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Heat tolerance responses in a *Bos taurus* cattle herd raised in a Brazilian climate

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ABSTRACT

Knowledge of thermoregulatory responses in taurine cattle contribute to identification of animals most adapted to heat and productive when raised under Brazilian climate. The objectives were to verify the morphological and physiological responses related to adaptation to heat of taurine breeds raised under in Brazilian meteorological conditions in different seasons of the year and day periods, and to detect differences within and between breeds to know breed is most adapted. Measurements were made of 74 young bulls (n = 31 Angus; n = 43 Simmental) for the morphological traits: hair length (HL), number of hairs (NH), and coat thickness (CT); and for the physiological traits: respiratory rate (RR) and hair coat surface temperature (ST). The temperature-humidity index (THI) was calculated. The data were subjected to analyses of variance, cluster analysis, and principal component analysis (PCA). The THI (< 74) indicates thermal comfort. In the winter, the HL and CT higher than in the spring season ($P < 0.0001$) in both breeds. Angus exhibited higher HL and CT ($P < 0.0001$). Within each breed, the animals differed from one another for HL ($P < 0.0005$). In the spring, CT was similar between the breeds, differing only in the winter season. Angus had higher values ($P < 0.0005$) of RR and lower values ($P < 0.0001$) of ST. Both breeds had higher ($P < 0.0001$) RR and ST in the afternoon. PCA showed that NH and HL better explained variation in adaptation. In general, the breeds have similar morphological responses in the hottest months, but have different physiological responses; Simmental proves to be more physiologically resistant. The afternoon was more stressful than the morning, even though the animals were in a thermal comfort zone. Measuring traits related to hair coat is sufficient for effective evaluation of adaptation, and the season affects the morphological and physiological traits of taurine cattle raised.

1. Introduction

Brazil is the second largest producer of beef worldwide and plays a significant role as exporter of animal protein (Latawiec et al., 2014; McAlpine et al., 2009; McManus et al., 2016). Taurine cattle was introduced in Brazil at the end of the nineteenth century and beginning of the twentieth century to further promote the livestock and meet the growing demand for animal products in quantity and quality (Dani et al., 2008). These animals, despite good productive performance and better meat quality, compared to typical Brazilian zebu cattle, suffer from the tropical climatic conditions, and their use in breeding systems adopted in warmer regions of the country is not very practicable.

Abbreviations: HL, hair length; NH, number of hairs; CT, coat thickness; RR, respiratory rate; ST, hair coat surface temperature; THI, temperature-humidity index; AT, air temperature; RH, relative humidity; Tm, air temperature in the morning; Ta, air temperature in the afternoon; RHm, relative humidity in the morning; RHa, relative humidity in the afternoon; A, Angus; S, Simmental; NHw, Number of hairs in the winter; NHs, number of hairs in the summer; HLw, hair length in the winter; HLs, hair length in the summer; CTw, hair coat thickness in the winter; CTs, hair coat thickness in the summer; RRm, respiratory rate in the morning; RRa, respiratory rate in the afternoon; STm, hair coat surface temperature in the morning; STa, hair coat surface temperature in the afternoon; PCA, principal component analysis

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However, the use of crossbreeding between *Bos taurus taurus* and *Bos taurus indicus*, such as the Angus and Simmental breeds, has immediately begun to provide benefits such as weight gain and improvements in carcass quality (Bianchini et al., 2008; Leira et al., 2017; Rosa et al., 2013).

The Aberdeen Angus breed has stood out in the national livestock, as it is among the taurine cattle with characteristics more desirable for the animal protein production sector such as precocity, rusticity, ease of delivery and mainly for meat quality a feature highly valued in foreign trade (MCGuire, 2013). According to the Brazilian Association of Angus, the breed has achieved a marked increase in the last six years, accounting for 51% of the semen sold throughout Brazil, exceeding the number of doses produced by the largest zebu cattle in the country, the Nelore (ABA, 2018).

Not unlike, the Simmental breed also has its relevance, due to its good growth rate and good yield of meat cuts (Cundiff, 2003). Another important characteristic of the breed is the reproduction in which cows' fertility reaches 92% and the interval between calving is usually short. Further evidence of this high fertility is also verified when we consider it to have been the first breed used for Embryo Transfer and Bi-Partitioning, In Vitro Fertilization and also to be the first clone produced in Brazil. Such facts demonstrate the economicity that the breed provides (ABCRSS, 2018).

Two-thirds of Brazilian territory is in the tropics, characterized by climate events of high temperatures and high solar radiation, which is a considerable challenge for animal thermoregulation (da Silva et al., 2010; da Silva and Maia, 2013). The negative effect is greater on animals from temperate zones, like taurine cattle, than animals from tropical zones, like zebu cattle (McManus et al., 2016). Heat stress in *Bos taurus* cattle affects their production in various regions of the world, and it is one of the biggest concerns in livestock raising since it causes a decline in herd production. The energy that could be directed toward production is redirected to activating thermoregulatory mechanisms, such as neuroendocrinological, physiological, and behavioral responses that will act to balance animal functions (Almeida et al., 2011)

Silva (2000) states that some morphological features of the hair coat, such as coat thickness, number of hairs, and hair length, are important for thermal equilibrium because they allow the animal to exchange heat with the environment. Changes in physiological traits, such as an increase in respiratory rate, is one of the first visible signs of animals under heat stress. Animals that have a lower respiratory rate are considered more heat tolerant (Martello et al., 2004; Moraes, 2010). Another trait is hair coat surface temperature, which is highly correlated with respiratory rate and is a measurement that represents the microenvironment around the animal (Collier et al., 2006).

