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Original Research Article

Thermoregulation in humid climate-adapted and Savannah breeds of goats exposed to West African cold (harmattan) season

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Abstract

The West African Dwarf (WAD) goats have hereditary dwarfism and are adapted to the humid climate. The study compared the cold tolerance of WAD and Savannah (Red Sokoto and Sahel) goats during the peak of the West African cold season in the Northern Guinea Savannah of Nigeria. A total of 18 adult non-pregnant, dry does comprising equal number of each breed (six per breed) were used for the study. Thermoregulatory variables were recorded four times in the morning (07:00 h) and afternoon (13:00 h) hours at two-day intervals. Results revealed that irrespective of the hour of day, the WAD had significantly ($p < 0.05$) higher respiratory rate when compared with Red Sokoto and Sahel goats. The diurnal afternoon rise in respiratory rate and the magnitude of afternoon rise in rectal temperature was higher ($p < 0.0001$) in WAD than Sahel and Red Sokoto goats. The body surface temperature in the morning hours was significantly lower in WAD compared with Sahel breed, while in the afternoon hours, the inter-digital space temperature was significantly lower in WAD compared with Savannah breeds. However, there were no significant ($p > 0.05$) differences in heart rate, rectal, head and leg temperatures between the breeds in both morning and afternoon hours. Discriminant analysis revealed that the morning hours induced greater homogeneity in the thermoregulatory responses between the breeds adapted to the humid and Savannah climates as compared with the afternoon hours. It was concluded that although WAD goats employed more intense peripheral vasoconstriction to survive cold exposure and demonstrated greater diurnal amplitude in thermoregulatory variables, they maintained comparable core body temperature as the indigenous Savannah breeds. Thus, suggesting that despite the hereditary dwarfism, the WAD goats could conserve body heat during the West African cold season in the Northern Guinea Savannah zone of Nigeria.

Keywords: Humid climate breed; Savannah breed; Northern Guinea Savannah; thermoregulatory variables; hereditary dwarfism

INTRODUCTION

Annually, from late November to the middle of March, goats and other livestock inhabiting the West African regions affected by the harmattan experience a combination of meteorological conditions described as cold-dry season or the "West African cold season" (Igono et al., 1982; Habibu et al., 2017). The season is different from the winter season of other climates, as it is not just cold, but also extremely dry, windy, dusty and shows wide diurnal variation in the ambient temperatures; from a temperature of as low as 12 °C in the morning hours, to a rise of up to 34 °C in afternoon hours (Habibu et al., 2016).

The Red Sokoto goat gained global recognition due to its high quality skin which is used for the production of Morocco leather. Together with the Sahel goats, they make up the Savannah group of West African goats. The most popular breed of goat in the humid region of West Africa is the West African Dwarf (WAD) goat. It is short, small and well adapted to the hot-humid coastal climate of West Africa, a climate established to have a relatively high annual ambient temperature that is rarely below 25 °C and a high annual relative humidity, ranging from 60% in the morning to 80% in the afternoon hours (Adedeji, 2012). In recent times, adoption of the WAD goats to West Africa regions affected by harmattan has been observed. Unlike the WAD breed, the Savannah breeds of goats are well adapted to the harmattan season due to high adaptation to their indigenous Savannah climate (Ngere et al., 1984; Gall, 1996).

Hereditary dwarfism is a common feature in the humid tropics and corresponds to the genotypic make-up of the WAD goat (Devendra and Burns 1970). According to the Bergmann's Rule: "In warm blooded animals, races from warm regions are smaller than races from cold regions" (Bergmann 1847). This implies a strong association between morphological variables and environmental temperature, such that the relatively larger body surface area of the smaller breeds helps to enhance the efficiency of heat dissipation in hot climates, while small body surface areas in larger breeds helps to conserve heat in cold climates (Mayr 1970; Daramola and Adeloye, 2009).

Despite the novelty of the harmattan season to WAD goat, no study, to our knowledge, has comparatively evaluated their thermoregulation and that of the Savannah breeds of goats during the harmattan season. Moreover, the thermoregulatory challenges associated with cold exposure is poorly handled by heat-adapted tropical livestock and may affect their productivity; due to redirection of the energy required for growth, milk production and reproduction to the maintenance of thermal homeostasis. We hypothesised that the thermoregulatory response of WAD goats differs from that of Savannah (Red Sokoto and Sahel) breeds of goats when exposed to the peak of the West African cold (harmattan) season in the Northern Guinea Savannah of Nigeria.

