Acta fytotechn zootechn, 25, 2022(1): 24–33
http://www.acta.fapz.uniag.sk

Original Paper

Effects of breed and sex on the adaptive profile of tropical goats

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Article Details: Received: 2021-06-12 | Accepted: 2021-12-16 | Available online: 2022-03-31

https://doi.org/10.15414/afz.2022.25.01.24-33

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This study was embarked upon to evaluate breed and sex effects on the thermo-physiology and blood parameters; predict heat stress index and appropriately classify Nigerian West African Dwarf (WAD) and Red Sokoto (RS) goats in a 2 × 2 factorial experiment involving twenty four goats. WAD goats had higher rectal temperature (38.93 ±0.10 versus 38.59 ±0.10) and pulse rate (54.78 ±0.24 vs. 53.67 ±0.24) compared to their RS counterparts. However, there was no significant difference in heat stress index between WAD and RS goats. Based on thermo-physiological parameters, male goats appeared to be more stressed. There was no significant Breed * Sex interaction effect on thermo-physiological traits. The results of haematological and serum biochemical and hormonal indices of goats also indicated that WAD goats appeared to be more stressed. The male goats had higher Cortisol (58.00 ±4.88 versus 37.67 ±4.88) and lower Thyroxine (111.50 ±8.32 vs. 141.18 ±8.32) levels. There was no significant Breed * Sex interaction effect on haematological indices. While male and female WAD goats were similar, female RS goats had higher value of TSH (1.20 ±0.21) than their male counterparts (0.57 ±0.21). The Artificial Neural Network algorithm revealed that respiratory rate, cortisol, pulse rate and WBC had more influence on heat stress prediction in goats compared to breed, sex and other haematological, serum biochemical and hormonal parameters. Haemoglobin, white blood cells, rectal temperature and pulse rate were sufficient to correctly assign WAD and RS goats to their appropriate breed. The present information may aid breed characterization and conservation of WAD and RS goats.

Keywords: Heat stress, blood markers, goats, prediction, tropics

1 Introduction

Goats play a significant role in complementing the large ruminants (i.e. cattle) in the provision of the protein need of the populace. It is generally acceptable as a delicacy in most functions in the African society. In Nigeria, goats are the predominant ruminant biomass and a source of income to most rural dwellers. It has been reported that, goats contribute 16.0% and sheep 5.0% of the total domestically produced meat, estimated to be about 813,000 tonnes annually. With the emergence of predominant goat breeds in Nigeria such as Red Sokoto (RS) and West African dwarf (WAD); enhancing their productivity is expected to improve the economy of the rural farmers. The RS goats are commonly found in the Guinea and Sudanian Savanna regions of the north, while their WAD counterparts predominate in the humid parts of Southern Nigeria where it's assumed to originate from (Oseni et al., 2017).

In recent years, there has been an observation on the adaptation of indigenous goat breeds to new geographical regions of Nigeria. However, in tropical environment, ambient temperature combined with high relative humidity has been a major challenge facing the production of goats negatively. Of importance is the stress that is exerted on the animal by the environment, which could play a big role in the adaptation processes of different breeds of goats (Bertolini et al., 2018). When an animal is thermally stressed, it is unable to cope with its environment resulting in its failure to achieve its genetic potential. Such animals also experience poor health and decline in growth and reproductive performance. During stress, physiological and biochemical changes occurs

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in the body of the animal which directly or indirectly affect their production (Shin et al., 2019). Heat stress is most common in the dry season, when the environment witnessed high temperature and relative humidity in addition to prolonged direct sunlight exposure. Generally, it detrimentally affects physiological equilibrium of goats and endocrine, nervous and immune systems which have been implicated in specific responses and reciprocal regulatory influences.

The blood profile of an animal is known to be highly sensitive to environmental changes and it is an important indicator of physiological responses to stressing agent in goats. Determination of specific reference intervals for each breed in term of haematological and biochemical values as well as thyroid hormone profile is of immense importance to pave way for correct diagnosis of the potential pathological processes. It is particularly useful especially to monitor metabolic processes, nutritional deficiencies as well as metabolic profiles of flocks (Antunovi´c et al., 2019; Idamokoro et al., 2019). Generally, the adaptability of indigenous breeds of goats to local environmental conditions is well known (Yakubu et al., 2017a). However, priority attention has not been given to the identification of the hidden intricacies of different adaptive mechanisms of the goat breeds to thermal stress in Nigeria. More so that there is dearth of literature on haematology, blood biochemistry and thyroid hormones of WAD and RS goats especially in north central part of the country. Therefore, there is need for information on possible indicators of heat stress on indigenous breeds of goats in Nigerian such as the WAD and RS goats. The data obtained may be reference values for researchers and producers to work out appropriate mechanism in ameliorating the detrimental effect of heat stress so as to improve the welfare and productivity of their goats.