Thus, the objectives of this study were to verify the morphological and physiological responses related to adaptation to heat of Angus and Simmental breeds animals raised under in Brazilian meteorological conditions in different seasons of the year and day periods, and to detect possible differences of adaptation within and between breeds to know which breed is most adapted to the conditions of the country. We hypothesized that the Angus breed will be less adapted to heat than the Simmental breed, for both types of characteristics analyzed, because this breed originated in a temperate region and due to the fact that the Simmental animals come from the South Africana, a region of similar climate to our country.

2. Materials and methods

2.1. Site and animals

This experiment was carried out on the Santa Éster Farm belonging to Casa Branca Agropastoril Ltda., in Silvianópolis, MG, Brazil (22° 01′ 46″ S, 45° 50′ 06″ W, 897 MASL). This region has a humid subtropical climate with a mean annual temperature of 19.9 °C. We used a total of 74 male animals born in 2011, with average age of 15 months at the beginning of the experiment, of the taurine breeds Angus (n = 31, average body weight = 281 ± 61; A) and a South African Simmental line (n = 43, average body weight = 286 ± 72; S). All the Angus animals had a black coat and all the Simmental animals had a standard red-white coat. The animals were kept in a confinement system in which they received water and commercial feed in covered feed troughs.

2.2. Evaluation of traits

The animals were herded to a handling corral 12 h before beginning morphological and physiological measurements. They remained without access to shade until all measurements had been obtained.

The following morphological traits were evaluated on a winter day (July) and on a day at the end of spring (November): number of hairs (NH, hairs/cm^2), hair length (HL, mm), and coat thickness (CT, mm). In each season, a hair sample was collected at 20 cm from the spinal column in the middle of the flank area of each animal with the aid of a flat nose pliers equipped with a spacer to hold the plier jaws open to a standardized distance of 21 mm. The pliers was placed at a 90° angle in relation to the epidermis of the animal and moved forward, passing over the hairs and touching the epidermis. The spacer between the jaws was removed, the hairs were grasped, and the pliers were firmly removed. Each hair sample was placed in a plastic bag that was duly identified with the number of the animal for later evaluation of the NH and HL. The CT measurement was made in the same region used for collection of hair samples, with the aid of a fine millimeter metallic ruler. The NH was obtained through counting the number of hairs in each sample, corresponding to the area of 21 mm of opening between the jaws of the pliers, which was then transformed into cm^2. The evaluations of CT and NH followed the methods described by (Silva, 2000). Hair length was considered as the distance between the hair end and the point of entry in the epidermis (Bertipaglia et al., 2007). The ten longest hairs were chosen through visual analysis of the sample, their length was measured using a digital caliper, and the arithmetic mean was calculated, following the procedures recommended by (Udo, 1978).

Physiological traits were evaluated once a month at 28-day intervals; the first data collection was made in August, the second in September, the third in October, and the fourth (and last) in November. Hair coat surface temperature (ST, °C) and respiratory rate (RR, movements/minute) were measured at 7:00 in the morning and once more at 1:00 in the afternoon on each day of evaluation. The ST was obtained using a digital infrared thermometer aimed in the direction of the dorsal region of the animal, near the location of hair sampling (Eustáquio Filho et al., 2011). The RR was evaluated by counting the number of respiratory movements in the flank region twice for a period of 15 s and multiplying the average of these two values by four to obtain the number of respiratory movements/minute (Silva, 2000).

2.3. Climate conditions

On the same days and times of evaluation of the physiological traits, data on air temperature (AT, °C) and relative humidity (RH, %) were collected with a digital thermohygrometer to obtain the environmental conditions at the site the animals were in. Maximum AT was 38 °C in the afternoon in August and minimum AT was 18.4 °C in the morning of the same month. The highest RH in the morning was in September and the highest RH in the afternoon was in November. The temperature-humidity index (THI) was also calculated from the model below, defined by Thom (1958), which ranged from 43.95 to 68.20 throughout the time of the study (Fig. 1).

$$THI = 0.8*AT + RH*[(AT-14.3) + 46.3],$$

where AT = air temperature (°C) and RH = relative humidity (%)

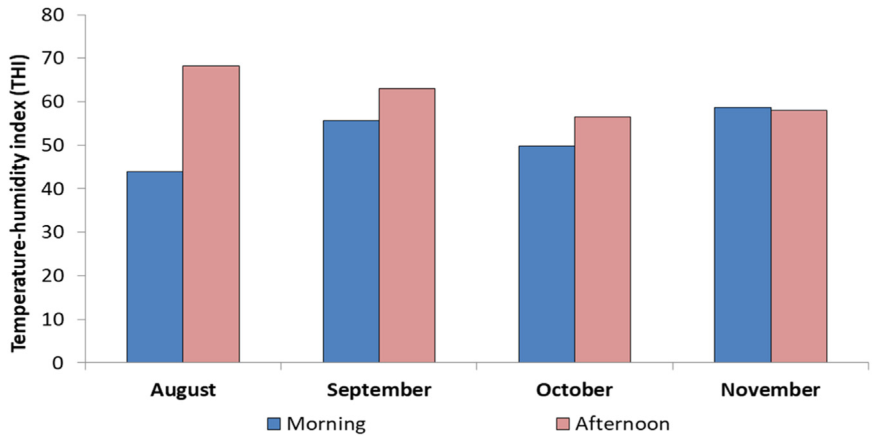

Fig. 1. Temperature – humidity index (THI) from August to November experienced by the Simmental and Angus breed animals raised under meteorological conditions of Brazil.

