Relationship of weight gain with infrared temperatures in Nelore and F1 (Nelore × Angus) heifers reared in two forage production systems¹

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ABSTRACT: Intensive production systems require high-yield genetics as obtained in *Bos taurus* × *Bos indicus* crossbreeding. Generally, high-producing taurine cattle are more susceptible to parasites and heat stress. This study evaluated animal performance, heat-stress measurement (infrared temperatures), and internal parasite infection with daily weight gain in heifers from 2 genetic groups (Nelore and F1—Nelore × Angus) reared in 2 forage production systems (with or without crop-livestock system) during 1 yr. The main objectives were to determine the relationship between infrared measures and animal performance and whether it differs between genetic groups and environments. Thirty-six heifers were randomly assigned to 2 forage production systems, one considered as high-input system with crop-livestock system and other exclusive livestock system considered as low input. At each 28 d, infrared thermography (IR) temperatures, weight, and internal parasite infection (fecal egg count) were measured. The temperatures of the eye, snout, forehead, dewlap, body, ground and squeeze chute were

determined. F1 heifers had higher weight gain than Nelore ($P < 0.05$) and both did not differ in internal parasite infection ($P > 0.05$). F1 heifers had higher IR than Nelore ($P < 0.05$). The main body points that differentiate between genetic groups were dewlap, forehead, and eye. Higher dewlap IR temperature (DW) was associated with higher average daily gain (ADG) during dry season (independently of genetic groups) ($ADG = -0.755 + 0.032 \times DW$; $R^2 = 0.44$). Otherwise, the IR temperatures had a negative relationship with ADG during rainy season and low forehead IR temperature was related to higher average daily gain ($ADG = 1.81 - 0.033 \times \text{forehead}$; $R^2 = 0.12$ for F1 animals and $ADG = 1.46 - 0.025 \times \text{forehead}$; $R^2 = 0.07$ for Nelore). The infrared temperatures were more related to animal performance during the dry season, which had high temperature and low humidity. The infrared temperatures were able to identify the animal response to the environment challenge. Animals with higher temperatures (dewlap and forehead) had higher daily gain during the dry season.

Key words: bovine, crop-livestock, crossbreeding, gastrointestinal parasite, season, tropical

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INTRODUCTION

Crop-livestock systems demand intensive beef systems with high-yield genetic resources, which can be achieved by crossbreeding (Mokolobate et al., 2014; Pereira et al., 2015). One of the main crossbreeding used in Brazil is between Nelore females (most part of the national herd) and meat-selected breeds, mainly the British breeds such as Angus.

Environmental conditions can affect the efficiency of cattle production in terms of the ability of animals to cope with the stressors in that region. The ability to contain or minimize the increase of body temperature in high heat and humidity conditions is considered a sign of environmental adaptation (Riley et al., 2012; Cardoso et al., 2015). Therefore, the characterization of genetic groups to heat tolerance and resistance/tolerance to parasites is of paramount importance in high-yield production systems (Oliveira et al., 2013).

Infrared thermography (IR) is a noninvasive method that measures the temperature by the emitted energy of any surface and transforms it into a visible image (Ng, 2009). This method has great potential to evaluate animal physiology, disease, and response to thermal changes (McManus et al., 2016; Kou et al., 2017). Infrared temperatures of different parts of the animal body have been related to feed efficiency, average daily gain (ADG), DMI, and methane emission (Montanholi et al., 2008, 2009, 2010; Martello et al., 2016).

This study evaluated infrared temperatures (as a proxy for heat tolerance) and gastrointestinal parasite load of F1 (50%Nelore $\times$ 50%Angus) and Nelore heifers reared in 2 different forage production systems (FPS; with crop-livestock system or exclusive livestock) during 1 yr (dry and rainy season). Thus, the main objective was to determine the relationship of weight gain with infrared temperatures in each season, and how it is affected by genetic groups and FPS. Thereafter, the goal was to verify which infrared body points had stronger relationship with weight gain, and if it is affected by the genetic groups.

