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ORIGINAL RESEARCH

Physiological and haematological indices suggest superior heat tolerance of white-coloured West African Dwarf sheep in the hot humid tropics

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Abstract Coat colour contributes to physiological adaptation in mammals and mediates response to thermal stress. Twenty-four adult West African Dwarf sheep of both sexes and with different coat colour types were used in this study. We measured rectal temperature (RT), respiratory rate (RR) and pulse rate (PR) before sunrise and sunset during the late dry season (January–March) and early rainy season (April–June) as well as packed cell volume (PCV), red blood cell (RBC) count, white blood cell (WBC) count, plasma sodium (Na^+) and potassium (K^+). Animals with black coat colour had the highest ($P<0.05$) mean values of 38.92±0.03 °C, 65.09±1.06 breaths/min, 81.35±0.78 beats/min, 1.70±0.01 for RT, RR, PR and heat stress index (HSI), respectively, followed by brown mouflon and brown with extensive white, while the Badger Face coloured sheep had the least mean values. There were significant ($P<0.05$) differences between male and female sheep for RT, RR, PR and HSI. Season had a significant ($P<0.05$) effect on RT, RR, PR and HSI. Coat colour and sex also significantly ($P<0.01$) affected RBC, WBC, Na^+ and K^+. Seasonal variation ($P<0.05$) in all the blood parameters was observed, with the exception of PCV. Interaction effect of coat colour and sex was significant ($P<0.05$) on RT and HSI. Correlation coefficients among the measured traits ranged from positive to negative values. These results indicate that selection of white-coloured sheep to attenuate heat stress is desirable in the hot humid tropics.

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Introduction

Sheep rearing is considered an important economic activity in various regions of the world for meat, wool and hide production (McManus et al. 2011). They are homoeothermic animals, which under thermoneutral conditions can keep body temperature within a normal range utilizing sensible heat loss (convection, conduction and radiation) to dissipate body heat to the surrounding environment. Homeostatic mechanisms are controlled by the hypothalamus via various neuroendocrine pathways, leading to different endogenous and behavioural responses that are measurable (Keim et al. 2002). The hyperthermia during exposure to heat stress is the result of decreased thermal gradient between an animal and the surrounding environment, and as a result, sensible heat loss becomes less effective (AL-Haidary 2004). Environmental factors such as ambient temperature, solar radiation and humidity have direct and indirect effects on animals (Altan et al. 2003; Scharf 2008; Hetem et al. 2011). Heat stress strongly affects animal bioenergetics, with adverse effects on the performance and well-being of livestock. An individual animal's susceptibility to heat stress is influenced by several factors including species, coat colour, condition score, temperament, sex, coat thickness and previous exposure (Brown-Brandl 2009). The ability to maintain homeostasis under heat stress is a valuable trait in subtropical and tropical regions which helps to maximize utilization of animal genetic resources (Foster et al. 2009).

Coat colour is a qualitative trait and an indicator of genetic superiority or productive adaptability of animals to heat tolerance (Helal et al. 2010; McManus et al. 2011). Coat colour is mostly controlled by alleles at three loci (A, B and S), although genes on the extension locus act as modifier genes (Ozoje 1998). It is a highly repeatable character with a high heritability estimate (Adalsteinsson et al. 1994; Renieri et al. 2008).

The West African Dwarf (WAD) sheep is the predominant breed of sheep in the trypanoendemic humid region of Nigeria characterized by high rainfall, temperature and relative humidity (Yakubu et al. 2010a, b). The trypanoendemic region usually spans the whole southern part of the country. The WAD sheep is a smaller bodied breed when compared to the other three main sheep breeds in Nigeria but not dwarf in the genetic sense. They have notable physical and sexual vigour and robustness that enables them to withstand the stress of the climate, disease and irregular feeding (Sanusi et al. 2012). However, there is paucity of information on their coat characteristics as related to heat tolerance. The present study was undertaken to determine the effects of coat colour on heat stress in West African Dwarf sheep using physiological indicators and blood parameters in a subhumid tropical environment. The information obtained will help to improve animal welfare and their production efficiency.