2.4. Statistical analyses

For the morphological and physiological traits, exploratory analyses of the data were performed with the aim of knowing the variability of these data to be able to detect outliers. Outliers were detected following the method described by (Freitas et al., 2008), in which evaluation by genetic group (Angus and Simmental) and by measurement (HL, NH, CT, RR and ST) were made. After this procedure, the physiological traits were analyzed by the MIXED procedure of SAS® (SAS Institute. User's Guide. Version 9. Cary 1999), considering a model that included the effects of breed (Angus and Simmental), time (7:00 a.m. and 1:00 p.m.), month (August; September; October, and November), and interactions of breed × time, breed × month, month × time, and breed × month × time, the random effect of animals within the breed and age as covariable.

The morphological traits were also analyzed by the MIXED procedure considering a mixed model with fixed effects of breed (Angus and Simmental), season (winter and spring), breed × season interaction, the random effect of animals within the breed and age as covariable.

The statistical model in the matrix was:

$$y = X\beta + Za + e,$$

where y is the vector of dependent variables, X is the incidence matrix of the fixed effects, β is the vector containing the overall mean (μ) and all the fixed effects, Z is the incidence matrix of the random effects, a is the vector of random effects, and e is the vector of random errors associated with each observation.

Principal component analyses (PC) containing the morphological traits in the two seasons, and the physiological traits in the two periods of the day were included in the study from the PRINCOMP procedure. The PC was used to choose the most representative characteristics of the entire data set.

The CLUSTER procedure was also used to visualize the formation of groups that may or may not be homogeneous among the animals of each breed and for the morphological and physiological traits.

3. Results

3.1. Climate

Although there was a significant increase in air temperature (AT) from the morning (21.06 ± 2.56 °C) to the afternoon (31.51 ± 6.34 °C), there was no difference among the months for this variable ($P < 0.10$) (Fig. 1). The opposite was observed for relative humidity (RH), which did not differ among the times of the day; however, it decreased from September (73.50 ± 0.71%) to October (49.00 ± 11.31%), though these values did not differ from the mean values of August (56.00 ± 2.83%) and November (68.75 ± 7.43%) ($P < 0.05$). There was also no difference among temperature-humidity index (THI) in the months of August (56.08 ± 17.15), September (59.35 ± 5.15), October (53.16 ± 4.82), and November (58.35 ± 0.50).

3.2. Morphological measurements

The mean values of coat thickness (CT), number of hairs (NH), and hair length (HL) are in Fig. 2. Considering the mean of the two breeds according to the seasons, the traits HL and CT had higher means in the winter (HL = 3.08 ± 0.13 mm; CT = 2.45 ± 0.60 mm) than in the spring (HL = 1.59 ± 0.14 mm; CT = 0.73 ± 0.18 mm) ($P < 0.0001$).

No differences of animals within the breed were observed for coat thickness ($P > 0.05$), but differences were found between the breeds and in the breed x season interaction ($P < 0.005$). CT was greater in Angus (1.96 ± 0.11 mm) than in Simmental (1.22 ± 0.08 mm) regardless of the season ($P < 0.0001$). In the winter, Angus had greater CT (3.04 ± 0.17 mm) than Simmental (1.86 ± 0.21 mm), but in the spring, there was no difference in CT between them (0.88 ± 0.23 mm in Angus and 0.59 ± 0.16 mm in Simmental).

No differences were observed between breeds, seasons, interaction and of animals within each breed for the trait of number of hairs ($P > 0.05$). The mean values were statistically the same between Angus (1147.08 ± 87.85 and 905.56 ± 122.60 hairs/cm^2 in the winter and in the spring) and Simmental (921.57 ± 109.44 and 931.32 ± 83.48 hairs/cm^2 in the winter and in the spring).

Hair length was greater in Angus (2.67 ± 0.09 mm) than in Simmental (2.01 ± 0.07 mm), regardless of the season ($P < 0.0001$). There was also a difference among animals within each breed ($P < 0.05$). In the breed × season interaction, Angus had a higher mean at 3.58 ± 0.13 mm than Simmental at 2.60 ± 0.17 mm in the winter. In the spring, Angus also had higher mean at 1.76 ± 0.19 mm than Simmental at 1.42 ± 0.13. For CT, Angus had higher mean at 3.04 ± 0.17 than Simmental at 1.86 ± 0.21in the winter, but Angus (0.88 ± 0.24 mm) did not differ from Simmental (0.59 ± 0.16 mm) in spring.