MATERIALS AND METHODS

Experimental site and animal management

The goats were housed in pens belonging the Small Ruminant Research Section of the National Animal Production Research Institute (NAPRI), Ahmadu Bello University, Shika, Nigeria, located on latitude 11°12′N, longitude 7°33′E, and altitude of 610 m above sea level (Habibu et al., 2014). The range of average ambient temperature and relative humidity that have been reported previously in Zaria were 16 °C–39 °C and 15–78%, respectively (Minka and Ayo, 2016; Habibu et al., 2016). The pens were well-ventilated and positioned in an east-west orientation with dimensions of 6.10, 6.10 and 2.22 m for length, width and height, respectively. The pens were roofed with galvanized metal sheets and the floor was made of concrete. The three breeds of goats were housed within the same farm together with other animals at a stocking density of 30 goats per pen.

The does were routinely screened for haemoparasites and helminths (using flotation and sedimentation tests) and only clinically healthy does were used for the study. The does grazed freely on *Digitaria smutsi* as basal diet and supplemented with concentrate ration of ground maize (20%), cotton seed cake (30%), wheat offal (40%), bone meal (5%) and salt (5%) at 300 g/head/ day. Portable drinking water was provided *ad libitum*.

Experimental design and animals

The study was conducted during the peak of cold-dry season (December–January; Igono and Aliu, 1982) in the Northern Guinea Savannah zone of Nigeria. A total of 18 adult non-pregnant, dry does comprising equal number (n = 6) of a humid (WAD) and two Savannah (Red Sokoto and Sahel) breeds were used for the study. Thermoregulatory variables were recorded four times in the morning (07:00 h) and afternoon (13:00 h) hours at three-day intervals.

The six-point scale method was used to score the body condition of the does (Santucci et al., 1991). The three groups were balanced for age (1.5 to 2.5 years), but the body condition score was 3.5–4 in the WAD breed and 3–3.5 in the Red Sokoto and Sahel breeds; due to the inherent chubby physical appearance of the former.

Determination of thermoregulatory variables

The respiratory rate was determined by counting each movement of the flank around the paralumbar fossa per unit time, and expressed in number of breaths per minute. Heart rate was determined by counting the beats of the heart using a stethoscope per unit time, and expressed in number of beats per minute. The body temperature of the goats was recorded by determining the rectal temperature of the does using a digital thermometer (Tro-Digitatherm, Hamburg Germany) and presented in °C (Habibu et al., 2016; Yaqub et al., 2016).

Body surface temperatures were determined using a pistol type laser sighting infrared thermometer (Rycom®, London, UK) positioned at approximately 2 cm from the target spoton the animal (Hargreaves et al., 2012). The head surface temperature was measured by separating the hair on the forehead using the fingers. The trunk temperature was recorded by separating the hair around the 13th left rib, while the leg temperature was measured by separating the hair on the lateral surface, distal to the elbow. The inter-digital space temperature was measured by positioning the thermometer to the less hairy space between the digits of the fore limb, respectively.

Determination of meteorological parameters

Dry and wet-bulb temperatures were obtained at 07:00 h and 13:00 h in the morning and afternoon, respectively, at three-day intervals during the experimental period. Relative humidity (RH) values were extrapolated from the wet and dry-bulb temperature values using conversion tables condensed from the Bulletin of the U.S. Weather Bureau No. 107. The temperature humidity index (THI) was used to evaluate the level of heat stress induced by the environment and was calculated using the equation reported by Ravagnolo et al. (2000):

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

Where:
T = ambient temperature (°C) and RH = relative humidity (%).

Data analysis

The values obtained were expressed as mean (± SEM). The data were subjected to repeated measures one way analysis of variance (ANOVA) followed by Duncan multiple range test to compare values between groups. Discriminant analysis was performed to identify variables that best discriminate the response of the three breeds to the cold-dry season. This was followed by discriminant analysis option of variable classification. The statistical package used was Statistical Package for Social Science (SPSS) version 20 (SPSS, 2012). Values of $p < 0.05$ were considered significant.

RESULTS

Table 1 shows the meteorological parameters recorded in the study area. The ambient temperature and THI significantly increased from morning to afternoon hours, while the relative humidity significantly decreased in the afternoon hours. Body surface and rectal temperatures (Figure 3, 4, 5 and 7) showed a rise ($p < 0.0001$) in the afternoon hours; except forehead temperature in Sahel goats, which showed no significant increase in the afternoon hours. Specifically, the magnitude of the afternoon rise in rectal temperature was higher in WAD goats ($p < 0.0001$) as compared with Red Sokoto ($p < 0.002$) and Sahel goats ($p < 0.01$). Similarly, only WAD goats showed a diurnal increase ($p < 0.0001$) in respiratory rate (Figure 1) in the afternoon hours; other groups showed no significant diurnality during the harmattan season. However, irrespective of breed, no significant influence of the hour of day on heart rate (Figure 2) was observed during the cold season.