Materials and methods

Study area and animals

The protocol for the experiment was approved by the Institutional Animal Use and Care Committee of the University of Agriculture, Abeokuta, Nigeria. The study was carried out at the Livestock Research Farm of University of Agriculture, Alabata (7° 10′ and 3° 2′ E), Abeokuta, Nigeria with 24 West Africa Dwarf sheep of different coat colours. Coat colours were classified according to Adalsteinsson (1970, 1974) and Adalsteinsson et al. (1994). The coat colour types were black (aaB-SS), brown with extensive white markings (aabbss), brown mouflon (Aabbss; dorsal part is pigmented with brown while the belly is white), Badger Face (A-B-ss; belly and face are pigmented, while the dorsal part is white) and black with extensive white markings (aaB-ss). The animals were managed semi-intensively and received Ivomec® against endoparasites, ectoparasites and skin infection at a dosage of 0.05 ml/kg. They were also treated with oxytetracycline LA® (a broad-spectrum antibiotic) at a dosage of 0.2 mg/kg and vaccinated with *Peste des petits* ruminant vaccine during the quarantine period. The animals were allowed to graze in the morning, and this was supplemented with concentrate feed in the afternoon. Clean water was provided ad libitum. The animals were periodically washed (dipped) with Prectosol® (a dipping solution with permethrin as active ingredient) against ticks and other ectoparasites during the study.

Physiological data collection and analysis

Rectal temperature (RT), respiratory rate (RR) and pulse rate (PR) were measured early in the morning between 7:00 a.m. and 8:00 a.m. before sunrise. The animals were then exposed to heat from solar radiation during the grazing period till 1:00 p.m. Repeated measurements for RT, RR and PR were carried out between 1:00 p.m. and 2:00 p.m. as follows:

RT — This was taken on each animal using a digital thermometer. The sensory tip was disinfected and inserted into the rectum at the display of L °C by a thermometer (which indicated that the thermometer is set for temperature reading). This was removed after the sound of the alarm signal. The displayed body temperature was then recorded.

RR — This was determined by counting the number of flank movements per minute.

PR — This was determined for each animal by placing the fingertips on the femoral

	arteries of the hind limb for 1 min.
Heat stress index (HSI)	The relationship between the measured RR and PR together with their normal average values was used to derive heat stress index according to the method of Oladimeji et al. (1996).

$$\mathrm{HSI} = (\mathrm{RR}/\mathrm{PR}) \times (\mathrm{NPR}/\mathrm{NRR})$$

Where, RR = measured respiratory rate, PR = measured pulse rate, NPR = normal pulse rate and NRR = normal respiratory rate.

Data were collected three times a week for 20 weeks in the late dry and early rainy seasons. The mean environmental temperature ranges from 32 to 36 °C for late dry season and 28 to 34 °C for early rainy season.

Blood collection and analysis

Blood samples were collected during the late dry season (January–March) and early rainy season (April–June) at the same period of the day time. About 4–5 ml of blood samples were collected by jugular venipuncture from each animal, 2 ml of which was dispensed into a clean bottle containing ethylenediaminetetraacetic acid as an anticoagulant and labelled. The rest were allowed to clot and also labelled accordingly. The packed cell volume (PCV), red blood cell (RBC) count, white blood cell (WBC) count, plasma sodium (Na^+) and potassium (K^+) were determined. All the parameters were determined according to the method described by Edington and Gilles (1981).

White blood cell count

The estimate of the total number of white blood cells in 1 mm^3 of blood sample was made using the method described by Edington and Gilles (1981). Dilution of blood was carried out by adding 0.02 ml of blood to 0.38 ml of Turk's solution in a clean test tube. The tube was tightly corked and the suspension mixed with a rotating mixer for 1 min. Neubauer counting chamber with an area of 1 mm^2 and a depth of 0.1 mm was used, a cover slip was fixed tightly in the chamber using a fine-bore pipette. The chamber was filled with the diluted blood. The solution spread evenly. This was then viewed under a microscope, and the cells in the four outer 1 mm^2 were counted using a 16-mm eyepiece and ×10 objective lens with reduced condenser aperture. The number of cells in cubic millimeter of blood was calculated as follows:

$$\text{Total number of cells(cubic centimeters)} = \frac{\text{cells counted} \times \text{blood dilution factor} \times \text{chamber depth}}{\text{area of chamber counted}}$$

Packed cell volume

The percentage of packed red cells in the blood was determined using the method described by Edington and Gilles (1981). A small capillary tube was dipped into a sample of blood to fill it to about three quarter length. The sides were wiped in order to give an accurate reading. One end of the tube was sealed over a Bunsen burner. The tube was then put into a PCV centrifuge to spin and separate serum from red cells. This was done at 4,900 revolutions for 5–6 min. The red cells which settle below are referred to as packed cells. The tube was then placed on a micro-haematocrit reader and the level of packed cell read off. The value which corresponds to the level of packed cells was regarded as the packed cell volume.