Differences between breeds occur when the coat thickness (CT) or hair length (HL) of the Angus is greater than the CT or HL of the Simmental ($P < 0.0001$). Differences in season occur when the CT or HL is greater in the winter than in the spring ($P < 0.0001$). Differences among animals within each breed were only observed for HL ($P < 0.05$). The breed × season interaction revealed differences. The CT and HL are greater in the Angus breed in the winter. However, the

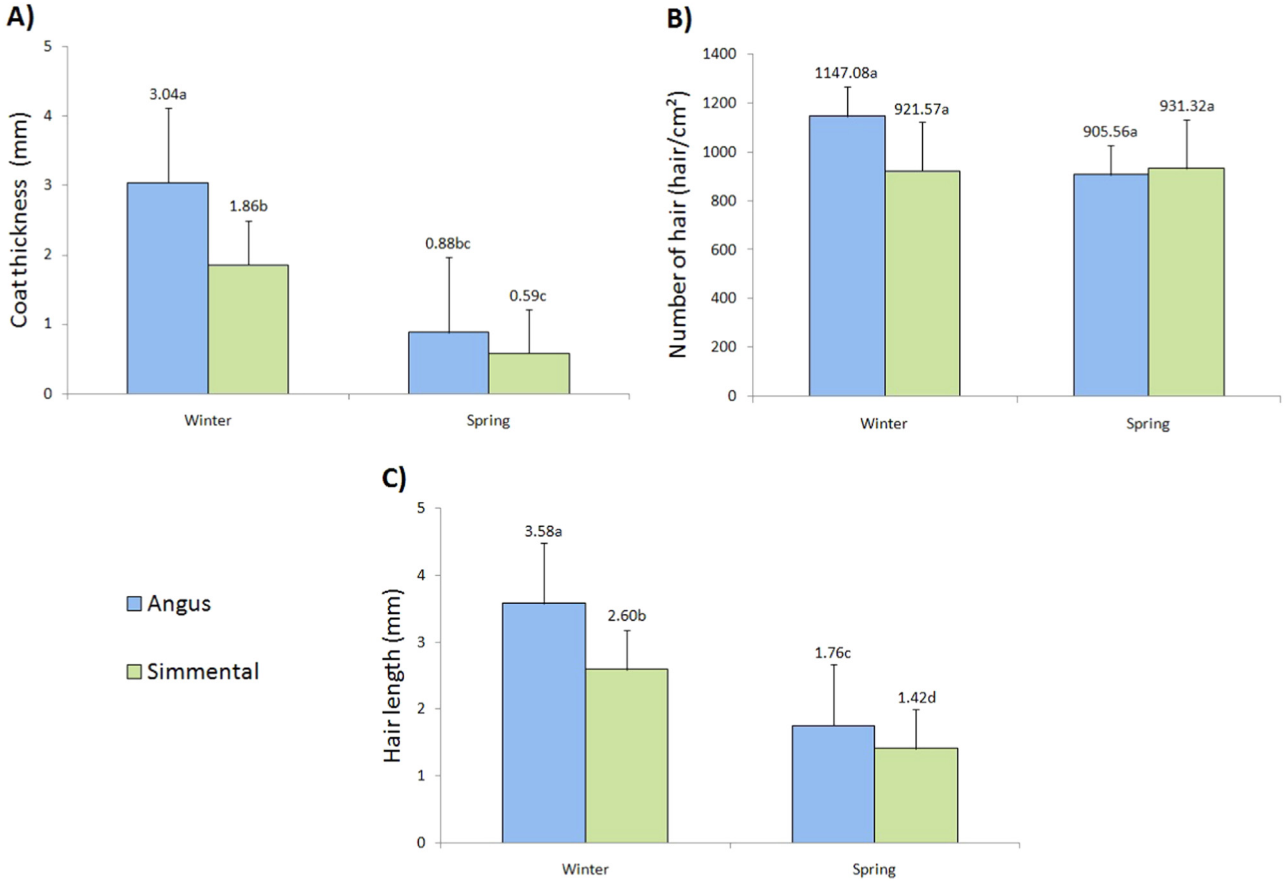

Fig. 2. Mean values of coat thickness (A), hair length (B), and number of hairs (C) in the winter and spring in Angus and Simmental breed animals raised under meteorological conditions of Brazil; the mean values above each bar followed by different letters diffe from each other by the Tukey test at the 5% level of significance; the vertical lines above each bar indicate standard error.

mean value of the CT for the two breeds do not differ in the spring ($P < 0.005$).

Using the hierarchical clustering method, three groups (clusters) could be established in relation to the hair length and coat thickness traits (Fig. 3).

3.3. Physiological measurements

Significant differences occurred in respiratory rates from the effects of month, breed, and time ($P < 0.05$). The highest mean values of respiratory rate (RR) were observed in August (63.70 ± 0.87 mov/min), followed by September (47.22 ± 0.75 mov/min), October (55.46 ± 0.77 mov/min) and November (45.64 ± 0.90 mov/min) ($P < 0.001$). There was no consistent pattern of increase in RR over the months of collection. A higher mean value of RR was observed in Angus (55.19 ± 0.86 mov/min) than in Simmental (50.83 ± 0.73 mov/min). The RR increased, as expected, from 47.66 ± 0.61 mov/min at 7:00 a.m. to 58.35 ± 0.61 mov/min at 1:00 p.m. in the mean value of

