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Thermoregulatory and Adaptive Responses of Dairy Goats Reared in A Sub Humid Tropical Environment Under Heat Stress Conditions: Physiological Approach

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Abstract: The objective this study was to evaluate the adaptability of Saanen and the crossbreed goats (Saanen- Red Maradi) reared in a semi-intensive system under a moderate and extreme heat stress conditions. The study involved hundred dairy goats, 45 of which were Saanen and 55 half Saanen and half Red Maradi (RM) crosses and was carried out during 2019 and 2020. Environmental variables were recorded and rectal temperature (RT), skin temperature (ST), respiratory rate (RR) and heart rate (HR) were taken in the morning (8:00 am), afternoon (2:00 pm) and evening (6:00 pm) during the moderate (May-June) and extreme stress (October-November) periods. Adaptability coefficient (AC) was calculated for both genotypes. The averages were evaluated using ANOVA by 5% probability. Our results showed a significant difference ($p < 0.05$) between the periods of stress for RT, ST and RR. RT, RR and HR were lower for Saanen-RM crosses goats than pure Saanen goats regardless of the period of stress conditions. In contrast, RT was lower for Saanen goat than Saanen-RM crosses. The results indicate that heat stress conditions had profound effect on physiological responses of Saanen and Saanen-RM crossbred dairy goats.

Key words: Heat Stress · Dairy Goats · Physiological Responses · Crossbreed · Sub Humid Tropical

INTRODUCTION

Goat rearing is an important economic activity for most farmers in developing countries. In Benin, goat rearing is widespread throughout the country and the number of goats was estimated at 1.871.977 during 2017 [1]. Most of these goats were reared in a stray and semi-intensive systems. In order to improve the level of production and productivity of these goats, individuals have taken the initiative to introduce on their farms the Saanen dairy goats, a specialized breed from temperate climatic regions as well as the Red Maradi goats from Sahelian countries. However, in many parts of the world, heat stress has become a major constraint of domestic animal's productivity [2, 3]. In fact, dairy goats introduced into Benin suffer the constant effect of thermal discomfort all year round [4]. It causes alterations in the organic functions and consequently in the productive performance [5]. Thus, the physiological mechanisms that limit and adjust tolerance to heat and cold resurface due to global warming [6]. In addition, heat stress in dairy animals occurs when heat dissipation capacity exceeds the range specified for normal activity and induces adjustments in the body to avoid physiological dysfunction [7, 8]. This stress is caused by a combination of environmental factors such as ambient temperature, relative air humidity, solar radiation and wind speed that affect the physiological parameters of dairy animals [9, 10]. Some studies showed negative effects of the climatic environment on the adaptability of dairy goats [11]. Indeed, the survival and productivity of animals in tropical regions depend on the existence of

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certain adaptive characteristics [12]. According to Rout *et al.* [13], these aspects are mainly based on the ability of animals to maintain their body temperature within a confined range. In addition, there is also evidence that goats have a high thermo-tolerance capacity compared to all other livestock species [14]. However, due to the differences between temperate and tropical climates [15], a thermal imbalance of the animals due to the greater dissipation of body heat as a function of the lower internal temperature of the animals was observed [16]. However, adaptive aspects were assessed by combining the thermal environment with physiological measures such as rectal temperature (RT), respiratory rate (RR) and heat rate (HR) [17, 18]. The heat load of dairy animals is generally evaluated using the temperature-humidity index (THI) defining the risk factors for heat stress in dairy animals [19] and determined by the combination of ambient temperature and relative humidity. According to Hamzaoui *et al.* [20], environmental conditions with a THI between 70 and 74 constitute a potential heat stress condition for dairy goats. However, little literature is available on thermoregulatory responses to changes in heat stress conditions in dairy goats particularly in humid tropical regions. Therefore, the present study aimed to evaluate the effect of different heat stress conditions in a semi-intensive farming system in Benin on the thermoregulatory responses of Saanen goats and the crossbreed Saanen× Red Maradi goats (*S-RM crosses*).

MATERIALS AND METHODS

Ethical Approval: The experimental design and procedure were carefully assessed and approved by the Human and Animal Ethical Committee of the University of Parakou.

Study Area and Experimental Protocol: This study was conducted at "Fermier Sans Frontière" which is an NGO private farm. This farm has a Sudano-Guinean region and is located between 9°40'07" East latitude and 2°40'26" North longitude at about 380.89 m altitude. Measurements of climatic variables and physiological responses were carried out every two weeks, in the morning (8 am), afternoon (2 pm) and evening (6 pm) during two consecutive years 2019 and 2020. Data were collected over 3 days (Monday, Wednesday and Friday) each week during the two experimental periods.

