UNIVERSIDADE FEDERAL DE PELOTAS
Faculdade de Veterinária
Programa de Pós-Graduação em Veterinária

Dissertação

Termotolerância na raça Angus

Caroline Farias Soares Falson

Pelotas, 2023

Caroline Farias Soares Falson

Termotolerância na raça Angus

Dissertação apresentada ao Programa de Pós-Graduação em Veterinária da Faculdade de Veterinária da Universidade Federal de Pelotas, como requisito parcial à obtenção do título de Mestre em Ciências (área de concentração: Reprodução e Patologia Animal).

Orientador: Rafael Gianella Mondadori

Coorientadores: Bernardo Garziera Gasperin e Juliana Sarubbi

Pelotas, 2023

Universidade Federal de Pelotas / Sistema de Bibliotecas
Catalogação da Publicação

F197t Falson, Caroline Farias Soares

Termotolerância na raça Angus [recurso eletrônico] / Caroline Farias Soares Falson ; Rafael Gianella Mondadori, orientador ; Bernardo Garziera Gasperin, Juliana Sarubbi, coorientadores. — Pelotas, 2023.
64 f.

Dissertação (Mestrado) — Programa de Pós-Graduação em Veterinária, Faculdade de Veterinária, Universidade Federal de Pelotas, 2023.

1. Adaptabilidade. 2. Termorregulação. 3. Hipertermia. 4. Bovinos de corte. 5. Clima tropical. I. Mondadori, Rafael Gianella, orient. II. Gasperin, Bernardo Garziera, coorient. III. Sarubbi, Juliana, coorient. IV. Título.

CDD 636.213

Elaborada por Gabriela Machado Lopes CRB: 10/1842

Caroline Farias Soares Falson

Termotolerância na raça Angus

Dissertação aprovada como requisito parcial para obtenção do grau de Mestre em Ciências, Programa de Pós-Graduação em Veterinária, Faculdade de Veterinária, Universidade Federal de Pelotas.

Data da Defesa: 23/02/2023

Banca examinadora:

Prof. Dr. Rafael Gianella Mondadori (Orientador)
Doutor em Ciências Biológicas pela Universidade de Brasília

Prof. Dr. Fernando Flores Cardoso
Doutor em Zootecnia pela Michigan State University

Prof. Dr. Rogério Ferreira
Doutor em Medicina Veterinária pela Universidade Federal de Santa Maria

Dr. José Victor Vieira Isola
Doutor em Medicina Veterinária pela Universidade Federal de Pelotas

Dedico este trabalho ao meu esposo, João Pedro Soares Falson, que esteve ao meu lado em todos os momentos, sendo meu braço direito, amigo e incentivador.

Agradecimentos

Agradeço primeiramente à Deus, pela vida, pelas oportunidades que surgem no meu caminho e por me entregar a calma quando eu mais precisei.

Ao meu pai, Marco Aurélio, que foi meu melhor amigo desde sempre e que se mantém ao meu lado, sempre positivo, parceiro e disposto para tudo.

Ao meu esposo, João Pedro, por segurar a barra quando eu precisei, pelo carinho, suporte e amor.

Aos meus sogros Ana Thereza e Bernardo e meu cunhado Luiz Antônio, por serem minha segunda família e me acolherem com carinho sempre.

Ao meu orientador, Rafael Gianella Mondadori, que é o maior responsável por eu chegar ao final deste trabalho e do mestrado, exemplo de professor e orientador, “um pai”.

Aos demais professores do Grupo FiBRA, Bernardo, Arnaldo e Thomaz, por todas as contribuições ao longo destes dois anos.

À minha companheira de mestrado, Jéssica Lazzari, e à Ísis Soares, da graduação, que me auxiliaram em tempo integral no experimento e que foram amigas e criaram muitas memórias e histórias comigo.

À UFPel e à CAPES, pela oportunidade da pós-graducação.

Ao proprietário da Fazenda da Barragem, Fernando Cardoso, e ao Mateus Pivato, da Associação Brasileira de Angus, pela parceria no trabalho, disponibilidade e incentivo.

Aos funcionários da Fazenda da Barragem, em especial ao Médico Veterinário Carlos Laske, pela disponibilidade de mudar toda sua rotina para o bem do experimento.

Sem todo apoio que tive, não estaria aqui hoje. Obrigada.

“Es mejor que aprender mucho, el aprender cosas buenas.”
Martín Fierro – José Hernandez

Resumo

FALSON, Caroline Farias Soares. **Termotolerância na raça Angus.** 2023. 64f. Dissertação (Mestrado em Ciências) - Programa de Pós-Graduação em Veterinária, Faculdade de Veterinária, Universidade Federal de Pelotas, Pelotas, 2023.

Embora o consumo interno de carne tenha diminuído no Brasil, as exportações alcançaram níveis recordes nos últimos anos. Os estados do sudeste, centro oeste e norte representam a maior parcela de produção e o clima tropical limita o uso da raça Angus, cuja criação poderia contribuir com o aumento das qualidades sensoriais da carne. O objetivo deste estudo foi avaliar a associação da pelagem (preta ou vermelha) e do pelame (classificado de 1 à 3, de acordo com as características de comprimento e espessura do pelo) no desempenho produtivo e reprodutivo de novilhas angus. Os animais foram avaliados em 3 momentos, com intervalo de 45 dias, sendo a terceira realizada em janeiro de 2022, quando as novilhas tinham 18 meses de idade. Nas três avaliações os animais foram pesados e classificados quanto ao Escore de Condição Corporal (ECC) e Escore de Trato Reprodutivo (ETR) e na avaliação de janeiro, além das já citadas, foram feitas coletas de temperatura interna (TI - termômetro intravaginal), temperatura superficial (TS - Termografia infravermelha), taxa de sudação e coletas de sangue para avaliação de cortisol sérico, além da mensuração do Índice de Temperatura e Umidade (THI), para melhor compreensão dos resultados. Os resultados indicaram que a cor da pelagem está relacionada com ETR e TI, sendo que os animais de pelagem preta tiveram um maior índice de ciclicidade, menor TI e também passaram menos tempo em hipertermia. O pelame, por sua vez, esteve relacionado com peso, ECC e TI, sendo que os animais com pelames maiores, principalmente o 3, tinham menor peso, menor ECC e passaram mais tempo em hipertermia em relação aos com pelames menores. A taxa de sudação e a TS não foram diferentes entre os diferentes fenótipos. Os dados de THI foram divididos em quartis, visando avaliar sua influência na TI dos animais. De uma maneira geral, animais vermelhos e de pelame 3 tiveram maior TI e passaram mais tempo em hipertermia em relação aos demais, em todos os quartis. Os animais vermelhos também apresentaram níveis mais altos de cortisol sérico em relação aos pretos. Contudo, outros estudos precisam ser realizados para aumentar o tamanho da amostra e a acurácia das avaliações, que servirão de base para a seleção de animais termotolerantes.

Palavras-chave: adaptabilidade; termorregulação; hipertermia; bovinos de corte; clima tropical

Abstract

FALSON, Caroline Farias Soares. **Thermotolerance in Angus breed.** 2023. 64f. Dissertation (Master degree in Sciences) - Programa de Pós-Graduação em Veterinária, Faculdade de Veterinária, Universidade Federal de Pelotas, Pelotas, 2023.

Although meat consumption has decreased in Brazil, exports reached record levels last year. The southeast, central-west, and north states are responsible for the largest volume of production, and the tropical climate limits the use of the Angus breed. The breed could contribute to increasing the sensory qualities of meat. The aim of this study was to evaluate the association of coat color (black or red) and hair coat (classified from 1 to 3, according to the length and thickness of the hair) on the productive and reproductive performance of Angus heifers. The animals were evaluated three times every 45-days, with the third evaluation taking place in January 2022 when the heifers were 18 months old. During all three evaluations, the animals were weighed and classified according to Body Condition Score (BCS) and Reproductive Tract Score (RTS), and in January, in addition to the above, data was collected on internal temperature (IT - intravaginal thermometer), surface temperature (ST - Infrared thermography), sweating rate, and blood samples were collected for serum cortisol evaluation, as well as measurement of the Temperature and Humidity Index (THI) to better understand the results. The results indicated that coat color is related to RTS and IT, with black-coated animals having a higher index of cyclicity, lower IT, and remaining less time in hyperthermia. Hair coat, in turn, was related to weight, BCS, and IT, with animals with thicker coats, particularly coat 3, having lower weight, lower BCS, and spending more time in hyperthermia compared to those with thinner coats. Sweating rate and ST were not different between the different phenotypes. THI data was divided into quartiles to evaluate its influence on animal IT. In general, red and coat 3 animals had higher IT and spent more time in hyperthermia compared to others in all quartiles. Red animals also had higher serum cortisol levels compared to black ones. However, further studies need to be conducted to increase the sample size and accuracy of evaluations, which will serve as a basis for selecting thermotolerant animals.

Keywords: adaptability; thermoregulation; hyperthermia; beef cattle; tropical weather

Lista de Figuras

Lista de Tabelas

Lista de Abreviaturas e Siglas

ºC	Graus Celsius
cm	Centímetros
ECC	Escore de Condição Corporal
ETR	Escore de Trato Reprodutivo
Fig	Figura
Tab	Tabela
THI	Índice de Temperatura e Umidade
TI	Temperatura interna
TS	Temperatura superficial

Sumário

1 Introdução

O Brasil atualmente possui o maior rebanho bovino do mundo, com 238 milhões de cabeças (IBGE, 2023) e figura também como segundo maior produtor de carne bovina, atrás apenas dos Estados Unidos (USDA, 2022). Embora o consumo *per capita* de carne bovina tenha caído em nosso país, as exportações cresceram e hoje aproximadamente 35% do produto nacional é exportado para outros países, como China (45,2%), Egito (13%) e EUA (4,9%) (IBGE, 2022).

Dentro do país, a maior produção de carne bovina vem dos estados do centro oeste e sudeste (IBGE, 2023), regiões de clima tropical, onde a maioria do gado é de origem zebuína, devido à sua melhor adaptação aos climas quentes. Contudo, há um grande apelo comercial pela melhora das características organolépticas da carne, principalmente relacionadas com grau de marmoreio e maciez nos cortes, que são encontrados predominantemente nas raças europeias, como o Angus e o Hereford.

A demanda da expansão das raças europeias para o restante do Brasil esbarra nas condições climáticas e na adaptabilidade dos animais e hoje vem sendo feita em cruzamentos industriais por meio do uso da inseminação artificial (IA), produzindo animais meio sangue que conseguem se desenvolver em um clima mais quente e agregar características desejáveis de carcaça. O uso das raças puras ainda esbarra nas dificuldades de adaptação, tornando importante a busca por animais termotolerantes (MACEDO et al., 2014; MATEESCU et al., 2017; DAVILA et al., 2019).