MATERIALS AND METHODS

Animal Care and Use Committee of Instituto Federal Goiano approved the experimental protocol (no. 14/2014), certifying that ARRIVE guidelines and EU Directive 2010/63/EU for animal experiments were followed. The study lasted 1 yr and consisted of 2 seasons (dry and rainy). The 2 seasons comprised the entire grass-fed backgrounding and finishing phases of heifers (from weaning

to slaughter). The first experimental phase (dry season) started on 1 July 2015 and ended on 17 October 2015, using an area of 9 ha. The second experimental phase (rainy season) started on 21 November 2015 and finished on 30 May 2016, using an area of 6.7 ha. Both experiments used the same 36 heifers, with an initial age of 7 mo (205.6 ± 25.76 kg), being 18 Nelore and 18 F1 (50%Nelore $\times$ 50%Angus).

These animals were randomly assigned to 2 FPS, one considered as high input with crop-livestock integrated system and other based on exclusive livestock system considered as low input. The total area used during dry season was 9 ha, divided in 18 paddocks with 2 animals (1 F1 and 1 Nelore) per paddock in continuous grazing. Therefore, each FPS used 4.5 ha divided in 9 paddocks. This design was chosen to allow enough repetition by area avoiding bias due soil fertility differences between areas.

Low-input FPS consists of previous-existent pasture in the area (mainly *Urochloa* genus) and minimal phosphorus fertilization (54 kg/ha of P_2O_5), representing the extensive beef system used in the mid-west region of Brazil. High-input FPS during dry season consisted of Paiaguás palisade grass (*Urochloa brizantha* cv. Paiaguás) intercropped with pigeon pea (*Cajanus cajan* cv. Super N).

During rainy season, low-input animals remained in the same paddocks (simulating the regular extensive beef system). High-input heifers were grouped in one rotational grazing system (2.2 ha) with Tanzania grass (*Panicum maximum* cv. Tanzânia), simulating an intensive crop-livestock integrated system. The rotational grazing comprehends 13 paddocks with 2 d of occupation and 24 d of resting.

High-input animals were moved to smaller area because the area grazed during dry season was used for soybeans cultivation in the rainy season, following the crop rotation. Thus, the animals used an intensive grazing area during the rainy season to release area for crop cultivation and, during the dry season, the entire area was used to grazing, which characterizes the crop-livestock integrated system.

During the dry season, all heifers received supplement [170.7 g/kg of CP, 21.6 g/kg of ether extract (EE), 345.9 g/kg of TDN, 121.4 g/kg of mineral matter (MM), 348.4 g/kg of NDF, 44.5 g/kg of ADF, and 14.2 g/kg of lignin, in DM basis] at the dose of 5 g/kg of BW. During rainy season, all animals received supplement at 3 g/kg of BW (143.4 g/kg CP, 21.2 g/kg EE, 313.4 g/kg TDN, 189.5 g/kg MM, 326.0 g/kg NDF, 45.6 g/kg ADF, and 8.5 g/kg lignin, in DM basis). The supplementation was

offered daily at 12 h to all heifers, and the orts were measured. The supplements were formulated according to [National Research Council \(2000\)](#) to provide protein and mineral supplementation.

Heifers received Doramectin 1% (1 mL per 50 kg of BW) at the beginning of the dry season trial. Heifers were weighted each 28 d after 14-h fasting, and at the same time, fecal samples were collected. Then, the fecal egg count (FEC) was measured following the method of [Gordon and Whitlock \(1939\)](#).

The thermographic images were taken on 6 different days along with BW assessment (every 28 d) in both seasons. The thermal infrared camera (ThermaCam T300 serie-i; FLIR Systems Inc., Wilsonville, OR) was used, applying an emittance coefficient equal to 0.95 ([Paim et al., 2013](#); [Cardoso et al., 2015](#); [McManus et al., 2015](#)). Two photos per animal at the same day were taken in the morning (from 8 to 10 h). One photo was taken with the animal restrained in the squeeze chute (1 m distant) in a shade area. Previously, the animal was kept in the shade for approximately 10 min. After the animal being released from the squeeze chute, another photo was taken with free animal in a nonshade

pen (3 m distant), totalizing 72 photos per evaluation day ([Fig. 1](#)).