Estimating the THI from Climatological Data: During the entire experimental period, the values of ambient temperature and relative humidity were recorded using a digital thermo-hygrometer placed inside the barn. The temperature-humidity index (THI) was calculated according to the formula proposed by Mader *et al.* [21]:

$$THI = (0.8 \times AT) + [(HR / 100) \times (AT - 14.4)] + 46.4$$

where: AT = ambient temperature in °C and RH in % = relative humidity

Measurement of Physiological Parameters: Rectal temperature (RT°C) was measured using a digital clinical thermometer MT-401R (Cooper 77020 Melum Cedex, France) with a scale up to 44°C and an accuracy of ± 0.1°C inserted directly into the animal's rectum to a depth of five centimetres so that the bulb was in direct contact with the goat's mucous membrane for a maximum of one minute. The heart rate (HR in beats/minute) was measured by measuring the heartbeats with a flexible stethoscope placed in the left thoracic region which is counted during one minute. Respiratory rate (RR, breaths min^{-1}) was determined by visually counting the flank movements of uninterrupted breathing for a period of 30 s with a stopwatch and then converted to breath per minute. The skin temperature (ST°C) was taken using an infrared laser thermometer (DT-8550 Handheld Non-Contact Laser Infrared Thermometer, France; Accuracy: ± 2%) in the pre-scapular region of the goats.

Statistical Analysis: Data were analysed using General Linear Model (GLM) performed with R 3.6.2 software. Analysis of Variance (ANOVA) allowed us to compare the means of the different heat stress periods regarding the environmental variables and physiological parameters introduced in the model.

The heat tolerance of goats was evaluated using the Benezra test [22] which is adapted for the goat species [23, 24] then, the adaptability coefficient (AC) the animals were calculated of value closer to 2 means more adapted to heat. AC was obtained by the following formula:

$$(AC=RT) / (39.1) + RR / 19$$

where:

TR: Rectal temperature (°C), measured at 1400 hours.

RR: Respiratory Rate (breaths/min), measured at 1400 hours.

39.1: Rectal temperature considered normal for goats.

19: Normal respiratory rate for goats.

RESULTS

Meteorological Parameters: Weather data recorded during moderate and extreme heat stress conditions were presented in Table 1. The mean values of ambient temperature (AT) and relative humidity (RH) were significantly different (P < 0.01) from one heat stress condition to another. The highest AT and RH were recorded during the period of extreme stress (P < 0.05). THI was also found to be significantly (P < 0.01) higher during the same period. AT was higher (P < 0.05) in the afternoon during both periods of heat stress conditions. RH showed an inverse behaviour to that of AT. It was higher (P < 0.05) in the morning and during the period of moderate stress conditions. For THI, the highest values were obtained in the afternoon during both study periods (Table 1).

Physiological Parameters: The influence of heat stress conditions on rectal temperature (RT°C), skin temperature (ST°C), respiratory rate (RR, breath / min) and heart rate (HR, beat/min) of Saanen and S-RM crosses dairy goats is shown in figure 1. The RT was relatively higher (P < 0.05) in Saanen goats than the crossbreed goats (*S-RM crosses*) under moderate stress. Meanwhile, no significant difference (P > 0.05) was observed between the two breeds under extreme stress (figure 1a). Under both moderate and extreme heat stress conditions, the ST of crossbred goats (*S-RM crosses*) was higher than in Saanen goats (figure 1b). RR of Saanen goats was higher (P < 0.05) during both periods of heat stress conditions than in crossbreeds (*S-RM crosses*) (figure 1c). HR showed the same trend as RR (Figure 1d). Saanen goats showed a higher HR (P < 0.05) than S-RM crosses goats.

