Influence of seasonal changes on physiological variables, haematology and serum thyroid hormones profile in male Red Sokoto and Sahel goats

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\section*{ABSTRACT}

The aim of this study was to evaluate the physiological responses of adult male Red Sokoto goats (n = 10; indigenous to the Guinea Savannah climate) and Sahel goats (n = 10; indigenous to the Sahel climate) at the peak of the cold-dry (CDS), hot-dry (HDS) and rainy seasons prevailing in the Guinea Savannah zone of Nigeria. Results revealed that Red Sokoto goats had significantly higher rectal temperature (RT), PCV, red blood cell (RBC), Hb, thyroxin (T\textsubscript{4}), but lower respiratory rate (RR) and total leucocyte count (TLC) than Sahel goats during the CDS. Comparison within breeds for the three seasons showed that both breeds exhibited the highest ($P < .05$) PR, RT, neutrophil-lymphocyte ratio (N:L), but lower mean corpuscular volume and triiodothyronine (T\textsubscript{3}) during the HDS. In addition, Red Sokoto goats showed higher ($P < .05$) RR and T\textsubscript{4} but lower RBC, Hb, lymphocyte counts and T\textsubscript{3}:T\textsubscript{4}. However, Sahel goats exhibited higher ($P < .05$) PCV, RBC, erythrocyte osmotic fragility, but lower circulating T\textsubscript{4}. It was concluded that the cold and hot seasons exerted different physiological effects on the two breeds of goats with marked variation in RT, composition of blood cellular components, thyroid physiology and erythrocyte membrane integrity.

\section*{1. Introduction}

Globally, about 80\% of goat production is confined to low-income countries, particularly in tropical Africa and Asia (Morand-Fehr et al. 2004). In developing countries of the world, small ruminants are described as 'village bank', while goats are known as the poor man's cow (Ikwuebu et al. 1994; Haldar & Ghosh 2014). Promoting small-scale livestock ownership has been reported to be a potential way of reducing poverty and improving human nutrition in rural Africa (Azzarri et al. 2014). The Red Sokoto and Sahel goats are important breeds of goat that are widely distributed in the West Africa subcontinent. Red Sokoto goats are indigenous to Niger Republic and the savannah region of Nigeria, while the Sahel goats are found in West Africa around the Sahel belt, south of the Sahara (Gall 1996). However, adaptation of Sahel goats to the Northern Guinea Savannah zone of Nigeria, mainly by institutional and commercial farms, and unregulated livestock markets has been observed in recent years (Makun et al. 2013).

The three distinct seasons of the Northern Guinea Savannah zone of Nigeria are: the cold-dry (CDS; harmattan), hot-dry (HDS) and rainy (RAS) seasons (Igono & Aliu 1982; Dzenda et al. 2011). These seasons have different combination of meteorological parameters, and domestic animals must adjust to the periodic changes in these parameters in order to adapt and remain productive. Similarly, these seasonal differences also affect the availability of feed since the growth of plants occur, mainly during the RAS, and the animals must be supplemented with hay and/or concentrate during the dry seasons (Scogings et al. 2015). High (Gaughan et al. 2013) or low (Zhao et al. 2013) ambient temperatures (ATs) as an aftermath of seasonal changes are well known to induce stress, with negative consequences on the physiology and productivity of livestock. Over the years, scientists have put intense efforts into understanding how domestic animals respond to climate stressors. However, most of these studies were conducted in developed countries with a significant amount of data generated on adaptation and the impact of environmental stress on the production, reproduction and health of animals (Scholtz et al. 2013). On the other hand, little is known about the adaptation of animals to the rapidly changing environmental conditions in developing countries of the arid and semiarid regions, where the stressors are different and the intensity of expected changes from one season to the other is greater (Thornton et al. 2007). Physiological changes in blood cellular components, free radical biology, as well as endocrine, respiratory and cardiovascular systems have been used as important parameters to evaluate the adaptation of animals to a given geographical location (Sejian et al. 2014; Ribeiro et al. 2015). This may help in the selection of animals that are capable of producing satisfactorily in harsh environments and outside the zone of thermal comfort (Ribeiro et al. 2015). Therefore, this study was carried out to evaluate the adaptation of Red Sokoto and Sahel bucks to the seasons of the Northern Guinea Savannah zone of Nigeria by evaluating...
the changes in physiological variables, haematology, erythrocyte osmotic fragility (EOF) as a biomarker of oxidative stress and serum thyroid hormones concentration.