Red blood cell count

Dilution of blood was made by adding 1.0 ml of blood to 4.0 ml of RBC diluting fluid in a clean test tube. The tube was tightly corked and the suspension mixed with a rotating mixer for 1 min. Neubauer counting chamber with an area of five inner 1 mm^2 and a depth of 0.1 mm was used. A cover slip was fixed tightly on the chamber. Using a fine-bore pipette, the chamber was filled with the diluted blood. The solution was spread evenly. This was then viewed under the microscope, and the cells were counted using a 16-mm eyepiece and 40× objective lens with reduced condenser aperture.

Potassium and sodium concentrations

The concentrations of potassium and sodium were read at wavelengths of 500 and 550 nm, respectively, using an atomic absorption spectrophotometer.

Statistical analysis

The data obtained from the physiological and blood parameters were analysed using the generalized linear model of SAS (2005) software package. The linear model employed was as follows:

$$Y_{ijkl} = \mu + A_c + B_s + P_p + (\mathrm{AB})_{\mathrm{cs}} + (\mathrm{AP})_{\mathrm{cp}} + (\mathrm{BP})_{\mathrm{sp}} + (\mathrm{ABP})_{\mathrm{csp}} + e_{\mathrm{cspr}}$$

Y_{ijkl}	The parameter of interest
μ	Overall mean for the parameter of interest
A_c	Fixed effect of *i*th coat colour (c=1–5)
B_s	Fixed effect of *j*th sex (s=1–2)
P_p	Fixed effect of *k*th season (p=1–2)
$(AB)_{cs}$	Interaction effect of *i*th coat colour and *j*th sex
$(AP)_{cp}$	Interaction effect of *j*th coat colour and *k*th season
$(BP)_{sp}$	Interaction effect of *j*th sex and *k*th season
$(ABP)_{csp}$	Interaction effect of coat colour, sex and season
e_{cspr}	Random error associated with each record (normally, independently and identically distributed with zero mean and constant variance)

Significant means were separated using the Duncan's multiple range test procedure.

Results and discussion

The least square means for the physiological parameters as affected by coat colour, season and sex are presented in Table 1. Coat colour had a significant effect (P<0.05) on all the physiological parameters studied. Animals with black coat (aaB-SS) had the highest mean RT values, while the least value was recorded for Badger Face coloured sheep (A-B-ss). The high RT of sheep with black coat could be a result of the absorption of solar radiation by the dark pigmentation. The light pigmentation of the dorsal part of Badger Face sheep reflects more and absorbs less solar radiation into the body. High ambient temperatures in tropical and subtropical regions constitute a major constraint on animal productivity, and this effect is aggravated when heat stress is accompanied by high ambient humidity (Shelton 2000; Daramola and Adeloye 2009). RT increases only when physiological mechanisms of body are nonproductive to counteract the unnecessary heat load (Saddiqi et al. 2011). These results on light pigmentation agree with Hansen (2004) that light-coloured and sleek and shiny hair coats reflect a greater proportion of incident solar radiation than dark hair coats. Da Silva et al. (2003) also found that animals with light-coloured hair coats have higher reflectance values than animals with dark-coloured hair coats. Silanikove (2000) and Keim et al. (2002) reported that the best physiological parameter to objectively monitor animal welfare in hot environment is the RT. When the physiological mechanism of an animal fails to negate the excessive heat load, RT increases. Such exposure of animal to heat stress evokes a series of drastic changes in the biological functions, which include a decrease in feed intake, disturbances in water, protein, energy and mineral balances, enzymatic reactions, hormonal secretions and blood metabolism (Marai et al. 2007; Gwatibaya et al. 2007). Similarly, Gebremedhin et al. (2008) reported that RT is perhaps the most reliable indicator of thermal heat stress because it drives other heat stress-alleviating mechanisms.