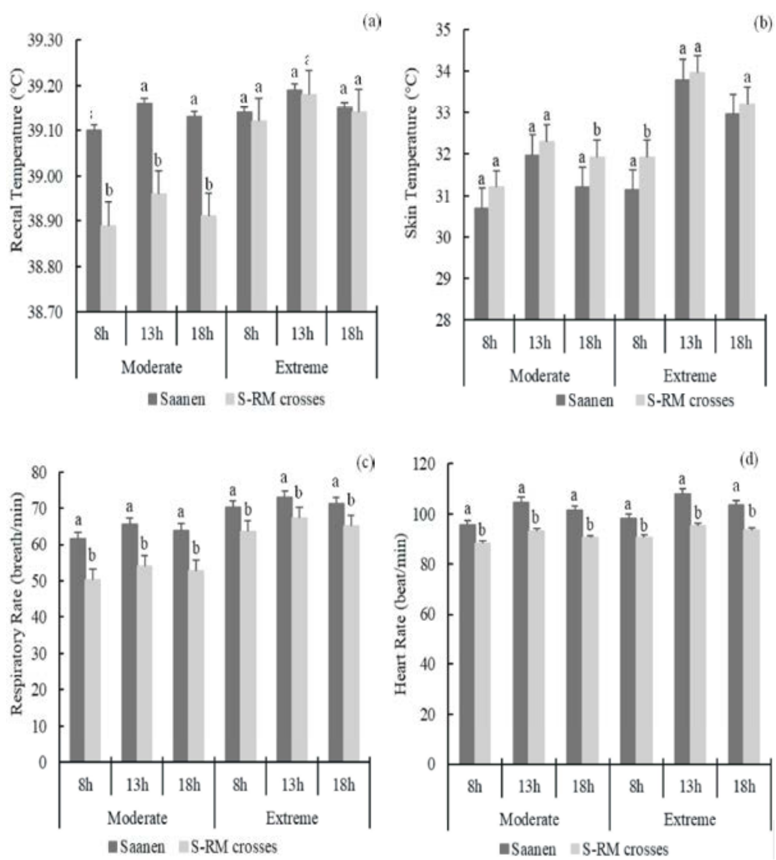

Fig. 1: Effect of time variation during the day and heat stress conditions on (a) rectal temperature (RT°C), (b) skin temperature (ST°C), (c) respiratory rate (RR, breath / min) and (d) heart rate (HR, beat/min) of Saanen and crossbreed dairy goats (*S-RM crosses)* kept in a tropical climate. Black columns correspond to Saanen goat and Gray columns to (S-RM crosses) goats. The lower case letters are different depending on the level of heat stress (P < 0.05)

Table 1: Means ±SE of the climatological data during the experimental period

	Ambient Temperature (°C)		Relative Humidity (%)		THI	
Heat stress conditions	Moderate	Extreme	Moderate	Extreme	Moderate	Extreme
Morning	23.57±1.04[a]	25.84±0.55[a]	80.42±9.03[a]	74.93±2.81[a]	72.62±2.55[a]	75.64±1.72[a]
Afternoon	28.12±0.54[b]	30.71±2.20[b]	66.20±0.99[b]	69.21±1.12[b]	77.96±2.77[b]	82.23±2.06[b]
Evening	27.52±0.24[b]	28.43±0.54[b]	70.76±0.47[b]	72.65±0.54[a, b]	77.12 ±1.57[b]	79.28±2.97[b]
P-Value	0.013	0.022	0.017	0.011	0.023	0.031

Means with different superscripts (a, b) within column are significant at P<0.05

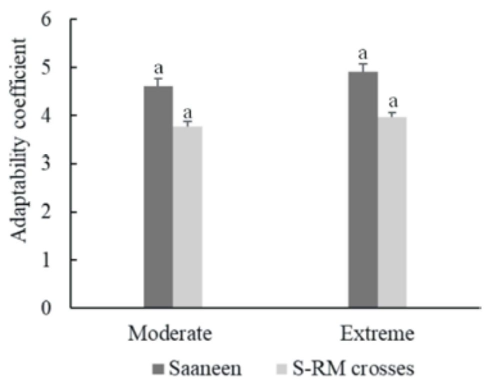

Fig. 2: Adaptability coefficient (AC) of Saanen and S-RM crosses goats during the period of moderate and extreme heat stress conditions in tropical climate. Black columns correspond to Saanen goats and Gray columns to S-RM crosses goats. The lower case letters do not differ according to the level of heat stress ($P > 0.05$)

Adaptive Profile: Adaptability coefficient (AC) of Saanen and S-RM crosses goats during moderate and extreme heat stress conditions is presented in Figure 2. Regardless of the heat stress condition, the Adaptability coefficient (AC) of Saanen goats was higher than that of S-RM crosses goats (extreme stress condition, 4.92±0.98 for Saanen and 3.97±1.02 for S-RM crosses; moderate stress condition, 4.61±1.36 for Saanen and 3.78±1.07 for S-RM crosses). No significant difference ($P > 0.05$) was observed between the two heat stress conditions for the two genotypes.