A raça Angus, juntamente com o Nelore, domina o mercado de venda de sêmen de corte no Brasil (DBO, 2021) – em 2020, 86% do total de doses comercializadas foi dividido entre as duas raças. Sendo as raças europeias originárias de ambientes temperados, condições adversas, principalmente nas estações mais quentes, geram estresse térmico e consequente perda produtiva (MATEESCU et al., 2017).

Nos rebanhos leiteiros, há uma maior gama de estudos referentes à busca pela termotolerância, visto que os prejuízos podem chegar a 40 bilhões de dólares por ano, apenas em função do estresse térmico (THORNTON et al., 2022). As perdas começam quando a termorregulação é ineficiente e resultam em redução da produção de leite, redução de sólidos no leite e aumento dos problemas sanitários (COLLIER et al., 2017).

Alguns estudos já tem demonstrado que a cor da pelagem influencia diretamente na termotolerância dos animais, pois pelagens mais escuras, como a preta, possuem uma elevada absorbância de calor (SILVA et al., 2003; BROWN-BRANDL, 2006). Além da pelagem, outras características já vêm sendo buscadas em alguns programas de melhoramento genético, como o pelame, relacionado as características da conformação do pelo, estando associadas com a capacidade do animal de trocar calor com o ambiente (PROMEBO, 2018). O pelo alto funciona como isolante térmico e dificulta a dissipação do calor para o ambiente.

Além das características fenotípicas que influenciam na termotolerância, há uma gama de genes específicos que estão diretamente relacionados com a adaptação dos animais, como é o caso do gene do pelo liso (Slick Hair Gene), que confere aos animais uma pelagem lisa, curta e brilhante quando em dominância, favorecendo as trocas de calor por evaporação, que é o principal meio de dissipação de calor dos bovinos (DIKMEN et al., 2008).

Em bovinos de leite, os principais genes estudados são aqueles relacionados com as proteínas de choque térmico (HSP), importantes ferramentas durante os períodos de estresse, pois evitam a degradação e desnaturação celular, mantendo suas estruturas saudáveis (COLLIER et al., 2008). A HSP70 é a proteína mais utilizada atualmente como marcador bioquímico de estresse por calor, pois é uma das primeiras proteínas a serem expressas quando o organismo entra em estresse (HASSAN et al., 2019).

Sendo assim, é necessário avaliar quais destas características, como cor e conformação do pelo, são efetivas para uma melhor regulação da homeostase nos bovinos, permitindo futuramente a seleção de animais com características de maior termotolerância. A partir da identificação da real influência destas características na adaptação animal, será possível a realização de manobras para expansão das raças europeias para os ambientes tropicais.

2 Revisão da Literatura

O estresse térmico se dá quando o organismo é incapaz de dissipar calor de forma efetiva e o calor ambiental se soma ao metabólico, elevando a temperatura corporal e causando danos produtivos e de bem estar animal (DIKMEN & HANSEN, 2009). Nos bovinos leiteiros, quando o organismo não consegue contornar o desafio de calor, observa-se diminuição da produção de leite, diminuição da produção e da porcentagem de gordura no leite, redução nos sinais de cio, queda de imunidade e aumento da contagem de células somáticas (COLLIER et al., 2017).

Em relação ao ambiente em que os animais se encontram, é possível utilizar o Índice de Temperatura e Umidade (THI) como base para determinar se os animais estão ou não em um ambiente de desafio (NOAA, 1976). A literatura relata que um animal estaria em estresse em THI superior a partir de 72, mas estes limiares podem variar de acordo com a genética, a raça e características do indivíduo (POLSKY & VON KEYSERLINGK, 2017). Para uma melhor compreensão dos organismos, é importante avaliar a resposta individual de cada animal, como a sudação e alterações na temperatura interna (WEST et al., 2003).

A temperatura interna e suas variações ao longo do dia fornecem informação que facilita a compreensão da rotina fisiológica dos animais, porém a mensuração manual frequente pode prejudicar a veracidade dos dados em função do manejo e da presença de humanos (BURDICK et al., 2012). A temperatura superficial dos animais, por sua vez, pode fornecer dados de estresse térmico de forma fácil e precoce, através da termografia infravermelha, sendo correlacionada positivamente com a temperatura interna (PENG et al., 2019).

Para reduzir a influência do manejo sobre os resultados, uma opção viável é o uso de termômetros intravaginais, que fazem mensurações da temperatura interna em intervalos programados e não interferem no comportamento animal. Outra vantagem é a possibilidade de manutenção deste termômetro por vários dias e sua maior sensibilidade em relação à temperatura corporal, quando comparado com a temperatura retal (BURDICK et al., 2012; KAUFMAN et al., 2018).

Ainda falando sobre a seleção de características que propiciem uma melhor adaptação aos animais, estudos mostram que animais com pelagem mais clara tem vantagens em ambientes quentes pela menor absorbância de radiação e também melhor refração do calor. Em estudos realizados por BROWN-BRANDL (2006) se identificou que animais pretos da raça Angus tiveram maior frequência respiratória (FR), maior taxa de ofegação (TO) e maiores temperaturas de superfície corporal em relação à outras raças de pelagem vermelha ou branca. A adaptação depende de fatores ambientais e genéticos e, como a genética é herdável, é preciso focar na seleção destas características de adaptação para a seleção de animais que produzam mais e com melhor conforto nos diferentes climas.

Segundo Dikmen et al. (2008), características de pelos finos, lisos e curtos estão relacionadas com melhor tolerância às altas temperaturas, pois facilita as trocas de calor por condução e convecção. Vacas portadoras do gene Slick Hair, quando submetidas à estresse térmico, apresentaram menor temperatura intravaginal, retal e superficial, menor intervalo entre partos, menor frequência respiratória e maior produção de leite (DIKMEN et al., 2008; DIKMEN et al., 2014; CONTRERAS-CORREA et al., 2016; SANCHEZ-RODRIGUEZ, 2019; ORTIZ-URIARTE et al., 2020).

Em animais com pelos grossos e compridos, acaba formando-se uma camada de ar na superfície da pele, que atua como isolante térmico, prejudicando as perdas de calor por evaporação. O aumento da sudorese é o primeiro mecanismo em casos de estresse térmico, juntamente com o aumento da frequência respiratória e, quando não são suficientes, ocorre o aumento da temperatura corporal do animal, intensificando ainda mais estas reações (POLSKY & VON KEYSERLINGK, 2017). A partir daí, são observadas mudanças mais acentuadas no comportamento, como aumento da ingestão hídrica, diminuição da ingestão de matéria seca, do tempo de pastejo e do tempo de ruminação (COLLIER et al., 2017).

3 Artigo

Thermotolerance in Angus cattle is related to hair coat characteristics but not to coat color

Caroline Oliveira Farias; Jessica Lazzari; Ísis Soares da Cunha; Paulo Bayard Dias Gonçalves; Bernardo Garziera Gasperin; Thomaz Lucia Jr; Eduardo Schimitt; Fernando Flores Cardoso; Juliana Sarubbi; Rafael Gianella Mondadori.

Publicado na revista Journal of Thermal Biology, v. 124, 103945, 2024.

Thermotolerance in Angus cattle is related to hair coat characteristics but not to coat color

Abstract

This study evaluated the impact of coat color (CC) and hair coat characteristics (HC) on productive and physiological traits related to thermotolerance in Angus heifers. The goal was to determine if HC and/or CC were reliable indicators of thermotolerance on a large scale for future breeding programs. Ninety-three 15-month-old Angus heifers (52 black, 41 red) were evaluated in three periods on a beef cattle farm in Brazil. Heifers were classified by CC and HC, and body weight, body condition score (BCS), and reproductive tract score (RTS) were compared between groups. In the summer evaluation, surface temperature (infrared thermography), internal temperature (intravaginal sensors), sweating rate, and behavior were assessed in a subset of heifers. Temperature-humidity index (THI) was calculated using meteorological data. The proportion of heifers with short, fine, and smooth hair (HC1) increased ($P < 0.05$) over the evaluations. Heifers with thick, long, and woolly hair (HC3) had lower ($P < 0.05$) body weights than those with finer coats, regardless of CC. Black heifers had greater ($P < 0.05$) puberty rates than red heifers in the first two evaluations. At a THI of 66, black heifers with HC1 exhibited a lower ($P < 0.05$) internal temperature compared to black heifers with HC3. At a THI of 75, all heifers with HC1 had lower ($P < 0.05$) internal temperatures, regardless of CC. Red heifers and those with HC3 experienced hyperthermia for longer ($P < 0.05$) periods. Neither HC nor CC affected ($P > 0.05$) surface temperatures or sweating rates. At a THI of 72, more black heifers remained standing, suggesting behavioral adaptation. In conclusion, coat color and characteristics influence thermal stress and performance in Angus heifers, though color impact is limited. Internal temperature monitoring

effectively determines thermotolerance. In tropical regions, selecting for short, fine, smooth hair may improve heat tolerance.

Keywords: heat stress, hyperthermia, infrared thermography, intravaginal sensors, tropical climate

1. Introduction

Brazilian beef production is the second largest in the world (IBGE, 2022). It faces numerous challenges due to high consumer demands regarding meat quantity and quality (Fernandez-Novo et al., 2020). Two-thirds of the country are in tropical climate zones, posing a challenge to produce high-quality meat from cattle in hot environments (Alvares et al., 2013).

The temperature-humidity index (THI) impacts animal performance and wellbeing, positively correlating with the activation of thermoregulatory mechanisms (Hammond et al., 1996). Failure in the animal's ability to maintain a stable body temperature and adjust to changes in the environment provokes heat stress (Silanikove, 2000), which decreases production and reproductive performance and animal welfare (Pires et al., 2019; Cordeiro et al., 2020; Aguilar-Quiñones et al., 2022).

Brazilian beef cattle herds use predominantly *Bos taurus indicus*, which are adapted to warm environments (Aguilar-Quiñones et al., 2022). However, *Bos taurus taurus* cattle have more tender meat (Wright et al., 2018) and reach maturity earlier than *B. indicus* cattle. Thus, crossbreeding these subspecies produces cattle with improved performance and meat quality, primarily by selecting *B. taurus* cattle adapted to hot environments (Davila et al., 2019).

Previous studies have shown that coat color and hair coat characteristics influence animal performance at high ambient temperatures due to different heat absorbance and thermal insulation properties (Brown-Brandl et al., 2006; da Silva et al., 2003). Coat color primarily influences heat absorbance, with black hair absorbing 90% of heat, red hair absorbing 70%, and white hair absorbing 40% (Stewart, 1953). High environmental temperature increases internal and superficial body temperature and changes herding and shade-seeking behavior. Cutaneous evaporation can account for up to 70% of evaporative heat loss, and a shorter hair coat promotes these exchanges (Maia et al., 2003; de Souza et al., 2018; Giro et al., 2019). Considering its importance in facilitating heat exchange with the environment, hair coat characteristics are already used in Brazil's genetic improvement programs (da Silveira et al., 2021; ANC, 2023).

