ORIGINAL ARTICLE

Thermoregulatory responses and adaptability of Anglo-nubian goats maintained in thermoneutral temperature and under heat stress

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Abstract This study aimed to evaluate the physiological responses and adaptability of Anglo-Nubian goat breeds by Ibéria and Benezra tests, maintained in bioclimatic chamber under different temperatures: 20, 24, 28 and 32ºC, where temperature and air relative humidity and black globe humidity index (BGHI) were measured. The design was completely randomized with four treatments and six replicates. With the increase of temperature and the BGHI, increased the surface temperature, the cardiac and respiratory frequency, and the thermal gradient, the rectal temperature remained within normal limits. The adaptability tests indicated that animals in the temperatures of 28 and 32°C had the physiological parameters altered to maintain the warm-blooded, which BGHI values corresponding were 78.21 and 82.55 respectively, characterizing a warning and danger situation.

Keywords: BGHI, climate chamber, physiological parameters

Introduction

Goats are warm-blooded animals, which keep internal body temperature constant through the heat flow, which is determined by processes that depend on factors such as temperature and relative humidity of the air and the loss and/or gain of heat, both in sensible heat (conduction, convection and radiation) and in the latent form (evaporation and respiration). Adaptability to different environments can be evaluated by the animal's ability to adjust to environmental conditions and climatic extremes, where adapted animals are characterized by maintenance or minimal reduction in productive performance, high reproductive efficiency, disease resistance, longevity and low mortality rate during exposure to thermal stress (Maia et al 2009; Nascimento et al 2014), with goats considered to be heat tolerant (Pinho et al 2010).

Animals kept under high temperatures, the energy from the metabolism, which would be used for production, can be deviated to maintain body temperature, negatively affecting the production and the productivity (Baêta and Souza 2010), which may alter the physiological and ingestive behavior of goats (Nascimento et al 2014). Thus, rectal temperature and respiratory and cardiac frequencies are considered good parameters for estimating the tolerance of animals to heat (Leite et al 2012; Lucena et al 2013; Kawabata et al 2013).

The maintenance of physiological variables at normal levels are fundamental for the production, productivity, productive efficiency and maintenance of warm-blooded animals, and in adult goats the rectal temperature can vary from 38.5 to 40ºC (Dukes and Swenson 1996), the respiratory rate (average of 25 mov min^{-1}), and the heart rate of 70 to 80 beat min^{-1}, values determined in animals at rest and susceptible to be influenced by muscular work, room temperature (Kawabata et al 2013, Lucena et al 2013), period of the day, food intake (Leite et al 2012), gestation, age and size of the animal.

From the physiological parameters, tests were developed and indexes were established to estimate the animal adaptability, such as the Ibéria or Rhoad tests used to determine the heat tolerance coefficient (HTC) and Benezra or adaptability coefficient (Baêta and Souza 2010).Thus, the aim of this study was to evaluate the physiological variables, thermal gradients and the adaptability of Anglo-Nubian goats in a controlled environment.

Materials and Methods

The study was developed in the Laboratory of Rural Constructions and Ambience of the Academic Unit of

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Agricultural Engineering, Federal University of Campina Grande - UFCG, in Campina Grande-PB, latitude 07º13’50’’S, longitude 35º52’52”W, altitude 551m in a climatic chamber, using six Anglo-Nubian goats, average age of eight months and average live weight of 33.63±0.48 kg, identified, weighed, vermifugated and randomly distributed in metabolic cages with area of 0.55 m^2, equipped with feeder and water fountain.

The animals were submitted to four treatments, 20ºC - lower limit temperature of the TCZ; 24 and 28ºC - within the TCZ and 32ºC - above the TCZ, relative air humidity (RH) of 60% (± 14%) and average wind velocity (WV) of 0.5 m s^{-1}.The animals were kept inside the bioclimatic chamber with lighting for 10 days in the predetermined climatic conditions (temperature), five days of adaptation (pre-experimental period) and five days of data collection (experimental period).