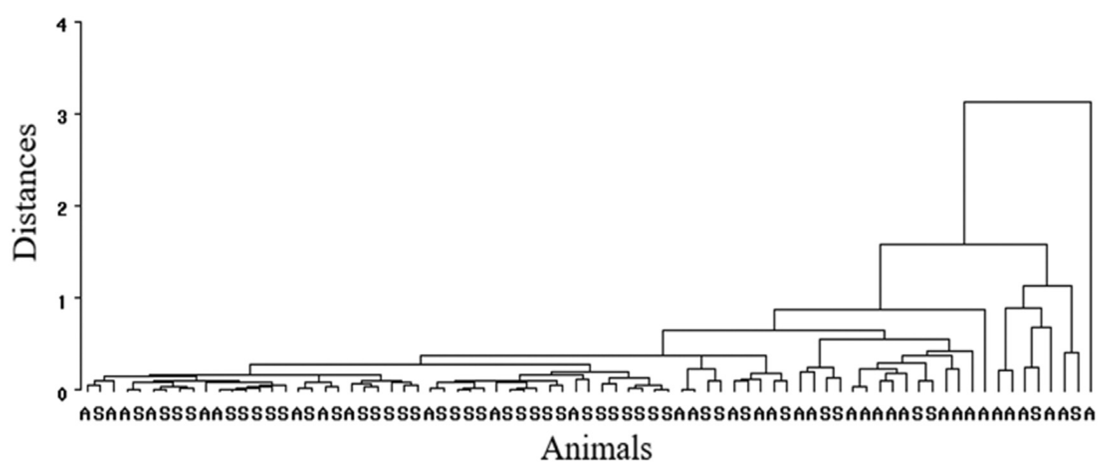

Fig. 3. Dendrogram based on genetic distances of morphological factors (hair length and coat thickness) obtained in the spring based on genetic distances of morphological factors (hair length and coat thickness) obtained in the spring in Angus and Simmental breed animals raised under meteorological conditions of Brazil; Angus (A); Simmental (S); Each letter "A" or "S" represents a different animal within each breed.

both breeds over all the months of evaluation.

There was no difference in the breed × time comparison. Contrary to expectations, the highest RR was observed in August, a winter month, in relation to the other months, for both breeds ($P < 0.001$). In the breed × month comparison, Angus had higher values of RR in August (69.85 ± 1.14 mov/min), September (50.25 ± 1.13 mov/min), and October (59.42 ± 1.22 mov/min) than Simmental (57.56 ± 1.20 mov/min, 44.20 ± 1.04 mov/min, and 51.49 ± 0.97 mov/min) in the same months. Simmental exhibited a higher RR (50.06 ± 0.99 mov/min) than Angus (41.23 ± 1.36 mov/min) only in November.

In the time × month comparison, the highest RR were found in August (75.48 ± 1.05 mov/min) and October (58.54 ± 0.97 mov/min) at 1:00 p.m.; and the lowest RR, in September (45.81 ± 0.96 mov/min) and November (40.54 ± 1.08 mov/min) at 7:00 a.m. In the breed × time × month comparison, the highest value of RR was observed in Angus in August at 1:00 p.m. (88.70 ± 1.47 mov/min), whereas the lowest values of RR were observed in November (spring) at 7:00 a.m., with mean values of 40.35 ± 1.63 mov/min for Angus and 40.74 ± 1.26 mov/min for Simmental. In general, the respiratory rate, considering distinct months and times, were always greater in Angus than in Simmental (Fig. 4) in the breed × month × time comparison.

The mean values of hair coat surface temperature (ST) are shown in Fig. 5. Significant differences in ST occurred from nearly all the effects of breed, time, and month. In comparing breeds, it is noteworthy that greater ST was observed in Simmental (30.37 ± 0.12 °C) than in Angus (29.43 ± 0.14 °C) during the study ($P < 0.0001$). As expected, analysis of time for ST exhibited an increase ($P < 0.0001$), from 28.77 ± 0.10 °C at 7:00 a.m. to 31.04 ± 0.10 °C at 1:00 p.m. As expected, ST increased as spring arrived; there was no difference between August (28.58 ± 0.14 °C) and September (28.66 ± 0.13 °C), but it increased to 30.76 ± 0.13 in October and reached the highest value in November (31.61 ± 0.15 °C) ($P < 0.001$).

Just as respiratory rate, the ST was also significant for the interactions, except for breed × time. In the breed × month interaction, the highest values of ST were found in November (in the spring) in Angus (31.62 ± 0.23 °C) and Simmental (31.59 ± 0.17 °C); and the lowest values in Angus: 27.74 ± 0.19 °C in August and 27.39 ± 0.18 °C in September. In the month × time interaction, higher values of ST were found during the afternoon in October (32.40 ± 0.16 °C) and November (32.26 ± 0.18 °C) and the lowest value in August at 7:00 a.m., with a mean value of 26.01 ± 0.18 °C. It is noteworthy that, in spite of the black hair coat of Angus, the lowest mean value of ST observed throughout the study was in this breed at 7:00 a.m. in August (24.48 ± 0.25 °C) and the highest mean values were obtained in October at 1:00 p.m. in Angus (32.45 ± 0.26 °C) and Simmental (32.35 ± 0.21 °C) and at the same time in November in Simmental (32.87 ± 0.21 °C). The pattern of increasing change in ST, which was expected for the two groups, was observed only for Angus at 7:00 a.m. during the time of the study, which increased with the change in seasons, passing from 24.48 ± 0.25 °C in August to 27.80 ± 0.25 °C in September, 29.52 ± 0.26 °C in October, and 31.59 ± 0.27 °C in November in the breed × month × time interaction.

Through the hierarchical clustering method, three groups (clusters) could also be established in relation to the respiratory rate and hair coat surface temperature traits (Fig. 6).

3.4. Principal component analysis

Principal component analysis showed that two eigenvectors explained 58% of the total variation among the characteristics examined, which were hair length (HL) in the spring and number hairs (NH) in the winter, traits responsible with eigenvalues of 0.37% and 0.21%, respectively (Fig. 7).

The first component shows, in general, that the increase in one of the morphological traits is accompanied by an increase in the other traits, except for hair coat surface temperature (ST), which is not positively related to these traits. In the second component, the NH is the dominant trait, followed by HL and, once more, ST is not very relevant.