2. Materials and methods

2.1. Experimental design and animal management

The animals were sourced from the Small Ruminant Research Programme, National Animal Production Research Institute (NAPRI), Ahmadu Bello University, Shika, Zaria, Nigeria located on latitude 11°12′ N, longitude 70°33′ E, and altitude 610 m.

Twenty apparently healthy Red Sokoto (n = 10) and Sahel (n = 10) male goats aged between 1.5 and 3.5 years, body weight ranging between 20 and 25 kg and body condition score of 2.90 ± 0.10 were used in all the seasons during the study period. Body condition was scored by the same person adopting a 6-point scale (0–5) method with 0.5 increment (Santucci et al. 1991). An animal of body condition score of 1.0 is extremely thin with no fat reserves and body condition score of 5.0 represents an obese animal. In each season, the animals were balanced for age, body condition score and body weight. The animals were managed intensively in a well-ventilated pen in east–west orientation with dimension of 20, 20 and 7.3 ft for length, width and height, respectively. The roof of the pen was made of galvanized metal sheets, while the floor was made of concrete. The pens had a stocking density of 20 goats. Animals in the farm were routinely screened for haemoparasites and helminths (using floatation and sedimentation tests). Only clinically healthy animals were used for the study. The animals were fed on Digitaria smutisi hay 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. The animals were provided with water ad libitum.

2.2. Meteorological parameters

The values of AT and relative humidity (RH) were collected from the Data Processing Unit, Institute of Agricultural Research, Ahmadu Bello University; Zaria is located about 6 km away from the experimental site. The AT and RH were recorded daily during the morning (08:00–10:00 h) and afternoon (13:00–16:00 h) hours in each season of study. 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):

\[
\text{THI} = (1.8 \times T + 32) - ((0.55 - 0.0055 \text{RH})(1.8 \times T - 26)),
\]

where \(T\) is the ambient temperature (°C) and \(\text{RH}\) the relative humidity (%).

2.3. Determination of physiological variables

The physiological variables recorded were: rectal temperature (RT), respiratory rate (RR) and pulse rate (PR). They were measured between 9:00 and 11:00 h two times at four days interval at the peak of each season. RR was obtained by counting the movement of the right flank at the paralumbar fossa per unit time and presented as number of breaths per minute. PR was obtained by counting the pulsations felt in the femoral artery per unit of time and presented as number of beats per minute. The body temperature of the goats was determined by measuring the RT using a digital thermometer (Trodigitaltherm, Hamburg, Germany) and presented in °C.

2.4. Blood sample collection and determination of haematological parameters

The bucks were sampled once in each season at the peak of the CDS, HDS and RAS seasons. This period coincided with the months of December, April and August, respectively. Blood sampling was done between the hours of 8 and 9 am and immediately transported (within an hour) in ice pack to the laboratory. In each season, 3 mL of blood was collected via jugular venipuncture into vacutainer tubes containing ethylene diamine tetraacetic acid (K3EDTA) for haematological analysis and determination of EOF. Another 3 mL of blood was collected in anticoagulant-free tubes and allowed to clot, followed by centrifugation at 2000 × g for 15 min. The serum was then harvested for thyroid hormones analysis.

Packed cell volume (PCV), red blood cell (RBC) count, total leucocyte count (TLC) and differential TLCs were determined as described by Dacie and Lewis (1991). Haemoglobin concentration (Hb) was determined using a haemoglobin meter (XF-1C Haemoglobin meter, China). Erythrocytic indices were calculated from PCV and RBC count as described by Schalm et al. (1975).