This study, therefore, aimed at evaluating the effects of breed and sex on the thermo-physiology, hematological and serum biochemical indices and thyroid hormones of WAD and RS goats in Nasarawa State, Nigeria during the hot-dry season. It also predicted heat stress index and classified WAD and RS goats.

2 Material and methods

2.1 Study area

This study was carried out at the Faculty of Agriculture, Nasarawa State University, Keffi, Shabu, Lafia Campus Teaching and Research Farm. The Farm is within the guinea savannah zone of North Central Nigeria, and on latitude 8° 35′ N and longitude 8°.33′E, respectively. The guidelines on research ethics of International Council for Laboratory Animal Science and NC3Rs ARRIVE (Animal Research: Reporting of *in vivo* Experiments) (https://www.nc3rs.org.uk/arrive-guidelines) were adhered to strictly while carrying out the research.

2.2 Experimental animals and their management

A total of twenty four (*n* =24) healthy, non pregnant goats of both sexes comprising equal number of West African Dwarf (WAD) (6 males + 6 females) and Red Sokoto (RS) (6 males + 6 females) with a body weight of 8.5–10 kg were used for the experiment. The experimental goats were sourced in local villages within the State. The animals were ear tagged and quarantined for a period of two weeks before the commencement of the experiment. A 2 × 2 factorial experiment in a completely randomized design was adopted for the project. The animals were randomly allocated to the experimental pens based on breed and sex. Each pen with a diameter of 6.1, 6.1 and 2.3 m high, was well ventilated. The semi-intensive management system was adopted for the experiment. The animals were fed groundnut haulms, cowpea hulks and wheat offal of 0.5kg (experimental animal) as supplement. Water was supplied *ad libitum* in all the pens. Health and routine management practices were also carried in line with best practices. The experiment lasted 9 weeks beginning from the 1st week of March to 1st week of May, 2017. This period corresponded to the hot-dry season in the study location (Yakubu et al., 2018).

2.3 Meteorological parameters

Air temperature, dew point, relative humidity, rainfall, solar radiation, pressure and wind speed records were obtained from the Meteorological Unit, of the Faculty of Agriculture, located about 200 meters away from the site of the experiment. The temperature humidity index (THI) was used to determine heat stress level imposed by the environment on the goats and was calculated using the following equation:

$$THI = (1.8 \times T + 32) - \{(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)\}$$

where:
T – ambient temperature (°C); RH – relative humidity (%)

2.4 Thermo-physiological data collection

Digital thermometer was used through the anus in taking the Rectal temperature (RT), of the animal. Respiratory rate (RR) and Pulse rate (PR) parameters were taken in the morning (between the hours of 7:00 am and 9:00 am) and in the afternoon (1:00 pm and 3:00 pm). RT, RR and PR were determined following the procedures outlined in an earlier study by Yakubu et al. (2017b) and the Heat stress index (HSI) calculated as shown below:

$$HSI = RR/PR \times NP/NR$$

where:
RR – actual respiratory rate; *PR* – actual pulse rate; *NP* – normal pulse rate, *NR* – normal respiratory rate

In both goat breeds, the basal reference value for *NR* was 30 breaths min^{-1} while that of NP was 90 beats min^{-1}

2.5 Haematological indices determination

On the last day of the experiment, blood samples (about 5 ml) were collected from the jugular vein of the experimental goats. Blood samples so collected were placed in two tubes, one containing anticoagulant ethylenediaminetetraacetic acid (EDTA) to determine haematological parameters and the other without anticoagulant and left to clot for serum biochemical analysis. The blood samples were transported in an ice pack to the laboratory before analysis. Using a manual haemocytometer, counting of erythrocytes [red blood cells (RBC)] and leukocytes [white blood cells (WBC)] was done according to standard methods. Packed cell volume (PCV) was determined applying the microhaematocrit method. As a result of the small size of Caprine erythrocytes, the centrifugation time was increased (3000 g for 15 min) to guarantee complete packing. A haemoglobin meter was used to determine the concentration of Haemoglobin (Hb). The mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH) and mean corpuscular haemoglobin concentration (MCHC) were derived using standard formulae.