4. Discussion

The temperature-humidity index (THI) throughout the experiment remained within the thermal comfort zone (Fig. 1) according to the classification of the U.S. Livestock Weather Safety Index (LCI, 1970), which classifies THI values up to 74 as normal thermal comfort, from 75 to 78 as alert, from 79 to 83 as danger, and values of 84 or greater as emergency. According to (Silva, 2000), consideration of the radiant

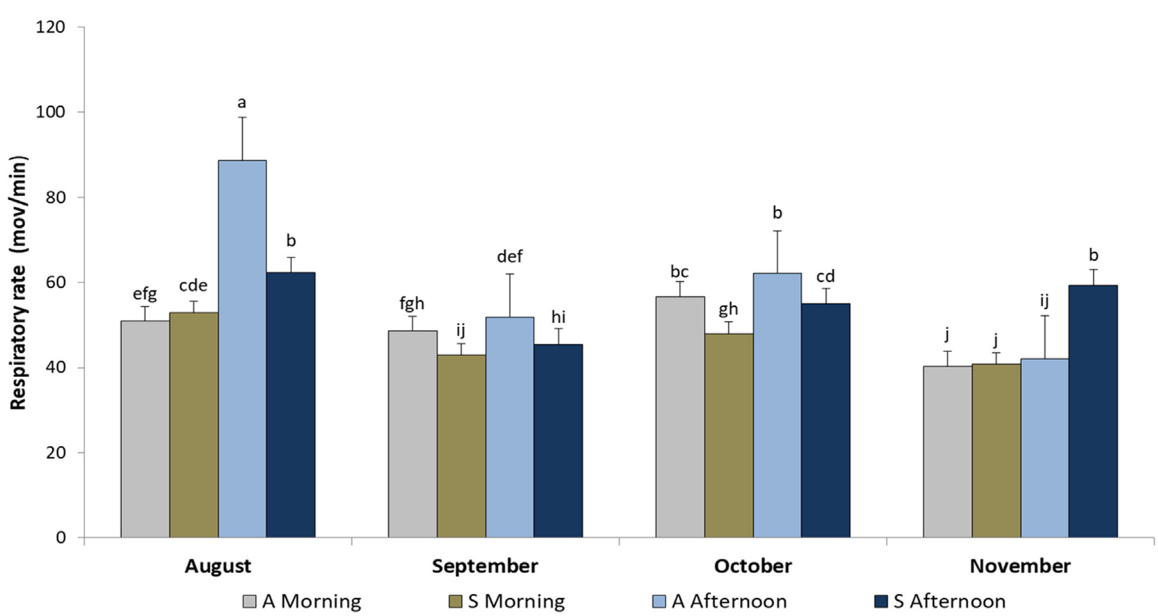

Fig. 4. Mean values of the respiratory rates obtained in the morning and afternoon periods from August to November in Angus and Simmental breed animals raised under meteorological conditions of Brazil; mean values above each bar followed by different letters differ from each other by the Tukey test at the 5%¨level of significance; vertical lines above each bar indicate standard error; Angus (A); Simmental (S).

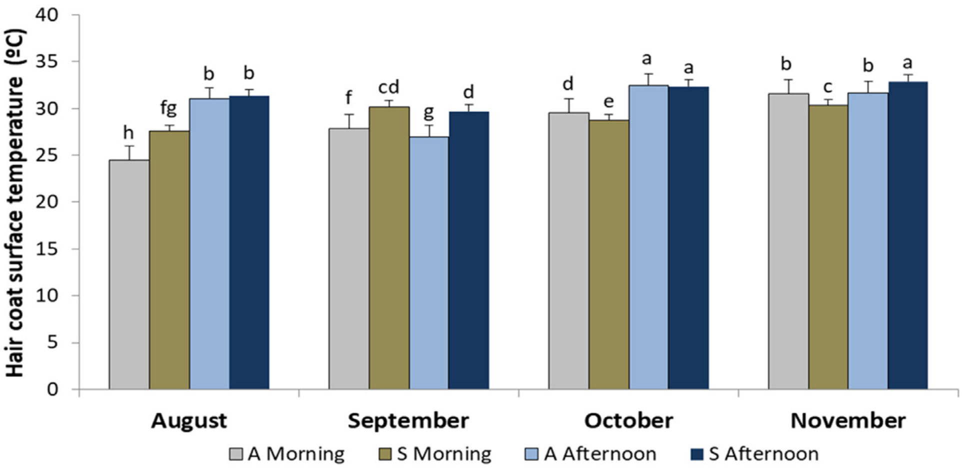

Fig. 5. Mean values of hair coat surface temperatures obtained in the periods of the morning and afternoon from August to November in Angus and Simmental animals raised under meteorological conditions of Brazil; mean values above each bar followed by different letters are different from each other by the Tukey test at the 5% level of significance; the vertical lines above each bar indicate standard error; Angus (A); Simmental (S).