2.5. Determination of EOF

EOF was determined according to the method described by Oyewale (1992) using a 1% NaCl stock solution prepared with phosphate buffer (3.22 g/L) at a pH of 7.4. The absorbance was measured at 540 nm using a spectrophotometer (Spectronic-20, Philip Harris Limited, Shenstone, England). Distilled water was used as blank to read the absorbance of supernatants in hypotonic and isotonic saline. Taking the haemoglobin concentration in the 0.0% NaCl solution as 100% haemolysis, haemolysis percentage values were calculated and their curves were drawn.

2.6. Determination of serum thyroid hormones

Thyroid hormones (total T4 and T3) were measured from serum using a commercial enzyme-linked immunoassay kit (AccuBind ELISA Microwells; Monobind Inc. USA). Assay sensitivities for total T4 and T3 were 3.2 ng/well and 0.04 ng/well, respectively. The intra- and inter-assay coefficients of variation for both T4 and T3 were less than 10%. All assays were performed in accordance with the manufacturer’s instructions.

2.7. Data analysis

The values obtained were expressed as mean ±SEM. The data were subjected to student’s t-test for comparison between breeds and repeated measure analysis of variance followed by Tukey’s post-hoc test to compare values between the three seasons. Pearson’s correlation test was used to determine
the relationship between variables. The statistical package used was GraphPad Prism version 5.01 for windows (2007) from GraphPad Software, San Diego California, USA (www.graphpad.com). Values of $P < .05$ were considered significant.

3. Results

3.1. Meteorological parameters

Mean values of meteorological parameters in the study area are presented in Table 1. The highest mean AT (39.21°C) and temperature-humidity index (THI; 84.62) were obtained in the afternoon hours of the HDS. The THI in the morning hours was lower than the THI during the afteroon hours in all the seasons. The highest RH (77.36%) was recorded during the RAS in the morning hours. The CDS in the morning hours had the lowest THI (56.76).

3.2. Effects of breed and season on physiological parameters

Mean ($\pm$SEM) values of RR, PR and RT in Red Sokoto and Sahel goats during the CDS, HDS and RAS are presented in Figures 1–3, respectively. The RR was significantly lower, while the RT was higher in Red Sokoto compared to Sahel goats during the CDS. The Sahel goats had higher ($P < .05$) PR compared to Red Sokoto goats during the HDS.

In the Red Sokoto goats, RR and RT were significantly lower in the RAS compared to the CDS and HDS, whereas the pulse was significantly higher during the HDS compared to the CDS. In Sahel goats, significantly ($P < .05$) higher RR, but lower RT was observed during the CDS compared to the RAS. The PR was significantly lower in the CDS compared to the HDS in Sahel goats.

3.3. Effects of breed and season on haematological parameters

Mean ($\pm$SEM) values of haematological parameters of Red Sokoto and Sahel goats during the CDS, HDS and RAS are presented in Table 2. Red Sokoto goats had significantly higher PCV, RBC and Hb than Sahel goats during the CDS. However,

Table 1. Mean values of meteorological parameters during the cold-dry (CDS), hot-dry (HDS) and rainy (RAS) seasons.

| Parameters | CDS | HDS | RAS |
|------------|-----|-----|-----|
| AT (°C)    |     |     |     |
| Morning    | 16.45$^a$ | 24.47$^{b}$ | 22.90$^b$ |
| Afternoon  | 30.47$^a$ | 39.21$^b$ | 31.00$^a$ |
| RH (%)     |     |     |     |
| Morning    | 19.96$^a$ | 54.29$^b$ | 77.36$^c$ |
| Afternoon  | 15.22$^a$ | 24.41$^b$ | 70.72$^c$ |
| THI        |     |     |     |
| Morning    | 56.76$^a$ | 72.17$^b$ | 70.22$^b$ |
| Afternoon  | 75.63$^a$ | 84.62$^b$ | 79.63$^b$ |

$^{\text{ab}}$Values between seasons with different superscript are statistically significant ($P < .05$).
the MCH was significantly higher in Sahel than Red Sokoto goats during the CDS. Values of WBC in Red Sokoto goats were significantly higher during the HDS, but lower during the RAS compared to Sahel goats.