Irrespective of the hour of day, WAD goats had a significantly higher respiratory rate when compared with Red Sokoto and Sahel goats. On the other hand, in the morning hours, the surface temperature of the body trunk was significantly lower in WAD goats compared with Sahel breed (Figure 4). Similarly, the inter-digital space temperatures in the afternoon hours were significantly lower in WAD compared with Sahel and Red Sokoto breeds.

Table 1. Meteorological parameters recorded in the pen during the study

Parameters	Morning	Afternoon
Ambient temperature (°C)	16.00 ± 0.71 a	32.25 ± 0.85 b
Relative Humidity (%)	33.50 ± 2.22 a	5.50 ± 1.85 b
THI	59.80 ± 0.82 a	80.11 ± 1.09 b

a, b indicate significant difference at $p < 0.001$
THI = temperature humity index

Table 2. Percentage of goats classified into the groups (breeds) during the morning hours

Group	Predicted Group Membership			Total
	Red Sokoto	Sahel	WAD	
Morning				
Red Sokoto	33.3	45.8	20.8	100.0
Sahel	20.8	66.7	12.5	100.0
WAD	8.3	25.0	66.7	100.0
Afternoon				
Red Sokoto	37.5	50.0	12.5	100.0
Sahel	58.3	37.5	4.2	100.0
WAD	4.2	4.2	19.6	100.0

Discriminant analysis result (Table 2) revealed a great homogeneity in the thermoregulatory responses of the breeds. Irrespective of the hour of day, a generally high misclassification (44.4%) of the breeds was observed with Red Sokoto and Sahel breeds having the highest misclassification, while WAD goats had the least. Moreover, the misclassification of the WAD goats was higher during the morning than afternoon hours (8.3 and 20.0% vs 4.2 and 4.2%).

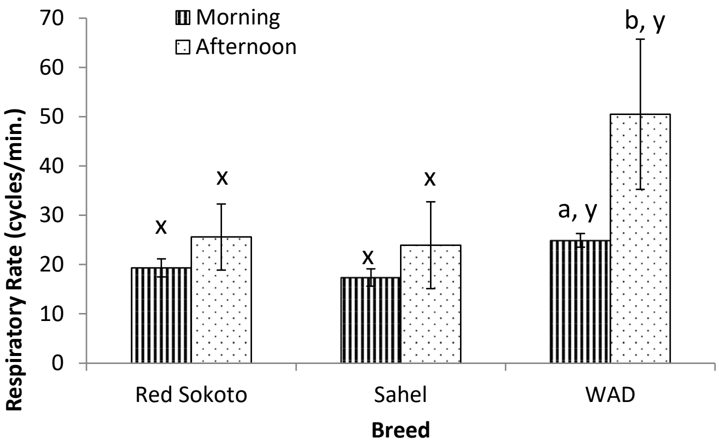

Figure 1. Changes in respiratory rate of Red Sokoto, Sahel and West African Dwarf (WAD) goats during the harmattan season; a, b (hours of the day) = $p < 0.0001$ and x, y (breed difference) = $p < 0.05$

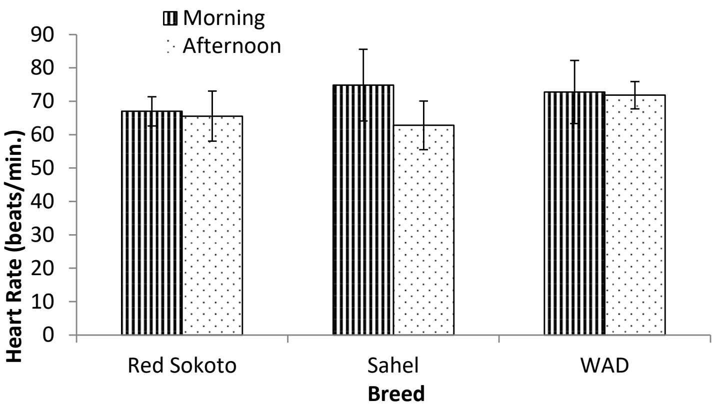

Figure 2. Changes in heart rate of Red Sokoto, Sahel and West African Dwarf (WAD) during the harmattan season