DISCUSSION

The purpose of this study is to evaluate thermoregulatory responses related to the physiological profile of dairy goats. Measurements of environmental parameters such as AT and RH are commonly used to quantify heat stress in dairy goats through the temperature-relative humidity index (THI). In the present study, AT and RH values were much higher than critical values during heat stress conditions. The animals were subjected to heat-stressed conditions during both periods in accordance with Silanikove [25]. The higher THI observed during the period of extreme stress condition was due to the substantial increase in RH during the period caused by the large amount of rainfall. During the period of extreme stress with higher AT, RH decreased, in contrast to the period of moderate stress. This is a desirable characteristic because during hot period the animal may lose heat through evaporation [26, 27]. According to Silanikove [25], a THI value less than or equal to 70 indicates a comfort condition Values from 71 to 78 are considered stressful values above 78 cause a great deal of stress in the animal when it is unable to maintain the thermoregulation mechanism and its normal body temperature. However, these values are generalized for domestic ruminants where more specific ranges are required for different categories of animals with respect to species, breed and fitness.

Physiological parameters such as RT, ST, RR and HR are values that determine the animal's adaptability to adverse climatic conditions [11]. According to Yadav *et al.* [28], these preliminary responses are necessary to know if the animal is under stress. For this reason, changes in physiological parameters are considered as indicators of adaptability to heat stress in animal species. In the present study, RT was relatively higher for Saanen goats than crossbreed goats (S-RM crosses) under moderate stress conditions. No significant difference was observed between the two genotypes under extreme stress conditions. Similar observations have also been reported by de Souza *et al.* [24], Hashem *et al.* [29] and Lallo *et al.* [30] in dairy goats. The reason could be the ambient temperature and relative humidity that are simultaneously high during extreme stress. RT between 38.5 and 39.7°C is considered normal for goats [31]. The average RT for both breeds was within the physiological range of the species as Reece *et al.* [31] noticed. According to Rout *et al.* [13] and Yousef [32], RT is a sensitive indicator and basic for selecting heat stress tolerance. By assessing physiological responses in

Anglo-Nubian and Saanen goats kept in shade, sun and partially in a shaded environment in a hot and humid climate, Medeiros *et al.* [33] obtained mean rectal temperatures of 40.16 and 41.32°C in the afternoon. The increase in RT under heat stress conditions can be explained by the higher THI value. According to Dangi *et al.* [34], animals improve their RT in order to best dissipate the additional body heat by vaporization in the surrounding environment. Under different environmental conditions, rectal temperature is maintained within a certain range for goats [5]. As elevated RT strongly indicates hyperthermia, this parameter may reflect the degree of adaptability of livestock to a particular environment [35].

Whether in conditions of moderate or extreme heat stress, the skin temperature of goats (*S-RM crosses*) was higher than that of Saanen goats. Similar results were observed by de Souza *et al.* [24] who indicated that regardless of the time of year (rainy or dry season), Saanen goats have relatively low skin temperature compared to other breeds. This result can be explained by the white colour of Saanen goats' coat which absorbs less light [36]. According to McManus *et al.* [37], white-haired breeds are more adapted to heat stress. Gaughan *et al.* [38] found that white animals were able to withstand three additional degrees of heat load before undergoing heat stress compared to animals with relatively black skin. In areas with tropical climate, many studies with dairy goats have shown higher skin temperature in the afternoon when the ambient temperature is relatively high [26, 39]. In the present study, it was found that the RR of Saanen goats was higher during both heat stress periods than ½S½RM goats. However, it was much more pronounced during periods of extreme stress. This increase could be attributed to the high THI values. As the respiratory rate is the most effective thermoregulatory dissipation mechanism, its activation only occurs at high ambient temperatures or when significant losses are ineffective [40]. de Souza *et al.* [24] found an increase in RR in Saanen goats during the dry and rainy season. Thus, the increase in RR in an attempt to lose heat was more pronounced for Saanen goats than *(S-RM crosses*) goats. A respiratory rate of a 15 breath/min with a range of a 12 to 25 breaths/min that was considered a reference value for goats [26]. The higher respiratory rate values for Saanen goats are probably due to its origins and the more productive characteristic of the breed while (*S-RM crosses*) has in its pedigree Maradi Red goat -a breed more adapted to warm climate. Nevertheless, they are less productive than Saanen goats. Medeiros *et al.* [33] also obtained a higher respiratory rate in Saanen goats (75.47 breath/min) than in Anglo-Nubian goats (48.33 breaths/min). In other studies, on adaptive physiological characteristics comparing different breeds of goats -Anglo-Nubian and crossbreds showed lower RR values [24]. This indicates that the best results for physiological parameters obtained by *(S-RM crosses*) goats in the present study are linked their Sahelian origin. During the two periods of heat stress conditions, the increase in respiratory frequency was important for the maintenance of homeostasis. The average values of the respiratory frequency in the period of moderate stress precisely indicate that in this period when RH values were lowest, the use of respiration for heat dissipation was necessary and more efficient. As a result, the HR mean values were lower during the period of moderate stress than extreme stress. Thus, in a low RH environment, evaporation by thermolysis is facilitated resulting in an increase in respiratory rate for maintenance of body temperature. Higher heart rate was registered for Saanen goats ($P < 0.05$) than (*S-RM crosses*) goats. HR for the genotypes was higher than the normal range proposed for goats, i.e. 70-80 beats/min at rest [30]. The increase in heart rate can be attributed to the increased muscle activity required as a result of increased heart rate as well as the reduction in peripheral vascular resistance. It then increases surface blood flow for heat dissipation through the skin [41]. For Boer and Anglo-Nubian goats, Martins Júnior *et al.* [23] found no difference between the dry and wet season. In contrast, Rocha *et al.* [42] found values of 79.44±14.89 beats/min and 65.75±7.29 beats/min for HR in rainy and dry periods for Saanen goats respectively. The opposite was observed by Ogebe *et al.* [12] in his study on African goat breed. A higher HR was found during the dry season.

