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Published online: 05 Dec 2017.

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Effects of the dry and the rainy season on endocrine and physiologic profiles of goats in the Brazilian semi-arid region

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ABSTRACT

This study investigated the effect of season on the endocrine and adaptive profiles of a Brazilian Creole goat population in a semi-arid region of Brazil during the dry and the rainy season. We considered physiological, morphological, biochemical, haematological, hormonal and anatomical profiles. The experiment used 80 adult goats (2- to 5-year-old) and lactating (160 ± 14 days of lactation length) goats, with an average daily milk yield of 500.9 ± 13 g. Physiological parameters (rectal temperature, RT; respiratory rate, RR; heart rate, HR; skin temperature, ST) were high ($p < .05$) in the afternoon in both seasons. There was a significant effect of season ($p < .05$) on anatomical parameters (hair diameter, HD; hair length, HL; coat thickness, CT). Haematological, biochemical and hormonal parameters were also significantly affected by season ($p < .05$). We measured the biochemical and hormonal characteristics changes during different seasons; metabolism was reduced during heat stress and accelerated during cold stress. These hormones facilitate the physiological parameters involved in the adaptation process. Our results confirm that the adaptive capacity of the animals cannot be described solely by RT and RR.

Introduction

Changes in environmental variables are recognised as a potential hazard in livestock growth and production. Over centuries, natural selection acted on local breeds, resulting in high animal fitness in different environmental conditions (Aengwanich et al. 2009). During this process, animals acquired unique adaptive traits such as disease resistance and tolerance to heat and cold (Silanikove 2000a). High ambient temperatures compromise the reproductive efficiency and performance (Nardone et al. 2010), and the coaction of the environmental elements and the breeding system represent one of the limiting factors for the development of regional goat raising. Seasonal variations are considered physiological stressors which affect the animal's biological systems (Alberghina et al. 2013; Casella et al. 2013; Mazzullo et al. 2014).

Goats are warm-blooded animals and as such are characterised by the ability to maintain their body temperature within narrow limits; the body temperature is controlled by internal homeostatic mechanisms. Animals respond differently to drastic temperature

changes by altering several aspects of their physiology and behaviour (Silva et al. 2010; Ribeiro et al. 2016). These changes include alterations in physiological parameters (rectal temperature, RT; heart rate, HR; respiratory rate, RR; surface temperature, ST) (Marai et al. 2007), the erythrogram (Al-Eissa et al. 2012), blood biochemical parameters (Abdelatif et al. 2009; Ribeiro et al. 2016), and cortisol and thyroid hormones (Helal et al. 2010).

Climate change has caused significant losses in animal production, which generates the need for detailed studies on the adaptive processes of breeds, especially goats, to better understand the adaptation parameters and processes of these animals in terms of sudden temperature changes (Silanikove 2000a, 2000b). The improvement of farming efficiency needs to consider the interactions between animals and the environment. Knowledge of climate variables and their effects on the physiological, haematological, blood biochemical, hormonal and genetic responses is critical for the optimisation of livestock-raising systems. Goat breeding is predominant in family production systems, which play a fundamental role in the development of

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rural marginal areas. Such systems contribute to an improved life quality and decrease poverty and hunger of hundreds of families in the region. Despite its economic and social importance, the Brazilian Creole goat population is classified as endangered (FAO 2007) and may disappear even before it is officially recognised as a national breed.

In this context, it is even more important for this population to establish appropriate physiological baseline values, which could facilitate the realistic evaluation of management practices, nutrition and health status. We therefore conducted this study to investigate the effects by of both the dry and the rainy season on the anatomical, physiological, biochemical, haematological and hormonal parameters in goats of a Brazilian Creole population in a semi-arid region of Brazil.

Materials and methods

Local and experimental animals

The experiment was approved by the ethical committee of the Universidade Federal da Paraíba. The study was performed in Caiçara do Rio do Vento, Brazil (5°45′36″ latitude and 35°59′52″ longitude), at an elevation of approximately 175 m above sea level. According to Thornthwaite's classification, the climate is tropical, with average annual temperatures ranging from 21 to 33 °C.