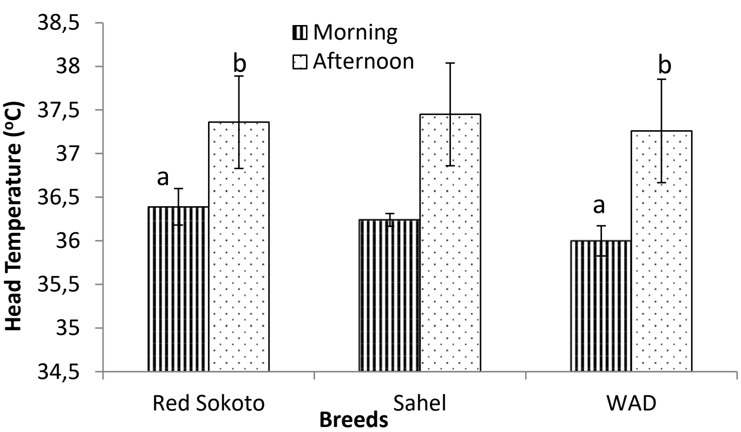

Figure 3. Changes in head temperature of Red Sokoto, Sahel and West African Dwarf (WAD) during the harmattan season; a, b (hours of the day) = $p < 0.0001$

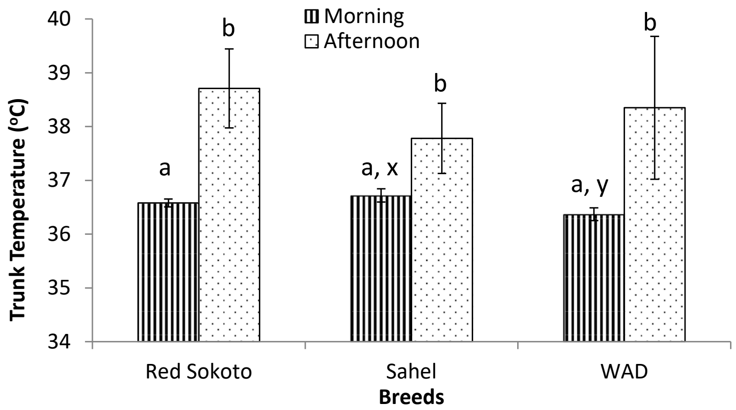

Figure 4. Changes in trunk temperature of Red Sokoto, Sahel and West African Dwarf (WAD) during the harmattan season; a, b (hours of the day) = $p < 0.0001$; x, y (Breed difference) = $p < 0.05$

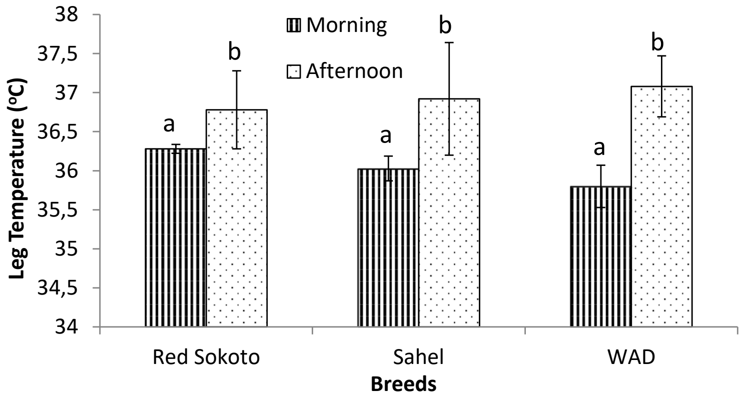

Figure 5. Changes in leg temperature of Red Sokoto, Sahel and West African Dwarf (WAD) goats during the harmattan season; a, b (hours of the day) = $p < 0.0001$

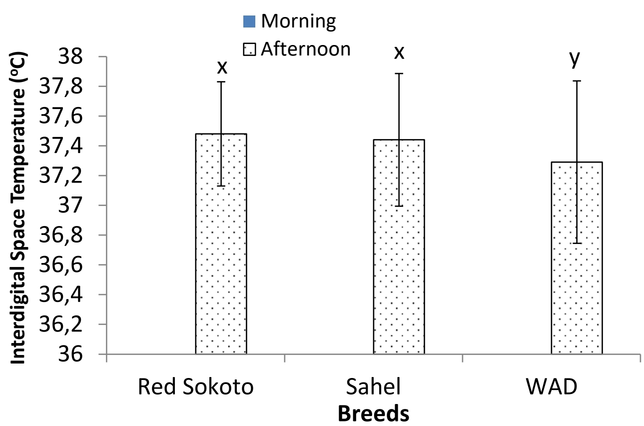

Figure 6. Changes in Interdigital space temperature of Red Sokoto, Sahel and West African Dwarf (WAD) goats during the harmattan season. Values during the morning hours were below the lower limit of the device used; a, b (hours of the day) = $p < 0.0001$

