCHC, WBC, L, B, M, and PLT within each parameter were higher after inoculation when compared to before inoculation, except for Sasso (MCV and M).

Table 6. Mean Values of haematological parameters of chicken genotypes before and after inoculation.

		Genotype		
Parameters (n = 17)		Sasso	Naked Neck	Fulani Ecotype
PCV (%)	Before	16.33 ± 2.95^b	32.50 ± 2.84^b	20.33 ± 7.64^b
	After	26.25 ± 1.72^a	34.50 ± 2.84^a	23.63 ± 4.41^a
HB (g/dL)	Before	7.600 ± 1.47^b	15.53 ± 1.29^b	9.13 ± 2.09^b
	After	12.76 ± 0.74^a	20.35 ± 1.29^a	10.99 ± 0.43^a
RBC (x10^6/µL)	Before	1.43 ± 0.28^b	2.65 ± 0.23^b	1.70 ± 0.38^b
	After	2.24 ± 0.15^a	3.59 ± 0.23^a	1.99 ± 0.39^a
MCV (fl)	Before	120.18 ± 6.46^a	113.11 ± 0.94^b	119.20 ± 2.10^b
	After	117.49 ± 1.12^b	126.35 ± 1.24^a	122.59 ± 2.10^a
MCH (pg)	Before	53.66 ± 0.64^b	58.73 ± 1.34^b	54.07 ± 0.38^b
	After	56.93 ± 0.89^a	61.50 ± 1.34^a	55.89 ± 0.38^a

MCHC (g/dL)	Before	453.88±19.9^{b}	479.50±14.27^{b}	452.33±9.02^{b}
	After	483.75±5.70 ^{a}	480.08±7.14^{a}	469.70±5.21^{a}
WBC (x10^{3}/μL)	Before	81.79±18.26^{b}	152.35±7.10^{b}	86.93±23.56^{b}
	After	112.875±3.90^{a}	154.35±7.10^{a}	107.51±23.56^{a}
L (x10^{3}/μL)	Before	84.75±2.76^{a}	69.25±3.90^{b}	88.00±1.00^{b}
	After	71.25±3.90^{b}	70.52±3.90^{a}	92.08±0.58^{a}
N (x10^{3}/μL)	Before	9.50±1.88^{b}	12.00±2.12^{b}	6.67±0.67^{b}
	After	11.50±2.11^{a}	16.85±2.12^{a}	9.14±0.67^{a}
M (x10^{3}/μL)	Before	2.50±0.59 ^{a}	4.25±1.03^{b}	3.27±0.17^{b}
	After	2.13±0.48^{b}	5.52±1.31^{a}	4.73±1.67^{a}
B (x10^{3}/μL)	Before	3.00±0.86^{b}	4.83±2.42^{b}	2.67±0.17^{b}
	After	13.75±2.62^{a}	16.07±2.42^{a}	11.52±0.07^{a}
E (x10^{3}/μL)	Before	0.00±0.00	0.50±0.50	0.00±0.00
	After	1.375±0.65	1.50±0.50	0.00±0.00
PLT (x10^{3}/μL)	Before	24.00±12.14^{b}	83.25±44.93^{b}	29.33±18.88^{b}
	After	43.87±6.04 ^{a}	85.43±22.46^{a}	31.29±10.90^{a}

Note: ^{abc} = Mean occupying the same column having different superscripts are significantly different ($p < 0.05$). OBS, PCV = Packed Cell Volume, HB = Haemoglobin, RBC = Red Blood Cell, MCV = Mean Corpuscular Volume, MCH = Mean Corpuscular Haemoglobin, MCHC = Mean Corpuscular Haemoglobin Concentration, WBC= White Blood Cell, N = Neutrophils, L = Lymphocytes, M = Monocytes, B = Basophils, E = Eosinophils, PLT = Platelet. Source: Authors, 2025.

The mean values of SNPs' effect on the heamatological parameters, as presented in (Table 7), showed that mutations had a significant ($p < 0.05$) effect on the haematological parameters of Sasso chickens except for eosinophil. SNPs 1G>C, 2G>T, 6 G>C, and 84C>T associated better with WBC and its differential count (N, L, M, and B).

Table 7. Effects of single-nucleotide polymorphisms (SNPs) on haematological parameters of Sasso chickens.