For environment evaluation, it was recorded the black globe temperature (BGT), air temperature (AT, °C) and air humidity (H, %). The BGT were taken using a mobile globe thermometer ITWTG-2000 (INSTRUTEMP, Measuring Instruments Ltda, SP, Brazil). The temperature and humidity index (THI) was calculated as follows ([National Research Council, 1971](#)):

$$THI = (AT \times 1.8 + 32) - 0.55 \times (1 - H/100) \times (AT \times 1.8 + 32 - 58).$$

The QuickReport software was used to collect data from thermographic images ([Cardoso et al., 2015, 2016](#)). The software used the input of the ambient temperature and humidity of the exact moment of the photo as adjust factors for the output. The area tool was used to get the mean temperatures at the snout and forehead, in the animal restrained photos, and the body temperature (side area of the animal's body), in the animal-free photos. The line tool was used to get mean temperature at the dewlap. The average inside the circle tool was used to get the eye temperature (only body point

Figure 1. Infrared images (at right) and regular picture (at left) of the heifers restrained in the squeeze chute (A) and free in paddock (B). The area tool was used to take the snout, forehead, and body temperatures. The line tool was used to taken dewlap temperature. The circle tool was used to obtain the temperature of the eyes in both images. The paddock ground and squeeze chute temperatures were taken with area tool to use for environmental characterization.

measured in both photos). In addition, the temperature of the ground of the paddock and of the squeeze chute were measured with area tool and considered as environmental descriptor (applied as covariate in Statistical Analysis).

The ADG was determined from each 28-d interval between weighing sections. It was determined an overall ADG and by season (dry and rainy). ADG was analyzed using mixed model with repeated measures (trial days) considering genetic group and FPS as fixed effect, as well as the interaction between them. The individual was considered as random effect. The covariance structure that best fit the model was a first-order autoregression (based on the lowest Bayesian information criterion). Means were obtained by least square means and compared by Tukey test ($P \leq 0.05$).

The thermographic temperatures were analyzed using the same previous mixed model adding the environmental variables as covariates. The season (dry and rainy) was included as fixed effect in the analysis of thermographic temperatures when using all dataset. If there was a significant fixed effect ($P \leq 0.05$), the Tukey test was used for means comparison.

To evaluate the relationship between the infrared temperatures (IR), environmental variables and ADG, a multiple regression, Pearson correlation, and factor analysis were performed using all data and separated by season (dry and rainy) and genetic group. Regression was carried out using ADG and THI as dependent variables and the IR points as independent variables. The factor analysis used the varimax rotation method. A discriminant analysis was used to verify which thermographic variables were able to discriminate between genetic groups and seasons (dry and rainy). The data analysis was generated using SAS software version 9.3 (SAS Institute Inc., Cary, NC).

RESULTS

The seasons represented different environmental challenges (Supplementary Table 1). Average black globe temperature was 41.9 °C in dry season and 33.3 °C in rainy season, respectively. Air humidity mean was 24.3% and 59.5% during dry and rainy season respectively (Supplementary Table 1).

The mean forage availability and nutritional quality are presented in Supplementary Table 2. During dry season, high-input forage had low NDF and high protein and lignin level than low-input forage. During rainy season, high-input forage had higher levels of all nutritional compounds than low-input forage, except TDN.

High-input forage system had higher weight gain than low input during both seasons (Supplementary Table 3). F1 heifers had 383 ± 32 and 716 ± 29 g animal⁻¹ d⁻¹ (dry and rainy season, respectively), whereas Nelore had 286 ± 33 and 621 ± 29 g animal⁻¹ d⁻¹ ($P = 0.041$ and $P = 0.026$, dry and rainy season, respectively). The interaction between the FPS and genetic group did not affect average daily weight gain (Supplementary Table 3).

The gastrointestinal parasite load was not affected by the genetic group and FPS (Table 1). The number of trial days had a significant effect on FEC. The FEC decreased through the dry season, peaked at the beginning of rainy season, and then declined again during the rainy season. The animals were dewormed at the beginning of the experiment and further treatment was not required because the animals did not have an average FEC greater than 500 eggs/g at any day during the evaluation (Molento et al., 2011).