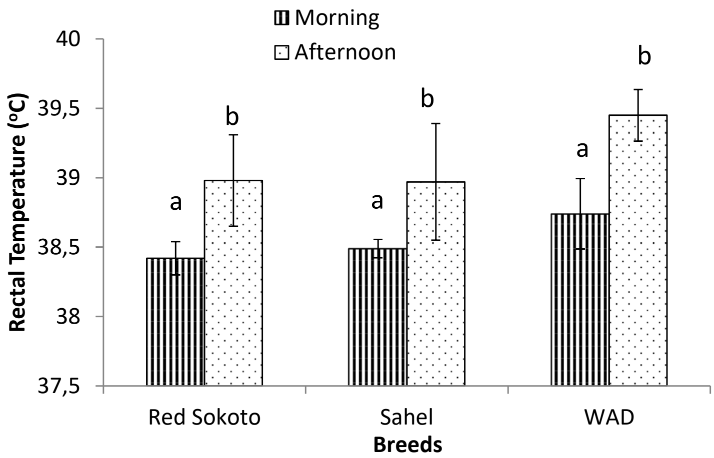

Figure 7. Changes in rectal temperature of Red Sokoto, Sahel and West African Dwarf (WAD) goats during the harmattan season; a, b (hours of the day) = $p < 0.002$ (Red Skoto), $p < 0.01$ (Sahel) and $p < 0.0001$ (WAD)

DISCUSSION

The ambient temperatures recorded in the current study are within the range previously reported in the study area during the morning (16.42 °C; range: 12.00 °C – 23.00 °C) and afternoon (30.61 °C; range: 28.00 °C – 39.00 °C) hours of the harmattan season. However, the relative humidity recorded was slightly different from previously reported data in the study area for morning (20.26%; range: 14.00%–27.00%) and afternoon (15.66%; range: 7.00%–22.00%) hours (Habibu et al. 2016). The meteorological parameters recorded in the morning hours were lower than the thermoneutral zone for THI (65–75) and ambient temperature (24 °C – 30 °C), indicating that the goats suffer from cold stress during the morning hours (Lu, 1989; Hamzaoui et al. 2013). The harmattan season has been reported to induce significant cold stress to goats, causing shivering thermogenesis in the early morning hours (Igono et al., 1982; Habibu et al., 2017).

Most available data on thermoregulation of Nigerian goats compared the response of individual breeds or the savannah breeds across different seasons (Habibu et al., 2017; Minka and Ayo, 2016; Adedeji, 2012). In agreement with the lower respiratory rate in WAD goats during the morning as compared to the afternoon hours, a previous study in Boer goats also reported lower respiratory rate in the morning than in the afternoon hours during winter (Al Yamani and Koluman, 2020). The expected decrease in alveolar ventilation due to lower respiratory rate in the morning hours is checked by decrease in respiratory dead space and increase in tidal volume (Diesel et al., 1985; Robertshaw, 2006; Habibu et al., 2019). This change helps to reduce heat loss to the inhaled cold air (Diesel et al., 1985; Habibu et al., 2019). Even with reduced respiratory rate, respiratory heat loss has been reported to be largely uncontrolled with the loss being countered by elevations in both metabolism and respiratory ventilation so as to maintain thermal homeostasis (Robertshaw, 2006).

A unique characteristic of the West African cold season, unlike other seasons, is its ability to induce wide variation in thermoregulatory variables, causing a high amplitude in daily rhythmicity of such variables (Ayo et al., 1998; Minka and Ayo, 2014; 2016). In the current study, the Red Sokoto and Sahel goats, unlike the WAD goats were able to minimise the variation in the diurnal fluctuation of respiratory rate and rectal temperature. These wide fluctuations in biological rhythms are induced by the wide difference between the morning and afternoon ambient temperatures and may be the major challenge of the WAD goats exposed to the West African cold season in the Northern Guinea Savannah climate of Nigeria.