	SNPs				
Parameters	1 G>C	2 G>T	6 G>C	84 C>T	145 C>T
PCV (%)	30.50±3.18^{b}	30.50±3.18^{b}	34.50±3.18^{a}	34.50±3.18^{a}	28.00±1.41^{c}
HB (g/dL)	14.45±1.20^{b}	14.45±1.20^{b}	14.45±1.20^{b}	16.60±1.62^{a}	13.60±0.50^{c}
RBC(x10^{6}/μL)	2.49±0.28^{b}	2.49±0.28^{b}	2.49±0.28^{b}	2.82±0.22^{a}	2.30±0.14^{c}
MCV (fL)	121.70±1.20^{c}	121.70±1.20^{c}	121.70±1.20^{c}	123.10±1.63^{a}	122.10±0.91^{b}
MCH (pg)	58.45±2.02^{b}	58.45±2.02^{b}	58.45±2.02^{b}	59.00±1.13^{a}	59.35±1.38^{a}
MCHC (g/dL)	480.00±12.02^{b}	480.00±12.02^{b}	480.00±12.02^{b}	479.00±2.83^{c}	486.00±7.78^{a}
WBC(x10^{3}/μL)	152.25±5.20^{a}	152.25±5.20^{a}	152.25±5.20a	152.45±11.14^{a}	140.80±2.90^{b}
N (x10^{3}/μL)	9.50±2.48^{c}	9.50±2.48^{c}	9.50±2.48^{c}	14.50±1.10^{a}	13.00±0.00^{b}
L (x10^{3}/μL)	72.50±1.77^{a}	72.50±1.77a	72.50±1.77^{a}	66.00±5.65^{b}	72.00±1.41^{a}
M (x10^{3}/μL)	25.00±0.35^{a}	25.00±0.35^{a}	25.00±0.35^{a}	6.00±0.00^{b}	4.00±1.41^{c}
B (x10^{3}/μL)	15.50±0.35^{a}	15.50±0.35^{a}	15.50±0.35^{a}	12.50±3.90^{b}	11.00±2.83^{c}
E (x10^{3}/μL)	0.00±0.00	0.00±0.00	0.00±0.00	1.00±0.71	0.00±0.00
PLT (x10^{3}/μL)	67.50±15.91^{a}	67.50±15.91^{a}	67.50±15.91^{a}	99.00±31.82^{a}	72.00±12.73^{b}

Note: ^{abc} = Mean occupying the same row within each parameter having different superscripts are significantly different ($p < 0.05$). PCV = Packed Cell Volume, HB = Haemoglobin, RBC = Red Blood Cell, MCV = Mean Corpuscular Volume, MCH = Mean Corpuscular Haemoglobin, MCHC = Mean Corpuscular Haemoglobin Concentration, WBC = White Blood Cell, N = Neutrophils, L = Lymphocytes, M = Monocytes, B= Basophils, E = Eosinophils, PLT = Platelet. Source: Authors, 2025.

The mean values of SNPs' effect on the heamatological parameters, as presented in (Table 8), showed that mutations had a significant ($p < 0.05$) effect on the haematological parameters of Fulani ecotype chickens except for eosinophil. SNPs 236C>G associated better with WBC and N, while SNPs 20A>C associated better with M and B.

Table 8. Effects of single-nucleotide polymorphisms (SNPs) on haematological parameters of Naked Neck chickens.

	SNPs				
Parameters	2 T>C	4 C>G	31 C>G	34 T>G	81 C>G
PCV (%)	26.25±0.61 ^{a}	26.25±0.61 ^{a}	22.67±1.68 ^{c}	24.00±1.41 ^{b}	25.00±1.00 ^{b}
HB (g/dL)	12.76±0.26 ^{a}	12.76±0.26^{a}	11.34±0.83^{b}	11.90±0.42^{b}	12.47±2.50^{a}
RBC(x10^{6}/µL)	2.24±0.05^{a}	2.24±0.05^{a}	1.96±0.14^{b}	2.13±0.10^{a}	2.11±0.70^{a}
MCV (fL)	117.49±0.40^{a}	117.49±0.40^{a}	116.47±1.12^{b}	114.35±1.17^{c}	117.967±1.83^{a}
MCH (pg)	56.93±0.31^{c}	56.93±0.31^{c}	57.43±0.46^{b}	55.65±0.60^{c}	58.97±0.82^{a}
MCHC (g/dL)	483.75±2.01^{c}	483.75±2.01^{c}	493.67±4.81^{b}	487.00±10.61^{b}	500.33±0.96^{a}
WBC(x10^{3}/µL)	112.87±1.40^{b}	112.87±1.40^{b}	107.00±4.64^{c}	109.00±0.21^{c}	115.90±2.09^{a}
N (x10^{3}/µL)	11.50±0.75^{c}	11.50±0.75^{c}	14.00±2.31^{b}	16.50±1.61^{a}	16.67±0.77^{a}
L (x10^{3}/µL)	71.25±1.38^{b}	71.25±1.38^{b}	72.00±5.84^{a}	70.00±2.12^{a}	62.00±3.28^{c}
M (x10^{3}/µL)	2.13±0.17^{b}	2.13±0.17^{b}	2.67±0.70^{a}	1.00±0.00^{c}	1.67±0.19^{b}
B (x10^{3}/µL)	13.75±1.20^{b}	13.75±1.20^{b}	10.33±0.23^{c}	11.50±0.56^{c}	17.00±0.81^{a}
E (x10^{3}/µL)	0.00±0.93	1.00±0.93	0.00±3.90	0.00±4.48	0.00±2.64
PLT (x10^{3}/µL)	67.50±1.22^{b}	99.00±1.35^{a}	72.00±2.07^{b}	29.33±0.82^{c}	67.50±1.25^{b}