The genetic group affected different points of thermographic temperatures (eyes—restrained and free, body, and dewlap). F1 heifers showed higher temperatures than Nelore. Season affected 3 body parts (eyes—restrained, forehead, and body). The dry season had a higher temperature than the rainy

Table 1. Summary of analysis of variance (P -values) and least square means of fecal egg count (FEC; number of eggs per gram of feces) from heifers from 2 genetic groups (GG; Nelore and F1—Nelore $\times$ Angus) reared in 2 forage production systems [FPS; high input with crop-livestock system (HI) and low input with exclusive livestock system (LI)] during 2 seasons (dry and rainy)

	Dry season	Rainy season
GG ¹	0.1106	0.8795
FPS ²	0.3978	0.4957
GG $\times$ FPS	0.5337	0.5314
Days ³	<0.0001	<0.0001
GG $\times$ days	0.7345	0.0463
FPS $\times$ days	0.4628	0.8577
GG $\times$ FPS $\times$ days	0.0537	0.4999
Means, number of eggs per gram, $\pm$ SE ⁴		
F1	115.3 $\pm$ 18.8	86.5 $\pm$ 26.81
Nelore	106.9 $\pm$ 18.8	67.1 $\pm$ 26.81
HI	129.2 $\pm$ 21.93	77.0 $\pm$ 45.83
LI	93.1 $\pm$ 21.93	76.6 $\pm$ 21.29

¹Genetic group effect.

²Forage production system effect.

³Number of experimental days (repeated measure).

⁴EPG data were log + 1 transformed to evaluation of fixed effects. The means showed were transformed to the original measure unit (number of eggs per gram) to easier biological understanding.

season for all the body points considering absolute values (Table 2). The air temperature influenced only forehead, whereas humidity and BGT influenced 4 and 5 body points, respectively. The interaction between genetic group and season was significant for forehead, body, and eye (free; Supplementary Table 4). For these body parts, F1 in dry season was hotter than Nelore in both seasons.

The discriminant analysis using the thermographic temperatures in both seasons classified correctly the F1 in 80.43% and Nelore in 75.82% of times. The variables that entered in the model were dewlap (partial $R^2 = 0.17$), forehead (partial $R^2 = 0.11$), and eye—free (partial $R^2 = 0.08$). The discriminant analysis using data from each season separately showed similar results compared to using all dataset. In the dry season, the body temperature (partial $R^2 = 0.23$) was the sole variable that entered in the model to discriminate genetic groups. In rainy season, the variables that entered

in the model were dewlap (partial $R^2 = 0.18$), forehead (partial $R^2 = 0.16$), and eye—restraint (partial $R^2 = 0.14$).

Using the thermographic temperatures of the animals, the discriminant analysis was able correctly classify the season in more than 80% of the cases, 80.95% for rainy, and 80.7% for dry season. The eye—free (partial $R^2 = 0.12$), snout (partial $R^2 = 0.18$), forehead (partial $R^2 = 0.02$), and dewlap (partial $R^2 = 0.01$) were the variables that entered in the discriminant model for season.

The environmental variables were able to correctly classify the season in 100% of the cases. The variables used in the model were air humidity (partial $R^2 = 0.74$), THI (partial $R^2 = 0.52$), air temperature (partial $R^2 = 0.18$), ground IR temperature (partial $R^2 = 0.03$), and BGT (partial $R^2 = 0.03$). These results highlight the large difference in air humidity between the seasons.

The factor analysis (Fig. 2) using the whole dataset classified the environmental variables (BGT,

Table 2. Summary of analysis of variance (P -values) and least square means (mean $\pm$ SE) of infrared thermographic temperatures (different points of animal's body) evaluating the fixed effect of genetic groups (GG; Nelore and F1—Nelore $\times$ Angus), season (dry and rainy), forage production system [FPS; high input with crop-livestock system (HI) and low input with exclusive livestock system (LI)] and environmental covariables