The bioclimatic chamber was programmed for the various temperatures at 6 h, sealed and opened for the entrance of the evaluator at the time of collection of the physiological parameters, at 9 a.m., 12 p.m. and 4 p.m.; after the entrance it was closed; after this last collection the climatic chamber door was opened and the animals were kept for 14 hours at an average ambient temperature of 23.45±2.75 ºC.

During the experimental period, the data of air temperature (AT), relative humidity (RH), dew point temperature (DPT) and black globe temperature (BGT) were collected at every minute and the average was done per hour. In order to maintain AT and RH inside the chamber, a MT-530 PLUS controller from the Full Gauge Controls® was used, controlled by computer via SITRAD®, software for acquisition, control, monitoring and visualization of data within the climatic chamber. The temperature sensor was a thermistor and of humidity a humidistat, both attached together inside a protective permeable wrap at the height of the center of the animals mass.

To determine the dew point temperature (DPT) and the black globe temperature (BGT), two HT-500 datalogger thermo-hygrometers of the Instrutherm® brand were used, both located at the height of the center of the animals mass. Based on these data, the black globe temperature and humidity index (GTHI) was calculated according to the equation proposed by Buffington et al (1981).

During the experimental period, the respiratory rate (RR) was collected by observing lateral flank movements; heart rate (HR), quantified with the aid of a stethoscope in the region of the third rib of the animal, in the lateral region of the thorax; rectal temperature (RT), using a veterinary clinical thermometer, introduced into the rectum of the animal and surface temperature (ST) determined through an infrared thermometer; all these parameters were collected at 9 a.m., 12p.m. and 4 p.m.. To evaluate the degree of animals’ heat dissipation, the thermal gradients between the rectal temperature and the surface temperature (RT-ST) and between the surface temperature and the ambient temperature (ST-AT) were calculated.

Tests of tolerance to the heat that are indicators of adaptation to the environment were also carried out: the Ibéria or Rhoad test and the Benezra test, all adapted for goats. The Ibéria or Rhoad test was carried out to determine the heat tolerance coefficient (HTC). Using the following equation:

$$HTC = 100 - [18(RT-38.60)]$$

That: HTC = heat tolerance coefficient; 100 = maximum efficiency in maintaining body temperature at 38.60ºC; 18 = constant; RT = final average rectal temperature; 38.60°C = average rectal temperature considered normal for goats in TCZ.

The same animals were submitted to the Benezra test to determine the adaptability coefficient 1 (AC_1), as an alternative to increase the efficiency of this test in detecting the animals’ adaptation, using the following formula:

$$AC_1 = RT/39.1 \pm RR/19$$

That: AC_1 = adaptability coefficient of the Benezra test; RT = rectal temperature in ° C; RR = respiratory rate, in movements per minute; 39.1 = rectal temperature considered normal for goats; 19 = respiratory rate considered normal for goats.

In order to increase the detection capacity of the test, the HR was added to the previous formula and the adaptability coefficient 2 (AC_2) was obtained.

$$AC_2 = RT/39.1 \pm RR/19 \pm HR/75$$

That: AC_2 = adaptability coefficient of the Benezra test; RT = rectal temperature in °C; RR = respiratory rate, in movements per minute; 39.1 = rectal temperature considered normal for goats; 19 = respiratory rate considered normal for goats; HR = heart rate; 75 = heart rate considered normal for goats.

The water and feed were provided at will, quantifying consumption during the thermal stress (10 h) and consumption at 14 h in open environment, by the difference between the water and feed supplied with what was left in the water fountain and feeder, the daily evaporation rate was also verified.

The experimental design was completely randomized, with four treatments (temperature) and six replicates (animals). The data were evaluated through analysis of variance and, when significant, were compared by the Tukey test at 5% of probability.

