

PHYSIOLOGICAL RESPONSE AND HEAT SHOCK EXPRESSION IN THE NIGERIAN INDIGENOUS GOAT BREEDS RAISED UNDER THERMAL STRESS IN SOUTHWEST NIGERIA

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➤ Supporting Information



ABSTRACT: Environmental stress remains a major threat to optimum productivity of livestock in tropical climates. Generally, goats often develop adaptive mechanisms to thrive in their native environment. However, little is known about the adaptation of the Nigerian indigenous goat breeds to different environmental conditions. The influence of varying periods of heat exposure on physiological response and HSP70 gene expression in the Nigerian indigenous goat breeds was therefore examined in this study. A total of 45 goats comprising West African dwarf (WAD), Red Sokoto (RS), and Sahel (SH) breeds were assigned to three treatments; 0, 4, and 8 hours of daily exposure to environmental temperature. Each treatment had two males and 3 females per breed of goats. Environmental variables were monitored while Temperature-Humidity-Index (THI) was calculated. Also, body temperature (BST), rectal temperature (RT), respiratory rate (RR), pulse rate (PR) were monitored while serum HSP70 level was determined. Average temperature (29.86 °C), relative humidity (73.57%) and THI (79.34) were recorded. Also, there was no significant effect of breed on all the physiological parameters, hours of exposure to heat had significant influence on BST, RT, RR and PR. Also, physiological indices monitored significantly ($P < 0.05$) increased with days of exposure while effects of sex on physiological responses of the various breeds exposed to environmental stress was not significant. For HSP70 expression, Red Sokoto goats had the highest level (30.08 ± 0.75 ng/mL), compared to WAD goats (22.66 ± 0.53 ng/mL) and Sahel goats (18.01 ± 0.55 ng/mL) while male goats (35.34 ± 0.50) had higher HSP level compared to female goats (14.49 ± 0.44). In conclusion, duration of exposure to heat influenced physiological responses and serum HSP expression in the Nigerian indigenous goats.

Keywords: Adaptation, Heat stress, HSP70 expression, Indigenous goat breeds, Physiological response.

INTRODUCTION

Small ruminants play a pivotal role in global livelihoods due to their economic, agricultural, and cultural importance (Mohamed et al., 2023). In Nigeria, goats represent the most dominant group of small ruminants, with an estimated population of five million (FAO, 2019). Indigenous goat breeds not only serve as financial assets and cultural symbols but also exhibit high productivity, strong disease resistance, hardiness, versatility, and adaptability, which makes them to be well-suited for hot and humid environments (Ofori et al., 2021).

The adaptability of the Nigerian indigenous goat breeds has been demonstrated by their geographical dispersion (Tella et al., 2024) over the last few decades. This adaptability to diverse environments is supported by specific anatomical and physiological features, such as smaller body size and effective thermoregulation (Nair et al., 2021; AL-Ramamneh, 2023). Nevertheless, environmental stressors in various forms have limited them from reaching their maximum productivity (Bertolini et al., 2018). In particular, high temperature and humidity in tropical regions significantly hampers goats from attaining their full genetic potentials (Bertolini et al., 2018) by inducing physiological and biochemical changes that adversely affect their development, reproduction, and overall health (Danso et al., 2024; Parsad et al., 2025).

According to Sejian et al. (2021), despite the ability of goats to adapt to diverse geographical space, they are still vulnerable to climate-induced heat stress, which impairs productivity, immunity, and overall health. Similar sentiments have been raised by other authors especially on the indigenous breeds of goats in Nigeria. Ayoola et al. (2025), reported that thermal stress, marked by increased body temperature and disruption in physiological functions negatively affects goat wellbeing. The author noticed that when goats are stressed, they experience elevated respiratory rates, reduced metabolic and physical activities, sweating and altered endocrine functions which threatens the sustainability of goat farming in tropical and subtropical regions.