P -value	Eyes (restrained)	Forehead	Snout	Body	Dewlap	Eye (free)
GG	0.0006	0.1022	0.7022	<0.0001	<0.0001	<0.0001
Season	0.0056	0.0320	0.1327	0.0387	0.2694	0.2418
GG $\times$ season	0.5056	0.0547	0.1901	0.0103	0.3993	0.0030
FPS	0.0444	0.0002	0.8810	0.1789	0.0224	0.4651
GG $\times$ FPS	0.1042	0.2489	0.5352	0.0983	0.1461	0.2642
Season $\times$ FPS	0.0533	0.7876	0.2551	0.2661	0.3316	0.0633
GG $\times$ season $\times$ FPS	0.7297	0.2020	0.7179	0.0035	0.5146	0.4730
AT ¹	0.5237	0.0065	0.0637	0.8694	0.7598	0.3131
Air humidity	0.0003	0.0020	0.0017	0.0092	0.0694	0.2082
BGT ²	0.0046	0.7824	0.0003	0.0090	0.0004	0.0117
THI ³	0.9749	0.8065	0.0303	0.6417	0.2860	0.6803
Squeeze chute	0.0943	0.4338	0.2845	—	—	—
Paddock ground	—	—	—	0.0375	<0.0001	0.0069
Means for genetic groups, °C (mean $\pm$ SE)						
F1	36.1 $\pm$ 0.12 ^a	33.2 $\pm$ 0.16	31.8 $\pm$ 0.24	36.3 $\pm$ 0.24 ^a	34.0 $\pm$ 0.21 ^a	35.9 $\pm$ 0.15 ^a
Nelore	35.5 $\pm$ 0.13 ^b	32.9 $\pm$ 0.16	31.7 $\pm$ 0.25	34.3 $\pm$ 0.24 ^b	31.9 $\pm$ 0.21 ^b	34.9 $\pm$ 0.16 ^b
Means for season, °C (mean $\pm$ SE)						
Rainy	35.2 $\pm$ 0.15 ^b	32.4 $\pm$ 0.21 ^b	31.3 $\pm$ 0.24	34.5 $\pm$ 0.23 ^b	32.5 $\pm$ 0.25	35.1 $\pm$ 0.19
Dry	36.4 $\pm$ 0.30 ^a	33.6 $\pm$ 0.40 ^a	32.2 $\pm$ 0.47	36.1 $\pm$ 0.54 ^a	33.4 $\pm$ 0.53	35.7 $\pm$ 0.39
Means for FPS, °C (mean $\pm$ SE)						
HI	35.6 $\pm$ 0.12 ^b	32.6 $\pm$ 0.15 ^b	31.8 $\pm$ 0.25	35.0 $\pm$ 0.25	32.6 $\pm$ 0.21 ^b	35.3 $\pm$ 0.16
LI	36.0 $\pm$ 0.15 ^a	33.5 $\pm$ 0.20 ^a	31.7 $\pm$ 0.29	35.5 $\pm$ 0.28	33.3 $\pm$ 0.26 ^a	35.5 $\pm$ 0.19

^{a,b}Different letters in the same column means statistical significant difference for the fixed effect ($P < 0.05$).

¹AT = air temperature.

²BGT = black globe temperature.

³THI = temperature and humidity index.

Figure 2. Plot of the first 2 factors from factor analysis (with the whole dataset and separated by season—dry and rainy) using infrared thermographic temperatures from different points of animal's body (eye—restraint and free, forehead, snout, body, and dewlap), average daily gain, and environmental variables. AT = air temperature; H = air humidity; BGT = black globe temperature; THI = temperature and humidity index; ADG = average daily gain during entire evaluation; ADG dry = average daily gain during dry season; ADG rainy = average daily gain during rainy season. Values between parenthesis mean the proportion of the variance explained by each factor.

AT, squeeze chute, and ground IR temperatures) together with the IR temperature of the animal, and this group opposing to air humidity. Therefore, the first ones increase together, as air humidity decreases. The snout temperature separated from the others when analyzing the whole dataset and only the rainy season.

The correlations of the IR temperatures of the animals and AT, BGT, and THI (Supplementary Tables 5 to 7) were positive and medium (close to 0.5). In general, the correlations were higher in dry season (Supplementary Table 6). The infrared temperatures of the animals showed a negative and

significant correlation with air humidity. The snout temperature showed lower correlations with environmental variables than other points and showed a negative correlation with air humidity only in the dry season.

The ADG had a different relationship with IR temperatures between the seasons (Fig. 2). In dry season, ADG was in the same quadrant of the IR temperatures. In rainy season, the ADG was in the opposite quadrant to the IR temperatures and in the same quadrant of air humidity. Therefore, in dry season, high thermographic temperatures are related to high ADG, and this relation did not

occur in the rainy season. The factor analysis was performed using data from each genetic group separately to evaluate if some specific trait of each group was affecting the factor results (as F1 coat is black and Nelore coat is white and F1 had higher ADG than Nelore in both seasons). However, the same relationship between IR and ADG was observed for both genetic groups.

Average daily gain during the entire period showed positive correlation with eye (restrained), body, and dewlap IR temperatures, but with small magnitude (close to 0.15). However, ADG during the dry season showed a positive correlation with all IR temperatures (Supplementary Table 6). On the other hand, the ADG during the rainy season showed a negative correlation with snout and forehead temperature (Supplementary Table 7).