Note: ^{abc} = Mean occupying the same column having different superscripts are significantly different ($p < 0.05$). PCV = Packed Cell Volume, HB = Haemoglobin, RBC = Red Blood Cell, MCV = Mean Corpuscular Volume, MCH = Mean Corpuscular Haemoglobin, MCHC = Mean Corpuscular Haemoglobin Concentration, WBC = White Blood Cell, N = Neutrophils, L = Lymphocytes, M = Monocytes, B = Basophils, E = Eosinophils, PLT = Platelet. Source: Authors, 2025.

The mean values of SNPs' effect on the heamatological parameters are presented in (Table 9). The Table showed that mutations had a significant ($p < 0.05$) effect on the haematological parameters of Naked Neck chickens, except for eosinophil. SNPs 81C>G, 34C>G, 31C>G, 81C>G, and 4C>G associated better with WBC and its differential count (N, L, M, and B), respectively.

Table 9. Effects of single-nucleotide polymorphisms (SNPs) on haematological parameters of Fulani Ecotype chickens.

	SNPs	
Parameters	20 A>C	236 T>C
PCV (%)	20.33±2.55^{b}	24.50±1.77^{a}
HB (g/dL)	9.13±1.22^{b}	11.15±1.21^{a}
RBC(x10^{6}/µL)	1.70±0.57 ^{b}	2.08±0.22^{a}
MCV (fL)	119.20±0.10^{a}	117.55±1.21^{b}

MCH (pg)	54.07±0.63[a]	53.85±0.22 [b]
MCHC (g/dL)	453.33±0.12[b]	458.00±3.01[a]
WBC(x10^3/µL)	86.93±1.49[b]	109.35±13.60[a]
N (x10^3/µL)	6.67±6.52 [b]	7.00±0.39[a]
L (x10^3/µL)	88.00±0.22	88.00±0.33
M (x10^3/µL)	6.67±6.52 [b]	2.50±0.10 [b]
B (x10^3/µL)	2.67±0.04 [a]	2.50±0.10[b]
E (x10^3/µL)	0.00±0.00	0.00±0.00[a]
PLT (x10^3/µL)	29.33±6.29[b]	37.50±8.84[a]

Note: [abc] = Mean occupying the same column having different superscripts are significantly different ($p < 0.05$). PCV = Packed Cell Volume, HB = Haemoglobin, RBC = Red Blood Cell, MCV = Mean Corpuscular Volume, MCH = Mean Corpuscular Haemoglobin, MCHC = Mean Corpuscular Haemoglobin Concentration, WBC = White Blood Cell, N = Neutrophils, L = Lymphocytes, M = Monocytes, B = Basophils, E = Eosinophils, PLT = Platelet. Source: Authors, 2025.

The mean values of the SNPs' effect on the physiological parameters are presented in (Table 10). The results of the analysis indicated that SNPs positive association with body weight, pulse rate, respiratory rate, rectal temperature, and heat stress index of Sasso chickens. SNPs 1G>C, 2G>T, 6G>C, and 84 C>T associated better with PR, RR, and W, while 84 C>T and 145 C>T associated better with RT and HSI, respectively.

Table 10: Effects of single-nucleotide polymorphisms (SNPs) on physiological parameters of Sasso chickens.

HIS	11.53±0.29 [b]	11.53±0.29 [b]	11.53±1.41[b]	10.95±0.88 [c]	11.59±1.17 [a]

Note: [abc] = Mean occupying the same row having different superscripts are significantly different ($p < 0.05$). BW: Body Weight, RT: Rectal Temperature, PR: Pulse Rate, RR: Respiratory Rate. Source: Authors, 2025.

The mean values of the SNPs' effect on the physiological parameters are presented in (Table 11). The results of the analysis indicated that SNPs positive association with body weight, pulse rate, respiratory rate, rectal temperature, and heat stress index of Naked Neck chickens. SNPs 34T>G associated better with PR, RR, and HIS, while 31 C>G associated better with RT, W, and HSI, respectively.

Table 11. Effects of Single Nucleotide Polymorphisms (SNPs) on physiological parameters of Naked Neck chickens.