Elsewhere in colder climates, goats increase metabolic heat production but experience reduced energy efficiency, affecting performance and production (García et al., 2020). The three Nigerian indigenous goat breeds (Sahel, Red

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Sokoto, and WAD) have distinct and unique traits which help them to adapt to their native regions. Very little is known about the adaptive nature of these breeds when raised outside their natural environment. A better understanding of this adaptive capacity and response to heat exposure is crucial to improve goat productivity and welfare. Also, genetic traits play a significant role in adaptation to environmental stress. HSPs, particularly HSP70, are produced in response to heat stress to protect cellular proteins and maintain homeostasis (Kaushik et al., 2023).

An adequate knowledge of the heat tolerance attributes of the indigenous breeds of goat could guide producers on the best management practices or strategies to adopt in order to maximize productivity in this breed of goats. This study was therefore designed to examine the influence of duration of exposure to heat stress on the physiological response and serum HSP70 expression in the Nigerian indigenous breeds of goats.

MATERIALS AND METHODS

Experimental site

This study was conducted at Bowen University farm, Iwo, Nigeria, within a derived savanna agro-ecological zone characterized by a tropical climate with distinct wet and dry seasons. Bowen University is situated in Iwo, one of the major cities in South West Nigeria on a 640 ha site. It lies on coordinates 7° 38' 6.97" N and 40° 10' 53.62" E at an altitude of 322 m above sea level. The study area is located in a derived savanna agro-ecological zone with a tropical climate characterized by double maximum rainfall and average annual temperatures of 29.66°C and vegetation interphase between the rainforest and savanna grassland with a mixture of deciduous trees and tall grasses (Oguntunji et al. 2019). The Wet (March–September) and dry (October–March) seasons are the principal seasons in the area (Oguntunji et al. 2015).

Experimental animals and design

A total of 45 goats comprising three indigenous breeds in Nigeria; West African dwarf (WAD) goats, Red Sokoto goats, and Sahel goats with average age between 3-4 months were purchased at Kaara Market, Iwo town, Osun state Nigeria and used for this study. The market is about 3-5 km from the main campus with estimated travel time to be 15-20 mins. Prior to the commencement of the study, the goats were subjected to a 5 day acclimatization period for the animals to adjust to the prevailing environmental condition of the study area. The goats (6 males and 9 females per breed) were assigned to three treatment groups based on duration of heat exposure. Each treatment comprised of 15 goats of two males and three females of each breed per treatment. Goats in T1 were assigned to 0 hours of heat exposure (control/ungrazed), T2 had 4 hours of exposure to heat (10 am–2 pm grazing), and T3 had 8 hours of exposure to heat (9 am–5 pm). All animals were offered access to roughages, concentrate feed, and water.

Data collection

Data were collected from each animal on days 0, 3, 6, 9, and 12. Ambient temperature (AT, °C) and relative humidity (RH%) were measured three times daily at 9.00am (morning), 1.00pm (afternoon) and 5.00pm (evening) using a digital thermohygrometer while Temperature-humidity index (THI) was calculated according to Helal et al. (2010) using the formula: $THI = 0.8 \times AT + RH \times (AT - 14.4) + 46.4$. Physiological parameters like respiratory rate (RR), panting rate (PR), body surface temperature (BST), and rectal temperature (RT) were also measured on days, 0, 3, 6, 9 and 12. The measured physiological parameters were as described by Oguntunji et al. (2019). The PR was monitored by placing the hand on the rib cage of the goats for 15 seconds and the number of pulse/heart beats was multiplied by 4 to obtain pulse rate per minute. BST measurement was monitored using a digital infrared thermometer (Model AR330, China) positioned at a distance of 12 inches from the animal while RT was measured using a digital clinical thermometer (COCET®, Kangfu Medical Equipment, China) inserted into the rectum of the goats until a beep is heard and readings recorded. Also, RR was measured by counting the number of breaths per minute.