2.6 Immunoglobulin G and Thyroid hormones determination

Immunoglobulin G (IgG) level was determined using Enzyme linked immunosorbent assay (ELISA) (Southern Biotech, Birmingham AL). Thyroid hormones were measured with an automated biochemistry analyzer (Access Immunoassay System – Beckman Instruments Inc – Chaska, USA), which operation principle is based on chemical luminescence. Commercially available immunoassay kit was used for cortisol (Beckman Coulter), total thyroxine (T_4 – ACCESS – Beckman Coulter – Fullerton, USA), total triiodothyronine (T_3 Beckman Coulter) and the thyroid-stimulating hormone (TSH – Hypersensitive hTSH – Beckman Coulter). Enzyme linked immunosorbent assay (ELISA) using a micro plate reader was used for the determination of hormonal variables as described by Pragna et al. (2017).

2.7 Statistical analysis

General Linear Model (GLM) procedure was used to test the fixed effects of breed and sex including their interactions on thermo-physiological traits (RT PR and RR), haematological parameters (RBCs, WBCs, HB and PCV), serum biochemical characteristic (Immunoglobulin G) and thyroid hormones (cortisol, total thyroxine, total triiodothyronine and thyroid-stimulating hormone). Least Significant Difference (LSD) procedure was used to separate the means at 95% confidence interval. The linear additive model used was:

$$Y_{ijk} = \mu + B_i + S_j + (BS)_{ijk} + e_{ijk}$$

where:
Y_{ijk} – individual observation; μ – general mean; B_i – fixed effect of i^{th} breed (*i* – WAD, RS); S_j – fixed effect of j^{th} sex (*j* – male, female); $(BS)_{ijk}$ – breed and sex interaction effect; e_{ijk} – random error associated with each error

Artificial Neural Network (ANN) algorithm was used to predict heat stress index from breed and sex of goats, PCV, Hb, MCHC, WBC, RBC, MCV, MCH, Immunoglobulin G, Cortisol, Triiodothyronine, Thyroxine and Thyroid stimulating hormone concentration. The standardized discriminant function was used to screen for the most discriminating variables (All the thermo-physiological traits, haematological parameters, serum biochemical characteristic and thyroid hormones) between the breeds. Wilks` lambda (U statistic) was used to test the significance of the discriminant function. This model ability to identify WAD and RS goats was indicated as the percentage of individuals correctly classified. All Analyses were carried out using IBM statistical package.

3 Results and discussion

The meteorological data during the study period indicated that the mean air temperature (°C) for the months of March, April and May were 31.90 ±0.05, 31.05 ±0.04 and 28.70 ±0.03, respectively. Average values for relative humidity were 43.04 ±0.17, 60.51 ±0.18 and 75.39 ±0.13. The corresponding temperature-humidity index (THI) is shown in Figure 1 with the highest being in the month of April (81.31) and the lowest recorded in the month of March (79.68). On the average, the THI was 80.35.

The effect of genetic group on the thermo-physiological indices of (WAD) and (RS) goats revealed significant (P <0.05) difference as presented in Table 1. Rectal temperature and pulse rate were higher in WAD goats than their Red Sokoto counterparts. However, the two genetic groups were not significantly (P >0.05) different in terms of respiratory rate (RR) and heat stress (HSI) index.

The influence of sex on thermo-physiological traits is shown in Table 2. Sex significantly (P <0.05) affected pulse rate and heat stress index. While pulse rate was higher in females (54.70 ±0.24 versus 53.73 ±0.24), heat stress index was higher in males (2.35 ±0.03 versus 2.26 ±0.03). No significant sex differences (P >0.05) were recorded for rectal temperature and respiratory rate.