	SNPs				
Parameters	2 T>C	4 C>G	31 C>G	34 T>G	81 C>G
PR	51.00±3.54 [b]	51.00±3.54 [b]	49.33±3.54 [c]	57.50±0.00 [a]	51.00±1.77 [b]
RR	59.13±2.83 [b]	59.13±2.83 [b]	54.33±2.83[c]	73.50±0.00 [a]	52.00±0.71[c]
RT	41.78±0.32[c]	41.78±0.32[c]	42.17±0.32[a]	41.95±0.00[b]	42.20±0.14[a]
W	1900.00±123.74[b]	1900.00±123.74[b]	2233.33±123.74[a]	1825.00±0.00[c]	1700.00±106.07[c]
HIS	10.06±0.49 [b]	10.06±0.49 [b]	10.22±0.49[a]	10.97±0.00[a]	9.19±0.45[c]

Note: [abc] = Means occupying the same row with different superscripts are significantly different ($p < 0.05$). BW: Body Weight, RT: Rectal Temperature, PR: Pulse Rate, RR: Respiratory Rate. Source: Ojua, 2024.

The mean values of SNPs' effect on the physiological parameters are presented in (Table 12). The results of the analysis indicated that SNPs positive association with body weight, pulse rate, respiratory rate, rectal temperature, and heat stress index of Fulani ecotype chickens. SNPs236T>C associated better with PR, RR, RT, and W, while 20 A>C associated better with HSI, respectively.

Table 12. Effects of single-nucleotide polymorphisms (SNPs) on physiological parameters of Fulani ecotype chickens.

	SNPS	
Parameters	20 A>C	236 T>C
PR	44.00±1.76^{b}	46.00±2.83^{a}
RR	54.33±2.22^{b}	56.00±4.24^{a}
RT	42.433±1.10^{b}	42.60±0.07^{a}
W	1250.00±76.38^{b}	1275.00±159.10^{a}
HIS	10.29±0.12^{a}	10.13±0.14^{b}

Note: ^{abc} = Mean occupying the same row having different superscripts are significantly different ($p < 0.05$). BW: Body Weight, RT: Rectal Temperature, PR: Pulse Rate, RR: Respiratory Rate. Source: Authors, 2025.

4. Discussion

The physiological response of any livestock is dependent on environmental and genetic factors (Ilori et al., 2021). The current finding showed that genotype had a significant effect on body weight, pulse rate, respiratory rate, and heat stress index, except for rectal temperature before inoculation. The results of this experiment showed that the physiological responses of chickens are genotype-dependent, which agrees with the report of Adedeji et al. (2015). These authors reported that genotype had significant effects on all the physiological parameters of chickens. Naked Neck chickens recorded the least mean values for all physiological parameters. This could be attributed to the reduced feather coverage of their Necks, which has been shown to boost heat dissipation, allowing for a higher rate of body heat radiation and improved thermoregulation.

The general physiological response that existed in this present study agrees with the direct observation of Ndlovu (2024) in local pullets reared in the humid tropical environment. The highest physiological responses as observed in Sasso chickens could be because Sasso chickens are dual-purpose birds, which may require more energy for growth and egg production, which can invariably affect the heat produced. Higher body weight affects the heat production by poultry, thus leading to panting (Defra, 2023). Naked Neck chickens have a higher capacity for heat tolerance than other genotypes (Zerjal et al., 2007). The highest heat stress index as witnessed in the Naked Neck genotype could be an indication that Naked Neck genotypes are tolerant to heat and can dissipate heat better than other genotypes, as earlier documented by Eberhart & Washburn (1993). The values of heat stress index as obtained generally for all chickens in this study agree with the works of El-Genoy et al. (2005) on genotype-environment interaction in relation to heat tolerance in chickens.

The results obtained on physiological response after inoculation with *S. enteridis* showed that the response of chickens is largely genotype-dependent. The results showed that genotype had a significant effect on body weight, pulse rate, respiratory rate, and heat stress index. Although, 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 chicken increased more distinctly, it is expected that metabolic activities will also increase which could bring about an increase in body temperature and hence, increase in all physiological characteristics (Ilori et al., 2021).

This is in agreement with the reports of Xie et al. (2000). In their findings, they concluded that genetic components that govern chickens' physiological characteristics and behavioral patterns might be directly or indirectly based on genotype, which is expressed in their phenotypes within a few hours of Salmonella enteritidis injection. Similarly, Ilori et al (2021) reported that genotype had a significant effect on body weight and physiological traits after inoculation with Salmonella enteritidis. The mean values of the three genotypes for rectal temperature fall within the normal range Ngongeh (2017); Ilori et al. (2021) in chicken and locally adapted turkey in Nigeria. Despite challenging the chickens with the *Salmonella* organism, the heat stress index of the three genotypes falls within the same range and is in consonance with what was reported (Ilori et al., 2011; Yakubu et al., 2012). These authors stated that the heat stress index of the exotic turkey genotype was almost in the same range as that of the local turkey genotype before and after inoculation with Salmonella enteritidis.