We used 80 lactating (multiparous) female Brazilian creole goats (40.0–55.0 kg of live weight): 40 animals were evaluated during the rainy season (July) and the other 40 during the dry season (December). The animals were raised on a family farm using semi-extensive farming practices and were confined only during the sampling time. The goat diet was mostly composed of natural pasture and water *ad libitum*, and few feed integrations with mixed hay were given during the unfavourable periods of the year. The age of the animals was estimated indirectly by dental chronology, and all animals were classified adults (2–5 years old). Average milk yield was 500.9 ± 13 g/day, with an average body condition score of 2.0 and 2.5 in the dry and rainy season, respectively.

Climatological data and thermal comfort indices

Data were collected on three consecutive days in each season. On the data collection days, climatological data were also recorded, using an automated meteorological station installed at the location where the animals spent the day. DBT, WBT, black globe temperature (BGT) and relative humidity (RH) were recorded every 15 s. Wind speed was measured with the aid of a digital anemometer every 2 h. The black globe and humidity index (BGHI) was then derived using BGT and dew point temperature, according to Buffington et al. (1981). The thermal radiation load (TRL) was calculated according to Esmay (1969), where the mean radiant temperature is the temperature of a surrounding region considered uniformly black, capable of eliminating the effect of reflection, with which the body (black globe) exchanges as much energy as the environment under consideration (Kelly and Bond 1971). The values obtained were then used to estimate the differences between season and period of the day for the environmental parameters.

Anatomical parameters

From each animal in both seasons, a hair sample was manually removed from the central-lateral trunk, 18 cm below the spinal column. Hairs were identified and stored in paper envelopes to determine the morphological characteristics of the hair and coat length. Coat thickness (CT) was measured with the aid of a millimetre ruler. Average hair length (HL) was determined by calculating the mean of the 10 largest hairs, measured with a digital calliper, as reported by Udo (1978); average hair diameter (HD) was measured using a digital micrometre with a precision of 0.001 mm (Digital 50, DIGIMESS, Mooca, Brazil) (Kassab 1964).

Physiological parameters

RT, RR, HR and ST were measured on three consecutive days in each season, in the morning period (starting at 8:00 h) and in the afternoon period (starting at 14:00 h).

Rectal temperature was measured with a digital clinical thermometer with the range of 32–43.9 °C. The thermometer was inserted into the rectum of each animal, with the bulb in contact with the mucosa, and remained in the rectum until temperature stabilisation. RT and HR were measured through auscultation of the heart sounds with the aid of a flexible stethoscope at the level of the laryngeal-tracheal region by counting the number of movements and beats for 20 s; the results were multiplied by 3 to express the values on a minute-time scale. Skin temperature was recorded using a digital infra-red thermometer (Minibar MT-350, São Paulo, Brazil) at a distance within 10–50 cm from the body (there is no difference in measurements between those distances), measured on the left flank. The RT–ST gradient was then calculated.

Erythrogram, blood biochemical and hormonal parameters

Blood samples were collected from each animal once every season in the afternoon (15:00 h) by puncturing the jugular vein after disinfection with iodine alcohol; samples were immediately stored at $-4\,^{\circ}$C and analysed on the following day. The animals were also evaluated with the FAMACHA© method (Kaplan et al. 2004) and screened for the presence of ectoparasites, lymphadenitis or other types of skin problems immediately after the blood collection. Blood was collected in 5-ml vacuum tubes containing 10% anticoagulant ethylene diamine tetra acetic acid (EDTA) for the evaluation of haematological parameters, according to Jain (1993).