HSP70 determination

100 µL of each standard (Goat HSP-70 ELISA Kit EG0033) and properly diluted sample are added to the pre-coated microplate wells. It is therefore sealed and incubated at 37 °C for 90 minutes, after which the plate is washed twice (no immersion). To the mixture, 100 µL of biotinylated detection antibody working solution was added and incubated at 37 °C for 60 minutes, and then washed thrice at one minute per wash. 100 µL of HRP-Streptavidin Conjugate was added and incubated at 37 °C for another 30 minutes, and then washed five times at intervals of 1 min. 90 µL of TMB substrate was added, and the mixture incubated 37 °C in the dark for another 10–20 minutes. 50 µL of stop solution was added as the color changed from blue to yellow. Absorbance was read at 450 nm the standard curve was plotted against known concentrations while HSP-70 concentration in serum samples was calculated via interpolation.

Statistical analyses

$$Y_{ijkl} = \mu + G_i + S_j + P_k + (GS)_{ij} + (GP)_{ik} + e$$

Where Y_{ijkl} = Individual observation; μ = fixed overall mean; i = fixed effect of genotype (WAD, RS, and SH); j = fixed effect of sex (males and females); k = fixed effect of duration of exposure period (0, 3, 6, 9); ij = effect of interaction of breed and sex; ik = effect of interaction of breed and exposure period; ijk = effect of interaction of breed, sex, and exposure period; e = experimental error. Data were subjected to descriptive analysis and ANOVA using SPSS 2020 while significant means were separated using NDMRT option of the same software.

RESULTS

The mean climatic parameters during the study period are presented in Table 1. Average environmental temperature ranged from 25.56 °C in the evening to 29.26 °C in the morning while relative humidity ranged from 61.0 %, in the afternoon to 84.12% in the evening. Temperature Humidity Index (THI) followed similar pattern as temperature as THI value ranged from 73.94 in the evening to 85.50 in the afternoon.

Table 1 - Average environmental parameters during the study period

Parameters	Morning	Mid-day	Evening	Mean	SEM $\pm$
Temperature (°C)	29.26	34.76	25.56	29.86	1.07
Relative Humidity (%)	75.60	61.0	84.12	73.57	2.73
Temperature-Humidity Index	78.60	85.50	73.94	79.34	1.45

Physiological response of the indigenous breeds of Nigerian goats to heat stress is shown in Table 2. There were no significant differences ($P > 0.05$) in the physiological parameters monitored among all the goat breeds. Body temperature ranged from 37.69 ± 2.21 °C in Sahel goats to 38.63 ± 2.38 °C in WAD. Rectal temperature ranged from 39.57 ± 1.14 °C in Sahel goats to 39.84 ± 1.42 °C in WAD goats. Pulse rate ranged from 73.13 ± 24.89 beats/min in Red Sokoto goats to 74.23 ± 26.23 beats/min in WAD goats while for respiratory rate, it ranged from 24.83 ± 5.01 breaths/min in Red Sokoto goats to 25.70 ± 5.63 breaths/min in Sahel goats.

The effects of hours of exposure to heat on physiological parameters of Nigerian indigenous goat breeds is shown in Table 3. The BST in goats subjected to T3 was significantly higher ($P < 0.05$) than BST in goats on T2 (38.35 ± 2.38 °C) and T1 (36.79 ± 0.53 °C). Similarly, goats on T3 (40.21 ± 1.38 °C) and T2 (39.93 ± 1.48 °C) had similar ($P > 0.05$) RT but differ significantly ($P < 0.05$) from those in T1 (38.84 ± 0.53 °C). Respiratory rate followed the same pattern as RT, as T2 (24.90 breaths/min) and T3 (29.87 ± 5.90 breaths/min) had significantly similar ($P > 0.05$) but higher ($P < 0.05$) value compared to T1 (21.00 ± 1.14 breaths/min). However, pulse rate in T1 (53.70 ± 2.67 bpm) was significantly lower ($P < 0.05$) than PR in T2 (77.90 ± 15.63 bpm) and T3 (93.50 ± 27.01 bpm) while PR in T3 was higher ($P < 0.05$) than in T2.