In Red Sokoto goats, the RBC was significantly \((P < 0.05)\) higher in the CDS compared to the HDS and RAS. The Hb in Red Sokoto goats was significantly lower during the HDS compared to the CDS and RAS. In HDS, however, Sahel goats had significantly \((P < 0.05)\) higher PCV and RBC than CDS. The mean corpuscular volume (MCV) in Red Sokoto goats was higher \((P < 0.05)\) during the RAS compared to CDS and HDS. Similarly, the MCV in Sahel goats was significantly \((P < 0.05)\) higher during the RAS compared with the CDS.

Results of the leucocyte parameters in Red Sokoto goats indicated significantly higher WBC and neutrophil-lymphocytes ratio (N:L) during the HDS compared to the CDS and RAS. The Red Sokoto goats had significantly \((P < 0.05)\) higher lymphocyte counts (LYMPH), but lower neutrophil (NEUT) counts in the RAS compared to CDS and HDS. Although, the TLC and lymphocyte counts were higher and neutrophil counts lower in Sahel goats during the HDS as compared to the CDS and RAS, the difference was not statistically significant \((P > 0.05)\). However, the values of N:L of Sahel goats was significantly higher in the HDS compared to the CDS.

### 3.4. Effects of breed and season on EOF

Mean \((±SEM)\) values of EOF in male Red Sokoto and Sahel goats at 0.1, 0.3, 0.5 and 0.7% NaCl are presented in Figures 4–7, respectively during the CDS, HDS and RAS. Erythrocytes of Red Sokoto goats were significantly \((P < 0.05)\) more fragile during the CDS compared to the RAS at 0.7% NaCl (Figure 6). In Sahel goats, the percentage haemolysis was significantly higher \((P < 0.05)\) in the HDS compared with the CDS at 0.3% NaCl (Figure 4). There was no significant \((P > 0.05)\) effect of breed on EOF.

### 3.5. Effects of breed and season on serum triiodothyronine and thyroxin

Results on the effect of breed and season on serum T₃, T₄ and T₃/T₄ in adult bucks of Red Sokoto and Sahel goats during the CDS, HDS and RAS are shown in Figures 8–10, respectively. Serum concentration of T₃ was significantly \((P < 0.05)\) higher in Red Sokoto than Sahel goats during the HDS. In the HDS, serum T₄ was significantly higher \((P < 0.05)\) in Red Sokoto than Sahel goats, while in the CDS, serum T₄ was lower \((P < 0.05)\) in

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**Table 2. Seasonal changes in haematological parameters of male Red Sokoto and Sahel goats.**