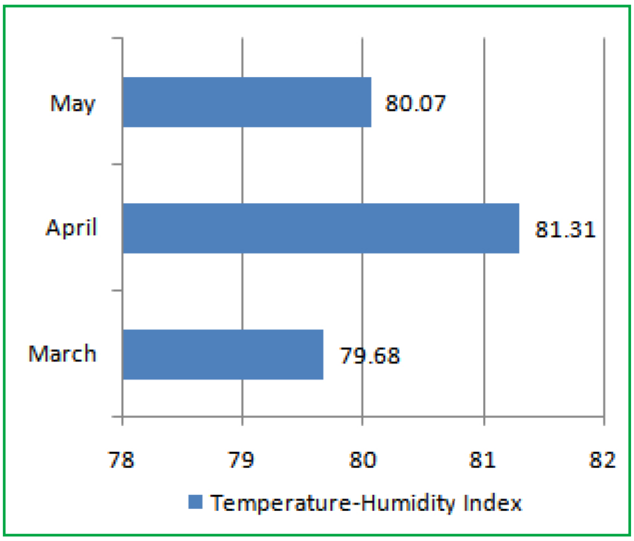

Figure 1 Temperature-Humidity Index during the study period

Breed and Sex interaction effects (B*S) on thermo-physiological indices of WAD and RS were not significant (P >0.05) (Table 3). However, the average values of pulse rate and respiratory rate tended more to significance compared to rectal temperature and heat stress index.

Effect of breed on haematological variables of goats is presented in Table 4. Significant (P <0.05) breed differences in PCV, Hb, RBC and MCHC were observed with higher values recorded for WAD goats compared to their Red Sokoto counterparts. However, mean values for WBC, MCV and MCH were not significantly (P >0.05) influenced.

Haematological parameters of goats are shown in Table 5. The two sexes did not significantly (P >0.05) vary in terms of PCV, Hb, MCHC, WBC, RBC, MCV, MCH and MCHC.

Table 1 Effect of genetic group on the thermo-physiological indices of goats

Parameters	Breed		*P*-value
	WAD (mean ±S.E.)	RS (mean ±S.E.)	
Rectal temperature (°C)	38.93 ±0.10	38.59 ±0.10	0.014
Pulse rate (beats min^{-1})	54.78 ±0.24	53.67 ±0.24	0.001
Respiratory rate (breaths min^{-1})	42.28 ±0.51	41.50 ±0.51	0.283
Heat stress index	2.31 ±0.03	2.29 ±0.03	0.648

WAD – West African dwarf; RS – Red Sokoto; S.E. – standard error of means; means within rows with P <0.05 are significantly different

Table 2 Effect of sex of goats on thermo-physiological parameters

Parameters	Sex		*P*-value
	female (mean ±S.E.)	male (mean ±S.E.)	
Rectal temperature (°C)	38.71 ±0.10	38.82 ±0.10	0.443
Pulse rate (beats min^{-1})	54.70 ±0.24	53.73 ±0.24	0.006
Respiratory rate (breaths min^{-1})	41.61 ±0.51	42.17 ±0.51	0.443
Heat stress index	2.26 ±0.03	2.35 ±0.03	0.041

S.E. – standard error of means; means within rows with P <0.05 are significantly different

Table 3 Breed and sex interaction effect on the thermo-physiological indices of goats

Parameters	WAD		RS		*P*-value
	female	male	female	male	
Rectal temperature (°C)	38.97 ±0.14	38.90 ±0.14	38.45 ±0.14	38.74 ±0.14	0.192
Pulse rate (beats min^{-1})	55.56 ±0.34	54.00 ±0.34	53.85 ±0.34	53.48 ±0.34	0.086
Respiratory rate (breaths min^{-1})	41.37 ±0.72	43.18 ±0.72	41.85 ±0.72	41.15 ±0.72	0.086
Heat stress index	2.24 ±0.05[a]	2.38 ±0.05	2.27 ±0.05	2.31 ±0.05	0.246

means within rows with P >0.05 are not significantly different for all interactions

Table 4 Effect of genetic group on the haematological parameters of goats

Parameters	Breed		*P*-value
	WAD (mean ±S.E.)	RS (mean ±S.E.)	
PCV (%)	30.33 ±0.86	24.83 ±0.86	0.001
Hb (g dl^{-1})	10.067 ±0.29	8.02 ±0.29	0.001
WBC (×10^9 l^{-1})	7.00 ±0.67	6.80 ±0.67	0.863
RBC (×10^{12} l^{-1})	3.02 ±0.09	2.43 ±0.09	0.001
MCV (fl)	100.40 ±0.68	102.23 ±0.67	0.073
MCH (pg)	33.30 ±0.40	33.27 ±0.40	0.954
MCHC (g dl^{-1})	33.15 ±0.31	32.13 ±0.31	0.030