Table 4 shows the effect of days of exposure to heat on physiological parameters of Nigerian indigenous goat breeds. Significant effect ($P < 0.05$) of heat exposure was observed on all parameters monitored. Average body temperature at days 0 (36.57 °C) and 3 (37.38 °C) were similar ($P > 0.05$) across breed but significantly lower ($P < 0.05$) than average body temperatures of 39.21 , 38.79 and 39.12 °C recorded at days 6, 9 and 12, respectively. The least ($P < 0.05$) average breed rectal temperature (RT) was obtained at day 0 (38.55 °C), followed by day 3 (39.32 °C). The RT at day 6 (40.27 °C) was not significantly different ($P > 0.05$) from those of days 9 (39.68 °C) and 12 (40.68 °C), though RT at day 12 was significantly higher ($P < 0.05$) than RT at day 9. Pooled pulse rate across breed was significantly lower ($P < 0.05$) at day 0 (53.78) compared to days 3, 6, 9, and 12 with PR of 74.56 , 78.94 , 82.83 , and 85.06 bpm, respectively. However, RR at day 0 (21.94 ± 1.70 brpm) was significantly lower ($P < 0.05$) than RR at day 6 (25.44 ± 4.72 brpm), day 9 (26.39 ± 5.57 brpm) and day 12 (27.89 ± 6.57 brpm) but was not significantly different ($P > 0.05$) from day 3 (24.61 ± 4.65 brpm).

Effects of environmental stress on the physiological parameters of Nigerian Indigenous breeds of goat according to their sex are shown in Table 5. There was no significant influence of environmental stress on the physiological responses observed according to sex of the various breeds monitored. The BST ranged from 37.15 ± 2.36 in Sahel male to 38.17 in WAD male while RT ranged from 39.61 ± 0.94 in Sahel male goats to 39.58 ± 1.40 in Red Sokoto goats.

Also, PR ranged from 67.13 ± 21.76 in Red Sokoto male goats to 73.20 ± 26.88 in WAD male goats while for RR the value ranged from 23.67 ± 4.13 in Red Sokoto male goats to 25.00 ± 5.4 in WAD male goats. However, for females BST ranged from 38.38 ± 2.42 in WAD female goats to 38.22 ± 1.99 and 38.06 ± 1.83 in Sahel and Red Sokoto female goats, respectively. The RT ranged from 39.39 ± 1.53 in Red Sokoto female goats to 39.91 ± 1.52 in WAD female goats and PR was from 70.40 ± 22.84 in Red Sokoto female goats to 76.73 ± 27.12 in WAD female goats while it was within 25.47 ± 6.13 for RR.

The heat shock protein (HSP) responses to environmental stress in Nigerian goat breeds according to breed, exposure duration, and sex are shown in Table 6. Red Sokoto goats had the highest HSP level (30.08 ± 0.75 ng/mL), followed by WAD goats (22.66 ± 0.53 ng/mL) and Sahel goats (18.01 ± 0.55 ng/mL). Duration of exposure showed that goats exposed 4 hours (30.08 ± 0.75 ng/mL) of daily environmental stress had the highest HSP level followed by those exposed to 8 hours (24.83 ± 0.52 ng/mL) while the least HSP level was obtained in goats with no exposure (15.24 ± 0.53 ng/mL) to environmental stress. For the days of exposure, HSP level of the goats at day 0 (22.06 ± 0.53 ng/mL) was relatively lower than 24.08 ± 0.71 ng/mL obtained at day 12 while male goats (35.34 ± 0.50) had higher HSP level compared to female goats (14.49 ± 0.44) in this study.

Table 2 - Effects of breed on the physiological parameters of Nigerian Indigenous breeds of goat exposed to environmental stress

Parameters	Sahel	Red Sokoto	WAD
Body surface temperature (°C)	37.69 ± 2.21	38.32 ± 1.93	38.63 ± 2.38
Rectal temperature (°C)	39.57 ± 1.14	39.58 ± 1.44	39.84 ± 1.42
Pulse rate (bpm)	74.73 ± 22.29	73.13 ± 24.89	77.23 ± 26.23
Respiratory rate (bpm)	25.70 ± 5.63	24.83 ± 5.01	25.23 ± 5.09