Haematological examination contributes immensely to the detection of some changes in the health status of birds that may not be obvious at the time of physical examination but undoubtedly affect the fitness of the birds (Lakurbe et al., 2018). Having this knowledge can be used to assess the health as well as the physiological status of farm animals. They are also a useful diagnostic tool for the nutritional, physiological, and health status of livestock (Odhaib et al., 2018). The haematological parameters observed in this research were genotype dependent and are consistent with the report of Abu-Awwad et al. (2025), strengthening the argument for inherent genetic differences. Red blood cell (RBC) transports oxygen to animal tissues for the oxidation process to release energy and transport carbon dioxide out of the tissues (Obeagu et al., 2024.

It plays important roles in the better understanding of normal physiology, pathology, and total health monitoring of birds. The normal range of RBC is 2.5-3.5 x 10^6 µL (Amana et al., 2025). Since the RBC observed values range between 1.43-2.63 x 10^6 µL, which is within the normal range for healthy chickens. It is indicative that the experimental birds were not anaemic. White Blood Cells (WBCs) defend the body against invasion by foreign organisms and supply antibodies for the immune response. The normal range of the WBC is 12-30 x 103 µl (Amana et al., 2025). The WBC values obtained in this study range from 81.79 to 152.35 x 10^3 µL, which is not in agreement with (Azekhumen; Ebomoyi, 2023).

This is higher than the normal range, indicating that birds' immune status is an intrinsic body defense system and will optimize performance under stressful conditions (van Mastrigt et al., 2025). Animals with high WBC values can generate antibodies and a high degree of disease resistance. Birds with low WBC are exposed to a high risk of disease infection, while an increase can produce antibodies in the process of phagocytosis and have a higher degree of disease resistance (Soetan et al., 2013). Furthermore, the increase in WBC indicates a superior disease-fighting ability. The differential leucocytes were used as indicators of stress response and sensitive biomarkers crucial to immune functions. It has, however, been reported by Sharaha et al. (2025) that bacterial and viral diseases affect the number of white corpuscles and the ratio between the different types of white corpuscles, and the percentages of the various types in healthy animals vary slightly but are greatly modified in sick animals.

After inoculation with the *Salmonella* organism for haematological parameters, the values reported for packed cell volume (PCV) are lower than the recommendation of Okafor et al. (2025) but agree with those of Ahmad et al. (2025). Okoro (2025) recommended the PCV for avian species to be 22 - 35%, which actually agreed with the PCV result of this study. Ilo et al. (2019) also had the same range of PCV value for broiler chickens in their study, which also agreed with the values reported in this study. Haemoglobin values were in line with the recommendation of Sunmola et al. (2019) for avian blood. The values for RBC are within the range reported by van Mastrigt et al. (2025).

More so, the WBC and its components play a phenomenal role in the immune system, as they protect the body against foreign bodies that can threaten its functionality (Odhaib et al., 2018). Leucocytosis (Increase in WBC) was observed, which is in line with the report of Opoola et al. (2020), who all reported significant increase in the total white blood cells count and this increase was attributed to fast multiplication of the Salmonella inside the phagocytes, with subsequent cell lysis and release of the bacteria into the extracellular compartment which evoked strong immune response. Generally, WBC differentials are involved in recognizing body intruders, killing harmful bacteria, and creating antibodies to protect the body against future exposure to some pathogens, such as bacteria and viruses.

The differential leukocyte counts showed slight changes except for Basophils. This differs from the reports of Mastrigt et al. (2025), which show a considerable increase in the differential leukocyte counts in broilers and layers, respectively. This difference may be attributed to variation in the breed used and the number of days for the parameter taken. The neutrophils and lymphocytes were lower and higher, respectively, and this is in line with the works of van Mastrigt et al. (2025) for broiler chickens. This could be due to breed, treatment, age of animal, and the virulence of the *Salmonella* organism. Neutrophil values of 9.14 -16.85% does not agree with the reference value of 21-26% recommended by Mastrigt et al. (2025) as neutrophils value range for broiler chickens. This implies that the ability of the chicken to fight against infection is a bit low.

The lymphocytes value ranged between 70.25 and 92.08% are higher than the recommended value of 58.10-71.70% reported by Okafor et al. (2025). This higher lymphocyte count is an indication that the body is dealing with an infection. Monocytes value ranges from 2.13-5.52% is lower than the 16-18% reported for (Sebastian et al., 2012). Monocytes are the largest members of the white blood cells differentials with migrating capacity to various tissues of the body to eliminate harmful and dead matter. This means that the chickens were more susceptible to infection.

The eosinophils and basophils values of 11.52-16.07% and 0.00-1.38 obtained do not fall within the normal range of 1.5- 2.5% and 1.2-3.1% reported by Okafor et al. (2025), respectively. Eosinophils fight against the activities of larger parasites, such as worms, and modulate allergic inflammatory responses, while basophils establish defense against allergic reactions from parasites and bacteria. This means that the birds were able to fight against the activity of the parasite introduced into the birds.