RR values followed the same pattern with that of RT with higher RR values recorded in black animals. The animals panted in order to increase body cooling by respiratory evaporation since the major evaporatory heat loss mechanism is panting. The PR values ranged from 73.23±0.47 to 81.35±0.78 beats/min. The highest PR value was recorded for black coat (aaB-Ss). Heat stress index ranged from 1.48 ±0.01 to 1.70±0.01 with the average value of 1.62. Black coat (aaB-SS) also had the highest estimated value, while Badger Face had the least value. HSI is commonly used as an indicator of thermal comfort (Kendall and Webster 2009).

Season significantly (P<0.05) influenced the physiological parameters. The mean RT recorded during the late dry

Table 1 Least square means for physiological parameters as influenced by coat colour, season and sex

	Rectal temperature (°C)	RR (breaths/min)	PR (beats/min)	Heat stress index
Coat colour				
Black (aaB-SS)	38.92±0.03a	65.09±1.06a	81.35±0.78a	1.70±0.01a
Brown with extensive white (aabbss)	38.77±0.03b	58.08±1.18bc	75.60±0.77b	1.66±0.00b
Brown mouflon (Aabb ss)	38.62±0.03c	55.58±1.08c	73.41±0.68c	1.64±0.01c
Badger Face (A-B-ss)	38.58±0.02c	51.31±0.65d	73.23±0.47c	1.48±0.01d
Black with extensive white (aaB-ss)	38.85±0.02a	58.82±0.84b	76.09±0.58b	1.65±0.01bc
Season				
Late dry season	38.93±0.01a	65.17±0.63a	80.86±0.50a	1.64±0.02a
Early rainy season	38.60±0.02b	50.87±0.54b	71.73±0.30b	1.59±0.17b
Sex				
Female	38.83±0.02a	59.94±0.65a	77.92±0.46a	1.63±0.02a
Male	38.69±0.02b	56.09±0.58b	74.67±0.39b	1.60±0.19b

Means in the same column with the different lowercase letters are significantly different (P<0.05) for coat colour, season and sex season was significantly higher than the value recorded for the early rainy season (38.93±0.01 versus 38.60±0.02 °C). The higher mean value of 65.17±0.63 breaths per minute of RR was observed during late dry season, while the lowest value of 50.87±0.54 breaths per minute was recorded during early rainy season. The mean value of PR for early rainy season (71.73±0.03 beats per minute) was significantly lower than that for the late dry season (80.86±0.50 beats per minute). The HSI value obtained for the late dry season was higher ($P<0.05$) than that obtained for early rainy season (1.64±0.02 versus 1.59±0.17). The lower RT, RR, PR and HSI in the wet season might be a result of lower ambient temperature and better nutrition status of the animals due to availability of pasture during the wet season. The hot climatic condition imposed stress on the animals. Higher RT observed in the late dry season might be due to high ambient temperature and relative humidity associated with this season which could exceed the comfort zone of the animals, resulting in imbalance in the heat energy produced and dissipated. Srikandakumar et al. (2003) reported that heat stress increased RT and RR in Omani and Merino sheep. The present study also agreed with the report of Alhidary et al. (2012) and Lallo et al. (2011) where exposure to high ambient temperature resulted in increased RT and RR. Shinde et al. (2002) recorded higher RR, heart rate and RT in monsoon and summer than in winter for goats on the semi-arid range in India. Oladimeji et al. (1996) also reported significant differences in RT, RR and PR during the hot dry season over cold dry season (harmattan season) among Yankasa sheep. In a related study in African giant rats, Dzenda et al. (2011) reported that RT was higher in the hot dry and harmattan seasons than the wet seasons.

Sex of sheep significantly affected the physiological parameters studied ($P<0.05$). The RT for females (38.69±0.02 °C) was significantly higher than that observed among males (38.69±0.02 °C). The RR was significantly lower among males as compared to their female counterparts (56.09±0.58 versus 59.94±0.45 breaths per minute). Female sheep equally had the highest beats per minute for PR, while the males had the lowest mean value. These are in agreement with the findings of Butswat et al. (2000) who reported that female Yankasa, Uda and Balami breeds of sheep had significantly higher RT, RR and PR than their male counterparts. Sejian et al. (2010) reported increase in RT and RR as a result of heat stress in female sheep, while Stockman (2006) submitted that high RR is a good indicator of the onset of thermal stress in ewes.