The results of physiological parameters obtained under the climatic conditions of the present study indicate a higher heat tolerance of S-RM crosses goats than the Saanen goats That finding was confirmed by the adaptation coefficient (AC). de Souza *et al.* [24], Medeiros *et al.* [43] applied a heat tolerance test to goats and observed a lower performance in the Saanen breed compared to the Anglo-Nubian breed. As in this study, Rocha *et al.* [42] also did not observe differences between periods of the year in relation to the AC of Saanen goats. They found similar averages of 5.13±1.54 and 5.86±1.39 respectively in rainy and dry seasons. The higher AC values described by de Souza *et al.* [24] are probably linked to the higher THI values obtained in their study. de Souza *et al.* [24] obtained AC values for Saanen breed and

½S½AN (Saanen Anglo-Nubian breed) that were 4.54±1.06 and 3.85±0.83 in the dry season and 4.83±1.20 and 3.86±0.97 in the rainy season, respectively. Martins Júnior *et al.* [23] had determined AC values for the Anglo-Nubian breed that were higher in the dry season (3.039±0.038) and (2.678±0.038) in the rainy season.

Implications: In order to cope with the various environmental stress in the context of climate change, it is important to rely on heat tolerance indicators. So, that necessitates selecting animals adapted to certain environmental conditions. It will be also important to set herd management programs. However, improving animal performance requires direct measurements such as body temperature, rectal temperature, respiratory rate and heart rate, which define direct indicators of heat tolerance. In the present study on the physiological responses of dairy goats to thermo-tolerance indicators confirms that RT and RR are good and reliable indicators of heat stress for dairy goats. Thus, to limit the effects of heat stress on goats in their environment, farmers could use this knowledge to instantly identify the heat status of their animals in order to immediately apply mitigation strategies. The higher values of RT, RR and HR observed in Saanen goats are probably due to their European origin, adapted to a temperate climate. S-RM crosses goats shows a genetic contribution of 50% from a breed considered rustic– Red Maradi goat which is heat tolerant. Among the physiological responses, RT is considered the most sensitive to heat stress. RR has been used to assess the level of heat stress in goats [44, 45]. In addition, RR can be a good indicator of heat tolerance and the ability of animals to dissipate heat under adverse climatic conditions as increasing the RR of some goats can increase thermo-tolerance without negatively affecting the production level. Selection for RR regulation is a potential strategy to mitigate the effects of heat stress on dairy goats. Indicators of heat tolerance are particular interesting as long as the associated phenotypes remain easy to collect in a cost-effective manner. Ideally, these indicators should be obtained from easily accessible, preferably non- or minimally invasive samples. In this perspective, this study may be a first step to continue our research which aims at identifying thermo-tolerance indicators for heat stress adaptation.

CONCLUSION

Based on the results obtained, we conclude that, the existence of upper critical AT, RH and THI in sub humid tropical climate which is indicative of heat stress in all the animals. Thus, change in physiological responses with varying heat stress conditions indicates that animals are not adapting to the existing stress. However, for the physiological parameters and the adaptability coefficient, S-RM crosses goats seem to be more adapted than Saanen goats to the sub humid tropical climate. Therefore, more studies are needed to allow the spread of adapted and resistant crossbred animals.

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Conflict of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

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