There is a significant relationship between body weight, physiological factors, and SNPs. This could be because the gene only had a relationship with the immune system generally. SNPs 1G>C, 2G>T, 6G>C, and 84 C>T associated better with PR, RR, and W, while 84 C>T and 145 C>T associated better with RT and HSI, respectively. However, SNP 145 C>T had the highest value for HSI. All SNPs had the normal value for RT (Olaniyan, 2024). SNPs 34T>G associated better with PR, RR, and HSI, while 31C>G associated better with RT, W, and HSI, respectively. All SNPs had the normal value for RT and W (Olaniyan, 2024). However, SNP 34T>G had the highest value for HSI. SNPs236T>C associated better with PR, RR, RT, and W, while 20 A>C associated better with HSI, respectively. All SNPs had the normal value for W and W (Olaniyan, 2024). However, SNP 34T>G had the highest value for HSI. This means that birds with this SNP can withstand heat stress better.

5. Conclusions

This study showed that there is a significant effect of genotype on body weight and physiological parameters before and after inoculation with *Salmonella enteritidis*, except rectal temperature. Naked neck chickens responded better in terms of physiological parameters, while the Sasso birds were the best in body weight. There is a significant effect of genotype on all haematological parameters except eosinophils before and after inoculation. Naked Neck had the highest values in all parameters except for mean corpuscular haemoglobin and lymphocytes. There is a significant association between exon 11 of the NRAMP1 gene polymorphisms and physiological and haematological parameters.

6. Acknowledgments

We thank the Department of Animal Production and Health and Animal Nutrition and Biotechnology, P.M.B. 4000, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria.

7. Authors' Contributions

Oluwatobi Elijah Ojua: project design, research, data processing, article writing, and publication. *Tosin Ademola Adedeji*: research, data processing, and article writing. *Temitope Oyeyemi Adegboyega*: raw data collection, data processing, and data analysis. *Abdulrahmon Adedire Bamgbose*: raw data collection, data processing, and data analysis. *Abimbola Deborah Matt-Obabu*: project writing, data processing, article writing, and publication.

8. Conflicts of Interest

No conflicts of interest.

9. Ethics Approval

Yes applicable. The study was approved by the Nigerian Animal Ethics Committee with the voucher: ANB/PG/2023011824.

10. References

Abu-Awwad, S. A., Abu-Awwad, A., Farcas, S. S., Popa, C. A., Tutac, P., Zaharia, I. M., & Andreescu, N. (2025). Correlations between immuno-inflammatory biomarkers and hematologic indices stratified by immunologic SNP genotypes. *Journal of Clinical Medicine*, 14(16), 5792. https://doi.org/10.3390/jcm14165792

Adedeji, T., Amao, S., Ogundairo, O., & Fasoyin, O. (2015). Heat tolerance attributes of Nigerian locally adapted chickens as affected by strain and some qualitative traits. *Continental Journal of Agricultural Science*, 9(2), 10-18. DOI:10.5707/cjagricsci.2015.9.2.10.18

Ahmad, U., Salisu, N., Kobo, P. I., Yusuf, H., Eshi, I. S. U., & Sani, D. (2025). *In vivo* antibacterial activities of aqueous stem bark extract of *Ficus abutilifolia* (Miq) in mice experimentally infected with *Salmonella typhi*. *Pharmacological Research-Natural Products*, 7, 100262. https://doi.org/10.1016/j.prenap.2025.100262

Alabi, R. A., Tariuwa, I. O., Onemolease, P. E., Mafimisebi, A., Isah, T. A., Esobhawan, A. O., & Oviasogie, D. I.

(2000). Risk management in poultry enterprises in Edo State through insurance Scheme. Proceedings of the 5th Annual Conference of Animal Science Association of Nigeria, Port Harcourt, Nigeria, 182-184 p.

Amana, O. C., Bello, M. O., Alfa, L. E., & Felix, V. (2025). Interaction effect of genotype and dietary treatment on haematological indices of pullet chickens. *Nigerian Journal of Animal Production*, 213-215.

Azekhumen, G. N.. & Ebomoyi, M. I. (2023). Hematological variation in female wistar rats treated with aqueous extract of *Xylopia aethiopica* fruit. *Journal of Applied Sciences and Environmental Management*, 27(12), 2897-2900. https://www.ajol.info/index.php/jasem/article/view/261665

Bamishaiye, E. I., Muhammad, N. O., & Bamishaiye, O. M. (2009). Haematological parameters of albino rats fed on tiger nuts (*Cyperus esculentus*) tuber oil meal-based diet. *The International Journal of Nutrition and Wellness*, 10(1), 1-5.