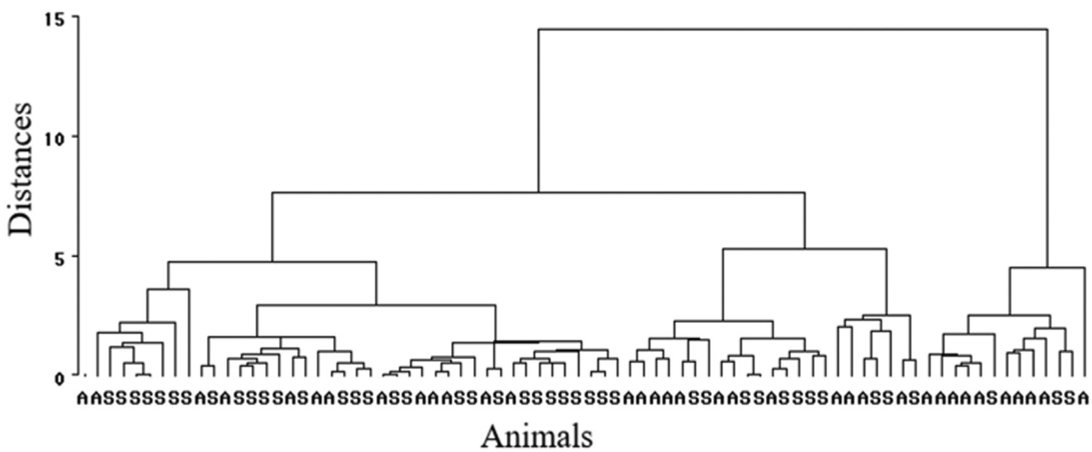

Fig. 6. Dendrogram based on genetic distances of physiological factors (respiratory rate and hair coat surface temperature) obtained in the spring in Angus and Simmental breed animals raised under meteorological conditions of Brazil; Angus (A); Simmental (S); Each letter "A" or "S" represents a different animal within each breed.

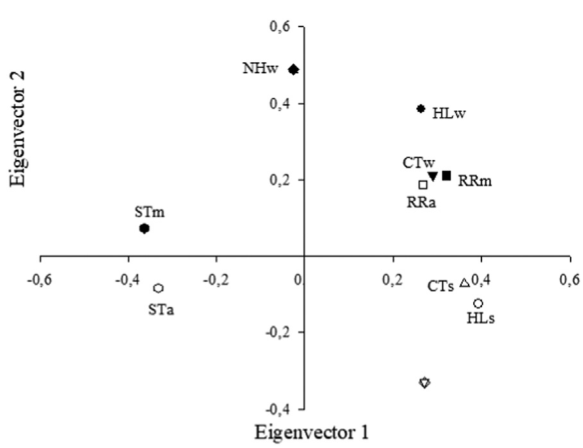

Fig. 7. Principal component analysis for the morphological and physiological traits of Angus and Simmental breed animals raised under meteorological conditions of Brazil. NHw = number of hairs in the winter; NHs = number of hairs in the summer; HLw = hair length in the winter; HLs = hair length in the summer; CTw = coat thickness in the winter; CTs = coat thickness in the summer; RRm = respiratory rate in the morning; RRa = respiratory rate in the afternoon; STm = hair coat surface temperature in the morning; STa = hair coat surface temperature in the afternoon.

heat load on animals raised in a tropical climate is of fundamental importance. When relative humidity is high, heat loss in the form of evaporation is hindered, and the animal is not able to lose heat through the epidermis in an efficient way since a certain amount of water in vapor form is already in the air. This factor associated with high temperature can bring about heat stress in the animal and, consequently, affect its productive and reproductive performance (Morrison, 1983), a fact not observed in the animals of this study confirmed by THI values.

In this experiment, an effect of breed was found on the traits of hair length and coat thickness, an effect of season on the morphological traits studied, and an effect of the animal within the breed for hair length. All these results were consistent with the results of Ribeiro et al. (2009) in evaluation of Nelore, Angus x Nelore, and Senepol x Nelore heifers in the same region of Brazil as this experiment. These results show that the genetic composition of the animals and the season are important variables when observing the adaptability of animals to a tropical environment. Thus, it is important to evaluate morphological traits in cattle herds to identify animals more adapted to heat so that these animals may better express their productive potential.

The effect of season on the traits of hair length and coat thickness found in this study are also consistent with what was found by Pinheiro and Silva (2000) in studying Holstein cattle in Ribeirão Preto in the state of São Paulo, Brazil, which has a climate similar to the climate in this study. This is related to the natural process of hair shedding by the animal so that it is able to adapt to a new climate condition.

Regardless of the breed, the hair was longer and the coat was thicker in the winter. These data are consistent with those reported by Ribeiro et al. (2009) for the same traits and by Nicolau et al. (2004) for coat thickness and hair length in Shorthorn breed animals. According to these authors, the morphological traits of the coat vary according to the season. In the coldest months of the year, the animals have a thicker coat and longer hair, whereas in the hottest months, the coat is not as thick and the hair is shorter, due to change in temperature, factors found in this study.

Silva (2000) also comments that variation in hair length from one season to another may be due to the process of hair shedding from the winter to the summer. This change generally occurs at the end of spring. The results of this study also indicate this process of the hair coat adapting to the climate conditions of each season (Fig. 2).

The differences in hair coat between the breeds, as well as among animals within a breed, may be due to genetic differences related to the adaptability of these animals. According to Prayaga (2003), the genetic differences that involve heat tolerance are related to thermoregulatory attributes, such as the type of hair coat, including the form of the coat and its pigmentation. Thus, it would be important to carry out studies to determine which genes are responsible for this adaptability, which would allow animals to be selected based on their genetic composition and, consequently, to achieve genetic gain for this type of trait.

According to Holmes (1981), animals with thicker, denser coats have greater difficulty in eliminating latent heat through evaporation through the skin, and the thickness of the hair cover can affect the amount of metabolizable energy used for animal maintenance. The difficulty in releasing latent body heat causes the organism to use compensatory mechanisms that lead to energy production, which is not favorable in animal production (Stone et al., 1992). This was observed in the Angus animals in this study.