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The average temperature values obtained inside the chamber were 20.76; 24.59; 28.22 and 31.79 °C, respectively; the average relative humidity for each temperature was 68.67; 64.71; 60.85 and 58.12 (Table 1).

Results and Discussion

There was no statistical difference (P> 0.05) in the rectal temperature (RT) of the animals at different temperatures (Table 2), demonstrating that, even in the most stressful conditions, with AT considered above the TCZ and GTHI, indicating alert status (78.21) and danger (82.55) (Baeta and Souza 2010), the rectal temperature was constant and within normal limits for the species (Dukes and Swenson 1996), demonstrating the good adaptation of Anglo-Nubian goats to environmental conditions that can be characterized as thermal stress.

Silva et al (2010) describe that goats maintained in environments with high GTHI values was not enough to promote stress in animals, and this ability to maintain normal RT, even in environments with AT considered above the TCZ was also reported by Leite et al (2012), working with confined native goats (Moxoto, Azul and Graúna) in the Paraíba semi-arid region, by Barreto et al (2011) with confined Canindé and Moxotó goats and by Lucena et al (2013) working in climatic chambers with Canindé and Moxotó goats, that also verified RT similar and within the normality, even when submitted to environments considered stressful.

The respiratory rate (RR) showed a significant difference (P> 0.05) between the various temperatures and GTHI, increasing with the increase of them. With the AT elevation up to 24°C, the animals maintained RR within normal range, ranging from 14 to 30 mov min^{-1} (Dukes and Swenson 1996); at a temperature of 28°C there was a slight increase and at 32°C it was quite high (103.48 mov min^{-1}), approximately five times above the normal RR, which leads to a stress situation for the animals and demonstrates that this physiological parameter is an efficient way that the goats use to eliminate the excess of internal heat to the environment.

Lucena et al (2013) reported this sharp increase in RR at 32ºC, which emphasize that this is an efficient way for animals to lose heat to the environment by the insensitive form. Leite et al (2012) and Kawabata et al (2013) also observed this increase in RR in goats kept in high AT environments. The respiratory rate can be considered a parameter of the animals thermoregulation, and if it is elevated it is a sign of thermal stress, but if the animal is efficient in eliminating heat, maintaining warm-blooded, there may be no caloric stress (Campos and Boere 2008), which is environment variable and depends on the efficacy of the heat-sensitive mechanisms, and if these are not effective, the animal organism uses insensitive heat dissipation mechanisms, such as sweating and/or respiratory rate in order to dissipate heat, for warm-blooded regulation.

Table 1 Averages of climatic variables, air temperature (AT), relative humidity (RH) and globe temperature and humidity index (GTHI) and standard deviation of the mean at different temperatures.

Variables	Temperature (°C)			
	20	24	28	32
AT (ºC)	20.76±0.06	24.59±0.16	28.22±0.21	31.79±0.08
RH (%)	68.67±1.80	64.71±2.56	60.85±1.52	58.12±0.32
GTHI	60.52±0.25	73.42±0.34	78.21±0.20	82.55±0.63

The heart rate (HR) showed significant difference (P>0.05) between the various temperatures (GTHI) and with the elevation of the climatic indexes, there was an increase in the HR. In the GTHI of 60.52 and 73.42, characterizing a comfort situation (Baêta and Souza 2010), the HR was 78.63 and 81.78 beat min^{-1}, respectively, within the normal range for the species, which is from 75 to 90 beat min^{-1} (Dukes and Swenson 1996); and when the GTHI was 78.21 and 82.55, the HR was 93.44 and 105.18 beat min^{-1}, respectively, above the value considered normal. Lucena et al (2013) reported an average HR in native goats of 104.3 beat min^{-1} in environments with 31.6°C, causing the animals to present in a breathless state, lying down, lethargic, low head and front limbs stretched on the floor as an attempt to eliminate the excess of heat through heat exchanges.