BATC (2004). British American Tobacco Company Meterological site. Ogbomoso. Nigeria.

Baylis, M., & Githeko, A. K. (2006). The effects of climate change on infectious Diseases of animals. Report of T7.3 Foresight: Infections diseases preparing for the future. Office of science and innovation, Department of trade and Industry.

Cobo-Simón, M., Hart, R. and Ochman, H. (2023). Gene flow and species boundaries of the genus *Salmonella*. *mSystems*, 8(4). https://doi.org/10.1128/msystems.00292-23

Defra, (2003). Heat Stress in Poultry: Solving the Problem, 5 p.

Eberhart, D. E., & Washburn, K. W. (1993). Assessing the effects of the naked neck gene on chronic heat stress resis- tance in two genetic populations. *Journal of Poultry Science*, 72(8), 1391-1399. https://doi.org/10.3382/ps.0721391

El-Gendy, E. A., Nassar, M. K. Salama, M. S., & Mostageer, A. (2005). Genotype-environment interaction in relation to heat tolerance in chickens. *Arab Journal of Biotechnology*, 9(1), 1-16.

Heise, H., Crisan A., & Theuvsen, L. (2015). The poultry market in Nigeria: Market structures and potential for investment in the market. *International Food and Agribusiness Management Review*, 18(1), 197-222. https://doi.org/10.22004/ag.econ.207011

Hu, G. S., Chang, G. B., Zhang, Y., Hong, J., Liu, Y., & Chen, G. H. (2011). Association analysis between polymorphisms of Nramp1 gene and immune traits in chicken. *Journal of Animal Veterinary*, 10(9), 1133-1136.

Ilo, S., Onwusika, A., Nnajiofor, N., & Ezenwosu, C. (2019). Haematological and serum biochemical characteristics of broiler finishers fed diets containing cassava peel meal. The Proceedings 44 Conference of the Nigerian Society for Animal Production, UNIABUJA, ABUJA, 184-187 p.

Ilori B. M, Oguntade D. O, Abiona, J.A., Durosaro, S. O., Isidahomen, C. E., & Ozoje, M. O. (2021). Genotypic differences in body weight and physiological response of local and exotic turkeys challenged with *Salmonella typhimurium*. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 122(2), 219-230. https://doi.org/10.17170/kobra-202110274960

Jain, N. C. (1993). Essentials of vet haematology. Philadephia. Lea and Fabigers, 20-86 p.

Lakurbe, O. A., Doma, U. D., Bello, K. M, & Abubakar, M. (2018). Haematological and serum biochemical indices of broiler chickens fed *Sorghum* SK-5912 (*Sorghum bicolor*, L. Moench) variety as a replacement for maize. *Nigerian Journal of Animal Production*, 45(3), 242-247.

Nassar, F. S., & Abbas, A. O. (2025). Crisis and risk management in poultry production: Preparing future leaders for sustainability and food security. *Poultry Science*, 104(12), 105903. https://doi.org/10.1016/j.psj.2025.105903

Ngongeh, L. A., Onyeabor, A., Nzenwata, E., & Samson, G. K. (2017). Comparative response of the Nigerian indigenous and broiler chickens to a Field Caeca isolate of *Eimeria oocysts*. *Journal of Pathogens*, 9. https://doi.org/10.1155/2017/2674078

Obeagu, E. I., Igwe, M. C., & Obeagu, G. U. (2024). Oxidative stress's impact on red blood cells: Unveiling implications for health and disease. *Medicine*, 103(9), e37360. DOI: 10.1097/MD.0000000000037360

Odhaib, K., Adeyemi, K., Ahmed, M., Jahromi, M., Jusoh, S., Samsudin, A., Alimon, A., Yakub, H., & Sazili, A. (2018). Influence of *Nigella sativa* seeds, *Rosmarinus officinalis* leaves and their combination on growth performance, immune response and rumen metabolism in Dorper lambs. *Tropical Animal Health and*

Production, 50, 1011-23. https://doi.org/10.1007/s11250-018-1525-7

Okafor, S. C., Ihedioha, J. I., & Ezema, W. S. (2025). Experimental *Salmonella gallinarum* infection in point of lay pullets: Correlation of hematology and oxidative stress with egg production. *Veterinary Integrative Sciences*, 23(3), 1-19. https://doi. org/10.12982/VIS. 2025.073.

Okoro, S. C. (2025). Physiological and behavioral heat tolerance traits in indigenous and exotic chickens in Southern Nigeria. *Agriculture and Environmental Sciences Journal*, 13(4), 16-23.