For the analysis of biochemical and hormonal parameters, blood was collected in 7-ml vacuum tubes containing separating gel and sodium fluoride (used for glucose analysis) and subsequently centrifuged in a digital centrifuge at $4\,^{\circ}$C and 3000 rpm (1100XG) for 15 min. After centrifugation, the supernatant was split into 1.5-mL aliquots for biochemical and hormonal tests; the analysis was performed on the day following the collection. Plasma was stored at $-20\,^{\circ}$C until assayed (Nijdda et al. 2014). Total protein (TP), albumin (ALB), glucose (GLU), triglycerides (TRI), cholesterol (CHO), urea (URE), magnesium (Mg), creatinine (CRE), gamma glutamyl transferase SL (GGT), aspartate aminotransferase (AST) and alanine amino transferase (ALT) were analysed using a biochemical analysis apparatus (Thermo Scientific Genesys 10S Vis, Centreville, VA, USA) with a multiple wave length photometer. All tests were performed using commercially available kits (Labtest). Intra- and interassay coefficients of variation (CV) were 1.35% and 2.39%, 0.79% and 1.78%, 1.59% and 4.54%, 2.08% and 2.00%, 1.86% and 2.76%, 3.3% and 3.8%, 3.0% and 2.0%, 1.07% and 2.15%, 1.5% and 3.0%, 2.9% and 3.1%, and 1.6% and 1.0% for TP, ALB, GLU, TRI, CHO, URE, Mg CRE, GGT, AST and ALT, respectively.

The concentrations of cortisol (COR), total thyroxine (T4) and total triiodothyronine (T3) were measured in a microplate absorbance spectrophotometer (BIO RAD xMark, Hercules, CA) in duplicate and quantified by a linked immuno sorbent assay (ELISA by competition). We used kits (In Vitro diagnostic Ltda., Itabira, Brazil) developed for the quantitative evaluation of hormones (Uribe-Velasquez et al. 1998). The sensitivity of these kits was below 0.05, 0.22 and 1.1 ng/dL for T3, T4 and COR, respectively. Intra- and interassay CV were 2.3–7.7%, 1.6–5.0% and 4.58–6.33 for T3, T4 and COR respectively.

Statistical analyses

Data were analysed by two-way analysis of variance with the GLM procedure of SAS (2003), considering the fixed effects of season and period of the day. The following mathematical model was used:

$$Y_{ijk} = \mu + S_i + P_j + E_{ijk},$$

where Y_{ijk} is the dependent variable, μ is the overall mean, S_i is the fixed effect of the season ($i = 1 =$ rainy, $i = 2 =$ dry), P_j is the fixed effect of the period ($j = 1 =$ morning, $j = 2 =$ afternoon) and E_{ijk} is the experimental error. The erythrogram values and the hair, blood chemical and hormonal parameters were analysed with a similar procedure, including only the season as fixed effect. Pearson's correlation coefficients between all variables were estimated using the CORR procedure of SAS (2003).

Results and discussion

Values of average air temperature (AT), RH, BGT, BGHI and TRL recorded both in the morning and in the afternoon for the two seasons considered are shown in Table 1. The highest values for AT, BGT, BGHI and TRL were observed in the afternoon during the dry season. The different AT values noted in the two periods influenced the physiological parameters of the animals. Such exposure of the animal to heat stress evokes several drastic shifts in the biological functions, including a decrease in feed intake, disturbed essential protein, energy, and mineral balances, and altered enzymatic reactions, hormonal secretions, and blood metabolism (Marai et al. 2007). Regarding RH, a significant difference was observed between periods where RH showed higher values in the morning due to the lower AT values noted at this time.

Values of BGHI were greater in the afternoon in both seasons. In the values found in the present study are higher than those observed by Malheiros Filho et al. (2014) for goats raised in the semi-arid region of

Table 1. Means ($\pm$SE) of environmental parameters during dry and rainy seasons of goats in the semi-arid region of Brazil.

	Rainy		Dry	
Parameters	Morning Mean ± SE	Afternoon Mean ± SE	Morning Mean ± SE	Afternoon Mean ± SE
AT, °C	34.8 ± 1.3^d	38.7 ± 2.6^c	39.6 ± 3.4^b	43.5 ± 2.5^a
RH, %	36.0 ± 11.2^a	33.2 ± 14.1^c	34.5 ± 11.9^b	32.0 ± 12.5^d
BGT, °C	34.5 ± 7.0^a	47.4 ± 6.8^b	43.9 ± 3.6^c	49.6 ± 2.8^a
BGHI	91.5 ± 1.4^d	$95.5 \pm 3.1b^c$	98.9 ± 1.6^b	101.3 ± 2.4^a
TRL, W/m²	678.9 ± 160.1^d	738.9 ± 157.7^c	813.5 ± 91.4^b	868.5 ± 88.7^a

SE: standard error.
[a,b,c,d]Means in the rows with different superscripts are significantly different ($p < .05$).