With the elevation of AT and GTHI, there was an increase in the intensity of ventricular pumping, thus, increasing the blood flow to the skin, allowing greater heat losses. According to Souza et al (2008), the exacerbated and prolonged elevation of GTHI exhaust the metabolic systems of the heart, causing weakness, damaging the productive processes and being able to lead the animal to death.

Souza et al (2005) report that, working at field, at an average temperature of 25ºC and an average RH of 51%, Moxotó goats have an average HR of 121 beat min^{-1}, which is higher than that observed in this study, in average ambient temperature of 24.8ºC. This discrepancy in the comparison of

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the data is due to the environmental conditions in which the experiments were carried out, that is, although they are animals of different races, the climatic variables and the management interferes in the results, the heart rate can present varied values due to the different environmental conditions.

The surface temperature (ST) showed significant difference (P>0.05) between the various temperatures (GTHI), and it increase with the increase of the temperatures. Lucena et al (2013) reported, working in climatic chamber in four temperatures (20, 24, 28 and 32 ºC) with goats, the ST increase with the increase of temperature, demonstrating that the animals used mechanisms to maintain warm-blooded, as peripheral vasodilation, which increases blood flow to the body surface, increasing the surface temperature of the animal (Baêta and Souza 2010), facilitating the dissipation of heat by non-evaporative mechanisms, however, the efficacy of these mechanisms depends on the thermal gradient between the animal body and the environment.

Table 2 Averages of physiological parameters, rectal temperature (RT), surface temperature (ST), respiratory rate (RR) and heart rate (HR) and average of the thermal gradients (RT-ST) and (ST-AT) and standard deviation of the mean at different temperatures.

Variables	20ºC	24ºC	28ºC	32ºC
RT (ºC)	38.53±0.18[a]	38.68±0.06[a]	39.13±0.06[a]	39.23±0.13[a]
RR (mov min^{-1})	26.11±1.67[a]	29.22±3.15[b]	50.78±1.89[c]	103.48±3.01[d]
HR (beat min^{-1})	78.63±2.33[a]	81.78±2.67[b]	93.44±1.00[c]	105.18±2.91[d]
ST (ºC)	26.27±0.54[a]	28.79±0.47[b]	31.92±0.70[c]	32.89±0.18[d]
RT-ST (ºC)	12.26±0.58[a]	9.89±0.46[b]	7.21±0.65[c]	6.34±0.15[d]
ST-AT (ºC)	5.51±0.55[a]	4.20±0.55[b]	3.70±0.58[c]	1.10±0.24[d]

Averages followed by the same letters do not differ from each other by Tukey test at 5% probability.

There was a significant difference (P>0.05) in the averages of the thermal gradients between RT-ST and ST-AT (Table 2), which decreased with the increase of temperature, demonstrating that as AT increases, the efficiency of losses of sensible heat decreases, due to the lower values in the temperature gradients. In this situation, the animal can maintain body temperature through vasodilation, which increases peripheral blood flow and skin temperature, but if the thermal stress persists, the animal becomes dependent on the loss of heat by evaporation, through respiration and/or sweating. The thermal gradient between rectal and superficial temperature and between superficial and ambient temperature can be influenced by the animal's skin color (Silva et al 2004), by day shift, genetic groups and by breeds (Souza et al 2005).

The values of the Ibéria and Benezra tests differed statistically from each other (P>0.05) in function of the variation of AT and GTHI (Table 3), with the highest values found at higher temperatures. Based on the value 100 as the ideal for the Ibéria test (Silva 2000), it can be observed in the temperature of 20ºC and 24ºC, these were in 101.23 and 98.50, this due to the fact that in these temperatures these physiology indexes were within the normal range for the species. To the animals submitted to temperatures close to and above the TCZ (28 and 32ºC), the test showed values of 90.53 and 88.73, thus, slightly below the ideal value, demonstrating high adaptability to heat by the animals, that even when being submitted to high temperatures and GTHI characterized as outside the thermal comfort zone, they maintained the normal RT and elevated the RR.

