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Research Article

Evaluation of Heat Stress Impacts on Physiological Responses in Two Indigenous Nigerian Goats

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Abstract: Stress comes in many forms for livestock, including physical, chemical, nutritional, thermal, and psychological stress. Changes in skin temperature, heart rate, respiration rate, and rectal temperature are indicators of physiological reactions to heat stress. Regression investigation of the physiological reactions of Nigerian native goat breeds (West African dwarf and Red Sokoto) to heat stress was the goal of this study. 400 goats (200 West African Dwarf and 200 Red Sokoto) from Osun, Ondo, and Ekiti states in Nigeria were subjected to varying climatic conditions (temperature and humidity) in order to gather data on physiological indicators (rectal temperature, pulse rate, and respiration rate). An analysis of variance (ANOVA) was performed to evaluate variations in the physiological parameters, and the temperature and humidity index (THI) was computed for the study's environmental conditions. The coefficient of determination (R^2), which represents the accuracy of the predictions, was calculated using regression analysis. The results demonstrated that both breeds' physiological characteristics reacted similarly, with higher THI values considerably increasing heart rate, respiration rate, and rectal temperature. Regression evaluation indicated that THI had a significant ($P \leq 0.05$) and positive effect on heart rate ($R^2 = 0.545$), respiration rate ($R^2 = 0.32$), and rectal temperature ($R^2 = 0.146$) for the Red Sokoto breed. These physiological adaptations enable goats to survive and thrive in challenging and variable environments.

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INTRODUCTION

The sustainability of cattle systems is currently under threat from global warming and climatic variability. The livestock industry faces formidable obstacles in its growth due to climate change (Ravagnolo et al., 2021). According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures are rising by 0.2°C every ten years, and by the end of the century, surface temperatures could rise by 1.5°C to 4.0°C (Noh et al., 2022). According to Meyer et al. (2020), stress is defined as an automatic reaction in animals brought on by unfavourable environmental circumstances. It can have a range of detrimental outcomes, from discomfort to death. It is anticipated that livestock will experience more severe heat stress as a result of climate change-induced temperature increases and altered precipitation patterns, which will negatively affect their capacity for reproduction and productivity (Hassan et al., 2023; Kharadi et al., 2022). Even with highly developed thermoregulatory systems, ruminants struggle to keep a steady homeostasis when under a lot of stress. The physiological capacities of these animals are severely strained by high ambient temperatures, strong sun radiation, and high humidity levels (Boksa et al., 2023). Their capacity to regulate energy levels, hydration, hormone and mineral balances, and general thermal control is disrupted by rising temperatures (Marai et al, 2018).

A major problem among the several stressors is thermal stress, especially given the changing environment of today. Rising ambient temperatures in tropical and subtropical regions provide significant obstacles to animal production, while dangerously low temperatures in temperate zones can negatively impact or even endanger the lives of cattle. Both heat stress from extended summer high temperatures and cold stress from the winter months are considered forms of thermal stress. In moderate climes, intense cold can also pose a threat, while high temperatures are particularly problematic in tropical and desert areas (Tella, 2024). Since temperature impacts an animal's heart rate, metabolism, and other vital physiological processes, abrupt changes in temperature can cause physiological suffering.

When heat stress and excessive humidity coexist, the detrimental effects of rising temperatures are intensified. According to Duncan et al. (2020), goats were first domesticated around nine thousand years ago, making them one of the oldest domesticated animals in the world. Millions of smallholder farmers around the world rely on goats for their livelihoods in a variety of climates and terrains. Goat husbandry, which frequently conflicts with traditional crop production techniques, is a traditional practice for marginal farmers and landless labourers in semi-arid, arid, and mountainous regions of many developing nations.

Goat husbandry has many advantages when compared to other livestock production systems. Because of their extremely nutritious milk, they are frequently referred to as the "poor man's cow" and are India's main source of meat (Singh et al., 2023). Goats might be the most sensible livestock option in many emerging nations, regardless of socioeconomic background. Their resilience, which is controlled by a number of factors, allows them to adapt to harsh climatic conditions better than other farmed animals (Khan et al., 2022). Because of their smaller size, lower body mass, lower metabolic rates, effective nitrogen utilisation, efficient digestive systems, and capacity for water conservation, goats are well-suited to live in hostile situations (Tella, 2024).

Goats are generally more resistant to heat stress than other animals, but when temperatures drop below their comfort zone—which for Nigerian goats normally spans from 13°C to 27°C—they can still become vulnerable to both heat and cold stress. Those that spend a lot of time in open areas are particularly susceptible to environmental stress. Regression investigation of the physiological reactions of native goat breeds in Nigeria, particularly the West African dwarf and Sokoto red, to heat stress is the goal of this study.