In addition to physiological stress indicators, we also considered reproductive development as a potential indicator of heat tolerance. The reproductive tract score in heifers predicts fertility and lifetime production of the cows (Holm et al., 2009), making it an essential tool for evaluating reproductive performance in the context of heat stress adaptation.

Despite the existing research on the impact of coat color and hair characteristics on the productive performance of beef cattle in warm environments, there is a need for more focused field trials to understand better the relationship between these factors and animal performance, particularly in Angus cattle. We hypothesize that coat color and hair coat characteristics significantly influence body weight gain, body condition score, reproductive tract score, superficial and internal body temperature, sweating rate, and behavior in Angus heifers subjected to high THI environment.

Therefore, this study aimed to evaluate the relationship of both coat color and hair coat characteristics with the variables mentioned above in Angus heifers subjected to moderate THI environment. In addition to making it possible to evaluate these relationships, the results of this study will identify easily accessible variables that reflect the thermotolerance of Angus cattle. This may be applied in breeding programs to improve the adaptation of *B. taurus* cattle to high THI environments, including those more severe than the conditions in this study, ultimately enhancing animal welfare and productivity, influencing the general quality of beef production.

2. Materials and Methods

The Committee for Ethics in Animal Experimentation of the Universidade Federal de Pelotas (UFPel) approved all animal procedures (134/2021/CEUA/REITORIA).

2.1 Animals and location

The study was conducted on a commercial beef cattle farm in Dom Pedrito, Rio Grande do Sul state, Brazil (31°02'52.7"S 54°52'04.1"W). The farm is located at an elevation between 100 and 200 meters above sea level. According to the Köppen climate classification, the region has a humid subtropical climate, classified as Cfa (Sparovek et al., 2007). The mean annual temperature is 18.5°C, and the total annual rainfall is 1,400 to 1,600 mm, evenly distributed throughout the year.

The evaluations were conducted at 45-day intervals in three periods: the first two during the spring (October and November) and the third in the summer (January). Ninety-three contemporary 15-month-old Angus heifers were included in the present study, with 52 being black and 41 red. Heifers were initially kept together in cultivated pastures (Ryegrass, *Lolium multiflorum*) and later transferred to native pastures (Carvalho et al., 2006), with a stocking rate of 335 kg live weight/hectare. Animals also had free access to water (pond), mineral salt, and shade from trees (*Eucalyptus* spp.). All heifers were dewormed before the beginning of the study.

2.2 Animal evaluations

The evaluations described in this section were consistently performed at the three predetermined assessment times: October, November, and January. In addition to their coat color, heifers were classified according to their hair coat characteristics: heifers with short, fine, and smooth hair (HC1); heifers with thick, long, and woolly hair (HC3), and those with intermediate hair characteristics (HC2; ANC, 2023). Heifers were weighed using an electronic scale (TRU TEST®), and average daily gain (ADG) was calculated based on the assessment's weight difference. They were also classified according to their body condition score (BCS) on a scale of 1 to 5 (Lowman et al., 1976), where 1 represented emaciated animals, and 5 represented obese animals. Heifers were then divided into three categories of BCS: lower than 3, 3, and higher than 3.

The reproductive tract score (RTS) was evaluated as described by Holm et al. (2009), using a score ranging from 1 to 5, with 1 being a prepubertal, infantile tract and 5 being a pubertal tract in luteal phase. This scoring system assesses the development of the uterus and ovaries in heifers, indicating their pubertal status. RTS is determined by rectal palpation, and it is a repeatable screening test that evaluates pubertal status in groups of heifers (Rosenkrans and Hardin, 2003). In our study, heifers were considered prepubertal if they had an RTS of 1, 2, or 3, whereas heifers were considered pubertal if they had a RTS of 4 or 5. A single experienced veterinarian performed all RTS evaluations to ensure consistency and reliability of the assessments.

Additionally, the third evaluation, conducted during Summer, followed the timeline described in Figure 1.

2.3 Surface and internal body temperature

Surface and body temperature were evaluated in 37 heifers (18 red and 19 black), with similar hair coat distribution in each category of coat color. Surface temperature was measured using infrared thermography (Testo 870-1® Super Resolutions), equipped with a camera with an accuracy of ± 2ºC and an infrared spectral range of 7.5-14.0 μ. Heifers were restrained in a chute every two days, where their left flank was thermographically scanned at a distance of 3 m. A rectangle was outlined in the flank image for temperature analysis, and a histogram of this area was created. Subsequently, the rectangle's average, minimum, and maximum temperatures were recorded (Montanholi et al., 2008).

Sensors (DS1921G-F5# iButton) were inserted in an adapted silicone intravaginal device initially designed for slow progestogen release in estrous synchronization protocols to measure the internal temperature. The silicone portion of the device, containing the progesterone, was removed and replaced by inert silicone hoses. The sensors remained in the heifer's vagina for eight days and were programmed to record temperature every 15 minutes. To assess the percentage of time that heifers experienced hyperthermia, a body temperature exceeding 39.2°C was the cut-off point (Smith et al., 1998).

2.4 Sweating rate

The sweating rate was assessed every other day, immediately after the thermographic evaluation, using the method described by Schleger and Turner (1965). First, an adhesive tape with three filter paper discs, each saturated with a 10% cobalt chloride solution, was attached to a clean, trichotomized area of the animal's skin, close to the dorsal margin of the scapula. The time was recorded for all three discs to change color from blue-violet hue (dry) to light pink shade (wet). This mean time, measured in seconds (t), was then substituted into the formula: sweating rate ($g/m^2/h$) = (22 * 3600) / (2.06 * t).

2.5 THI

The THI was calculated every hour during the assessment period using the equation provided by NOAA (1976): "THI = (1.8 x DT + 32) - (0.55 - 0.0055 x RH) x [(1.8 x DT + 32) - 58]", where DT represents the dry-bulb temperature and RH refers to the relative air humidity. The data were obtained from an official automated meteorological station 24 km from the beef cattle farm at 150 m above sea level.

For the October and November evaluation days, which focused on assessing reproductive status and development (BCS and RTS), we recorded average daily THI values. The mean THI for the October evaluation day was 57.10, while for the November evaluation day it was 65.63. For analysis purposes, the THI data collected during the January (summer) evaluation period were categorized into quartiles. The specific ranges for each quartile were determined based on the observed THI distribution and are presented in the Results section.

2.6 Behavioral assessment

As described in Figure 1, the heifers' behavior was monitored every two days in the native pasture, where heifers had free access to water, shade, and mineral salt. The evaluations involved a 1-hour observation period within a 2-hour interval conducted between 08:00 and 17:00. Observations were conducted at the maximum feasible distance using binoculars, with heifers identified by a number on the flank. The behavior was evaluated based on the heifers' location (either shade or sun), position (either standing or lying down), and activity (ruminating, grazing, or resting) at the time of the observation.

2.7 Statistical analysis

The statistical model used was a 2 x 3 factorial arrangement, with coat color (2 levels: black and red) and hair coat characteristics (3 levels: HC1, HC2, HC3) as factors. The interaction between hair color and hair coat was tested in analyses of variance models. When the interaction was significant, the results were presented with the animals divided into six groups, representing the three categories of hair coat characteristics within each coat color (black and red). In cases where the interaction was insignificant, the results were presented separately for hair color and hair coat characteristics.

Body weight and ADG were compared within each period. Body weight was analyzed using analysis of variance; in contrast, ADG was analyzed using the Kruskal-Wallis analyses of variance for non-parametric data, due to a lack of normality ($P < 0.05$) for this variable, as determined by the Shapiro-Wilk test.

Frequencies of BCS and RTS (puberty status) were also compared across categories within each evaluation period through either the Chi-square test or the Fischer's exact test, depending on the sample size within each category.

THI data obtained during the evaluation period were grouped into four quartiles: Q1, from 55.670 to 62.615; Q2, from 62.616 to 65.719; Q3, from 65.720 to 69.435; and Q4, from 69.436 to 75.538. Afterward, the frequency of time spent in hyperthermia was compared among categories of coat color and hair coat characteristics and their interaction within each temperature quartile, using either the Chi-square test or the Fischer's exact test.

The frequencies of distinct behaviors were compared among categories of coat color and hair coat characteristics and their interaction at the lowest and greatest THI measured during the evaluations, which were 61 and 72, respectively. Such comparisons were conducted with either chi-square or Fischer's exact test, depending on the sample size within each category.

Due to a lack of normality, as determined by the Shapiro-Wilk test, sweating rate data were converted to a logarithmic scale. After that, a Pearson correlation analysis was performed to assess the relationship between sweating rate and THI and the data were compared using analysis of variance across categories of THI, coat color, hair coat, and their interactions, with adjustment for the individual effect of heifers.

For all analyses of variance models, means comparisons were conducted with the Tukey test at a significance level of 0.05. The internal temperature data were analyzed through the linear mixed model in R-nlme Package (Pinheiro et al., 2023; Team, 2023), whereas the remaining data were analyzed with Statistix® (2013). The Tukey test also compared the average internal temperatures at THI 56, 66 and 75.

3. Results

Figure 2 depicts the fluctuation of the THI recorded during the 8-day evaluation period in January. The THI values ranged from a minimum of 55.67 to a maximum of 75.54, indicating a substantial variation in the environmental conditions experienced by the cattle. The graph also clearly illustrates the diurnal pattern of THI, with distinct changes observed throughout the 24-hour cycle.

As shown in Table 1, there was a shift in the distribution of heifers with distinct hair coat characteristics among assessment periods. From October to November, the frequency of heifers with HC1 increased, while the frequency of heifers with HC2 decreased ($P < 0.05$). However, the proportion of heifers with HC3 did not differ across evaluation periods ($P > 0.05$).

3.1 Weight, ADG, and BCS

A significant interaction (P = 0.012) between hair color and hair coat characteristics for body weight was observed only in the first evaluation (October). No significant interactions (P > 0.05) were found in the second and third evaluations for this variable. During the October evaluation, black heifers with HC1 (286.57 ± 7.88 kg), red heifers with HC1 (280.02 ± 6.35 kg), and black heifers with HC2 (273.18 ± 4.34 kg) exhibited the greatest (P < 0.05) mean body weight. The lowest (P < 0.05) body weight was observed in red (244.19 ± 11.12 kg) and black (258.7 ± 5.94 kg) heifers with HC3. The body weight of red heifers with HC2 (263.81 ± 4.76 kg) was similar (P > 0.05) to that of black heifers within the same hair coat characteristics. In summary, HC1 heifers had the greatest body weight for both coat colors, while HC3 heifers had the lowest.

In the November evaluation, body weight did not differ between black (309.6 ± 4.8 kg) and red (204.5 ± 4.9 kg) animals. However, animals with HC1 (317.48 ± 6.65 kg) had a significantly higher body weight (P < 0.05) compared to those with HC2 (306.2 kg ± 4.5) and HC3 (297.5 ± 6.3 kg). During the summer evaluation (January), body weight also differed significantly (P < 0.05) only among animals with different hair coat characteristics. Heifers with HC1 had the highest body weight (322.9 ± 5.6 kg), followed by those with HC2 (309.3 ± 3.9 kg) and HC3 (298.7 ± 4.9 kg). Average daily gain across periods was 0.544 ± 0.034 kg, with no differences (P > 0.05) between red and black heifers or among hair coat categories.