WAD – West African Dwarf; RS – Red Sokoto; S.E. – standard error of means; means within rows with $P < 0.05$ are significantly different

Table 5 Effect of sex on the haematological indices of goats

Parameters	Sex		*P*-value
	female (mean ±S.E.)	male (mean ±S.E.)	
PCV (%)	28.83 ±0.86	26.33 ±0.86	0.054
Hb (g dl^{-1})	9.37 ±0.29	8.72 ±0.29	0.128
WBC (×10^9 l^{-1})	6.80 ±0.67	7.00 ±0.67	0.836
RBC (×10^{12} l^{-1})	2.84 ±0.09	2.61 ±0.09	0.060
MCV (fl)	101.55 ±0.68	101.07 ±0.68	0.621
MCH (pg)	32.92 ±0.40	33.65 ±0.40	0.209
MCHC (g dl^{-1})	32.42 ±0.31	32.87 ±0.31	0.313

WAD – West African Dwarf; RS – Red Sokoto; S.E. – standard error of means; means within rows with $P > 0.05$ are not significantly different

Table 6 Breed and sex interaction effect on the haematological indices of goats

Parameters	WAD		RS		*P*-value
	female	male	female	male	
PCV (%)	30.67 ±1.22	30.00 ±1.22	27.00 ±1.22	22.67 ±1.22	0.149
Hb (g dl^{-1})	10.17 ±0.41	9.97 ±0.41	8.57 ±0.41	7.47 ±0.41	0.285
WBC (×10^9 l^{-1})	7.33 ±0.95	6.67 ±0.95	6.27 ±0.95	7.33 ±0.95	0.373
RBC (×10^{12} l^{-1})	3.06 ±0.12	2.98 ±0.12	2.63 ±0.12	2.23 ±0.12	0.200
MCV (fl)	100.13 ±0.96	100.67 ±0.96	102.97 ±0.96	101.47 ±0.96	0.303
MCH (pg)	33.20 ±0.57	33.40 ±0.57	32.63 ±0.57	33.90 ±0.57	0.356
MCHC (g dl^{-1})	33.13 ±0.43	33.17 ±0.43	31.700 ±0.43	32.57 ±0.43	0.349

means within rows with $P > 0.05$ are not significantly different for all interactions

Breed Sex interaction effect (B*S) on haematological indices of the goats was not significant ($P > 0.05$) (Table 6). This is with regard to PCV, Hb, MCHC, WBC, RBC, MCV and MCH.

Effect of genetic group on the biochemical and hormonal indices of goats is presented in Table 7. Immunoglobulin G and cortisol were significantly ($P < 0.05$) higher in WAD goats than RS. However, mean values for Triiodothyronine, Thyroxine and Thyroid stimulating hormone concentration did not vary ($P > 0.05$) in both breeds.

Sex effect on biochemical hormonal indices of goats is shown in Table 8. Cortisol and thyroxine concentrations were significantly ($P < 0.05$) different in female and male goats. However, no significant difference ($P > 0.05$) effects were recorded for immunoglobulin G, Triiodothyronine and Thyroid stimulating hormone.

The effect of breed and sex interaction on biochemical and hormonal indices of goats is as shown in Table 9. There was a significant ($P < 0.05$) interaction effect on thyroid stimulating hormone (TSH). While male and female WAD goats were similar, female

Table 7 Effect of genetic group on the biochemical and hormonal indices of goats

Parameters	Breed		*P*-value
	WAD (Mean ±S.E.)	RS (Mean ±S.E.)	
Immunoglobulin G (mmol l^{-1})	1.82 ±0.13	1.40 ±0.13	0.030
Cortisol (nmol l^{-1})	57.83 ±4.88	37.83 ±4.88	0.009
Triiodothyronine (µmol l^{-1})	1.00 ±0.07	1.033 ±0.07	0.744
Thyroxine (µmol l^{-1})	125.35 ±8.32	127.33 ±8.32	0.868
Thyroid stimulating hormone (µIU ml^{-1})	0.60 ±0.15	0.88 ±0.15	0.185

WAD – West African Dwarf; RS – Red Sokoto; S.E. – standard error of means; means within rows with P <0.05 are significantly different