| Parameters | CDS | HDS | RAS |
|------------|-----|-----|-----|
| PCV (%)    |     |     |     |
| RSG        | 35.31 ± 1.25 x | 33.79 ± 5.03 x | 35.54 ± 1.96 x |
| SHG        | 27.20 ± 1.48 a | 36.00 ± 2.42 b | 31.30 ± 1.65 a |
| RBC (10⁶/µL) |     |     |     |
| RSG        | 17.91 ± 0.57 a | 11.61 ± 1.17 x | 13.89 ± 0.60 x |
| SHG        | 8.43 ± 0.45 b | 10.89 ± 1.17 x | 8.7 ± 0.42 x |
| HB (g/dL)  |     |     |     |
| RSG        | 11.65 ± 0.41 x,a | 9.56 ± 0.47 x,b | 11.8 ± 0.28 x,b |
| SHG        | 9.38 ± 0.53 b | 9.56 ± 0.75 | 10.37 ± 0.34 |
| MCV (fL)   |     |     |     |
| RSG        | 19.79 ± 0.32 x | 18.85 ± 0.55 x | 21.30 ± 0.37 x |
| SHG        | 20.26 ± 0.05 a | 18.94 ± 1.27 x | 21.6 ± 0.48 x |
| MCH (pg)   |      |     |     |
| RSG        | 6.31 ± 0.08 a | 5.76 ± 0.49 | 6.42 ± 0.29 |
| SHG        | 6.40 ± 0.05 b | 6.58 ± 0.72 | 7.07 ± 0.28 |
| MCHC (g/dL) |     |     |     |
| RSG        | 33.49 ± 0.1 a | 32.37 ± 3.57 | 31.29 ± 1.80 |
| SHG        | 33.4 ± 0.16 a | 32.89 ± 3.61 | 32.94 ± 1.64 |
| TLC (10⁶/µL) |     |     |     |
| RSG        | 8.75 ± 0.44 x,a | 18.51 ± 1.43 x,b | 10.51 ± 0.86 x,b |
| SHG        | 10.28 ± 1.64 a | 14.51 ± 1.53 a,b | 13.40 ± 1.35 a,b |
| LYMPH (%)  |     |     |     |
| RSG        | 53.22 ± 2.88 a | 41.71 ± 2.51 a,b | 44.41 ± 2.87 a,b |
| SHG        | 67.48 ± 4.6 a | 58.64 ± 3.5 | 66.33 ± 6.39 |
| NEUT (%)   |     |     |     |
| RSG        | 46.78 ± 2.88 a | 59.29 ± 2.02 a | 34.83 ± 2.99 a,b |
| SHG        | 32.52 ± 4.6 a | 41.36 ± 3.5 | 33.47 ± 6.39 |

Notes: RSG, Red Sokoto goats; SHG, Sahel goats. Values of the same parameters with different superscript are statistically significant \((P < 0.05)\). a,b: between breeds, x,y: between season.
Red Sokoto than Sahel goats. In both breeds, circulating T₃ was significantly lower \((P < .05)\) during the HDS compared with the CDS and RAS. On the other hand, circulating T₄ was significantly higher \((P < .05)\) during the HDS compared with the CDS in Red Sokoto goats. However, circulating T₄ was significantly lower \((P < .05)\) during the HDS compared with the RAS in Sahel goats. In Red Sokoto goats, T₃:T₄ was significantly lower \((P < .05)\) in the HDS compared with the RAS. However, there was no significant breed difference \((P > .05)\) in T₃:T₄ in all the seasons.

3.6. Relationship between thyroid hormones and physiological parameters

Values of coefficient of correlation \((r)\) between serum thyroid hormones and physiological variables in male Red Sokoto and Sahel goats during the CDS, HDS and RAS are presented in Table 3. Significant positive correlation \((P < .05)\) was observed...
between physiological parameters (RR and RT) and thyroid hormones in Sahel goats during the CDS and RAS. There was a significantly positive correlation ($r = 0.942$) between $T_3$ and RR during the CDS. Similarly, a positive correlation ($P < 0.05$) was observed between $T_3$ and RT ($r = 0.736$) and $T_3$-$T_4$ and RT ($r = 0.942$) in the CDS. In the RAS, a significantly ($P < 0.05$) positive correlation was observed between $T_3$ and RT ($r = 0.736$) and between $T_3$-$T_4$ and PR ($r = 0.663$). There was no significant correlation ($P > 0.05$) between thyroid hormones and physiological variables in Red Sokoto goats.

### 4. Discussion

#### 4.1. Meteorological parameters

THI has been used as a measure of the ease with which animals maintain normal body temperature in an environment. In goats, if the THI is below 65 or above 75, the animal may experience thermal stress (Hamzaoui et al. 2013). In the present study, the AT and THI were higher than the thermoneutral zone in the afternoon hours of the HDS and RAS, suggesting that the goats experienced heat stress in these seasons. Similarly, in the morning hours during the CDS, the THI was below the thermoneutral zone suggesting that the goats were exposed to cold stress. In the tropics, as seasons change, different breeds of animals undergo some physiological changes necessary for survival (Scholtz et al. 2013; Sejian et al. 2014). The efficiency of such changes in various physiological systems determines the adaptation of the breeds to the given environment. To the best of our knowledge, this is the first study that extensively evaluates the response of Red Sokoto and Sahel breeds of goat to different seasons of the tropical Savannah region of West Africa.