Olaniyan, M. F., Oladele, A. A., Tijani, A., Muhibi, M. A., & Olaniyan, T. B. (2024). Susceptible genes and polymorphisms associated with communicable and noncommunicable diseases. *Journal of Bio-X Research*, 7, 0001. https://doi.org/10.34133/jbioxresearch.0001

Omodewu, I. A., & Tiamiyu, A. K. (2021). Comparative evaluation of the physiological responses and blood profile of the Fulani eco-type chicken, Arbor acre broilers and its crosses during the dry season. *Nigerian Journal of Animal Science*, 23(1), 1-7.

Opoola, M. A., Adenaike, A. S., Jegede, O. A., Akutubuola, N. I., Fajemisin, A. J., Takeet, M. I., & Ikeobi, C. O. N. (2020). Immune response kinetics in Nigerian indigenous chickens challenged with attenuated *Salmonella*. *Nigerian Journal of Animal Production*, 47(2), 57-67.

Rist, C. L., Ngonghala, C. N., Garchitorena, A., Brook, C. E., Ramananjato, R., Miller, A. C., Randrianarivelojosia, M., & Wright, P. C. (2015). Modelling the burden of poultry disease on therural poor in Madagascar. *One Health Journal*, 1, 60-65. https://doi.org/10.1016/j.onehlt.2015.10.002

SAS. (2003). Statistical Analysis System package (SAS), Version 9.2 software. SAS Institute Inc. Cary, NC, USA.

Sharaha, U., Eshel, Y. D., Bykhovsky, D., Mazar, J., Lapidot, I., Huleihel, M., & Kapelushnik, J. (2025). Augmentation of infrared microscopy of white blood cells and medical measures for rapid and accurate diagnosis of bacterial or viral infections in febrile pediatric oncology patients: An expert system-based study. *Analytical Chemistry*, 97(25), 13386-13395. https://doi.org/10.1021/acs.analchem.5c01728

Sia, C. M., Pearson, J. R., Howden, B. P., Williamson, D. A., & Ingle, D. J. (2025). *Salmonella* pathogenicity islands in the genomic era. *Trends in Microbiology*, 33(7), 752-764.

Soetan, K. O., Akinrinde, A. S., & Ajibade, T. O. (2013). Preliminary studies on the haematological parameters of cockerels fed raw and processed guinea corn (Sorghum bicolor). Proceedings of 38th Annual Conference of Nigerian Society for Animal Production, 49-52 p.

Sunmola, T., Tuleun, C., & Oluremi, O. (2019). Growth performance, blood parameters and production cost of broiler chickens fed dietary sweet orange peel meal diets with and without enzyme addition. *Nigerian Society for Animal Production Nigerian Journal of Animal Production*, 46(1), 37-50.

Tabor, H. K., Risch, N. J., & Myers, R. M. (2002). Candidate-gene approaches for studying complex genetic traits: Practical considerations. *Nature Reviews Genetics*, 3(5), 391-397. https://doi.org/10.1038/nrg796

Togun, V. A., Oseni, B. S. A., Ogundipe, J. A., Arewa, T. R., Hammed, A. A., Ajonijebu, D. C., & Mustapha, F. (2007). Effects of chronic lead administration on the haematological parameters of rabbits – a preliminary study. Proceedings of the 41st Conferences of the Agricultural Society of Nigeria, 341 p.

van Mastrigt, T., Matson, K. D., Lagerveld, S., Huang, X. S., de Boer, W. F., & van der Jeugd, H. P. (2025). Effects of immune status on stopover departure decisions are subordinate to those of condition, cloud cover and tailwind in autumn ‐ migrating common blackbirds, *Turdus merula*. *Journal of Avian Biology*, 2025(2), e03368. https://doi.org/10.1111/jav.03368

Waugh, A., Grant, A. W., & Ross, J. S. (2001). Ross and Wilson Anatomy and Physiology in Health and Illness, 59-71 p.

Wongnaa, C. A., Mbroh, J., Mabe, F. N., Abokyi, E., Debrah, R., Dzaka, E., Cobbinah, S., & Poku, F. A. (2023). Profitability and choice of commercially prepared feed and farmers' own prepared feed among poultry producers in Ghana. *Journal of Agriculture and Food Research*, 12, 100611. https://doi.org/10.1016/j.jafr.2023.100611

Yakubu, A., Peters, S. O., Ilori, B. M., Imumorin, I. G., Adeleke, M. A., Takeet, M. I., Ozoje, M. O., Ikeobi, C. O. N., & Adebambo O. A. (2012). Multifactorial discriminant analysis of morphological and heat-tolerant traits in indigenous, exotic and cross-bred turkeys in Nigeria. *Journal of Animal Genetic Resources*, 50, 21-27. https://doi.org/10.1017/S2078633611000610

Zerjal, T., Gourichon, D., Rivet, B., & Bordas, A. (2007). Performance comparison of laying hens segregating for the Frizzle gene under thermo neutral and high ambient temperatures. *Poultry Science*, 92(6), 1474-1485. https://doi.org/10.3382/ps.2012-02840

Funding

Not applicable.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.