Irrespective of the hour of day, the WAD goats had higher respiratory rate than the Red Sokoto and Sahel goats. The higher respiratory rate in the WAD goats may be genetically related to their miniature body size as compared with the other breeds (Ngere et al., 1984). Moreover, increased alveolar ventilation and metabolic rate caused by higher respiratory rate and small body size, respectively, (Bennett and Tenney, 1982) may collectively enhance thermogenesis and maintain body temperature comparable with other breeds, despite their novelty to the West African cold season.

The most important cardiovascular response to cold exposure is an increase in cardiac output to pump more blood to heat generating tissues like the liver and skeletal muscle, as well as peripheral vasoconstriction to reduce blood supply to the skin (Horwitz 1971;

Broucek et al., 1991). A previous study in temperate climate indicated a higher heart rate and cardiac output in goats subjected to cold stress (Thompson and Thompson, 1972). However, the study of Habibu et al. (2017) reported a decrease in pulse rate of Red Sokoto and Sahel goats during the West African cold season as compared to the hot-dry season. In the current study, the expected diurnal change in heart rate between the morning and afternoon hours, as observed in the respiratory rate, was not recorded. In addition, the well-established high heart rate (>87 beats per min.) in WAD goats (Sodipe et al., 2014; Azeez et al., 2018) due to their small body size (Detweiler, 2010), was not observed during the cold season. The weak diurnality in heart rate of there breeds and the low heart rate in WAD goats in the current study reflect the intense effects of the West African cold season on the cardiovascular activities of these breeds. Similarly, the poor diurnality in heart rate may infer that unlike the other cardinal thermoregulatory variables, the magnitude of the afternoon rise in ambient temperature was not high enough to influence cardiovascular activities in female tropical breeds of goats. The study of Al Yamani and Koluman (2020) reported no diurnality in pulse rate of Boer goats, but a distinct diurnality in pulse rate of Alpine and Saanen goats during winter. Also, higher pulse rate has been reported in adult male Sahel than Red Sokoto goats during the cold-dry season (Habibu et al., 2016b). The difference may be due to sexual dimorphism.

The low ambient temperature, especially in the morning hours and the strong wind of the cold season increase the loss of body heat leading to a reduction in surface and core body temperature in livestock (Thompson and Thompson, 1972; Broucek et al., 1991; Minka and Ayo; 2016). In the current study, the three breeds maintained the lower range of the normal rectal temperature in tropical goats, i.e. 38 °C – 40 °C (Igono et al., 1982; Ayo et al., 1998), which significantly increased when the ambient temperature rose in the afternoon hours. In endotherms, a marked decrease in body surface temperature occurs upon exposure to low ambient temperature in order to prevent hypothermia of the internal tissues (Refinetti, 2010); and the decrease is due to reduced cutaneous blood supply caused by vasoconstriction (Thompson and Thompson, 1972; Broucek et al., 1991). The current study demonstrated a greater reduction in body surface temperature towards the appendages, such that the legs had lower surface temperature, while the inter-digital space had the least, with the values being lower than 35.5 °C (below the functional limit of the device). Lower surface temperature of the trunk and inter-digital space during the morning and afternoon hours, respectively, in WAD goats suggests that this breed utilised vasoconstriction more extensively than savannah breeds to maintain homoeothermy during the West African cold season. Moreover, despite the relatively larger body surface area due to smaller body size of the WAD goats, they were able to maintain comparable homoeothermy with the savannah breeds during cold exposure. This may not be unconnected to thyroid activity, as high tri-iodothyronine (T_3) concentrations have been reported in kids of WAD goats compared to those of the savannah breeds (Habibu, 2021).

The higher classification error of the Savannah breeds during the afternoon and morning hours suggests greater similarity in their thermoregulatory response to cold; affirming previous studies that demonstrated high genetic similarity between Red Sokoto and Sahel goats (Yakubu et al., 2013; 2016; 2017). Unlike the afternoon hours when the misclassification between humid and savannah breeds was less; during the morning hours, the misclassification was higher since the three breeds showed uniform thermoregulatory adjustments, which include a reduction in respiratory frequency and a decrease in body surface and core body temperatures due to low ambient temperature. The high discrimination in thermoregulatory response between humid and savannah breeds during the afternoon hours was due to rise in ambient temperature which induced a greater magnitude of increase in respiratory rate and rectal body temperatures in WAD goats.