Across assessment periods, BCS did not differ (P > 0.05) for red and black heifers (Table 2). In October (spring) and January (summer), BCS did not differ (P > 0.05) in heifers with different hair coat characteristics. However, in November, when the heifers were 16.5 months old, HC3 heifers presented a lower (P = 0.001) BCS compared to HC1 and HC2 heifers, which did not differ from each other (Table 2).

3.2 Reproductive tract score (RTS)

In October and November, the frequency of black heifers reaching puberty was greater ($P = 0.04$ and $P = 0.005$, respectively) than red heifers (Figure 3A). In all three assessment periods, there was no difference ($P > 0.05$) in the frequency of pubertal heifers based on their hair coat characteristics (Figure 3B).

3.3 Internal temperature

During summer, at a THI of 56, the average internal temperature was 38.61°C, with no differences ($P > 0.05$) between red or black heifers or heifers with different hair coat characteristics. At THI of 66, black heifers with HC1 exhibited a lower ($P < 0.0001$) internal temperature (38.9°C) compared to black heifers with HC3 (39.2°C).

The internal temperatures for heifers in both categories did not differ ($P > 0.05$) from black heifers with HC2 (38.97 °C). Additionally, there were no differences ($P > 0.05$) in internal temperatures among red heifers with different hair coats characteristics. With THI of 75, HC1 heifers had lower ($P < 0.05$) internal temperatures (40.2 °C) than HC2 and HC3 heifers (40.6 °C and 40.8 °C, respectively) regardless of CC.

3.4 Superficial temperatures and hyperthermia

Considering the entire study period, the frequency of hyperthermia periods in red heifers (44.9%) was greater ($P < 0.0001$) than in black heifers (38.7%). The frequency of hyperthermia periods also differed ($P < 0.05$) for HC3 (51.9%), HC2 (38.8%), and HC1(36.8%) heifers. Except for Q3, red heifers were in hyperthermia for longer periods ($P < 0.05$) in all THI quartiles (Table 3). In Q2 and Q4, heifers with HC3 presented longer periods of hyperthermia ($P < 0.05$), indicating lower efficiency in heat exchange with the environment. No differences were observed ($P > 0.05$) in average surface temperatures between black (34.3 ºC) and red heifers (34.0 ºC) or among those with different hair coat characteristics.

3.5 Animal behavior

At a THI of 61, heifers with different coat color and hair coat characteristics exhibited similar behavior (Table S1). However, at a THI of 72, a greater frequency of black heifers remained standing ($P = 0.01$) compared to red heifers (Table 4). No other differences in behavioral characteristics were detected ($P > 0.05$).

3.6. Sweating rate

Sweat was not associated ($P > 0.05$) with coat color and hair coat characteristic. However, the sweating rate increased ($P < 0.05$) with increased THI, regardless of both coat color and hair coat characteristics (Figure 4). Also, a strong positive correlation was observed between sweating rate and THI ($r = 0.92$, $P < 0.001$), indicating that as THI increased, the sweating rate of the heifers also increased significantly.

4. Discussion

This is the first study to assess various thermoregulation-related characteristics and associate them with coat color and hair coat characteristics in Angus heifers. The internal temperature was the variable that could be evaluated in a larger number of animals to implement breeding programs for thermotolerance. Our results demonstrate that hair coat characteristics have a more profound effect on animal performance than coat color. Moreover, the results indicate that there is minimal interaction between hair coat characteristics and coat color on the variables evaluated in the present study. Black heifers exhibited earlier cyclicity and had shorter periods of hyperthermia. Higher hair coat scores were generally associated with lower body weight, lower BCS, and higher internal temperature.

Previous research indicated that black Angus animals had lower body weights than red or white animals (Brown-Brandl et al., 2006). Nonetheless, no difference in ADG was observed between black and red Angus heifers in the present study, indicating that, within the same breed, the coat color did not influence this variable. In contrast to the results of the present study, Brown-Brandl et al. (2006), in a temperate climate, observed that dark-coated breeds (Angus and MARC III) spent less time feeding and exhibited more behavioral changes compared to light-coated breeds, suggesting that dark-coated animals may experience more heat stress. Similarly, Angus bulls had higher dry matter intake under thermoneutral conditions than Nelore bulls (Valente et al., 2015). However, in a warm environment, Angus bulls reduced their feed intake, just as *B. indicus* cattle do. These findings suggest that the variation in feed intake and body weight across breeds observed in the abovementioned studies was likely due to breed differences rather than coat color.

Although Angus heifers with both coat colors in the present study presented similar body weight, black heifers reached sexual maturity earlier than red heifers, as indicated by their RTS scores. Despite the influence of hair coat characteristics on body weight, BCS, and internal temperature, our study did not find a significant association between hair coat characteristics and the onset of puberty in Angus heifers. Previous studies have shown that feeding and reproductive function are affected by thermal stress (Baumgard and Rhoads Jr, 2013), and heat stress can impair ovarian function, decrease blood flow to the uterus, and increase uterine temperature, negatively affecting fertility (Reynolds et al., 1985; Wilson et al., 1998). However, the lack of effect in our study may be attributed to the genetic background of the heifers, which belonged to the same herd, and the moderate THI levels experienced by heifers during the evaluation period (maximum THI of 75).

The main factor that likely contributed to the lack of seasonal influence on the proportion of heifers with thick, long, and woolly hair (HC3) in our study was the genetic background of the animals (Sarlo Davila et al., 2019), considering that all belonged to the same herd. On the other hand, the increase in animals with short, fine, and smooth hair (HC1) at the expense of HC2 animals observed during the transition from spring to summer can be attributed to the influence of climatic factors on hair coat characteristics (Berman and Volcani, 1961; Bertipaglia et al., 2007).

To investigate potential associations of coat color and hair coat characteristics with animal comfort and wellbeing, indicators of behavioral traits were assessed in the present study. Animals experiencing discomfort exhibit behaviors consistent with changes in their circadian rhythm and the expected temperature throughout the day (Avendaño-Reyes et al., 2010). As rumination activity has been associated with improved rumen health (Schirmann et al., 2009), its decrease may indicate the presence of stressors or diseases (DeVries et al., 2009; Schirmann et al., 2009). Since the grazing behavior of animals can also be an indicator of thermal comfort, the availability of shades in pastures is essential to promote wellbeing, increasing grazing time and potentially enhancing weight gain (Souza et al., 2010). In some cases, cattle may increase rest time during periods of increased THI and decrease grazing time to reduce heat production (Borges et al., 2012). Our results demonstrate that the coat color and hair coat characteristics of Angus heifers did not significantly influence their behavior during most of the observations. The lack of behavioral differences among heifers in the various categories evaluated can probably be attributed to the maximum THI reaching 75 and the availability of shade for heifers.

Despite the lack of association with coat color, Angus heifers with higher hair coat characteristics scores generally presented lower body weight. This result could be attributed to the fact that HC3 heifers apparently had greater thermal insulation (Maia et al., 2003), which impairs heat exchange with the environment and reduces dry matter intake, consequently, weight gain (Aguilar-Quiñones et al., 2022). In November, HC3 heifers presented lower BCS, supporting the hypothesis that their grazing time was reduced, although this was not measured in the present study. As the reproductive system is the last system to mature in growing heifers, the nutritional status and behavioral changes resulting from heat stress should be carefully evaluated due to potential adverse effects on the ADG, body weight, and BCS (Holm et al., 2009), as occurred in HC3 heifers.

At the lowest THI (56), the internal temperature did not differ among Angus heifers with distinct coat colors and hair types. Meanwhile, at the highest THI (75), heifers with smoother and shorter hair (HC1) maintained lower internal temperature than those with longer and thicker hair (HC2 and HC3 heifers). Thermal stress increases body temperature, and sometimes, there may be little or no recovery at night (Brown-Brandl et al., 2006). Given that morphological coat characteristics, such as thickness and length, influence thermal insulation, it is crucial to aim for the lowest possible level of thermal insulation in tropical environments (Silva, 1999). Although a THI up to 74 may indicate a comfortable environment that may vary among breeds, depending on their productivity (Baena et al., 2019). In the present study, heifers remained hyperthermic even at lower THIs for significant periods.

Furthermore, even in less challenging environments, surface body temperature is influenced by dry bulb temperature, solar radiation, and wind speed, along with breed-specific factors (Baena et al., 2019). In the present study, the surface temperature was similar among heifers with different hair coat characteristics and color. However, black coats absorb more solar radiation (Stewart, 1953), although the effect of coat color on the animals' surface temperature is quite variable. Martello et al. (2004) reported that a surface body temperature between 31.6 ºC and 34.7 ºC in cattle does not indicate thermal stress. In our study, the average surface temperature of heifers did not exceed this limit, regardless of the hair coat characteristics and color. In contrast to our findings, a study with four breeds evaluated through infrared thermography (Brown-Brandl et al., 2006) showed that black (Angus) and dark red (MARC III) animals exhibited a higher surface body temperature compared to light red and white animals (Gelbvieh and Charolais, respectively). Moreover, Baena et al. (2019) reported a lower surface temperature for black Angus cattle than red Simmental cattle. In contrast, no difference between black Angus and white Nellore cattle was observed (Valente et al., 2015). Therefore, coat color apparently does not consistently influence the body surface temperature. In addition to the lack of homogeneity described in the studies mentioned above, which can be attributed to different variables, another factor that possibly contributed to the absence of differences in external temperature in our study was the homogeneity of the animals' breed.

Our study did not identify a relationship between coat color and hair coat characteristics with sweating rate. However, as THI increased, the sweating rate of the heifers also increased, regardless of their coat color or hair coat characteristics. This finding is consistent with the well-established physiological response of cattle to high THI, where increased sweating is a crucial mechanism for thermoregulation (de Souza et al., 2018).

5. Conclusions

The hair coat color and characteristics influence thermal stress and productive performance, even though coat color does not exert a great influence. Monitoring the internal temperature can efficiently determine thermotolerance in Angus cattle on a large scale. Mainly in tropical regions, the selection of animals with short, fine, and smooth hair may improve their tolerance to the challenge posed by high THI environments.

References

Aguilar-Quiñones, J.A., Avendaño-Reyes, L., Macías-Cruz, U., Guerra-Liera, J.E., Vicente-Pérez, R., Gastélum-Delgado, M.A., Barajas-Cruz, R., Wittayakun, S., Vicente-Pérez, A., 2022. Increasing shade area in feedlot heifers during heat stress: physiological and performance parameters. Trop. Anim. Health Prod. 54, 152. https://doi.org/https://doi.org/10.1007/s11250-022-03152-4

Alvares, C.A., Stape, J.L., Sentelhas, P.C., Gonçalves, J.L. de M., Sparovek, G., 2013. Köppen's climate classification map for Brazil. Meteorol. Zeitsch. 22, 711–728. https://doi.org/10.1127/0941-2948/2013/0507

ANC, 2023. Beef Cattle Improvement Program - PROMEBO [WWW Document]. National Association of Breeders "Herd-Book Collares." URL https://www.herdbook.org.br/site/ (accessed 1.9.23).