Table 8 Effect of sex on the biochemical and hormonal indices of goats

Parameters	Sex		*P*-value
	female (mean ±S.E.)	male (mean ±S.E.)	
Immunoglobulin G (mmol l^{-1})	1.60 ±0.13	1.62 ±0.13	0.926
Cortisol (nmol l^{-1})	37.67 ±4.88	58.00 ±4.88	0.008
Triiodothyronine (µmol l^{-1})	0.93 ±0.07	1.10 ±0.07	0.113
Thyroxine (µmol l^{-1})	141.18 ±8.32	111.50 ±8.32	0.020
Thyroid stimulating hormone (µIU ml^{-1})	0.65 ±0.15	0.83 ±0.15	0.399

WAD – West African Dwarf; RS – Red Sokoto; S.E. – standard error of means; means within rows with P <0.05 are significantly different

Table 9 Breed sex interaction effect on biochemical and hormonal indices of goats

Parameters	WAD		RS		*P*-value
	female	male	female	male	
IgG (mmol l^{-1})	1.97 ±0.18	1.67 ±0.18	1.27 ±0.18	1.53 ±0.18	0.506
Cortisol (nmol l^{-1})	65.67 ±6.89	50.00 ±6.89	50.33 ±6.89	25.33 ±6.89	0.128
T_3 (µmol l^{-1})	1.17 ±0.10	0.83 ±0.10	1.03 ±0.10	1.03 ±0.10	0.113
T_4 (µmol l^{-1})	112.00 ±11.77	138.70 ±11.77	111.00 ±11.77	143.67 ±11.77	0.802
TSH (µIU ml^{-1})	0.46 ±0.21[a]	0.73 ±0.21[a]	1.20 ±0.21[a]	0.57 ±0.21[b]	0.042

IgG – Immunoglobulin G; T_3 – Triiodothyronine; T_4 – Thyroxine; TSH – Thyroid stimulating hormone; [ab] – means within rows with P <0.05 are significantly different

Table 10 Observed and predicted heat stress index descriptive statistics

Parameter	Minimum value	Maximum value	Mean	Standard error
Observed	1.91	2.76	2.40	0.05
ANN Predicted	1.91	2.75	2.40	0.05

RS goats had higher value of TSH (1.20 ±0.21) than their male counterparts (0.57 ±0.21). However, immunoglobulin G, cortisol, Triiodothyronine and Thyroxine concentrations did not indicate any significant (P >0.05) difference.

The observed and predicted heat stress index of goats' summary statistics is shown in Table 10. The predicted HSI mean value (2.40) was the same with observed value (2.40). The standard error term was 0.05 for both observed and predicted, respectively.

The parameters that are of paramount importance in predicting heat stress index using ANN are presented in Table 11. Respiratory rate, Cortisol, Pulse rate and WBC had more influence on heat stress prediction.

The relationship between the predicted and observed heat stress index is shown in Figure 2. The coefficient of determination (R^2) and Adjusted R^2 values of 0.999 and 0.999 were very high with a very low (0.00740) root mean square error (RMSE).

Table 11 Variables of importance to predict heat stress index

Variables	Importance	Normalized Importance (%)
Breed	0.017	12.1
Sex	0.012	8.7
PCV	0.047	32.8
Hb	0.025	17.5
WBC	0.077	54.1
RBC	0.058	40.3
MCV	0.023	16.0
MCH	0.074	51.8
MCHC	0.060	41.9
Cortisol	0.105	73.8
Immunoglobulin G	0.067	46.8
Triiodothyronine	0.075	52.8
Thyroxine	0.019	13.0
Thyroid stimulating hormone	0.044	31.0
Rectal temperature	0.067	46.7
Pulse rate	0.087	61.0
Respiratory rate	0.143	100.0

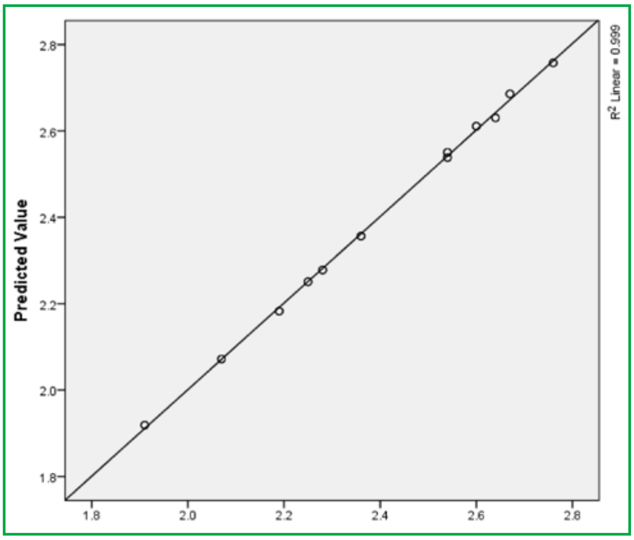

Figure 2 The scatter plot of the predicted and observed heat stress index in goats

The parameters that are of paramount importance in separating West African Dwarf and Red Sokoto goats are shown in Table 12. Haemoglobin, White blood cells, rectal temperature and Pulse rate were sufficient to classify WAD and RS goats into their genetic group.