Table 2. Means ± SE anatomical parameters during rainy and dry seasons of goats in the semi-arid region of Brazil.

	Rainy		Dry	
Variable	Mean ± SE	Min–max	Mean ± SE	Min–max
Hair diameter, mm	0.077 ± 0.010^b	0.061–0.092	0.080 ± 0.008^a	0.061–0.103
Hair length, cm	4.010 ± 1.110^a	2.980–7.040	3.037 ± 0.470^b	2.460–4.440
Coat thickness, mm	1.540 ± 0.350^a	1.000–2.000	1.204 ± 0.247^b	0.950–1.500

SE: standard error.
[a,b]Means in the rows with different superscripts are significantly different by the t test ($p < .05$).

Table 3. Means ± SE of physiological parameters during rainy and dry seasons of goats in the semi-arid region of Brazil.

Season	Shift	RT, °C Mean ± SE	RR, mov/min Mean ± SE	HR, beat/min Mean ± SE	ST, °C Mean ± SE	RT–ST, °C Mean ± SE
Rainy	Morning	39.5 ± 0.4^b	27.5 ± 6.4^d	78.5 ± 11.3^d	35.5 ± 0.3^d	4.0 ± 0.5^a
	Afternoon	39.7 ± 0.4^a	34.2 ± 6.7^c	85.5 ± 16.3^c	37.8 ± 1.4^c	1.9 ± 1.2^b
	Mean	39.6 ± 0.4	30.8 ± 7.3^B	82.0 ± 14.3^B	36.7 ± 1.5^B	3.0 ± 1.4^A
Dry	Morning	39.2 ± 0.6^d	38.0 ± 8.6^a	92.6 ± 20.6^a	39.9 ± 2.1^b	-0.7 ± 2.0^c
	Afternoon	39.5 ± 0.6^c	36.3 ± 12.5^b	88.5 ± 22.5^b	41.1 ± 2.7^a	-1.6 ± 2.5^d
	Mean	39.4 ± 0.6	37.1 ± 10.7^A	90.5 ± 21.5^A	40.5 ± 2.5^A	-1.2 ± 2.3^B

SE: standard error.
[a,b,c,d]Means in the column with different superscripts are significantly different by the t test ($p < .05$).
[A,B]Means in the column with different superscripts are significantly different by the t test ($p < .05$).

Brazil, even if the RT values could be considered to be within the normal range for goat species (Swenson and Reece 2006). The TRL showed the statistically highest value in the afternoons in the dry season, followed by the evenings in the rainy season; however, it did not differ between the two morning samplings. The higher TRL values in the afternoons were most likely due to high AT and BGT as well as low RH values (Ribeiro et al. 2008).

In addition to HL, HD assists in defining the adaptive profile of the animals, as this can vary throughout the year (Table 2). Hair variation helps to maintain the homeostasis of the animal, while seasonal changes of the HD allow to maintain a rather constant RT. Significant differences ($p < .05$) in the hair anatomy between the two seasons were observed due to the climatic variation. Silva et al. (2001) and Maia et al. (2005) noted that animals with short, thick and well-seated hair, on a pigmented epidermis, are well suited to tropical conditions. In the rainy season, the hair is longer and has a smaller diameter, while in the dry season, it is shorter with a larger diameter, thus enabling air circulation to cool the skin. In the rainy season, the animals had greater CT values ($p < .05$), which may help to protect them from excessive wind; on the contrary, during the dry season, the CT was lower, facilitating heat dissipation.

As shown in Table 3, values of RR, ST, HR and the thermal gradient RT–ST were significantly different (Table 3; $p < .05$) between periods and seasons, whereas RT did not show any differences. These findings are probably due to the fact that the

goats were active during the day, promoting changes in their physiological parameters. There were no significant differences between the RT values in the two seasons. The daily variation in RT was 0.3 and 0.2 °C in the rainy and the dry season, respectively; this result is in agreement with the findings of Piccione and Refinetti (2003), stating that this variation can range from 0.3 to 1.9 °C. Working in different environmental conditions, other authors (Aiura et al. 2010; Phulia et al. 2010; Lucena et al. 2013) have also shown that the rectal temperature is maintained within an adequate range.