^{abc} values along the same row with different superscripts are significantly different ($P < 0.05$). WAD = West African Dwarf

Table 3 - Effects of hours of exposure to environmental stress on the physiological parameters of Nigerian Indigenous breeds of goat across the treatments

Parameters	T1	T2	T3
Body surface temperature (°C)	36.79 ± 0.53^c	38.35 ± 2.38^b	39.50 ± 2.23^a
Rectal temperature (°C)	38.84 ± 0.53^b	39.93 ± 1.48^a	40.21 ± 1.38^a
Pulse rate (bpm)	53.70 ± 2.67^c	77.90 ± 15.63^b	93.50 ± 27.01^a
Respiratory rate (bpm)	21.00 ± 1.14^c	24.90 ± 2.48^b	29.87 ± 5.90^a

^{abc} values along the same row with different superscripts are significantly different ($P < 0.05$). T1 = 0, T2 = 4, T3 = 8 (hours)

Table 4 - Pooled effects of days of exposure to environmental stress on physiological response in the Nigerian Indigenous breeds of goat

Parameters \ Day	0	3	6	9	12
Body surface temperature (°C)	36.57 ± 0.57^b	37.38 ± 1.47^b	39.21 ± 2.36^a	38.79 ± 2.06^a	39.12 ± 2.65^a
Rectal temperature (°C)	38.35 ± 0.61^d	39.32 ± 1.03^c	40.27 ± 1.24^{ab}	39.68 ± 1.04^b	40.68 ± 1.35^a
Pulse rate (bpm)	53.78 ± 1.59^b	74.56 ± 24.37^a	78.94 ± 25.57^a	82.83 ± 23.62^a	85.06 ± 24.88^a
Respiratory rate (bpm)	21.94 ± 1.70^b	24.61 ± 4.65^{ab}	25.44 ± 4.72^a	26.39 ± 5.57^a	27.89 ± 6.57^a

^{abc} values along the same row with different superscripts are significantly different ($P < 0.05$) 226

Table 5 - Effects of breed and sex on the physiological parameters of Nigerian Indigenous breeds of goat exposed to environmental stress

Parameter	Sahel		Red Sokoto		WAD	
	Male	Female	Male	Female	Male	Female
Body temperature (°C)	37.15 ± 2.36	38.22 ± 1.99	37.66 ± 1.46	38.06 ± 1.83	38.17 ± 2.09	38.38 ± 2.42
Rectal temperature (°C)	39.61 ± 0.94	39.52 ± 1.34	39.32 ± 1.46	39.39 ± 1.53	39.58 ± 1.40	39.91 ± 1.52
Pulse rate (bpm)	74.13 ± 20.72	75.33 ± 24.48	67.13 ± 21.76	70.40 ± 22.84	73.20 ± 26.88	76.73 ± 27.12
Respiratory rate (bpm)	25.93 ± 5.30	25.47 ± 6.13	23.67 ± 4.13	24.47 ± 4.85	25.00 ± 5.45	24.73 ± 5.16

^{abc} values along the same row with different superscripts are significantly different ($P < 0.05$)

Table 6 - Heat shock Protein in Nigerian indigenous breeds of goats exposed to environmental stress

Variables		HSP (ng/mL)
Goat breed	Sahel	18.01 ± 0.55 ^b
	Red Sokoto	30.08 ± 0.75 ^a
	WAD	22.66 ± 0.53 ^b
Period of exposure (hrs)	0	15.24 ± 0.53 ^c
	4	30.08 ± 0.75 ^a
	8	24.83 ± 0.52 ^b
Days of exposure	0	22.06 ± 0.53
	12	24.08 ± 0.71
Sex	Male	35.34 ± 0.50 ^a
	Female	14.49 ± 0.44 ^b

^{abc} values along the same row with different superscripts are significantly different (P < 0.05)