CONCLUSION

Diurnality in pulse rate during seasonal cold exposure is weak in tropical goats. WAD goats seem to employ more intense peripheral vasoconstriction to survive cold exposure and experienced wider diurnal fluctuations in respiratory rate and rectal temperature during the West African cold (harmattan) season. Nonetheless, they maintained similar core body temperature with the indigenous Savannah breeds. This may imply that the WAD goats can efficiently conserve body heat, reduce the impact of cold stress. Future studies involving larger sample size should explore the role of metabolic hormones and productivity of WAD goats during the West African cold season in the Northern Guinea Savannah zone of Nigeria.

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CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

ETHICAL COMPLIANCE

The study protocol and experimental design got the approval of Animal Use and Welfare Committee of Ahmadu Bello University, Zaria; and obtained an approval number: ABUCAUC/2019/13. The study was conducted in line with the international guidelines for animal welfare.

REFERENCES

Adedeji T. A. (2012): Effect of some qualitative traits and non-genetic factors on heat tolerance attributes of extensively reared West African Dwarf (WAD) goats. International Journal of Applied Agriculture and Apiculture Research 8: 68–81.

Al Yamani H. M. M., Koluman N. (2020): Impact various seasons on expression patterns HSP60 and physiological parameters. Journal of Dairy and Veterinary Animal Research 9: 1–4. DOI: 10.15406/jdvar.2020.09.00270.

Ayo J. O., Oladele S. B., Fayomi A., Jumbo S., Hambolu J. O. (1998): Body temperature, respiration and heart rate in the Red Sokoto goat during the harmattan season. Bulletin of Animal Health Production Africa 46: 161–166.

Azeez O. M., Basiru A., Akorede G. J., Adah S. A. (2018): Electrocardiographic parameters in West African Dwarf and Red Sokoto (Maradi) goats. Sokoto Journal of Veterinary Sciences 16: 41–46.

Bennett F. M., Tenney S. M. (1982): Comparative mechanics of the mammalian respiratory system. Respiratory Physiology 49: 131-140.

Bergmann C. (1847): Über die Verhältnisse der Wärmeökonomie der Thiere zu ihrer Grösse. Göttinger Studien 3: 595–708.

Broucek J., Letkovicova M., Kovalcuj K. (1991): Estimation of cold stress effect on dairy cows. International Journal of Biometeorology 35: 29–32.

Daramola J. O., Adeloye A. A. (2009): Physiological adaptation to the humid tropics with special reference to the West African Dwarf (WAD) goat. Tropical Animal Health Production 41: 1005–1016.

Detweiler D. K. (2010): The mammalian electrocardiogram: comprehensive features: interspecies correlations: body size, heart rate and time intervals. In: MacFarlane P. W., van Oosterom A., Pahlm O., Kligfield P., Janse M., Camm J., eds. Comprehensive Electrocardiology, Vol. 4. Springer-Verlag, London, 1922 p.

Devendra C., Burns M. (1970): Goat production in the Tropics (Technical Communication No 19). Commonwealth Bureau of Animal Breeding and Genetics: Edinburgh, UK.

Diesel D. A., Tucker A., Robertshaw D. (1985): Cold-induced changes in breathing pattern as a strategy to reduce respiratory heat loss. Journal of Applied Physiology 69: 1946–1952.

Gall C. (1996): Goat breeds of the world. CTA–Margraf Verlag, Germany, 186 p.

Habibu B., Kawu M. U., Makun H. J., Aluwong T., Yaqub L. S., Ahmad M. S., Tauheed M., Buhari H. U. (2014): Influence of sex, reproductive status and foetal number on erythrocyte osmotic fragility, haematological and physiologic parameters in goats during the hot-dry season. Veterinarni Medicina 59: 479–490.

Habibu B., Kawu M. U., Makun H. J. Aluwong T., Yaqub L. S. (2016): Seasonal variation in body mass index cardinal physiological variables and serum thyroid hormones profiles in relation to susceptibility to thermal stress in goat kids. Small Ruminant Research 145: 20–27.

Habibu B., Yaqub L. S., Dzenda T., Kawu M. U. (2019): Sensitivity, impact and consequences of changes in respiratory rate during thermoregulation in livestock – A review. Annals of Animal Science 19: 291–304.

Habibu B., Kawu M. U., Aluwong T., Makun H. J. (2017): Influence of seasonal changes on physiological variables, haematology and serum thyroid hormones profile in male Red Sokoto and Sahel goats. Journal of Applied Animal Research 45: 508–516.

Habibu B. (2021): Influences of breed, haemoglobin genotype, birth-weight, litter-size and sex on neonatal behaviour, thermoregulation, metabolic changes, production performance and mortality rate of Nigerian goats (Ph.D. Thesis), Ahmadu Bello University, Zaria.