The animals dissipate heat effectively; even at high temperatures in the dry season, RT was maintained within the limits indicated for this species. These findings are indicative of a good adaptive capacity of the animals to stressful conditions. The physiological functions of the animals, such as RT, RR and HR, can facilitate survival in a hot climate. Respiration rate and RT are useful indicators of thermal stress and can be used to assess the adversity of the environment (Daramola and Adeloye 2009), indicating an adaptation to high temperatures and natural selection in these animals caused by the alteration of the thermoregulatory point at the central level or the sensitivity of temperature receptors to a higher threshold.

In the present study, RR was greater ($p < .05$) in the afternoon in both seasons. However, the mean RR was greater during the dry than during the rainy season. The RT is influenced by the time of day, as AT is greater during the afternoon (Sejian et al. 2010; Silva et al. 2010). In the dry season, afternoon RR was 36.3 mov/min, indicating that the animals were not

subjected to considerable stress during this period. Morning RR values were within the limit for goats (Silanikove 2000a). However, a greater RR value does not necessarily indicate heat stress, as the animals maintained their RT at an appropriate level, indicating effective heat dissipation.

The HR was higher in the afternoon in both seasons, with 85.5 and 88.5 beats/min in the rainy and the dry season, respectively. Normally, the HR increases with increasing AT levels, which are usually higher in the afternoon (Silva et al. 2010). Skin temperature was significantly greater in the dry season (Table 3), indicating that the animals were able to dissipate heat by increasing RR. When AT is greater than ST, heat dissipation by sensitive heat exchange is inefficient. In this study, the thermal gradient (RT–ST) was higher during the rainy period ($p < .05$). When AT increased, the gradient decreased because these parameters are inversely proportional. Body heat is dissipated primarily because of the temperature gradient, and we found both a strong correlation between AT and ST (41%) and a weak correlation between AT and RR (15%), indicating the independence of the latter variables. Those findings suggest that these animals are well adapted to the local climate where they are raised. The transfer of blood flow to the body surface and vasodilation contribute to increase ST and facilitate the dissipation of heat by a non-evaporative mechanism. When AT increases, the temperature gradient between the body surface and the environment decreases, impeding heat dissipation and thereby increasing the importance of evaporative mechanisms, such as RR.

There was a seasonal effect on erythrocytes (RBC), haematocrit (Hct), haemoglobin, mean corpuscular volume (MCV), and mean corpuscular haemoglobin concentration (CHCM) (Table 4). The animals alter haematological parameters to maintain a stable body temperature, i.e. to maintain RT and RR within the limits recommended for this species. They have adjusted RBC to survive both food and water shortages as well as high temperatures. The values obtained in this study are in agreement with those reported in previous studies (Kaneko et al. 2009; Piccione et al. 2010; Carlos et al. 2015; Ribeiro et al. 2016). These changes are likely adaptive and have been acquired over the years as a result of the environmental conditions of the studied region. The haematological values most likely reflect the adaptive capacity of the animals, as they have acquired this characteristic trait by adapting to the local climate over several generations.

There are many studies on the effect of season on biochemical blood parameters (Sejian et al. 2010;

Ribeiro et al. 2016). In our study, these parameters were significantly different between seasons ($p < .05$). The GLU and CHO levels were considerably higher ($p < .05$) in the rainy period. In the dry season (high temperature), the GLU requirement increases, causing the mobilisation of TRI for energy production. The values found in this study are consistent with those observed by Mundim et al. (2007) and Kaneko et al. (2009). CRE was significantly lower in the dry season ($p < .05$). Higher AT leads to increased respiration and decreased muscle CRE, which can be attributed to the slower catabolism. The CRE level was positively correlated with RR (0.38; $p < .05$) and negatively correlated with AT (-0.36; $p < .05$); these observations were consistent with the results of Piccione et al. (2010), who also studied Brazilian Creoles.