Eustáquio Filho et al (2011) report, working with Santa Inês sheep in a bioclimatic chamber, similar results to those of this study, when animals were submitted to temperatures of 10 and 20ºC (105.2 and 103.6); Martins Junior et al (2007) working with Boer and Anglo Nubian goats in the northern of Brazil, cite values of 89.6 and 84.8.

Table 3 Benezra test values in Anglo-Nubian goats in bioclimatic chamber and standard deviation of the mean at different temperatures.

Temperature (ºC)		Benezra	
	Ibéria	AC_1	AC_2
20	101.23±2.56[a]	2.35±0.02[a]	3.40±0.01[a]
24	98.50±1.49[b]	2.52±0.06[b]	3.62±0.07[b]
28	90.53±1.77[c]	3.68±0.08[c]	4.92±0.10[c]
32	88.73±3.03[d]	6.44±0.09[d]	7.85±0.11[d]

Averages followed by the same letters do not differ from each other by Tukey test at 5% probability.

Rocha (2009) working with Saanen and Azul goats in two periods of the year (rainy and dry) in the state of Piauí report that the two genetic groups behaved in a similar way, but in the dry period the Saanen breed was more tolerant to sun exposure (P>0.05), because their HTC was closer to 100. The best performance of the Saanen goats in this test is probably due to their white coat, with a high power of reflection of the solar rays.

The adaptability coefficient (AC_1) in the animals submitted to temperatures of 20 and 24ºC was 2.35 and 2.52, therefore close to the ideal value (2.0), characterizing that this environment can be considered good for the animals, but when the animals were kept at temperatures 28 and 32 ºC, a significant increase occurred in AC_1, caused by the increase of the RR of the animals, demonstrating that to survive in environments with bioclimatic indexes considered outside the TCZ, the animals elevate the RR, being an excellent mechanism of heat dissipation.

Martins Junior et al (2007) carried out the Benezra test in Boer and Anglo-Nubian goats and found values of

2.49 and 3.03, respectively, reporting the higher hardiness in the Boer breed than the Anglo-Nubian. Rocha et al (2009) determined, in the state of Piauí, that the AC_1 of the Azul breed group was closer to the ideal than the Saanen breed, signaling a better adaptation to the hot climate, both in the rainy and dry periods. In similar climatic conditions, Martins Júnior et al (2007) verified greater adaptability of the Anglo-Nubian breed in the rainy period and Boer in the dry period, indicating a higher tolerance of Boer animals at higher temperatures when associated with lower humidity.

The AC_2 behaved in the same way as AC_1, when the temperature at which the animals were submitted was increased, the values for AC_2 (3.40, 3.62, 4.92 and 7.85), also increased, proving that with the increase of AT, the goats use efficient mechanisms of heat exchange, such as the increase of the RR and the HR. In relation to AC_2, Rocha et al (2009) described, working with Saanen and Azul goats, the greater adaptability of the Azul group to the conditions in which the test was carried out, since they found lower values 5.49 (Saanen) and 3.06 (Azul) at two periods of the year. Martins Júnior et al (2007) found greater adaptability of the Boer breed in the dry period than the Anglo-Nubian, but found no difference ($P > 0.05$) between the two breeds in the rainy period; perhaps this is probably due to the African origin of Boer while the Anglo-Nubian, although it is also African, was subjected to selection in Europe.

Conclusions

Anglo-Nubian goats with the increase of the ambient temperature and the black globe temperature index and humidity maintained the rectal temperature constant and within normality, but raised superficial temperature, respiratory and heart rate as warm-blooded mechanisms.

The ambient temperature from 20 to 24ºC and the black globe temperature index and humidity, ranging from 60.52 to 73.42, were shown to be ideal for Anglo-Nubian goats, which was confirmed by the Rhoad and Benezra adaptability tests.

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