Other authors have also stated that hair length and coat thickness are some of the important traits linked to adaptation of the animals in the tropics, where longer hair is connected with animals more highly affected by heat stress (Yeates, 1955). Shorter hair length may be an advantage in hot environments since longer hair, such as the hair of Angus in this study, impedes heat transfer from the surface of the animal, due to the physical barrier offered by the hair fibers.

The mean values of coat thickness and hair length of the Angus animals were higher than the mean values observed by Cardoso et al. (2014) in a study of half-blood Angus, with similar age and during the same seasons as the animals in the present study. This result denotes the superiority of crossbred animals in relation to purebred (such as those in the present experiment), probably through the contribution of heterosis and the complementary between the breeds.

Shiota et al. (2013) worked with Nelore cattle between 12 and 18 months of age in the region of Uberaba, Minas Gerais, Brazil, in the summer and winter. They observed much lower values for mean number of hairs and hair length compared to the mean numbers observed in this study for both breeds; this confirms the greater adaptability of zebu cattle compared to the taurine cattle evaluated in this study.

Lower values were also found by Nicolau et al. (2004) in Caracu breed cattle, with a mean number of hairs of 168.67 hairs/cm^2 in the winter and of 145.47 hairs/cm^2 in the summer, as well as hair length with mean values of 11.77 mm in the winter and 8.08 mm in the summer. Based on these results, the animals of this study may be less adapted than the animals of the taurine breed Caracu. According to Andrade (2001), the Caracu breed is the taurine breed most adapted to tropical Brazilian conditions, thus explaining the results obtained.

The hierarchical clustering method demonstrated true differences between and within the breeds analyzed in relation to the hair length and coat thickness traits (Fig. 3) by means of cluster formation. This shows that it is important to select the most adapted animals within each breed and, consequently, exclude less adapted animals.

In this study, Angus animals exhibited higher values of coat thickness and hair length in the winter than Simmental. However, in the hotter season, the spring, they were similar for CT. This suggests that although there may be a significant difference between the breeds, when each morphological trait is analyzed separately, the breeds may have the same level of adaptation because they resemble each other in the hotter season, which is the season of greatest interest in the study of taurine animals raised in a tropical climate. Nevertheless, other traits can be analyzed.

There was also no difference between THI in August (56.1 ± 17.2), September (59.4 ± 5.15), October (53.2 ± 4.82), and November (58.4 ± 0.50).

Effects of breed, time (of the day), and month for respiratory rate and hair coat surface temperature were found in the two breeds studied (Figs. 4 and 5). Consideration of these two traits shows a genetic difference between the breeds in relation to adaptation to heat. In addition, there is a difference between the measurements made in the morning compared to the afternoon, due to temperature change in these periods, and there are differences in the traits according to the month of data collection, probably due to differences in temperature, humidity, and change in season.

In general, Angus animals had a higher mean value of respiratory rate than Simmental animals; however, the opposite was observed for hair coat surface temperature. The black hair coat and epidermis of the Angus animals may explain their higher respiratory rate because they absorb a greater amount of thermal energy than Simmental animals, which have a light-colored coat and epidermis.

The respiratory rate of Simmental in the present study was greater than the 35 mov/min that was found by Carvalho et al. (1995) in Brazilian native Simmental cattle, and near the 64.3 mov/min in imported Simmental cattle obtained by the same authors. In the hotter months, coat temperature was consistent with that found by Kazama et al. (2008) from September to November in animals crossbred between Red Angus, Nelore, Guzerá, Limousin, Simmental, and Marchigiana.

The respiratory rates observed in the two breeds, in both time periods, and on nearly all the days, were within the physiological threshold because they are values up to 60 movements per minute, which indicate animals still without signs of heat stress. Values that exceed 120 mov/min already reflect excess heat load, and above 160 requires the use of emergency measures to reduce this load (Baccari Júnior, 2001; Hahn and Mader, 1997).

Hair coat surface temperature (ST) is one of the main parameters for evaluating heat dissipation from the animal (Silva, 2000). The ST values, whether dependent on the breed or not, were lower than 35 °C. This indicates, according to Collier et al. (2006), that the cattle under these temperature conditions are still able to efficiently use other mechanisms of heat exchange with the environment.

The hierarchical clustering method (Fig. 6) also shows that there are differences between and within the breeds analyzed for the traits of respiratory rate and hair coat surface temperature.

The results of principal component analysis with all the morphological and physiological traits (Fig. 7) showed that measuring hair length (HL) in the hotter months and number of hairs (NH) in the winter may be sufficient to identify variation in adaptability to heat, and hair coat surface temperature was not relevant for any of these components. Consequently, the number of traits to be measured can be reduced, and the HL and NH traits are important for maintaining thermal equilibrium in cattle.

5. Conclusions

The genetic groups Angus and Simental resemble most of the morphological factors in a hotter season.

The breeds differ in relation to physiological factors that affect heat tolerance; the Simmental breed proves to be more resistant.

The afternoon was more stressful than the morning in terms of response to heat even though the animals were in the thermal comfort zone.

The season of the year affects the morphological and physiological traits of Angus and Simmental cattle raised in Brazil.

Counting of hair and measuring its length is sufficient for effective evaluation of adaptation to heat in these breeds.

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Declarations of interest

None.

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