DISCUSSION

Relatively higher temperature and low relative humidity were recorded in the afternoon compared to other periods of the day during the trial while average environmental temperature of 29.86 °C and relative humidity of 73.57% were recorded for the study period. The high average temperature, and low RH values recorded during the mid-day compared to other period of the days were indication of stressful conditions livestock generally are exposed to in tropical climates. Although goats are able to thrive within relative humidity of 60- 80%, however when coupled with high temperature, the resultant effect is discomfort in animals. The comfort or thermo-neutral zones in animals is the range of temperature under which an animal can thrive without distress (Adedeji and Ogunwale, 2017). Mean average temperature recorded in this study was higher than the thermo-neutral zone of 12 – 27 °C adjudged comfortable for goats (Mason and Rushen, 2006; Helal et al., 2010). From our study, high mean average temperature in addition to high mean average relative humidity recorded in this study suggest that the goats were exposed to heat stress. Reports by Bhawa et al. (2023) and Onagbesan et al. (2023) have shown that an increase in environmental temperature with a concurrent increase in relative humidity constitutes stress.

Also, high average THI were recorded in the afternoon compared to the other periods of the day while the mean average THI recorded for the period were higher than those recorded either in the morning or evening. Temperature Humidity Index is a metric used to evaluate the level of environmental discomfort and heat stress experienced by animals. Zhou et al. (2023) in their study noted that a THI of 74.80 – 76.51 is the comfortable threshold for goats while a THI of 85.24 is the maximum tolerable limit in goats. Also, according to Helal et al. (2010), a temperature-humidity index of ≤ 74 is regarded as normal, 75 - 78 = alert level, 79 - 83 = danger, and ≥ 84 is emergency. Going by the study of Zhou et al. (2023), THI below 74.8 observed in the evening was below the thermoneutral zone for goats which may be the onset of cold stress. This when coupled with the lower average temperature recorded in the evening period may also suggest that goats experience less stress in the evening compared to other periods of the day while in the noon, goats are in a high state of distress. Nevertheless, mean average THI recorded in this study surpassed the comfort threshold for goats which is suggestive of stress. This result is consistent with reports in literature (Salama et al., 2013; Das et al., 2025). For instance, a study by Salama et al. (2014) suggested that THI above 75 is indicative of stress in goats while recent findings by Das (2025) noted that temperatures of 38°C and THI above 75, predispose goats to thermal discomfort. According to Gupta and Mondal (2021) in a study on heat stress and thermoregulatory responses in goat, the authors noted that heat stress triggers a variety of complex reactions which are essential for cell survival. Elevated heart and/or pulse rate, respiration rate, and rectal temperature are frequently employed in this case as markers of physiological adaptation to heat stress in small ruminant (Danso et al., 2024). Body temperature/rectal temperature have been reported to be directly influenced by ambient or environmental temperature (Ayo et al., 1999; Tucker et al., 2023). Body surface temperature recorded in this study was higher than 34.3 ± 0.2 - 36.8 ± 0.4 °C reported by Adeiza et al. (2024) in Red Sokoto goats. The observed variation in the results might be due to geographical location and different mean average temperature of 25.6 ± 0.26 °C recorded in their study compared to 29.8 °C in this study. Similarly, values reported by Habibu et al. (2021) in Sahel, Red Sokoto and WAD goats exposed to harmattan season in Nigeria were lower than those obtained in this study. This is due to the variations in seasonal environmental conditions in which the goats from the two studies were exposed. The RT of 38.58 – 40.35, 39.23 – 41.52, and 38.95 – 40.13 °C in Sahel, WAD and, Red Sokoto goats respectively reported by Oguntade et al. (2024) were within the range observed in this study and also within 39 - 40 °C specified in literature (Ayo et al., 1999; Minka and Ayo, 2013) as normal in goats. When the ambient temperature increases beyond the threshold level, there is a consequent increase in core body temperature (Das, 2025). Goats like other homeotherms constantly attempt to maintain their core body temperature around 39 °C. This they achieve

by transferring heat load from the core body to the periphery like the rectum (Battini et al., 2015a, 2015b). According to Sophia et al. (2016), native breeds evolve special behavioral and physiological responses to deal with environmental challenges, such as heat stress. Perhaps this may be the reason; the physiological indices of the Nigerian indigenous breed of goats were similar. Also, comparable genetic composition among native breeds and their ability to adapt to the hot-humid climate of southern Nigeria may also be the reason there was no notable variations in physiological indices monitored (Caroprese et al., 2015). This observation is contrary to reports elsewhere on similarity in rectal temperatures in indigenous goat breeds (Das, 2025).