Hamzaoui S., Salama A. A. K., Albanell E., Such X., Caja G. (2013): Physiological responses and lactational performances of late-lactation dairy goats under heat stress conditions. Journal of Dairy Science 96: 6355–6365.

Hargreaves A. L., Hutson G. D. (2007): Handling system for sheep. Livestock Production Science 49: 121–138.

Horwitz B. A. (1971): Brown fat thermogenesis: Physiological control and metabolic basis. In: Nonshivering thermogenesis. Proceedings of Symposium, Praha, pp. 63–65.

Igono M. O., Aliu Y. O. (1982): Environmental profile and milk production of Friesian-zebu crosses in Nigerian Guinea Savannah. International Journal of Biometeorology 26: 115–120.

Igono M. O., Molokwu E. C. I., Aliu Y. O. (1982): Body temperature responses of Savanna Brown goat to the harmattan and hot-dry season. International Journal of Biometeorology 26: 225–230.

Lu D. C. (1989): Effects of heat stress on goat production. Small Ruminant Research 2: 151–162.

Mayr E. (1970): Population, species and evolution. Harvard University Press: Cambridge, Massachusetts, USA.

Minka N. S., Ayo J. O. (2014): Influence of cold–dry (harmattan) season on colonic temperature and the development of pulmonary hypertension in broiler chickens, and the modulating effect of ascorbic acid. Open Access Animal Physiology 6: 1–11. DOI: http://dx.doi.org/10.2147/OAAP.S51741.

Minka N. S., Ayo J. O. (2016): Effects of cold-dry (harmattan) and hot-dry seasons on daily rhythms of rectal and body surface temperatures in sheep and goats in a natural tropical environment. Journal of Circadian Rhythms 14: 1–11.

Ngere L. P., Adu I. F., Okubanjo O. (1984): The indigenous goats of Nigeria. Animal Genetic Research Information 3: 1–9.

Ravagnolo O., Misztal I., Hoogenboom G. (2000): Genetic component of heat stress in dairy cattle, development of heat index function. Journal of Dairy Science 83: 2120–2125.

Refinetti R. (2010): The circadian rhythm of body temperature. Frontiers in Bioscience 15: 564–594.

Robertshaw D. (2006): Mechanisms for the control of respiratory evaporative heat loss in panting animals. Journal of Applied Physiology 101: 664–668.

Santucci P. M., Branca A., Napoleone M., Bouche R., Aumont G., Poisot F., Alexandre G. (1991): In: body condition scoring of goats in extensive conditions. Goat nutrition. Wageningen: EAAP Publication, Pudoc III. p. 240–256.

Sodipe O. G., Sowande O. S., Abioja M. O., Adeleye O. O., Akintayo H., Adebowale R. A. (2014): Haematological and physiological parameters of West African Dwarf goats as influenced by coat variation and sex. Bulletin of Animal Health and Production in Africa 62: 305–314.

Thompson G. E., Thompson E. M. (1972): Effect of cold exposure on mammary circulation, oxygen consumption and milk secretion in the goat. Journal of Physiology 272: 187–196.

Yaqub L. S., Ayo J. O., Kawu M. U., Rekwot P. I. (2017): Diurnal thermoregulatory responses in pregnant Yankasa ewes to the dry season in a tropical Savannah. Tropical Animal Health Production 49: 1243–1252. DOI 10.1007/s11250-017-1322-8.

Yakubu A., Salako A. E., Donato M. D., Takeet M. I., Peters S. O., Whetog M., Okpeku M., Imumorin I. G. (2016): Interleukin-2 ((IL-2) gene polymorphism and association with heat tolerance in Nigerian goats. Small Ruminant Research 141: 127–134.

Yakubu A., Salako A. E., De Donato M., Peters S. O., Takeet I. M., Wheto M., Okpeku M., Imumorin I. G. (2017): Association of SNP variants of MHC Class II DRB gene with thermo-physiological traits in tropical goats. Tropical Animal Health Production 49: 323–336.

Yakubu A., Salako A. E., De Donato M., Takeet M. I., Peters S. O., Adefenwa M. A., Okpeku M., Wheto M., Agaviezor B. O., Sanni T. M., Ajayi O. O., Onasanya G. O., Ekundayo O. J., Ilori B. M., Amusan S. A., Imumorin I. G. (2013): Genetic diversity in Exon 2 at the major histocompatibility complex DQB1 locus in Nigerian indigenous goats. Biochemical Genetics 51: 954–966.

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