Avendaño-Reyes, L., Álvarez-Valenzuela, F.D., Correa-Calderón, A., Algándar-Sandoval, A., Rodríguez-González, E., Pérez-Velázquez, R., Macías-Cruz, U., Díaz-Molina, R., Robinson, P.H., Fadel, J.G., 2010. Comparison of three cooling management systems to reduce heat stress in lactating Holstein cows during hot and dry ambient conditions. Livest. Sci. 132, 48–52. https://doi.org/https://doi.org/10.1016/j.livsci.2010.04.020

Baena, M.M., Costa, A.C., Vieira, G.R., Rocha, R. de F.B., Ribeiro, A.R.B., Ibelli, A.M.G., Meirelles, S.L.C., 2019. Heat tolerance responses in a Bos taurus cattle herd raised in a Brazilian climate. J. Therm. Biol. 81, 162–169. https://doi.org/https://doi.org/10.1016/j.jtherbio.2019.02.017

Baumgard, L.H., Rhoads Jr, R.P., 2013. Effects of heat stress on postabsorptive metabolism and energetics. Annu. Rev. Anim. Biosci. 1, 311–337. https://doi.org/https://doi.org/10.1146/annurev-animal-031412-103644

Berman, A., Volcani, R., 1961. Seasonal and regional variations in coat characteristics of dairy cattle. Aust J Agric Res 12, 528–538. https://doi.org/https://doi.org/10.1071/AR9610528

Bertipaglia, E.C.A., da Silva, R.G., Cardoso, V., Fries, L.A., 2007. Hair coat characteristics and sweating rate of Braford cows in Brazil. Livest Sci 112, 99–108. https://doi.org/https://doi.org/10.1016/j.livsci.2007.01.159

Borges, C.R. de A., Azevedo, M. de, Lima, I. de A., Brasil, L.H. de A., Ferreira, M. de A., 2012. Heterogeneous genetic cows of three genetic groups in feedlot system in the state of Pernambuco, Brazil. Acta Sci 34, 91–96. https://doi.org/https://doi.org/10.4025/actascianimsci.v34i1.11306

Brown-Brandl, T.M., Nienaber, J.A., Eigenberg, R.A., Mader, T.L., Morrow, J.L., Dailey, J.W., 2006. Comparison of heat tolerance of feedlot heifers of different breeds. Livest Sci 105, 19–26. https://doi.org/https://doi.org/10.1016/j.livsci.2006.04.012

Carvalho, P.C. de F., Fisher, V., Santos, D.T. dos, Ribeiro, A.M.L., Quadros, F.L.F. de, Castilhos, Z.M.S., Poli, C., Monteiro, A.L.G., Nabinger, C., Genro, T.C.M., 2006. Produção animal no bioma campos sulinos. Brazilian Journal of Animal Science 35, 156–202.

Cordeiro, A.L.L., Satrapa, R.A., Gregianini, H.A.G., Gregianini, J.T.F., Maia, G.F.N., Landim-Alvarenga, F.C., 2020. Influence of temperature-humidity index on conception rate of Nelore embryos produced in vitro in northern Brazil. Trop Anim Health Prod 52, 1527–1532. https://doi.org/https://doi.org/10.1007/s11250-019-02141-4

Da Silva, R.G., La Scala Jr, N., Tonhati, H., 2003. Radiative properties of the skin and haircoat of cattle and other animals. Transactions of the ASAE 46, 913. https://doi.org/10.13031/2013.13567

Da Silveira, D.D., Tineo, J.S.A., Schmidt, P.I., Campos, G.S., de Souza, F.R.P., Roso, V.M., Boligon, A.A., 2021. Hair coat score in Angus cattle: Comparison of linear and threshold models, genetic gain and correlations with growth, morphological and reproductive traits. Livest Sci 249, 104512. https://doi.org/https://doi.org/10.1016/j.livsci.2021.104512

Davila, K.M.S., Hamblen, H., Hansen, P.J., Dikmen, S., Oltenacu, P.A., Mateescu, R.G., 2019. Genetic parameters for hair characteristics and core body temperature in a multibreed Brahman–Angus herd. J Anim Sci 97, 3246–3252. https://doi.org/10.1093/jas/skz188

De Souza Jr, J.B.F., de Queiroz, J.P.A.F., dos Santos, V.J.S., Dantas, M.R.T., de Lima, R.N., de Oliveira Lima, P., de Macedo Costa, L.L., 2018. Cutaneous evaporative thermolysis and hair coat surface temperature of calves evaluated with the aid of a gas analyzer and infrared thermography. Comput Electron Agric 154, 222–226. https://doi.org/https://doi.org/10.1016/j.compag.2018.09.004

DeVries, T.J., Beauchemin, K.A., Dohme, F., Schwartzkopf-Genswein, K.S., 2009. Repeated ruminal acidosis challenges in lactating dairy cows at high and low risk for developing acidosis: Feeding, ruminating, and lying behavior. J Dairy Sci 92, 5067–5078. https://doi.org/https://doi.org/10.3168/jds.2009-2102

Fernandez-Novo, A., Pérez-Garnelo, S.S., Villagrá, A., Pérez-Villalobos, N., Astiz, S., 2020. The effect of stress on reproduction and reproductive technologies in beef cattle—A review. Animals 10, 2096. https://doi.org/https://doi.org/10.3390/ani10112096

Giro, A., Pezzopane, J.R.M., Junior, W.B., de Faria Pedroso, A., Lemes, A.P., Botta, D., Romanello, N., do Nascimento Barreto, A., Garcia, A.R., 2019. Behavior and body surface temperature of beef cattle in integrated crop-livestock systems with or without tree shading. Science of the Total Environment 684, 587–596. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.05.377

Hammond, A.C., Olson, T.A., Chase Jr, C.C., Bowers, E.J., Randel, R.D., Murphy, C.N., Vogt, D.W., Tewolde, A., 1996. Heat tolerance in two tropically adapted Bos taurus breeds, Senepol and Romosinuano, compared with Brahman, Angus, and Hereford cattle in Florida. J Anim Sci 74, 295–303. https://doi.org/https://doi.org/10.2527/1996.742295x

Holm, D.E., Thompson, P.N., Irons, P.C., 2009. The value of reproductive tract scoring as a predictor of fertility and production outcomes in beef heifers. J Anim Sci 87, 1934–1940. https://doi.org/https://doi.org/10.2527/jas.2008-1579

IBGE, 2022. Agricultural Production [WWW Document]. Instituto Brasileiro de Geografia e Estatística. URL https://www.ibge.gov.br/explica/producao-agropecuaria/bovinos (accessed 10.17.23).

Lowman, B.G., Scott, N.A. and Somerville, S.H., 1976. Condition Scoring of Cattle. East of Scotland College of Agriculture. Animal Production, Advisory and Development Department Edinburgh: Edinburgh School of Agriculture Bulletin, No. 6.

Maia, A.S.C., Silva, R.G. da, Bertipaglia, E.C.A., 2003. Características do pelame de vacas Holandesas em ambiente tropical: Um estudo genético e adaptativo. Revista Brasileira de Zootecnia 32, 843–853. https://doi.org/https://doi.org/10.1590/S1516-35982003000400009

Martello, L.S., Savastano Júnior, H., Silva, S. da L., Titto, E.A.L., 2004. Physiologic and performance responses of holstein cows in milking under different environments. Revista Brasileira de Zootecnia 33, 181–191. https://doi.org/https://doi.org/10.1590/S1516-35982004000100022

Montanholi, Y.R., Odongo, N.E., Swanson, K.C., Schenkel, F.S., McBride, B.W., Miller, S.P., 2008. Application of infrared thermography as an indicator of heat and methane production and its use in the study of skin temperature in response to physiological events in dairy cattle (Bos taurus). J Therm Biol 33, 468–475. https://doi.org/https://doi.org/10.1016/j.jtherbio.2008.09.001

NOAA, 1976. Livestock hot weather stress.

Pinheiro, J., Bates, D., Team R Core, 2023. Linear and Nonlinear Mixed Effects Models. R package version 3.1-162.

Pires, B. V, Stafuzza, N.B., Lima, S., Negrão, J.A., Paz, C.C.P., 2019. Differential expression of heat shock protein genes associated with heat stress in Nelore and Caracu beef cattle. Livest Sci 230, 103839. https://doi.org/https://doi.org/10.1016/j.livsci.2019.103839

Reynolds, L.P., Ferrell, C.L., Nienaber, J.A., Ford, S.P., 1985. Effects of chronic environmental heat stress on blood flow and nutrient uptake of the gravid bovine uterus and foetus. J Agric Sci 104, 289–297. https://doi.org/https://doi.org/10.1017/S002185960004394X

Rosenkrans, K.S., Hardin, D.K., 2003. Repeatability and accuracy of reproductive tract scoring to determine pubertal status in beef heifers. Theriogenology 59, 1087–1092. https://doi.org/https://doi.org/10.1016/S0093-691X(02)01171-8

Rubiano, G.A.G., Arrigoni, M.D.B., Martins, C.L., Rodrigues, É., Gonçalves, H.C., Angerami, C.N., 2009. Performance, carcass traits and meat quality of young Canchim, Nellore and crossbread bulls. Revista Brasileira de Zootecnia 38, 2490–2498. https://doi.org/https://doi.org/10.1590/S1516-35982009001200027

Sarlo Davila, K.M., Hamblen, H., Hansen, P.J., Dikmen, S., Oltenacu, P.A., Mateescu, R.G., 2019. Genetic parameters for hair characteristics and core body temperature in a multibreed

Brahman–Angus herd. J Anim Sci 97, 3246–3252. https://doi.org/https://doi.org/10.1093/jas/skz188

Schirmann, K., von Keyserlingk, M.A.G., Weary, D.M., Veira, D.M., Heuwieser, W., 2009. Validation of a system for monitoring rumination in dairy cows. J Dairy Sci 92, 6052–6055. https://doi.org/https://doi.org/10.3168/jds.2009-2361

Schleger, A. V, Turner, H.G., 1965. Sweating rates of cattle in the field and their reaction to diurnal and seasonal changes. Aust J Agric Res 16, 92–106. https://doi.org/https://doi.org/10.1071/AR9650092

Silanikove, N., 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livest Prod Sci 67, 1–18. https://doi.org/https://doi.org/10.1016/S0301-6226(00)00162-7

Silva, R.G. da, 1999. Estimate of radiation heat balance of Holstein cows in the sun and under the shade in a tropical environment. Revista Brasileira de Zootecnia 28, 1403–1411. https://doi.org/https://doi.org/10.1590/S1516-35981999000600031

Smith, B.I., Donovan, G.A., Risco, C., Littell, R., Young, C., Stanker, L.H., Elliott, J., 1998. Comparison of various antibiotic treatments for cows diagnosed with toxic puerperal metritis. J Dairy Sci 81, 1555–1562. https://doi.org/https://doi.org/10.3168/jds.S0022-0302(98)75721-2

Souza, W. de, Barbosa, O.R., Marques, J. de A., Costa, M.A.T., Gasparino, E., Limberger, E., 2010. Microclimate in silvipastoral systems with eucalyptus in rank with different heights. Revista Brasileira de Zootecnia 39, 685–694. https://doi.org/https://doi.org/10.1590/S1516-35982010000300030

Sparovek, G., De Jong Van Lier, Q., Dourado Neto, D., 2007. Computer assisted Koeppen climate classification: a case study for Brazil. Int J Climatol 27, 257–266. https://doi.org/https://doi.org/10.1002/joc.1384

Stewart, R.E., 1953. Absorption of solar radiation by the hair of cattle. Agric. Engng. 34, 235–238.