Banerjee et al. (2015) observed differences in RT in among breeds of Indian goats. Nevertheless, RR in this study was lower than 47.98 and 51.20 reported by Shittu et al. (2023) in WAD and Kalahari Red raised in Southwest Nigeria while PR in this study were higher than 60.2 and 61.5 bpm in their study. Oseni and Ajayi (2014) noted that native goats in Nigeria had developed adaptive mechanism through higher respiration rates and sweat gland activity to control body temperature. This study found that hours of exposure to heat stress resulted in elevated physiological responses as goats exposed to T3 had the highest indices, thus suggesting that beyond elevated environmental temperature, the extent of time spent outdoor also determines the level of stress they are exposed to. In support of these findings, other authors have also found a direct relationship between exposure to prolonged period of sunshine and higher physiological indices (Garba et al., 2024; Deori et al., 2024) in goats. For example, in a study conducted by Aleena et al. (2018), in Osmanabadi, Malabari and Salem Black goat breeds of Southern India, and by Dangi et al. (2015) in Barbari goats of Northern India, the authors noted that there were significant differences in RT of goats exposed to 0, 4 and, 8 hours of heat stress. In addition, further observation from Naga et al. (2021) showed notable alterations in physiological markers from Day 3 which may also suggest that heat stress in native goats from Nigeria begins within this period. Becker and Stone (2020) in their study noted that body surface temperature was directly correlated with ambient solar radiation level, thus implying that length of exposure to solar radiation will increase body temperature. Elevated RT for instance has been identified as a reliable predictor of stress in livestock (Fadare et al., 2012), therefore high RT in goats placed in T3 compared to those housed indoor and in T2 suggest heat stress. These values are comparable to those found in heat-stressed WAD sheep by Fadare et al. (2012). Respiration rate is also used as a measure of heat stress to assess the negative impacts of ambient temperature (Al-Haidary et al., 2021). According to Okoruwa (2014), respiratory rate exceeding 12 to 20 breaths per minute is a sign of heat stress. This further buttressed the narrative that length of exposure of goats to heat/ solar radiation increases their RR as evident in goats subjected to T2 and T3 compared to T1 that had normal RR.

Also, it was observed that the physiological parameters monitored initially increased with days of exposure to environmental stress and then remain constant at certain periods. This observation may suggest that as the goats were stressed, they responded with increment in these physiological indices up to the point when they begin to adapt to the stressor thus resulting to similar values observed within some period. Although the effect of breed and sex were not significant on physiological response in Nigerian indigenous goats, there seems to be sex specific variations with relative reduction in these responses in male breeds compared to the females. This observation is supported by Timveh et al. (2022) who also reported no significant influence of breed and sex on these traits. Contrarily, Oguntade et al. (2024) in a study on the genetic variation in indigenous breeds of goats in Nigeria noted that there were significant variations in the thermotolerant traits monitored. Also, Mallam et al. (2025) in their study revealed that breed × sex significantly influenced rectal temperature (RT) as WAD male and Red Sokoto male had higher RT than the female counterparts. However, in their study, breed and sex did not influence PR, and RR. Observations of relative increase in responses from female goats in this study found support from previous works (Akinyemi et al., 2019; Sejian et al., 2019). Adeyemi et al. (2019) in their study noted that RT, PR and RR in female sheep were higher than in the male sheep while Sejian et al. (2019) also observed elevated RR and RT in female sheep compared to male sheep in their study. Differences noted in physiological responses due to sex by these authors were attributed to many probable factors. Oseni et al. (2017) noted that hormonal changes and reproductive demands in females may have resulted to such variations. Also, lower cortisol levels in bucks, scrotal temperature regulation, and the size and structure of male bodies may have contributed to less stress experienced in bucks (Perumal et al., 2022).