The original group membership which indicates that both WAD and RS goats were correctly classified (100%

Table 12 Variables of importance in separating WAD and RS goats

Parameters	Wilks' Lambda	F-value	df1	df2	Significance
Haemoglobin	0.486	23.227	1	22.000	0.001
White blood cells	0.308	23.618	2	21.000	0.001
Rectal temperature	0.244	20.642	3	20.000	0.001
Pulse rate	0.191	20.154	4	19.000	0.001

Table 13 Assignment of goat populations into breeds

		Breed	Predicted Group Membership		Total
			WAD	RS	
Original	number	WAD	12	0	12
		RS	0	12	12
	%	WAD	100.0	0.0	100.0
		RS	0.0	100.0	100.0
Cross-validated	number	WAD	10	2	12
		RS	2	10	12
	%	WAD	83.3	16.7	100.0
		RS	16.7	83.3	100.0

WAD – West African Dwarf; RS – Red Sokoto; 100.0% of original grouped cases correctly classified. 83.3% of cross-validated grouped cases correctly classified in both cases) is shown in Table 13. The cross-validation was also high (83.3%) as only two WAD and two RS goats were wrongly classified.

High Temperature-Humidity index (with mean value of 80.35) was recorded during the period of the study. The result indicated that the WAD and RS goats were not within their thermal comfort zone. The implication of this condition is the inability of the animals to thermoregulate (Baena et al., 2019; Vasconcelos et al., 2021), thereby adversely affecting their adaptive capacity, which could eventually lead to low productivity (Lallo et al., 2018).

WAD goats had higher rectal temperature and pulse rate. However, these did not result in higher heat stress index when this value was compared with that of RS goats. The apparent high mean values of rectal temperature and pulse rate observed in the goats could be an indication of higher heat load occasioned by intense solar radiation in the tropics during the hot-dry season. Increased pulsation in the WAD goats could have resulted from increase in blood flow from the core to the surface for more heat to be lost from the skin. The hot-dry season being characterized by high ambient temperature, high humidity and long sunshine duration could take the animal beyond the comfort zone, thus resulting in increased heat production and energy dissipation. The relatively similar respiratory rate and heat stress index in WAD and RS goats agree with the findings that, of all the domesticated ruminant species, indigenous breeds of goats are the best in times of adaptation to harsh climates. Despite the well-developed mechanism of thermo-regulation, goats are regarded as physiological or habitual, as they are not always able to maintain homeothermy under heat stress (Ribeiro et al., 2018).

The female goats had higher pulse rate, but the male goats appeared to be more stressed based on heat stress index. Although both sexes respond to heat stress, female small ruminants appear to have ability to handle heat stress than their male counterparts (Schoenian, 2019). The higher heat stress index observed in male goats is contrary to the report in sheep. The difference might be attributed to species, location and age of the animals.

Based on haematological indices of goats, WAD goats appeared to be more stressed compared to their RS counterparts. The higher PCV value in WAD goats could be attributed to haemolysis. As a result of stress, there is every possibility for the breakdown of erythrocytes thereby releasing haemoglobin (oxygen-carrying pigment). This is in consonance with the report of Biobaku et al. (2018) in Kalahari goats. The higher magnitude of RBC in WAD compared to those of RS goats implies higher loss of thermoregulatory fluid. High level of Hb also in WAD goats could be due to stress-induced lysis of the RBC.

There was no significant sex influence on the haematological parameters. This is congruous to the report of Soul et al. (2019) where Hb, RBC, WBC, MPV MCH and MCHC were statistically similar in male and female goats. Haematological parameters based on breed, sex, age and season are used generally in small ruminants to monitor and evaluate their health status. Seasonal fluctuations may greatly influence haematological profile of goats.