MATERIALS AND METHODS

In this study, 400 animals were used for the experiments. This includes two hundred goats of the West African dwarf and two hundred Red Sokoto varieties, which are primarily found in the country's southwest and northern region, respectively. Between November 2020 and February 2021, around midday, data and animal samples were gathered from several farms in the Nigerian states of Osun, Ondo, and Ekiti. The Bio-safety Research Laboratory of the Federal University of Technology, Akure, Ondo State, is where the laboratory analysis was carried out.

The study focused on the Red Sokoto and West African Dwarf (WAD) goat breeds, that appeared to be in good health. Usually raised in extensive or semi-intensive husbandry methods, these breeds in the agro-ecological zone are fed crop leftovers, kitchen scraps, corn stalks, cassava peels and often forage from trash piles. To lessen human-goat conflict for food resources, the local community has adopted this agricultural method. Sadly, there were insufficient records kept about the animals, and ethno-veterinary procedures were frequently used.

A total of 200 West African Dwarf (WAD) goats and 200 Red Sokoto goats were sampled in Osun, Ondo, and Ekiti states. Rectal temperatures (RT), respiration rates (RR), and heart rates (HR) were recorded as physiological indicators of heat stress. Measurements of RR and HR were taken during the hottest part of the day, between 13:30 and 14:30. The physiological responses for each group were assessed three times over a period of 10 to 12 days. A digital clinical thermometer with an accuracy of 0.1 °C was used to record the RT as a percentage. The RR was determined by counting the number of inhalations and exhalations over 60 seconds, while heartbeats were measured per minute using a stethoscope. Based on the recorded respiratory rate (RR) and heart rate (HR), phenotyping for heat stress susceptibility was conducted. Goats with an RR of 50 and an HR of 130 were categorized as heat stress susceptible (HSS) phenotypes, whereas those with an RR of 30 and an HR of 100 were classified as heat stress tolerant (HST) individuals, reflecting the distribution of RR and HR among the different breeds within the population.

Following national and international guidelines for the ethical treatment of animals in research, every animal-related procedure in the study on regression investigations of the physiological responses of Red Sokoto and West African dwarf goats to heat stress has been carried out with the utmost care for their welfare.

Data collected from the physiological parameter measurements were analysed using the SAS package. The linear model used is as shown below:

$$Y_{ij} = \mu + {}_{+}A_i + E_{ij}$$

Where:

Y_{ij} = single observation.
μ = Overall mean (constant).
A_i = Fixed effect of breed
E_{ij} = Random residual error

Means were separated using Duncan multiple range test. Linear regression analysis between the parameters was also carried out, generating the coefficient of determination (R^2) to indicate the efficiency of the prediction. The regression model used was of the form:

$$Y = a + bx$$

Where;

Y = Dependent variable
a = Intercept
b = Regression coefficient,
x = Independent variable

RESULTS AND DISCUSSION

The physiological reactions of Red Sokoto and West African Dwarf (WAD) goats to different Temperature-Humidity Index (THI) levels are influenced by breed, as shown in Table 1. There were no significant changes in respiration rate, although there were significant differences ($p < 0.05$) in heartbeat rate and rectal temperature measures. For every indicator that was measured, there were notable differences in THI ratings. Furthermore, there was a noteworthy significant interaction between breed and THI for both respiratory rate ($p < 0.05$) and heartbeat rate ($p \leq 0.05$).

Table 1: Effect of breed on the physiological response to varying THI values in Red Sokoto Breed and WAD

Parameters	Breed	THI			EFFECT		
		≤82.70	82.71 – 87.39	≥87.40	Breed	THI	Breed*THI
Heartbeat rate (bpm)	Red Sokoto	81.24±1.89[b]	81.21±2.21[b]	90.86±1.80[a]	0.002	0.000**	0.000**
	WAD	88.02±2.36[b]	87.22±2.11[b]	91.17±1.81[a]			
Respiration rate (bpm)	Red Sokoto	60.61±.2.71[a]	60.72±2.89[a]	71.43±3.06[b]	0.275	0.002**	0.004**
	WAD	63.27±2.44[a]	61.07±2.47[a]	74.91±2.01[b]			
Rectal temperature (^{0}C)	Red Sokoto	38.73±0.13[a]	39.11±0.11[b]	39.41±0.13[b]	0.001	0.000**	0.449
	WAD	39.10±0.09[a]	39.61±0.10[b]	39.61±0.08[b]			