#### 4.2. Physiological variables

Breed difference was observed in RR, PR and RT during CDS and HDS. In agreement with the present study, breed difference has been reported in Indian goats with the RR, PR and RT being lower in breeds adapted to high AT and higher in breeds adapted to low AT (Banerjee et al. 2014). High RT in Red Sokoto compared to Sahel goats during the CDS may indicate that the Red Sokoto goats are more adapted to the CDS, which is characterized by low AT, particularly in the morning and evening hours. However, the RR was higher in Sahel compared to Red Sokoto goats during the CDS. This may be a physiological response in Sahel goats to increase oxygen delivery to the lungs, which could improve heat production and subsequently, elevate body temperature. During the cold season, high uptake of oxygen has been observed when compared with the hot season (Nishimura et al. 2015). The oxygen, when available, may increase non-shivering thermogenesis, via the actions of thermogenic hormones such as triiodothyronine. The PR was significantly higher in Sahel than Red Sokoto goats during the HDS, while the HDS was characterized by higher PR compared to the CDS and RAS. This may suggest increased rate of blood flow to the periphery and thus improved heat loss via sensible and insensible means (Marai et al. 2007; Habibu et al. 2014). In the Red Sokoto goats, RT was higher during the CDS and HDS compared to RAS. On the other hand, in Sahel goats, the RT was higher in HDS and RAS compared to the CDS. Since the AT was lowest during the CDS, the lower RT during the CDS in Sahel goats suggests their inability to efficiently maintain homeostasis. This inefficient thermoregulatory response may affect the survival of Sahel goats during the harmattan season in the Northern Guinea Savannah of Nigeria.

#### 4.3. Haematological parameters

Blood cellular parameters recorded in this study were within the normal range reported in earlier studies (Jain 1986; Banerjee et al. 2014). However, during the CDS, significantly higher PCV, RBC and Hb were observed in Red Sokoto than Sahel goats. Similarly, breed difference in haematological parameters of goats during the winter season has been reported by Ribeiro et al. (2015). The low erythrocyte parameters in Sahel compared to Red Sokoto goats is probably due to the lower body temperature in the Sahel goats. As animal with low body temperature do not sweat and, thus maintain blood volume (Indu et al., 2014; Ribeiro et al., 2015). In addition, decrease in RBC has been reported in animals exposed to extreme cold and has been associated with reduction in the half-life of erythrocytes (Ruiz et al. 2004).

Both increase and decrease in erythrocytic parameters (PCV, RBC and Hb) due to increase in AT has been reported in livestock. The decrease is associated with enhanced water intake due to heat stress, while the increase is related to elevated loss of body fluid through heat stress induced evaporative heat loss (Marai et al. 2007; Indu et al. 2014). In the present study, both reduction and a rise in values of erythrocytic parameters were observed depending on breed. The decrease in RBC and Hb in Red Sokoto goats during the HDS compared to the CDS and RAS in the present study is in agreement with the findings of Banerjee et al. (2014), where RBC and Hb values in goats were lower in the hot season compared to the cold season. On the other hand, the Sahel goats had high PCV and RBC during the HDS as compared to the CDS. This agrees with the findings of other studies in goats exposed to high AT (Hashem 2014; Indu et al. 2014). This difference in haematological response of Red Sokoto and Sahel goats is

### Table 3. Pearson’s correlation coefficient between physiological variables and circulating concentrations of $T_3$, $T_4$ and values of $T_3:T_4$ for Red Sokoto and Sahel goats.