The TP and globulin levels were significantly higher ($p < .05$) in the dry season. The amount of TP was moderately and positively related to AT (0.50; $p < .05$). Differences in the globulin values are related to physiological and genetic factors of animal adaptation. Abdelatif et al. (2009) and Al-Eissa et al. (2012) observed higher levels of globulin in the rainy period, resulting in a low ALB/globulin ratio.

There was a significant effect of season on the enzymes GGT, AST and ALT; however, this was not observed by Mundim et al. (2007) and Kaneko et al. (2009) in similar studies. AST and GGT values were higher in the rainy season, but ALT levels were greater in the dry season and showed a strong correlation with AT (0.38; $p < .05$). Magnesium was significantly greater ($p < .05$) in the dry season, as reported by Kaneko et al. (2009). Magnesium supports the conversion of blood sugar to energy and is also considered as an anti-stress mineral, regulating HR and blood clots.

The hormone levels varied between the two seasons, which revealed the combined action of meteorological and animal physiological parameters (Table 4). There was a significant effect of season ($p < .05$) on the hormone levels (Figure 1), showing the influence of the combined action of meteorological variables on the endocrine and thermoregulatory physiology of the animals.

The plasma concentrations of T3 and T4 decreased during the dry season (Table 1). This could be considered as an adaptive mechanism to reduce heat production, helping in maintaining the RT within adequate limits. The thyroid hormones showed higher values in the rainy season when the temperature was reduced. The concentrations of thyroid hormones depend on various genetic, environmental and nutritional factors (Todini et al. 2007). The thyroid and

Table 4. Means ± SE of erythrogram and blood biochemical parameters during rainy and dry season of goats in the semi-arid region of Brazil.

Variable	Rainy (38.7 °C)		Dry (43.5 °C)	
	Mean ± SE	Min–max	Mean ± SE	Min–max
RBC, ×10⁶/mL	17.8 ± 2.1^a	14.5–23.4	14.6 ± 4.1^b	9.4–22.1
Hct, %	38.2 ± 3.6^a	34.0–49.0	23.0 ± 6.4^b	12.0–34.0
Haemoglobin, g/dL	12.7 ± 1.2^a	11.3–16.3	10.4 ± 3.5^b	7.2–21.1
MCV, f/L	21.8 ± 2.7^a	17.0–27.5	7.7 ± 2.1^b	4.0–11.3
CHCM, g/dL	33.3 ± 0.1	33.2–33.4	33.3 ± 0.1	33.1–33.5
Glucose, mg/dL	100.8 ± 6.2	78.1–112.2	99.7 ± 4.6	88.0–106.3
Urea, mg/dL	75.6 ± 12.5	41.9–98.3	76.1 ± 14.1	58.0–94.0
Cholesterol, mg/dL	204.4 ± 14.3^a	180.0–234.7	164.6 ± 36.2^b	55.0–199.2
Triglycerides, mg/dL	13.7 ± 20.5^b	11.3–20.5	16.9 ± 39.3^a	10.9–24.0
Creatinine, mg/dL	1.3 ± 0.4^a	0.6–1.9	1.1 ± 0.4^b	0.7–1.8
Total protein, g/dL	3.8 ± 0.4	3.0–4.3	7.2 ± 0.7^a	6.3–9.7
Albumin, g/dL	1.7 ± 0.5^b	0.9–3.0	2.8 ± 0.4	2.0–3.8
Globulin, g/dL	2.1 ± 0.6^b	0.7–3.4	4.4 ± 0.8^a	2.9–7.0
Albumin/globulins	0.8 ± 0.8^a	0.4–1.5	0.6 ± 0.2^b	0.3–1.2
GGT, U/L	40.9 ± 8.5^a	27.0–70.0	38.7 ± 8.8^a	27.0–70.0
AST, U/L	81.2 ± 15.0^a	34.6–99.9	72.6 ± 13.3^b	38.0–95.0
ALT, U/L	68.6 ± 17.4^b	50.2–118.8	96.8 ± 11.0^a	73.5–119.9
Magnesium, mg/dL	2.3 ± 0.3^b	1.7–3.3	2.7 ± 0.5^a	1.6–3.9