Higher immunoglobulin (IgG) and cortisol levels were observed in WAD compared to RS goats. Increase in IgG levels has also been observed in Dhonfari goats in the hot-dry period. It is possible that high IgG (which is involved in phagocytic activity) level is related to high cortisol level. The current observation is contrary to a similar study in cattle, where exposing heifers to heat stress resulted in reduced concentrations of IgG. The discrepancies could however be attributed to species-associated differences and the physiological stage of the animals. It has been reported that there was an increase in the level of cortisol in goats after acute heat stress compared to their counterparts that were under chronic heat stress. When animals are severely stressed, this can lead to increase in cortisol concentrations, thereby reducing the fitness of individuals through the body defense tissues' immunosuppressant and atrophy. Also, the energy available to the immune system may be reduced by cortisol thereby making the animals more susceptible to infectious diseases. The primary function of Cortisol is enabling the animal to escape from the stressor at that moment. Exposure to heat in the tropics could disrupt the goats' homeostasis due to the potential to elicit a stress response. Frequent increases in circulating cortisol can modify the cell mediated immune response in such a way that the response to a specific antigen challenge is compromised. Similar assertion was made by Dhama et al. (2019) in another study.

Based on sex, male goats had higher cortisol and lower thyroxine than their female counterparts in the current study. These are further indications of stress tendencies of male goats in comparison with females. An elevated cortisol concentration is associated with reduced thyroid gland activity. The lower thyroxine of male goats could be an adaptive strategy to attenuate heat stress through reduction in the rate of metabolism and production of heat. The present observations are in conformity with earlier findings in goats (Al-Dawood, 2017) where thermal stress decreased thyroxine concentration.

The observations from the use of ANN model indicated that respiratory rate, cortisol, pulse rate and WBC had more influence on heat stress prediction in goats. The high R^2 and Adjusted R^2 including the very low RMSE estimates gave credence to the ANN model. The observation on respiratory rate further confirms earlier submissions that it is a good indicator of thermal stress in goats (Ribeiro et al., 2018; Berihulay et al., 2019; Contreras-Jodar et al., 2019). The importance of pulse rate stemmed from the fact that it occurred as a result of corresponding increase in respiratory rate due to more activities of the muscle. This also includes heat through the skin as a result of greater blood perfusion promoted by low peripheral vascular resistance (Lima et al., 2018; Machado et al., 2020). Genetic group and sex have little influence on heat stress index. Therefore, it can be submitted that WAD goats can also thrive in Nasarawa State, north central Nigeria being a different environment compared to the Southern States where WAD goats originated from. This possible geographical spread could be a boost to WAD goat production in the country. It was difficult to compare the results from the study with others in literature due to dearth of information on the use of ANN model for thermal stress prediction. However, Kannan et al. (2018) suggested the use of ANN in predicting responses to stress in goats as a result of transportation: They reported that predicted and observed cortisol correlation ($r = 0.87$) was better in ANN model.

In order to correctly assign WAD and RS goats to their appropriate Breed, it was observed that haemoglobin, white blood cells, rectal temperature and pulse rate were sufficient to correctly assign WAD and RS goat to their respective breed and therefore may be used in breed identification and characterization.

4 Conclusions

This study revealed that rectal temperature and pulse rate were higher in WAD than RS goats. However, there was no significant difference in the value for heat stress index between WAD and RS goats. Heat stress index indicated that male goats were more stressed than females. There was no significant Breed * Sex interaction effect on thermo-physiological traits. The result of the serum biochemical analysis of goats also indicated that WAD goats appeared to be more stressed. The hormonal indices showed that male goats appeared more stressed than their female counterparts. There was no significant Breed * Sex interaction effect on haematological parameters. However, there was a significant interaction effect on thyroid stimulating hormone. While male and female WAD goats were similar, female RS goats had higher value of thyroid stimulating hormone than their male counterparts. From the observed values in the Artificial Neural Network, respiratory rate, cortisol, pulse rate and WBC had more influence on heat stress prediction in goats compared to breed, sex including haematological, serum biochemical and hormonal indices. Haemoglobin, White blood cells, rectal temperature and pulse rate were sufficient to correctly assign WAD and RS goats to their respective Breed. These have implications in understanding the adaptation processes in both goat breeds under tropical conditions.

Acknowledgments

The study permission granted by the Federal Capital Territory (FCT), Abuja, Nigeria to the first author to undertake his MSc. programme is gratefully acknowledged.

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