| RT     | RR     | PR     |
|--------|--------|--------|
|        | RSG    | SHG    | RSG    | SHG    | RSG    | SHG    |
| $T_3$  | $-0.432$ | $0.736^*$  | $0.188$  | $0.942^*$  | $0.024$  | $-0.239$  |
| $T_4$  | $0.453$  | $-0.005$  | $-0.506$  | $0.428$  | $0.537$  | $0.041$  |
| $T_3:T_4$ | $-0.570$ | $0.942^*$  | $0.376$  | $0.091$  | $-0.270$  | $-0.289$  |
| $T_4$  | $0.169$  | $0.425$  | $-0.241$  | $0.002$  | $0.165$  | $0.395$  |
| $T_3$  | $0.131$  | $-0.488$  | $0.111$  | $0.336$  | $0.166$  | $-0.392$  |
| $T_3:T_4$ | $-0.142$ | $-0.462$  | $0.383$  | $0.141$  | $-0.259$  | $-0.499$  |
| $T_4$  | $0.453$  | $0.428$  | $0.506$  | $0.074$  | $0.537$  | $-0.179$  |
| $T_3$  | $-0.432$ | $0.736^*$  | $0.188$  | $-0.420$  | $0.187$  | $-0.227$  |
| $T_3:T_4$ | $-0.530$ | $-0.167$  | $0.350$  | $-0.352$  | $-0.146$  | $0.663^*$  |

Notes: RSG, Red Sokoto goats; SHG, Sahel goats. Values with asterisk are statistically significant ($P < 0.05$).
presumably due to variation in the physiological responses of goat breeds to the seasonal changes in the Guinea Savannah climate.

The MCV as an indirect measure of the average size of individual erythrocytes was lower in both breeds during the HDS in comparison to the CDS and RAS. Similarly, exposure to natural heat stress has been reported to cause an increase in MCV of Brazilian Azul goats (Ribeiro et al. 2015) and Piemontese cattle (Mazzullo et al. 2014). The decrease in MCV during the heat stress of the HDS may be due to an increase in body temperature, which causes an increase in the number of erythrocyte membrane vesicles formed and shed from the erythrocytes with a resultant decrease in the size of the parent erythrocytes (Foller et al. 2010; Moore et al. 2013). This suggests that decrease in MCV may have the potential of being used as an animal-based indicator of heat stress in tropical goats naturally exposed to heat stress. On the other hand, the increase in MCV during the RAS agrees with a study in donkeys, conducted in the same region (Zakari et al. 2015). This may be due to seasonal changes in the quantity and nutritional quality of availability pasture. During the RAS season, most plant species are richer in nutrients such as N and P and digestibility is high due to low amount of secondary metabolites such as tannins and polyphenols in most grasses found in the savannah regions (Martz et al. 2010; Basha et al. 2013; Scogings et al. 2015).

A pronounced change in leucocytic parameters was observed during the HDS probably due to heat stress. The values of WBC in Red Sokoto goats during the HDS were higher than values recorded in CDS and RAS; and also higher when compared to values in Sahel goats. The present study agrees with the finding of Omran et al. (2013), who reported an increase in WBC in buffalo calves exposed to high AT. Also, the N:L was higher during the HDS compared to CDS and RAS in both breeds of goats. This is in agreement with the high N:L reported in goats subjected to transport stress (Minka et al. 2009), and also suggests that both breeds of goat were exposed to heat stress.

### 4.4. Erythrocyte osmotic fragility (EOF)

In the present study, the increase in EOF during the HDS compared to the CDS and RAS in Sahel goats may be due to heat stress (Brzezinska-Slebodzinska 2001; Habibu et al. 2014). Heat stress indicated by increase in body temperature during the HDS may have enhanced the production of free radicals and subsequently, occurrence of lipid peroxidation. The ultimate consequence is an increase in the fragility of the erythrocytes membrane and thus, elevation in EOF (Brzezinska-Slebodzinska 2001; Habibu et al. 2014; Yaqub et al. 2014). Similarly, higher EOF has been reported in animals exposed to transport stress compared to those in which the effect of transport stress was ameliorated using antioxidant (Yaqub et al. 2014). On the contrary, higher EOF has been demonstrated during the CDS compared with the HDS in goats in the middle belt of Nigeria (Adenkola et al. 2011). This difference is probably due to variation in geographical location and differences in adaptation of the goats. In Red Sokoto goats, however, the erythrocytes were more fragile during the CDS than RAS. This may be attributed to the wide fluctuation in AT between the morning and afternoon hours (16.45 vs. 30.47°C) during the CDS, which may have stimulated the biological stress mechanism of the goats (Adenkola et al. 2009).