Regression analysis (Table 3) showed that dewlap temperature had a positive relationship with ADG in dry season and the forehead temperature had a negative relationship with ADG in rainy season. As observed in other analysis, the relationship between IR temperature, ADG, and environmental variables was different between the seasons. The coefficient of determination of the regressions equations was higher for the data from dry season, showing that infrared measures were able to capture the impact of the heat stress challenge in the animal performance during this season.

DISCUSSION

F1 heifers gained more weight than Nelore in both seasons, which was expected due to the heterosis effect and the higher growth capacity of Angus breed (Fialho et al., 2015; Reggiori et al., 2016). Therefore, the crossbred animals can increase the productive of the beef system, which highlight the importance of knowing more about

the heat tolerance and parasite resistance/tolerance of this genetic resource. The gastrointestinal parasite seems not to be a barrier for the use of Angus crosses because no difference in FEC between the genetic groups was seen.

The crop-livestock integrated system used in high-input systems produces forage with higher quality than exclusive livestock system (Santos et al., 2016). Therefore, the high-input system had a higher yield as expected.

Crop-livestock integrated system uses the land for forage production only during dry season and one rainy season (no more than 18 mo with pasture), followed by crop cultivation (De Moraes et al., 2014). Therefore, it can break the parasite cycle because the land stays more than 4 mo without cattle. However, as the gastrointestinal parasite load did not differ between FPS in this study, the environmental conditions were not ideal for parasite development, and the initial parasite load in the environment was very low (Stromberg, 1997; Valcárcel and Romero, 1999). Consequently, the different management strategies did not show an effect in the 1-yr evaluation. The year fluctuation of parasite load, with a peak at the beginning of the rainy season, was expected due to the activation of the quiescent eggs in the environment (Gettinby and Byrom, 1991) as reported in previous studies (Molento et al., 2011; Oliveira et al., 2013).

Genetic groups affected the IR temperature of the eyes, body, and dewlap. The discriminant analysis showed that dewlap, forehead, eyes, and body as the main IR temperature body points to differentiate between genetic groups. The regression analysis showed dewlap as an important variable to determine ADG during dry season. The dewlap is known as an important body organ for heat exchange (Bro-Jørgensen, 2016) and was previously identified as an important IR temperature body point

Table 3. Regression analysis using infrared thermographic temperatures from different points of animal's body to predict the average daily gain (ADG) in 2 genetic groups (GG; Nelore and F1—Nelore × Angus)

Season ^a	GG ^b	Regression	R ^{2c}
Both	Both	ADG = 0.257 + 0.0071 × dewlap	0.022
Dry	Both	ADG = -0.755 + 0.032 × dewlap	0.436
	F1	ADG = -1.308 + 0.048 × dewlap	0.407
	Nelore	ADG = -0.633 + 0.028 × forehead	0.476
Rainy	Both	ADG = 0.684 + 0.049 × eyer ^d - 0.053 × forehead	0.163
	F1	ADG = 1.81 - 0.033 × forehead	0.116
	Nelore	ADG = 1.46 - 0.025 × forehead	0.066

^{a,b}The analysis was carried out using all dataset (both) and separated by season (dry and rainy) and by genetic group (Nelore and F1—crossbred Angus × Nelore).

^cCoefficient of determination.

^dInfrared temperature measured in the eye with the animal restrained in the squeeze chute.

for heat tolerance evaluation (Cardoso et al., 2015, 2016). Nelore animals exposed to air temperatures higher than 30 °C exchanged heat mainly by cutaneous evaporation (Costa et al., 2018) for which the dewlap region plays an important role. Eye IR temperature (maximum temperature point) was seen as highly correlated with rectal temperature in previous studies (Stewart et al., 2008; Hoffmann et al., 2013; George et al., 2014). Eye temperature had the advantage of not being directly affected by coat color. Therefore, eye and dewlap IR temperature seem to be important body points to evaluate cattle response to thermal environmental conditions (thermoregulation).