Heat shock protein 70 (Hsp70), is a highly conserved protein, induced in organisms by elevated temperatures (Ross et al., 2003). They are important to thermal stress adaptation (Kumar et al., 2018) and finds expression in cells when animals are exposed to high environmental temperature. Red Sokoto goats had the highest HSP levels among the indigenous breeds, suggesting experience or respond more to stress than WAD and Sahel goats. This however did not translate to higher physiological indices as observed in Table 2. This may probably be that the Red Sokoto breed though highly stressed as observed from the HSP expression than its contemporary (Sahel goats) with similar origin from the northern part of Nigeria was able to develop better adaptive mechanism in coping with stress. According to Akinyemi et al. (2019), high HSP production in Red Sokoto may imply that the breed is more sensitive to stressors or engage a stronger protective response through HSP

production. For period of exposure, the observed difference in the secretion of HSP during the hours of exposure is consistent with report of increase in the expression of HSP when animals are exposed to hot conditions (Aleena et al. 2018; Syafiqa et al., 2023; Tella et al., 2024). The high HSP expression at 4hour period of exposure coincides with the peak of heat exposure for the goats. This confirms the reason HSP level was elevated at this period due to increase in ambient temperature associated with the noon. Hours of exposure beyond the noon, HSP levels begin to drop suggesting that there is a threshold period during which the goats experience the maximum stress, after which the HSP response stabilizes. This finding is consistent with studies on livestock stress responses, which often peak in the early exposure period and stabilizes as the animals acclimate. Earlier report suggests that HSP showed higher expression levels during heat stress in goats (Dangi et al., 2015), in order to protect cells from heat stress (Hassan et al., 2019). HSP expression at days 0 and 8 were similar. This may suggest that the goats were able to acclimatize better over this period. Experiments conducted in cattle showed that HSP expression under chronic heat stress showed 2 peaks on the 2nd and 17th day of heat stress which was similar to the observation from this study. Although male goats had relatively lower responses to heat stress compared to the females, HSP expression in males however was significantly higher than in the females. High HSP genes in the male serum dictates the extent of expression of stress specific genes in the male goats implying that they were more stressed. However, the relatively lower physiological responses in the males may be due to their more effective adaptive mechanism developed in mitigating heat stress.

CONCLUSION AND RECOMMENDATION

This study showed that breed had no influence on physiological responses in goats while 8 hours duration of heat exposure, 6-12 days of exposure, and sex influenced physiological response. Also, breed, duration of exposure to heat, and sex influenced HSP70 expression in Nigerian indigenous goat breeds. Future studies should investigate how breed-specific HSP70 variations in WAD, Red Sokoto, and Sahel goats correlate with genetic polymorphisms, endocrine profiles, and long-term production traits. Additionally, research should transition to longitudinal seasonal field trials to evaluate the efficacy of sex- and breed-specific management and nutritional interventions against chronic thermal stress.

DECLARATIONS

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Ethical approval

The authors confirm that the research reported herein conforms to the ethical policies of the journal, as noted on the journal's author guidelines page. The methods/procedures used in this study were in concomitant with those outlined in the Animals ARRIVE guidelines and were carried out by the U.K. Animals (Scientific Procedures) Act, 1986 and associated guidelines; EU Directive 2010/63/EU for animal experiments; or the National Institutes of Health guide for the care and use of laboratory animals (NIH Publications No. 8023, revised 1978). The study was conducted with the approval of the Bowen University Ethics Committee with reference number BUREC/COAES/AGR/0015

Authors' contributions

M.O. AYoola and D.O. FATOKI contributed to conception and design of study; D.O. FATOKI and G.A. BERENA contributed towards acquisition of data, analysis and interpretation of data; D.O. FATOKI was involved in drafting the manuscript G.A. BERENA revised it critically for important intellectual content; M.O. AYoola supervised the conduct of the research; All authors read and agreed to the version to be published.

Availability of data and materials

The data presented in this study are available on request from the corresponding author.

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Competing interest

The authors declare no conflict of interest.

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