Team, R.C., 2023. R: A language and environment for statistical computing. . R Foundation for Statistical Computing, Vienna, Austria.

Valente, É.E.L., Chizzotti, M.L., de Oliveira, C.V.R., Galvão, M.C., Domingues, S.S., de Castro Rodrigues, A., Ladeira, M.M., 2015. Intake, physiological parameters and behavior of Angus and Nellore bulls subjected to heat stress. Semin Cienc Agrar 36, 4565–4574.

Wilson, S.J., Kirby, C.J., Koenigsfeld, A.T., Keisler, D.H., Lucy, M.C., 1998. Effects of controlled heat stress on ovarian function of dairy cattle. 2. Heifers. J Dairy Sci 81, 2132–2138. https://doi.org/https://doi.org/10.3168/jds.S0022-0302(98)75789-3

Wright, S.A., Ramos, P., Johnson, D.D., Scheffler, J.M., Elzo, M.A., Mateescu, R.G., Bass, A.L., Carr, C.C., Scheffler, T.L., 2018. Brahman genetics influence muscle fiber properties, protein degradation, and tenderness in an Angus-Brahman multibreed herd. Meat Sci 135, 84–93. https://doi.org/https://doi.org/10.1016/j.meatsci.2017.09.006

Figure captions

Figure 1: Timeline of the third (January-Summer) evaluation. Weighing, RTS and Behavioral Assessment (n=93). Body temperature, Infrared thermography and Sweating rate (n=37)

*THI: Temperature-Humidity Index

**RTS: Reproductive Tract Score

Figure 2: Daily variation of the Temperature-Humidity Index (THI) during the 8-day evaluation period in January. The lowest recorded value was 55.67 and the highest reached 75.54.

Figure 3: Puberty rate (%) in the three evaluation periods for Angus heifers with distinct coat color (A) and hair coat (B).

*HC1: short, fine, and smooth hair; HC2: intermediate hair; HC3: thick, long, and woolly hair - ANC (2023)

Asterisk (*) denotes significant differences between groups within each evaluation ($P < 0.05$).

Figure 4: Sweating rate (g /m²/h) for Angus heifers with distinct coat color (A) and hair coat (B) according to the temperature-humidity index (THI)*.

*CC: coat color; HC 1: short, fine, and smooth hair; HC 2: intermediate hair; HC 3: thick, long, and woolly hair - ANC (2023)

Figure 1

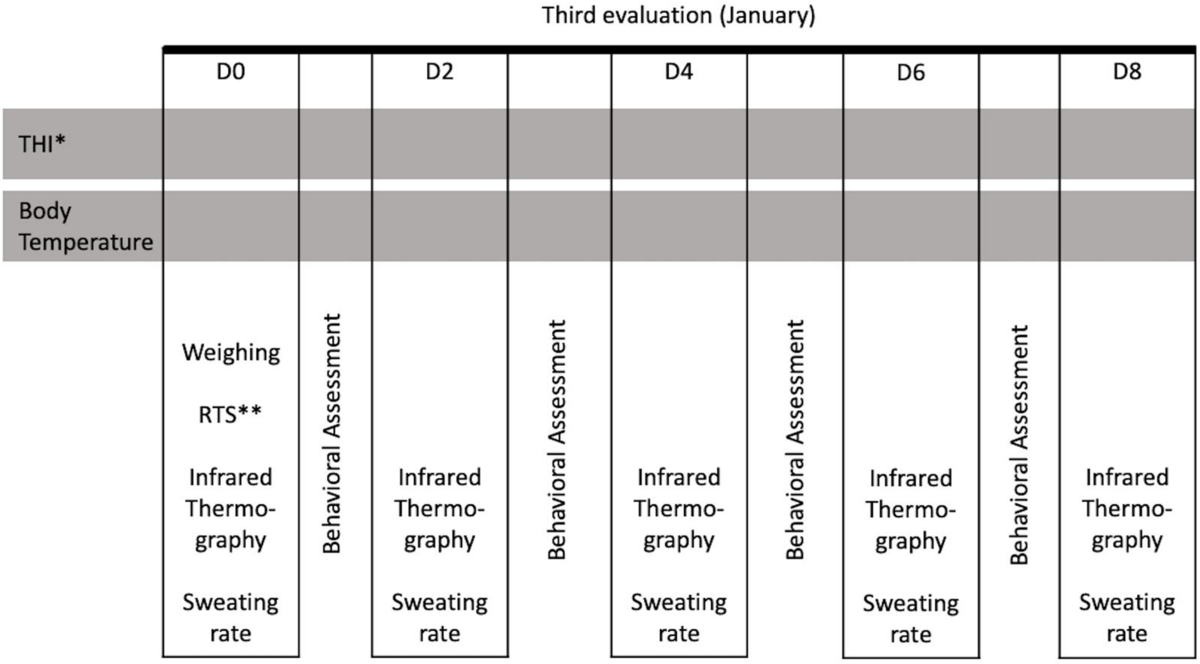
Third evaluation (January)
D0
D2
D4
D6
D8
THI*
Body Temperature
Weighing
RTS**
Infrared Thermo-graphy
Sweating rate
Behavioral Assessment
Infrared Thermo-graphy
Sweating rate
Behavioral Assessment
Infrared Thermo-graphy
Sweating rate
Behavioral Assessment
Infrared Thermo-graphy
Sweating rate
Behavioral Assessment
Infrared Thermo-graphy
Sweating rate

Figure 2

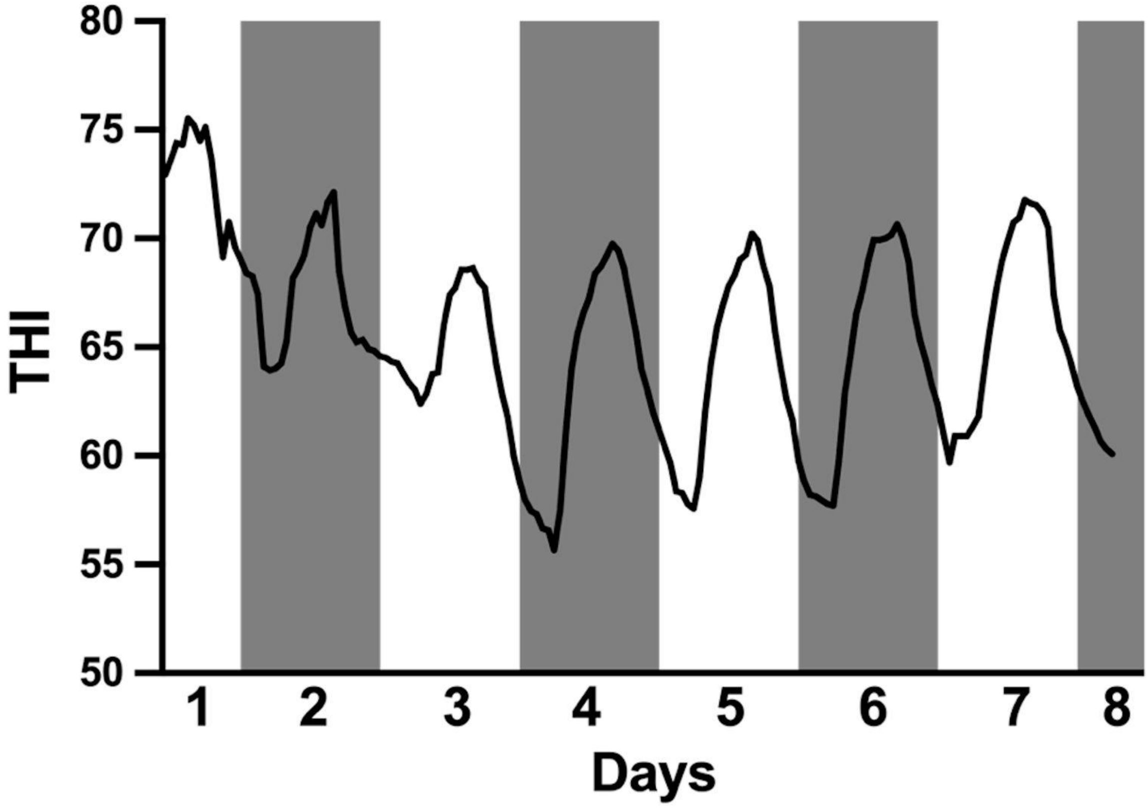

Figure 3

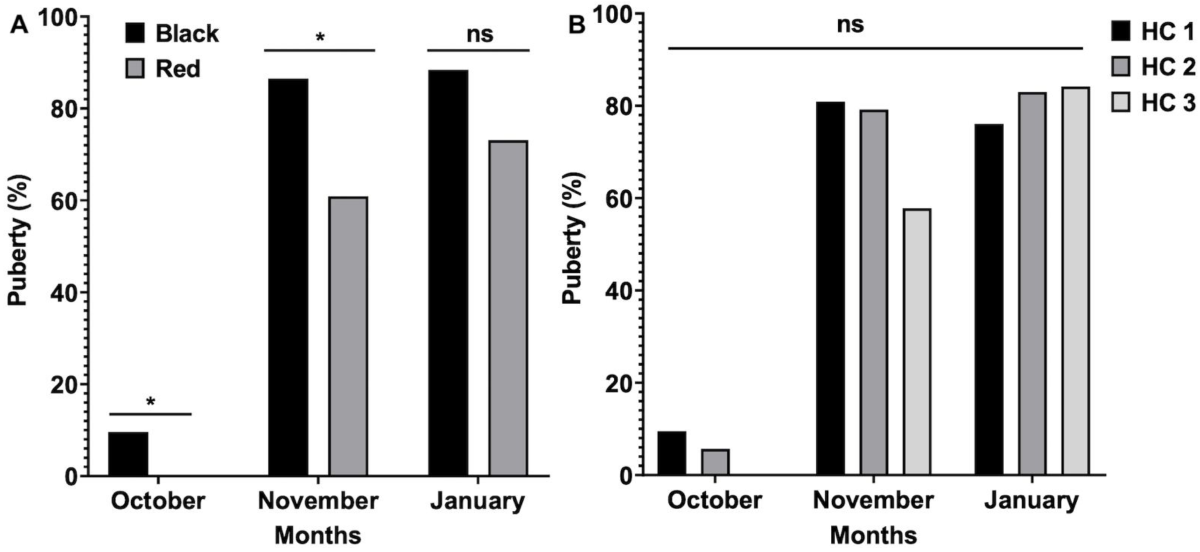
A
Black
Red
Puberty (%)
100
80
60
40
20
0
*
*
ns
October
November
January
Months
B
HC 1
HC 2
HC 3
Puberty (%)
100
80
60
40
20
0
ns
October
November
January
Months