**Significant at 5% alpha level a,b: significant difference

Regression Evaluation of the effect of THI on the physiological response of Red Sokoto and WAD

The findings of the regression evaluation looking at how the Temperature-Humidity Index (THI) affects the physiological reactions of the Sokoto Red goat breed are shown in Table 2. With an R2 value of 0.545, the data suggests that THI explains 54.5% of the variation in pulse rate and has a positive and significant effect ($p < 0.05$) on the Red Sokoto goats' heartbeat rate. Likewise, THI has a positive and significant effect on this breed's respiration rate ($p < 0.05$). Its R2 value of 0.32 means that THI accounts for 32% of the variation in respiration rate.With an R^2 value of 0.146, the research also shows that THI has a positive and significant effect ($p < 0.05$) on the Red Sokoto breed's rectal temperature, accounting for 14.6% of the fluctuation in rectal temperature. These results demonstrate a strong and favourable correlation between THI and the Red Sokoto goat breed's physiological reactions.

Table 2: Regression analysis of the effect of THI on the physiological response of Red Sokoto

	Coefficient	SE	t-value	Sig.	R^2	Adjusted R^2
Effect of THI on Heartbeat rate of Red Sokoto						
Constant	-222.917	25.868	-8.617	0.001	0.545	0.542
THI	3.484**	0.305	11.419	0.001		
THI on Respiration Rate of Red Sokoto						
Constant	-196.293	36.989	5.307	0.001	0.32	0.318
THI	2.907**	0.436	6.663	0.001		
THI on Rectal Temperature of Red Sokoto						
Constant	31.673	1.894	16.722	0.001	0.146	0.145
THI	0.086**	0.022	3.841	0.001		

**Significant at 5% alpha level; SE: Standar Error

Regression analysis of the effect of THI on the physiological response of WAD

The empirical results of regression analysis on the effect of the Temperature-Humidity Index (THI) on the physiological responses of the West African Dwarf (WAD) goat breed are shown in Table 3. With an R^2 value of 0.550, the results show that THI has a positive and significant effect ($p < 0.05$) on the WAD breed's heartbeat rate, accounting for 55.0% of the variation in heartbeat rate. Furthermore, the data shows that THI has a positive and substantial impact on the WAD breed's respiration rate ($p < 0.05$). With an R^2 value of 0.33, THI accounts for 33% of the variation in respiration rate. With an R^2 value of 0.156, the data also show that THI has a positive and significant effect ($p < 0.05$) on the rectal temperature of the WAD breed, indicating that THI accounts for 15.6% of the fluctuation in rectal temperature. All of these results point to a strong and favourable correlation between THI and the physiological reactions of the WAD goat breed.

Table 3: Regression Evaluation of the effect of THI on the physiological response of WAD

	Coefficient	SE	t-value	Sig.	R^2	Adjusted R^2
Effect of THI on Heartbeat rate of WAD						
Constant	-156.744	17.174	-9.127	0.001	0.550	0.542
THI	2.744**	0.198	13.829	0.001		
THI on Respiration Rate of WAD						
Constant	-163.083	24.052	-6.781	0.001	0.33	0.31
THI	2.630**	0.278	9.464	0.001		
THI on Rectal Temperature						
Constant	31.848	1.269	25.089	0.001	0. 156	0.154
THI	0.088**	0.015	6.027	0.001		

**Significant at 5% alpha level; SE: Stadard Error

Temperature Humidity Index and Physiological Parameters

The critical temperature thresholds of 24-27°C were consistently below the ambient temperatures observed during the study across various animal species (El-Halawany et al., 2022). Similar patterns were noted with the Temperature-Humidity Index (THI), which remained significantly above the 25.6 threshold identified by Marai et al. (2018) as indicative of severe heat stress. This indicates that all goats were experiencing heat stress throughout the testing period. These findings align with numerous studies that have documented elevated THI values for livestock in tropical regions. Additionally, research by Makhdoom et al. (2021) indicated that THI values tended to be higher on days without rainfall, a condition that persisted during this study. Studies by Ahmad et al. (2023) also observed that THI values typically increased from morning to evening, while relative humidity decreased during the same period, contributing to prolonged heat stress for the animals throughout the day.

In tropical and arid regions, heat presents a significant challenge to animal productivity (Tella, 2024). The average heart rate (70–90 beats per minute) and rectal temperature (39–40°C) of the goats remained within normal limits, as noted by Pagot et al. (2021) and Aye et al. (2022). However, the respiration rates recorded during the study exceeded the typical resting respiration rates of goats (12–20 breaths per minute), as indicated by the Agricultural Research and Extension Program (Adedeji et al. 2019).