RBC: erythrocytes; Hct: haematocrit; MCV: mean corpuscular volume; MCHC: mean corpuscular haemoglobin concentration; SE: standard error.
[a,b]Means in the rows with different letters differ by the t test ($p < .05$).
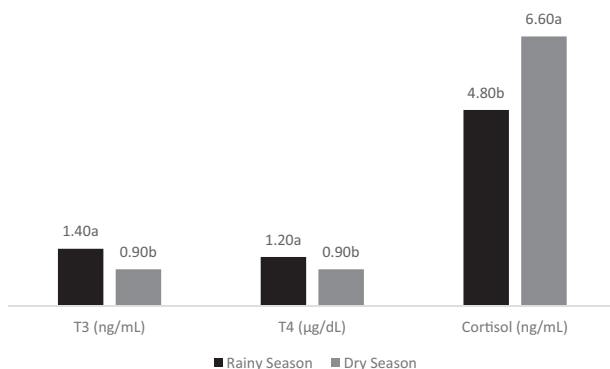

Figure 1. Concentration of thyroid and cortisol hormones of goats in the semi-arid region of Brazil, according to year season.

adrenal glands play key roles in the adaptation mechanism; well-adapted animals respond quickly to environmental changes through physiological adjustments (Uribe-Velasquez et al. 1998; Starling et al. 2005; Coelho et al. 2008; Sejian 2013; Ribeiro et al. 2016).

The lower levels of T3 and T4 during the dry season are consistent with other studies (Helal et al. 2010; Abdel-Fattah 2014; Costa et al. 2015; Ribeiro et al. 2016) in which an inverse correlation was observed between thyroid hormone concentration and AT (-0.55; $p < .05$) in goats. These findings suggest that this decrease is also an adaptive mechanism to reduce heat (Starling et al. 2005; Helal et al. 2010; Costa et al. 2015, Ribeiro et al. 2016).

The average COR levels were higher during the dry season ($p < .05$). The level of COR found in this study corresponds to the values reported previously for different goat breeds, mostly ranging from 3 to 15 ng/ml

(Ortiz-de-Montellano et al. 2007; Aoyama et al. 2008). Cortisol was positively correlated with AT ($r = 0.92$), whereas T3 and T4 hormones were inversely correlated with AT (-0.55; $p < .05$). Cortisol levels were negatively correlated with T3 (-0.89; $p < .05$) and T4 concentrations (-0.87; $p < .05$). Cortisol is released in response to stress, and its highest production occurred during the dry season. With increased AT levels in the dry season (Table 1), the COR concentration increases, supporting the homeostasis of the animal. This response supports a greater energy substrate for cells, reducing cellular GLU consumption, with minor importance in stress. In times of fasting or stress, COR increases cellular TRI and TP use as a source of energy (Swenson and Reece 2006).

In the environment studied, the goats showed an adaptation to cold and heat stress. In the dry season, the animals had a greater ability to maintain RT, with lower RR levels and a greater capacity for heat dissipation. In the rainy season, the animals showed an increased heat-production capacity. Physiological, biochemical and hormonal characteristics differ between seasons. Metabolism is reduced during heat stress and accelerated during cold stress. These changes are controlled by T3, T4 and COR, which facilitate the physiological adaptation to changing climatic conditions. It is well known that blood and physiological seasonal variations could be due to the activity of the hypothalamic suprachiasmatic nuclei, which regulate metabolic and endocrine functions (Piccione et al. 2011, 2012). Endocrine and physiological changes reflect endogenous adaptive mechanisms to environmental changes associated with the seasons

(Piccione et al. 2009; Ribeiro et al. 2015). The adaptive capacity of the animals cannot be described solely by RT and RR. Therefore, adequate assessment of the adaptive profile requires the consideration of physiological and behavioural responses to environmental conditions.

Conclusions

The Brazilian Creole goat population showed the capacity to adapt its physiological traits to face environmental changes in each season. The biochemical and hormonal characteristics undergo changes during different seasons, controlled by the thyroid and cortisol hormones. The adaptive capacity of the animals cannot be described solely by rectal temperature and RT. Therefore, adequate assessment of the adaptive profile requires the consideration of physiological and hormonal responses to environmental conditions.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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