Figure 4

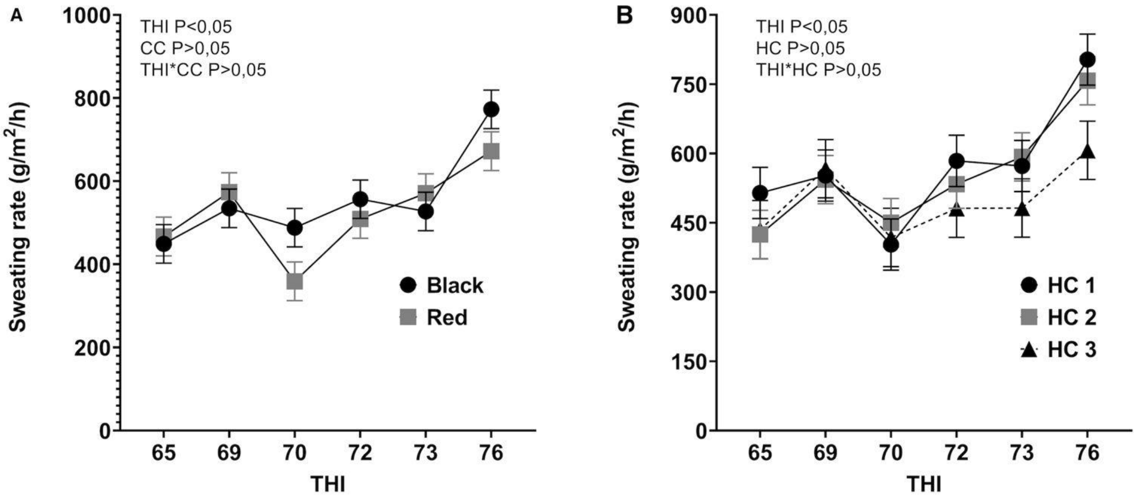
A
THI P<0,05
CC P>0,05
THI*CC P>0,05
Sweating rate (g/m2/h)
1000
800
600
400
200
0
65
69
70
72
73
76
THI
Black
Red
B
THI P<0,05
HC P>0,05
THI*HC P>0,05
Sweating rate (g/m2/h)
900
750
600
450
300
150
0
65
69
70
72
73
76
THI
HC 1
HC 2
HC 3

Table 1

Table 1: Distribution of hair coat of Angus heifers at three assessment periods*

Hair coat	Periods		
	October	November	January
HC1	9.7 (9/93)^{b}	22.6 (21/93)^{a}	20.4 (19/93)^{a}
HC2	77.4 (72/93)^{a}	57.0 (53/93)^{b}	63.4 (59/93)^{ab}
HC3	12.9 (12/93)^{a}	20.4 (19/93)^{a}	16.1 (15/93)^{a}

*HC1: short, fine, and smooth hair; HC2: intermediate hair; HC3: thick, long, and woolly hair - PROMEBO (2018)

^{a,b}Distinct superscripts indicate significant difference in rows ($P < 0.05$)

Table 2

Table 2: Frequency (%) of body condition score (BCS) in the three evaluation periods for Angus heifers with distinct coat color and hair coat

Periods		October (Spring)			November (Spring)			January (Summer)		
BCS		< 3	3	> 3	< 3	3	> 3	< 3	3	> 3
Coat color	Black	21.1	61.5	17.3	13.5	48.1	38.4	15.4	44.2	40.4
	Red	21.9	56.1	21.9	4.9	56.1	39.0	14.6	46.3	39.0
Hair coat*	HC1	14.3	57.1	28.6	0.0	38.1	61.9	4.8	38.1	57.1
	HC2	24.5	58.5	17.0	9.4	50.9	39.6	15.1	43.4	41.5
	HC3	21.0	63.2	15.8	21.0^{a}	68.4^{a}	10.5^{b}	26.3	57.9	15.8

^{a,b}Distinct superscripts indicate significant difference among BCS categories within each period ($P < 0.05$)

*HC1: short, fine, and smooth hair; HC2: intermediate hair; HC3: thick, long, and woolly hair - PROMEBO (2018)

Table 3

Table 3: Period in hyperthermia (temperature above 39.2°C) for Angus heifers with distinct coat color and hair coat according to the temperature-humidity index (THI)

		Period in hyperthermia (%)			
		THI quartile*			
		Q1	Q2	Q3	Q4
Coat color	Black	16.4[a]	29.8[a]	41.7[a]	65.9[a]
	Red	27.4[b]	36.6[b]	43.4[a]	71.5[b]
Hair coat	HC1	23.9[x]	27.7[y]	36.3[z]	58.9[z]
	HC2	18.2[y]	28.6[xy]	39.6[y]	67.9[y]
	HC3	24.5[x]	44.8[x]	52.8[x]	79.4[x]

* Q1, from 55.670 to 62.615; Q2, from 62.616 to 65.719; Q3, from 65.720 to 69.435; and Q4, from 69.436 to 75.538.

HC1: short, fine, and smooth hair; HC2: intermediate hair; HC3: thick, long, and woolly hair - PROMEBO (2018)

[a,b,c]Distinct superscripts indicate significant difference among coat color categories within column ($P < 0.05$)

[x,y,z]Distinct superscripts indicate significant difference among hair coat categories within column ($P < 0.05$)

Table 4

Table 4: Behavioral characteristics (%) for Angus heifers with distinct coat color and hair coat at temperature-humidity index of 72

Behavior		Location		Position		Activity		
		Shade	Sun	Standing	Lying	Ruminating	Grazing	Resting
Coat color	Black	21.0	78.2	47.5[a]	52.5[a]	52.5	6.9	40.6
	Red	11.4	88.6	28.6[a]	71.4[b]	50.0	7.1	42.9
Hair coat*	HC1	21.4	78.6	40.5	59.5	40.5	7.1	52.4
	HC2	12.9	87.1	39.8	60.2	61.3	7.5	31.2
	HC3	25.0	75.0	38.9	61.1	38.9	5.6	55.6

*HC1: short, fine, and smooth hair; HC2: intermediate hair; HC3: thick, long, and woolly hair - PROMEBO (2018)

[a,b]Distinct superscripts indicate significant difference among coat color categories within a row ($P < 0.05$)

Title page with autor information

Thermotolerance in Angus cattle is related to hair coat characteristics but not to coat color

Caroline Oliveira Farias[a]; Jessica Lazzari[b]; Ísis Soares da Cunha[c]; Paulo Bayard Dias Gonçalves[d]; Bernardo Garziera Gasperin[e]; Thomaz Lucia Jr[f]; Eduardo Schmitt[g]; Fernando Flores Cardoso[h]; Juliana Sarubbi[i]; Rafael Gianella Mondadori[j]

[a]Veterinary Medicine Graduate Program, Federal University of Pelotas, Av. Eliseu Maciel, Capão do Leão, RS, Brazil – carolinefarias.f1@gmail.com

[b]Veterinary Medicine Graduate Program, Federal University of Pelotas, Av. Eliseu Maciel, Capão do Leão, RS, Brazil – jelazzari@hotmail.com

[c]Faculty of Veterinary Medicine, Federal University of Pelotas, Av. Eliseu Maciel, Capão do Leão, RS, Brazil - isissoaresdacunha04@gmail.com

[d]International Affair Secretary, Federal University of Santa Maria, Av. Roraima nº 1000, Santa Maria, RS, Brazil - bayard@ufsm.br

[e]Department of Animal Pathology, Federal University of Pelotas, Av. Eliseu Maciel, Capão do Leão, RS, Brazil – bggasperin@gmail.com

[f]Department of Animal Pathology, Federal University of Pelotas, Av. Eliseu Maciel, Capão do Leão, RS, Brazil – tluciajr@gmail.com

[g]Department of Veterinary Clinics, Federal University of Pelotas, Av. Eliseu Maciel, Capão do Leão, RS, Brazil - schmitt.edu@gmail.com

[h]Pecuária Sul, Brazilian Agricultural Research Corporation (EMBRAPA), BR 153, Km 633, Vila Industrial, Bagé, RS - fernando.cardoso@embrapa.br

[i]Department of Animal Science, Federal University of Santa Maria, Av. Independência, 3751, Palmeira Das Missões, RS, Brazil - jusarubbi.ufsm@hotmail.com

[j]Department of Morphology, Federal University of Pelotas, Av. Duque de Caxias, 250, Pelotas, RS, Brazil – rgmondadori@gmail.com

Acknowledgment

The authors would like to thank the entire team at Fazenda da Barragem. Special acknowledgment is extended to veterinarian Carlos Henrique Laske for his invaluable support throughout the experimental period. Additionally, we also like to recognize the support of Mateus Pivato, development manager of the Brazilian Angus Association.

Corresponding author

E-mail: rgmondadori@gmail.com

Postal address: Av. Duque de Caxias, 250, Pelotas, RS, Brazil

4 Considerações Finais

O estresse térmico, suas consequências e as formas de reduzir seus impactos são assuntos de extrema importância dentro do cenário produtivo a nível mundial, pois a produção de produtos de origem animal de alta qualidade depende do bom desempenho dos animais nos mais diversos ambientes, bem como de seu bem-estar. Embora a literatura traga parâmetros de temperatura e umidade que afetam a capacidade produtiva dos animais, é preciso estabelecer limites dentro de cada raça e sistema, pois a adaptabilidade dos animais está também relacionada com fatores genéticos e de produção.

Os parâmetros avaliados no presente estudo permitem inferir que existem, dentro da mesma raça, animais com maior capacidade termorregulatória, portanto capazes de, mesmo em ambientes desafiadores manterem seus parâmetros fisiológicos o que beneficia a produção e o bem-estar animal. Assim sendo, a partir das informações geradas é possível dar início a estudos de seleção que podem servir de base para a disseminação da raça Angus para ambientes tropicais, onde hoje os animais enfrentam dificuldades de adaptação.

O pelame, utilizado nos programas de melhoramento, constitui uma barreira de isolamento importante na troca de calor e a busca por animais com um grau menor desta característica se torna indispensável para a evolução no ambiente tropical. A pelagem, por sua vez, também pode ser utilizada para a seleção animal, mesmo que sua influência seja menor, tendo por fim o objetivo de expandir animais termotolerantes para o restante do Brasil.