Overall, heart rate, rectal temperature, and respiration rates exhibited significant changes in response to increasing THI values. Specifically, heart rates rose markedly with higher THI levels. Both respiration rates and rectal temperatures also increased alongside rising THI. These physiological responses were consistent across different breeds. Although the findings regarding heart rate were contrary to those of Adedeji et al. (2019), who reported a decrease in heart rate with rising environmental temperatures, the initial increase in heart rate can be attributed to enhanced blood flow to the skin's surface, facilitating heat dissipation through conduction, convection, radiation, and insensible water loss via diffusion. This observation supports the findings of Alexiev et al. (2021), who noted increased heart rates in ewes during peak heat loads. The subsequent decline in heart rate might result from reduced metabolic and physical activity in response to heightened thermal conditions, allowing the animals to minimize heat production (Aharoni et al., 2020).

The elevated respiration rates observed in goats may be a physiological response aimed at evaporating body heat through panting, which is a key mechanism for evaporative heat loss in ruminants (Katamoto et al., 2021). Similar responses have been documented in cattle (Gaughan et al., 2022) and sheep (Gadberry et al., 2023). An increase in respiratory rate is one of the immediate reactions of goats to environmental stress (Hales & Brown, 2022). As THI values increase, rectal temperatures also rise, suggesting that the thermoregulatory efficiency of animals diminishes under heightened thermal conditions, leading to increased body temperatures (Maria & Habeeb, 2023). Breed-specific analysis revealed significant differences in rectal temperature measurements between the two goat breeds.

Table 3: Regression Evaluation of the effect of THI on the physiological response of WAD

Effect of THI on Heartbeat rate of WAD	Coefficient	SE	t-value	Sig.	R^2	Adjusted R^2
Constant	-156.744	17.174	-9.127	0.001	0.550	0.542
THI	2.744**	0.198	13.829	0.001		
THI on Respiration Rate of WAD						
Constant	-163.083	24.052	-6.781	0.001	0.33	0.31
THI	2.630**	0.278	9.464	0.001		
THI on Rectal Temperature						
Constant	31.848	1.269	25.089	0.001	0. 156	0.154
THI	0.088**	0.015	6.027	0.001		

**Significant at 5% alpha level; SE: Stadard Error

Regression analysis indicated that THI had a positive and statistically significant ($p \leq 0.05$) impact on the heartbeat rate of the Red Sokoto breed, explaining 54.5% of the variation ($R^2 = 0.545$). Similarly, THI significantly affected the respiration rate, accounting for 32% of the variation ($R^2 = 0.32$), and also influenced rectal temperature, with THI explaining 14.6% of the variation ($R^2 = 0.146$). This suggests a significant correlation between THI and the physiological responses of the Red Sokoto goats. For the West African Dwarf (WAD) breed, regression analysis also revealed a positive and significant ($p \leq 0.05$) effect of THI on heartbeat rate, explaining 55% of the variation ($R^2 = 0.550$). The analysis indicated similar significant relationships for respiration rate ($R^2 = 0.33$) and rectal temperature ($R^2 = 0.156$). These findings affirm the significant relationship between THI and the physiological responses of the WAD breed (Malau-Aduli et al., 2023). Given the current climate challenges, it is essential to develop strategies to enhance goats' adaptability to heat stress to maximize their genetic potential. Exposure to high temperatures severely limits goat productivity, particularly in tropical and subtropical regions where they are directly exposed to sunlight. Elevated ambient temperatures, particularly when combined with high humidity, lead to decreased feed efficiency and intake, disrupted energy homeostasis, altered hormone secretion, and changes in blood metabolite profiles. This situation directly and indirectly affects livestock owners by degrading meat quality, reducing milk yield, and impairing reproductive performance. A deeper understanding of goats' adaptive mechanisms to heat stress is crucial for formulating effective strategies. There is a pressing need for innovative approaches to enhance goats' heat tolerance without compromising their productivity. Comprehensive research in this area is critical and requires sustained effort.

CONCLUSION

Maintaining thermoneutrality is crucial for the optimal productivity of goats. Heat stress occurs due to the heightened metabolic heat and can trigger various adaptive responses. The diverse physiological, biochemical, and molecular reactions in goats complicate the accurate assessment of the severity of heat stress. Additionally, heat stress impacts energy metabolism and modifies the metabolism of water and minerals (such as Na+, K+, and Cl-) through behavioral adaptations, including increased sweating, changes in urination and defecation patterns, and heightened water consumption and drinking frequency.

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