Interaction effect of coat and sex was significant ($P<0.05$) on RT and HSI (Table 2). Badger males seemed to be well adapted to hot environment than their black female counterparts, an indication of separate ranking of each sex under each coat colour. Interaction effect of coat colour and sex was not significant on RR and PR. Interaction effect of coat colour and season, interaction effect of sex and season as well as the three-way interaction of coat colour season and sex were not significant on the physiological parameters.

The least square means of PCV, RBC, WBC, Na^+ and K^+ concentrations as affected by coat colour, season and sex are shown in Table 3. Coat colour had a significant effect ($P<0.05$) on the RBC. The black coat (aaB-SS) had the highest RBC, while the Badger Face had the least value. The differences in the mean value of RBC among brown mouflon (Aabbss), brown with extensive white markings (aabbss) and black with extensive white markings (aaB-ss) were however not significant ($P>0.05$). Black coat (aaB-SS) type had the highest RBC count as a result of high heat burden on black animals. Heat stress increased the number of RBC count in black sheep. This could be a result of physiological need for increase in haemoglobin to cope with oxygen circulation during panting of heat-stressed animals. This is consistent with the findings of Borges et al. (2003) who reported increase in the quantity of RBC with heat stress. WBC was also significantly ($P<0.05$) affected by coat colour. Badger Face coat-coloured sheep had the highest count of 6,550.00±60.92 no/mm^3. The black coat had the least value of WBC of 6,033.32±41.44 no/mm^3. The mean WBC value for Black with extensive white markings (aaB-ss) was significantly lower than brown with extensive white markings (aabbss) (6,200.00±65.13 and 6,366.67±95.45 no/mm^3, respectively). The lower WBC counts in heat-stressed animals confirm the report of Borges et al. (2003)

Table 2 Least square means for physiological parameters as influenced by interaction effect of coat colour and sex

Coat colour	Sex	Rectal temperature (°C)	Heat stress index
Black	Female	39.02±0.04a	1.70±0.01a
	Male	38.82±0.03b	1.69±0.01b
Brown with extensive white	Female	38.77±0.03c	1.66±0.00c
Brown mouflon	Male	38.62±0.03cd	1.64±0.01c
Badger Face	Female	38.68±0.03c	1.49±0.01d
	Male	38.48±0.02d	1.46±0. 01d
Black with extensive white	Female	38.87±0.02b	1.65±0.08c
	Male	38.84±0.02b	1.64±0.01c

Means in the same column with the different lowercase letters are significantly different ($P<0.05$)

Table 3 Least square means of blood parameters as influenced by coat colour, season and sex

	PCV%	RBC (mil/mm^3)	WBC (no/mm^3)	Na^+ (mmol/L)	K^+ (mmol/L)
Coat colour					
Black	25.75±0.65a	3.25±0.13a	6033.23±41.44a	81.00±1.26d	2.16±0.04d
Brown with white	25.38±0.49 a	2.92±0.12b	6366.67±95.45b	86.33±3.27c	2.53±0.05b
Brown mouflon	25.00±1.06 a	2.98±0.12b	6400.23±51.64b	91.00±4.74b	2.58±0.04b
Badger Face	24.92±0.54 a	2.55±0.04c	6550.00±60.92a	104.33±2.75a	2.71±0.04a
Black with white	24.83±2.17 a	3.02±0.15b	6200.00±65.13c	89.92±1.66b	2.31±0.04c
Season					
Late dry season	24.12±0.39 a	3.25±0.08a	6166.67±47.65b	84.17±2.34	2.36±0.65b
Early rainy season	25.71±0.41 a	2.63±0.04b	6416.67±50.96a	97.19±1.46	2.56±0.19a
Sex					
Female	25.04±0.43 a	2.92±0.09a	6316.67±56.35a	89.54±2.22b	2.38±0.04b
Male	25.29±0.40 a	2.97±0.09a	6266.67±54.72a	92.42±2.42a	2.49±0.04a

Means in the same column with the different lowercase letters are significantly different (P<0.05) for coat colour, season and sex

that heat stress reduces the quantity of white blood cells in animals. Adedeji (2009) also reported that black goats had significantly lower WBC count than brown with white marking goats. However, Festus et al. (2005) did not observe any effect of coat colour type on WBC of crossbred pigs.