Nelore heifers showed lower IR temperatures than F1 in the present study, which may be representing a lower body temperature due to lower heat production for maintenance requirements and better thermoregulation in Nelore animals compared to F1. *Bos indicus* cattle can easily regulate the body temperature with lower metabolic rate and increased heat loss due to larger sweat glands and hair coat properties that enhance conductive and convective heat loss (Hansen, 2004). Several studies (Paim et al., 2013, 2014; Cardoso et al., 2015; McManus et al., 2015, 2016) had demonstrated the ability of IR temperatures to determine the environmental adaptation ability of different genetic groups. In these studies, the IR temperatures, mainly eye and dewlap (Cardoso et al., 2015), showed a high positive correlation with respiratory frequency and rectal temperature, which are considered gold standards to heat tolerance evaluation. Therefore, low IR temperatures were associated with low respiratory frequency and rectal temperature. Consequently, the F1 (Nelore × Angus) heifers seem to be less adapted to heat stress of tropical climate than purebred Nelore.

The environment variables affected the eye, snout, forehead, and dewlap temperatures, which is similar to observed by Cardoso et al. (2015). The eye, forehead, and dewlap temperatures also appeared in the regression analysis with ADG and in the genetic group comparison and discriminant analyses. Snout IR temperature was the main point affected by environmental variables (H, BGT, and THI) and was not influenced by GG, FPS, and season. In addition, Snout IR temperature showed a different pattern in factor analysis, not clustering with the other IR temperatures. Therefore, snout IR temperature seems to be more related to the environment than with the animal physiology.

The discriminant analysis used eye, snout, forehead, and dewlap IR temperatures to classify the

observations inside the seasons. This highlights the ability of thermographic measures to identify the animal response to thermal environmental conditions. These results support eye, dewlap, and forehead as related to animal response to environment (thermoregulation) and snout as an environmental descriptor (Cardoso et al., 2015; McManus et al., 2016).

The IR temperatures during rainy season in our study had a negative relationship with ADG, and low forehead IR temperature was related to higher ADG. More efficient animals were associated with lower body surface temperature (Montanholi et al., 2008). According to these authors, lower maintenance energy requirements are associated with less heat production in more efficient animals and, therefore, a lower amount of heat to be dissipated through the body surface. However, during the dry season, higher dewlap and forehead temperature were associated with higher ADG. Montanholi et al. (2010) also found positive correlations between eye IR temperature and ADG and residual feed intake (RFI). Another study with Nelore in feedlot during dry season showed that front IRT (the same forehead in our study) was higher for the more efficient animals (low-RFI group) than that for the high-RFI group (Martello et al., 2016).

Differences in climatic conditions in each season could be a plausible reason for these discordant results. In conditions of heat stress with low humidity, as the dry season, the cutaneous evaporation is an important thermoregulatory mechanism for exchanging heat (Hansen, 2004; Costa et al., 2018). Thus, the higher IR temperatures may be related to better heat dissipation by the body surface.

On the other hand, the rainy season had lower temperatures and higher humidity compared to the dry season, characterizing a different environmental challenge (both seasons had similar THI). The cutaneous evaporation is not efficient for heat exchange in a high humidity environment (Hansen, 2004). Therefore, in this condition, the animals need to use others thermoregulatory mechanisms to maintain body temperature equilibrium. Probably, in this case, the lower IR temperatures are related to a better regulation of body temperature, which can be associated with lower heat production for maintenance requirements, better thermoregulation mechanisms, and less heat being dissipated by radiation (Montanholi et al., 2008, 2009). Therefore, lower IR temperature in rainy season is an indicator of animals that better regulate their body temperature.

In summary, the IR temperature in the dry season represented the heat exchange by cutaneous

evaporation. Therefore, animals with higher temperature were dissipating more heat, leading to a better thermoregulation, which consequently improved ADG. In the rainy season, the forehead IR temperature represented a measure of animal core temperature. Therefore, an animal with a lower temperature indicates a lower heat production and better utilization of other thermoregulation mechanisms and, consequently, improved daily gain.

The animal's ability to cope with heat stress had a higher impact on the animal performance during the dry season when the environmental challenge is higher (high temperature with poor nutrition). The infrared temperature was able to capture this animal response to the environment and consequently the impact of this environment conditions in animal performance. The IR temperatures and ADG were positively correlated in the dry season and negatively correlated in the rainy season. The genetic groups and FPS did not change these relationships. Therefore, dewlap and forehead infrared temperature measurement can be used to predict the animal performance, mainly during the dry season.

SUPPLEMENTARY DATA

Supplementary data are available at *Journal of Animal Science* online.

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