### 4.5. Thyroid hormones

As seasons change, animals undergo a highly integrated physiological adjustment aimed at maintaining homeostasis (Sharma et al. 2013). In seasons with low AT, the physiological responses are aimed at reducing heat loss and increasing heat production, while in seasons with high AT, the responses aim to decrease heat production and increase heat loss. The primary function of thyroid hormones is to increase metabolic rate in order to maintain a relatively constant body temperature. When the AT increases, serum levels of thyroid hormones decrease and vice versa (Todini 2007). Thus, suggesting that as seasons change, breeds that can effectively regulate thyroid hormone secretion may survive better, particularly in the tropical countries where animals are not be provided with special housing according to the prevailing season of the year. In the present study, circulating concentrations of T4 and T3 were lower in the HDS compared to the CDS and RAS in Sahel goats. In Red Sokoto goats, however, serum concentration of T3 and conversion of T4 to T3 (i.e. T3:T4) were lower in the HDS compared to the CDS and RAS. Similarly, the study of Indu et al. (2014) and Ribeiro et al. (2015) in goats demonstrated high T4 and T3 during the cold compared to the hot seasons. The reduction in serum concentration of T4 and T3 during the HDS could reduce metabolism and heat generation so as to prevent a rise in body temperature. Furthermore, the positive correlation between RT and T3 and RT and T4 in Sahel goats during the CDS and RAS (characterized by low ATs, particularly in the morning hours) confirms the role of T3 in thermogenesis. In Red Sokoto goats, serum T4, unlike T3, did not decrease during the HDS compared to CDS and RAS. This is probably due to the reduction in enzymatic conversion of T4 to T3 indicated by decreased in T3:T4. This may suggest a more efficient thyroid hormone metabolism in male Red Sokoto goats aimed at preventing a significant seasonal fluctuation in serum T4.

The result of this study showed that, though Red Sokoto and Sahel goats are assumed to be phylogenetically related and belong to the Savannah or Sahel type of goats, their physiological response differ in different seasons of the year. Missohou et al. (2006) studied the genetic relationship between seven West African goat breeds, including Red Sokoto and Sahel goats. The seven breeds were clearly separated genetically in conformation with their geographical origin rather than their type or morphological grouping into long-legged (Savannah) and dwarf types. The difference in physiological response is presumably due to the fact that the Sahel goats are originally indigenous to the Sahel zone, which is characterized by higher ATs and lower RH (due to the closeness of the Sahel zone to the Sahara desert) when compared to the Guinea Savannah zone of West African.

### 5. Conclusion

When seasons change, the Red Sokoto and Sahel goats experience an integrated physiological response in thyroid function, blood cellular components, EOF and physiological variables so
as to efficiently adapt to the existing meteorological parameters. In both breeds of goats, the CDS and HDS altered the composition of blood cellular components, thyroid physiology and decreased resistance and size of erythrocytes, with the HDS being more stressful. During the CDS, the male Sahel seems to be less adapted to the harsh environmental conditions of Guinea Savannah zone of West African. Thus, it is logical to infer that this may affect the productivity of male Sahel goats in Guinea Savannah climate. The thermoregulatory changes seemed to be strongly associated with changes in serum T3 in Sahel goats.

The effect of heat stress in Red Sokoto and Sahel goats during the HDS should be mitigated by providing shades, free access to water, and possibly the use of antioxidants. Introduction of Sahel goats to the Northern Guinea Savannah zone of Nigeria should be done strategically to include the possibility of cross-breeding with Red Sokoto goats since they are less efficiently adapted to the cold environmental conditions of the CDS. This will ensure the attainment of optimum production potentials of Sahel goats in the Northern Guinea Savannah climate of West Africa.

Disclosure statement
No potential conflict of interest was reported by the authors.

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