Badger Face (Ab-Bbss) had the highest (P<0.05) Na^+ value, while solid black (aaB-SS) had the least. The mean value for blown mouflon at 91.00±4.74 mmol/L was significantly higher than that of brown with extensive white markings (aabbss) at 85.33±3.27 mmol L. There was no significant difference in the mean values for black with extensive white markings and brown mouflon (Aabbss; 89.92±1.66 and 91.00±4.74 mmol/L, respectively). The plasma K^+ concentration was also significantly (P< 0.05) affected by coat colour. The mean value ranged from 2.16±0.04 to 2.71±0.07 mmol/L with the Badger Face having the highest value, while the black coat coloured sheep had the least value. There was no significant difference in the mean values for brown mouflon and brown with extensive white markings (aabbss). Animals with dark pigmentation had a lower value of Na^+ and K^+ concentration probably as a result of high net solar radiation impinging on the skin of dark-coloured animals. Heat stress reduces Na^+ and K^+ concentration. This reduction may be due to an increase in urinary sodium excretion due to increased total urinary output or expanded blood volume due to an increase in water intake (Scharf et al. 2010). The decrease in plasma electrolyte especially the cations with increase in body temperature is in agreement with the report of Borges et al. (2003), but contradicts the report of Srikandakumar and Johnson (2004) that heat stress increased plasma K^+ in Holstein and Jersey cows, but lowered the concentration in Australian milking zebu.

The RBC was significantly (P<0.05) affected by season. Higher mean value of 3.25±0.08 mil/mm^3 was recorded during late dry season, while a lower value of 2.63± 0.04 mil/mm3 was recorded for early rainy season. The mean WBC value of 6,416.67±50.96 no/mm^3 for early rainy season was significantly (P<0.05) higher than the 6,166.67±47.65 no/mm^3 for late dry season. Season also significantly (P<0.05) affected the Na^+ concentration. A lower value of 84.17±2.34 mmol/L was recorded during the late dry season compared to the value of 97.19±1.46 recorded during the early rainy season. A similar result was obtained for K^+ concentration as the mean value of 2.56± 0.19 mmol/L recorded during early rainy season was significantly (P<0.05) higher than 2.36±0.65 mmol/L recorded during late dry season. Lower levels of Na^+ and K^+ concentrations during the hot weather might be due to loss of Na ions in sweat under the tropical environmental conditions. This is in consonance with Adedeji (2009) that WAD goats had significantly lower values of Na and K ions during the hot season compared to the rainy season. However, Scharf et al. (2010) reported that Na^+ and K^+ were not significantly affected by heat stress in cattle. Broucek et al. (2009) also did not find the effect of hot temperature on the RBC of cattle. The difference between their findings and ours might be due to the intensity of heat or temperature ranges.

The plasma electrolytes studied were significantly (P< 0.05) affected by sex. Males had higher Na^+ concentration compared to their female counterparts. The mean K^+ concentration for females was significantly (P<0.05) lower than the mean value for males. Sex did not influence the mean values of the PCV. A similar result was obtained for the RBC count as the difference in the mean values for females was not significantly different from those of males. The result obtained on PCV is consistent with that reported

Table 4 Pearson's correlation coefficients of the physiological and blood parameters according to each coat colour type

	RT	RR	PR	HSI	RBC	WBC	Na	K	PCV
RT		0.903***	0.842***	0.877***	0.183***	0.091**	0.274***	0.178***	−0.181***
RR	0.920***		0.967***	0.904***	0.134***	0.141***	0.309***	0.209***	−0.187***
PR	0.821***	0.943***		0.768***	0.153***	0.108**	0.266***	0.184***	−0.157***
HSI	0.906***	0.928***	0.754***		0.077*	0.186***	0.345***	0.232***	−0.218***
RBC	0.231***	0.217***	0.204***	0.201***		−0.723***	−0.646***	−0.805***	0.287***
WBC	−0.030ns	−0.004ns	−0.010ns	0.006ns	−0.594***		0.732***	0.774***	−0.406***
Na	0.332***	0.349***	0.306***	0.348***	−0.718***	0.656***		0.762***	−0.453***
K	0.311***	0.340***	0.306***	0.331***	−0.531***	0.224***	0.723***		−0.335***
PCV	−0.067ns	−0.109*	−0.099ns	−0.108*	0.404***	−0.817***	−0.512***	−0.487***	
RT		0.865***	0.710***	0.902***	0.635***	−0.626***	0.550***	0.765***	0.107*
RR	0.853***		0.931***	0.931***	0.700***	−0.661***	0.567***	0.770***	0.131**
PR	0.745***	0.880***		0.737***	0.645***	−0.599***	0.514***	0.683***	0.120*
HSI	0.776***	0.889***	0.571***		0.660***	−0.639***	0.549***	0.757***	0.122*
RBC	0.059 ns	0.498ns	0.054ns	0.036ns		−0.564***	0.650***	0.680***	0.175***
WBC	−0.273***	−0.229***	−0.233***	−0.170***	−0.542***		−0.564***	−0.355***	−0.138**
Na	−0.263***	−0.195***	−0.201***	−0.138***	−0.612***	0.802***		0.605***	−0.221***
K	0.009 ns	0.047ns	0.022ns	0.069ns	−0.493***	0.844***	0.751***		−0.167**
PCV	−0.198***	−0.220***	−0.226***	−0.163***	0.025ns	0.420***	−0.046 ns	0.386***	
RT		0.890***	0.802***	0.866***	0.196***	−0.265***	0.128***	−0.049ns	0.577***
RR			0.945***	0.912***	0.186***	−0.221***	0.176***	−0.007ns	0.584***
PR				0.730***	0.167***	−0.191***	0.168***	−0.003ns	0.537***
HSI					0.185***	−0.229***	0.158***	−0.015ns	0.561***
RBC						−0.443***	−0.317***	−0.497***	0.200***
WBC							0.778***	0.560***	−0.250ns
Na^+								0.714***	0.430***
K^+									−0.034ns
PCV									

Black (*first upper diagonal*), brown with extensive white (*first lower diagonal*), brown mouflon (*second upper diagonal*), Badger Face (*second lower diagonal*) and black with extensive white (*third upper diagonal*)

RT rectal temperature, *RR* respiratory rate, *PR* pulse rate, *HSI* heat stress index, *RBC* red blood cell count, *WBC* white blood cell count, Na^+ sodium concentration, K^+ potasium concentration, *PCV* packed cell volume;

*$P<0.05$; **$P<0.01$; ***$P<0.001$

by Saddiqi et al. (2011). The interaction effect of coat colour and sex, coat colour and season, sex and season as well as the three-way interraction of coat colour, sex and season were not significant ($P>0.05$) in all the blood parameters measured.

The phenotypic correlations between the physiological and blood parameters are presented in Table 4. Low to high positive and negative correlations were found among the traits. Differences were also observed in the pattern of the correlations among the different coat colour types. RT was highly correlated with RR and HSI in all the coat colour types. This is an indication that an increase in the level of one will lead to a corresponding increase in the level of the other. Scharf et al. (2010) reported that the positive association between RL and RR is an indication of their reliability as heat stress indicators. Dzenda et al. (2011) reported a positive and significant relationship between RT and heat stress index in African giant rats. However, McManus et al. (2011) reported low to medium correlations among the physiological traits of sheep. In line with this study, McManus et al. (2009) reported that in general, correlations between physiological traits and blood parameters were medium and negative.

Conclusion

The physiological and blood parameters of heat-stressed WAD sheep were affected by coat colour, season and sex. Sheep with dark pigmentation were more prone to heat stress than those with light pigmentation. Thermal stress was higher in the hot dry season compared to the rainy season, while females appeared to be more affected by it. Interaction effect of coat colour and sex was significant on RT and HSI. The present results could aid management and selection decisions. While black sheep and others with dark pigmentation will need more shade and allowed to graze only in the early hours of the morning and in the evenings to avoid direct exposure to sunshine during hot season, selection should target animals with light coat colour in order to improve animal welfare and production efficiency.

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