Outros estudos são necessários para aprimorar a seleção destas características e, assim, identificar indivíduos que se destaquem pelas características adaptativas, que são secundariamente utilizadas nas criações atualmente. A partir da identificação desses indivíduos, por estudos em populações maiores e mais diversas, poderá ser possível a busca por marcadores genéticos ligados a capacidade de adaptação dos animais a climas tropicais. A maior adaptabilidade acarretará na produção de animais menos suscetíveis ao estresse e, consequentemente, menos suscetíveis a doenças e quedas produtivas em função do calor.

Referências

AGUILAR-QUIÑONES, J. A.; AVENDAÑO-REYES, L.; MACÍAS-CRUZ, U.; GUERRA-LIERA, J. E.; VICENTE-PÉREZ, R.; GASTÉLUM-DELGADO, M. A.; BARAJAS-CRUZ, R.; WITTAYAKUN, S.; VICENTE-PÉREZ, A. Increasing shade area in feedlot heifers during heat stress: physiological and performance parameters. **Tropical Animal Health and Production,** v. 54, n.152, 2022.

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. DE M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift,** v. 22, p. 711–728, 2013.

AMARAL, C. S.; KOCH, J.; CORREA JÚNIOR, E. E.; BERTOLIN, K.; MUJICA, L. K.; FIORENZA, M. F.; ROSA, S. G.; NOGUEIRA, C. W.; COMIM, F. F.; PORTELA, V. V. M.; GONÇALVES, P. B. D.; ANTONIAZZI, A. Q. Heat stress on oocyte or zygote compromises embryo development, impairs interferon tau production and increases reactive oxygen species and oxidative stress in bovine embryos produced in vitro. **Molecular Reproduction and Development**, v. 87, n. 8, p. 899-909, 2020.

ANC, 2023. **Beef Cattle Improvement Program - PROMEBO [WWW Document]. National Association of Breeders "Herd-Book Collares."** Disponível em: <https://www.herdbook.org.br/site/>. Acesso em: 01 set. 2023.

ARIAS, R. A.; DELGADO, C.; KEIM, J. P.; GANDARILLAS, M. Use of the Comprehensive Climate Index to estimate heat stress response of grazing dairy cows in a temperate climate region. **Journal of Dairy Research**, v. 88, n. 2, p. 154-161, 2021.

AVENDAÑO-REYES, L.; ÁLVAREZ-VALENZUELA, F. D.; CORREA-CALDERÓN, A.; ALGÁNDAR-SANDOVAL, A.; RODRÍGUEZ-GONZÁLEZ, E.; PÉREZ-VELÁZQUEZ, R.; MACÍAS-CRUZ, U.; DÍAZ-MOLINA, R.; ROBINSON, P. H.; FADEL, J. G. Comparison of three cooling management systems to reduce heat stress in lactating Holstein cows during hot and dry ambient conditions. **Livestock Science,** v. 132, p. 48–52, 2010.

BAENA, M. M.; COSTA, A. C.; VIEIRA, G. R.; ROCHA, R. F. B.; RIBEIRO, A. R. B.; IBELLI, A. M. G. MEIRELLES, S. L. C. Heat tolerance responses in *Bos taurus* cattle herd raised in a Brazilian climate. **Journal of Thermal Biology,** v. 81, p. 162-169, 2019.

BAUMGARD, L. H. & RHOADS JR, R. P. Effects of heat stress on postabsorptive metabolism and energetics. **Annual Review of Animal Biosciences,** v. 1, p. 311–337, 2013.

BERMAN, A. & VOLCANI, R. Seasonal and regional variations in coat characteristics of dairy cattle. **Australian Journal of Agricultural Research,** v. 12, p. 528–538, 1961.

BERTIPAGLIA, E. C. A.; DA SILVA, R. G.; CARDOSO, V.; FRIES, L. A. Hair coat characteristics and sweating rate of Braford cows in Brazil. **Livestock Science,** v. 112, p. 99–108, 2007.

BLACKSHAW, J. K.; BLACKSHAW, A. W. Heat stress in cattle and the effect of shade on prodution and behaviour: a review. **Australian Journal of Experimental Agriculture,** v. 34, p. 285-295, 1994.

BORGES, C. R. A.; AZEVEDO, M.; LIMA, I. A.; BRASIL, L. H. A.; FERREIRA, M. A. Heterogeneous genetic cows of three genetic groups in feedlot system in the state of Pernambuco, Brazil. **Acta Scientiae,** v. 34, p. 91–96, 2012.

BROWN-BRANDL, T. M.; NIENABER, J. A.; EIGENBERG, R. A.; MADER, T. L.; MORROW, J. L.; DAILEY, J. W. Comparison of heat tolerance of feedlot heifers of different breeds. **Livestock Science,** v. 105, n. 1-3, p. 19-26, 2006.

BURDICK, N. C.; CARROLL, J. A.; DAILEY, J. W.; RANDEL, R. D.; FALKENBERG, S. M.; SCHMIDT, T. B. Development of a self-contained, indwelling vaginal temperature probe for use in cattle research. **Journal of Thermal Biology,** v. 37, n. 4, p. 339-343, 2012.

CARVALHO, P. C. F.; FISHER, V.; SANTOS, D. T.; RIBEIRO, A. M. L.; QUADROS, F. L. F.; CASTILHOS, Z. M. S.; POLI, C.; MONTEIRO, A. L. G.; NABINGER, C.; GENRO, T. C. M. Produção animal no bioma campos sulinos. **Brazilian Journal of Animal Science,** v. 35, p. 156–202, 2006.

COLLIER, R. J.; COLLIER, J. L.; RHOADS, R. P.; BAUMGARD, L. H. Invited review: genes involved in the bovine heat stress response**. Journal of Dairy Science**, v. 91, n. 2, p. 445-454, 2008.

COLLIER, R. J.; HALL, L. W.; RUNGRUANG, S.; ZIMBLEMAN, R. B. Quantifying heat stress and its impact on metabolism and performance. **Department of Animal Sciences University of Arizona**, v. 68, 2012.

COLLIER, R. J.; RENQUIST, B. J.; XIAO, Y. A 100-year review: stress physiology including heat stress. **Journal of Dairy Science**, v. 100, n. 12, p. 10367-10380, 2017.

CONEXÃO DELTA G. Sumário de touros Hereford e Braford 2019. 2019. Disponível em: <https://gensys.com.br/wpcontent/uploads/2019/08/SumarioConexaoDeltaG_2019-1.pdf>. Acesso em: 05 mai. 2021.

CONTRERAS-CORREA, Z.; MUÑIZ-COLÓN, G.; PAGÁN-MORALES, M.; MESONERO-MORALES, A.; RODRÍGUEZ, J. C.; SÁNCHEZ-RODRÍGUEZ, H. L. Hematocrit, milk yield, and production related parameters comparisons between slick and wildtype-haired Puerto Rican Holstein cows. **Journal of Animal Science**, v. 94, p. 517-517, 2016.

CORDEIRO, A. L. L.; SATRAPA, R. A.; GREGIANINI, H. A. G.; GREGIANINI, J. T. F.; MAIA, G. F. N.; LANDIM-ALVARENGA, F. C. Influence of temperature-humidity index on conception rate of Nelore embryos produced in vitro in northern Brazil. **Tropical Animal Health and Production,** v. 52, p. 1527–1532, 2020.

DA SILVA, R. G. & MAIA, A. S. C. The Enviroment. **Principles of Animal Biometeorology.** Springer, New York, 2013, p. 1–37.

DA SILVA, R. G.; LA SCALA JR, N.; TONHATI, H. Radiative properties of the skin and haircoat of cattle and other animals. **Transactions of the ASAE,** v. 46, p. 913, 2003.

DA SILVEIRA, D. D.; TINEO, J. S. A.; SCHMIDT, P. I.; CAMPOS, G. S.; DE SOUZA, F. R. P.; ROSO, V. M.; BOLIGON, A. A. Hair coat score in Angus cattle: Comparison of linear and threshold models, genetic gain and correlations with growth, morphological and reproductive traits. **Livestock Science,** v. 249, 104512, 2021.

DAVILA, K. M. S.; HAMBLEN, H.; HANSEN, P. J.; DIKMEN, S.; OLTENACU, P. A.; MATEESCU, R. G. Genetic parameters for hair characteristics and core body temperature in a multibreed Brahman–Angus herd. **Journal of Animal Science**, v. 97, p. 3246-3252, 2019.

DBO, 2021. Nelore e Angus lideram o mercado de sêmen para corte. <https://portaldbo.com.br/nelore-e-angus-lideram-o-mercado-de-semen-bovino-para-corte-no-brasil/>. Acesso em: 19 jun. 2025.

DE RENSIS, F. & SCARAMUZZI, R. J. Heat Stress and seasonal effects on reproduction in the dairy cow – a review. **Theriogenology**, v. 60, p 1139-1151, 2003.

DE SOUZA JR, J. B. F.; DE QUEIROZ, J. P. A. F.; DOS SANTOS, V. J. S.; DANTAS, M. R. T.; DE LIMA, R. N.; DE OLIVEIRA LIMA, P.; DE MACEDO COSTA, L. L. Cutaneous evaporative thermolysis and hair coat surface temperature of calves evaluated with the aid of a gas analyzer and infrared thermography. **Computers and Electronics in Agriculture,** v. 154, p. 222–226, 2018.

DEVRIES, T. J.; BEAUCHEMIN, K. A.; DOHME, F.; SCHWARTZKOPF-GENSWEIN, K. S. Repeated ruminal acidosis challenges in lactating dairy cows at high and low risk for developing acidosis: Feeding, ruminating, and lying behavior. **Journal of Dairy Science**, v. 92, p. 5067–5078, 2009.

DIKMEN, S.; ALAVA, E.; PONTES, E.; FEAR, J. M.; DIKMEN, B. Y.; OLSON, T. A.; HANSEN, P. J. Differences in thermoregulatory ability between slick-haired and wild-type lactating Holstein cows in response to acute heat stress. **Journal of Dairy Science,** v. 91, n. 9, p. 3395-3402, 2008.

DIKMEN, S. & HANSEN, P. J. Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in a subtropical environment? **Journal of Dairy Science,** v. 92, n. 1, p. 109-116, 2009.

DIKMEN, S.; KHAN, F. A.; HUSON, H. J.; SONSTEGARD, T. S.; MOSS, J. I.; DAHL, G. E.; HANSEN, P. J. The SLICK hair locus derived from Senepol cattle confers thermotolerance to intensively managed lactating Holstein cows. **Journal of Dairy Science**, v. 97, n. 9, p. 5508-5520, 2014.

ESPINOZA, J. V.; ORTEGA, R. P.; PALACIOS, A. E.; GUILLÉN, A. T. Tolerancia al calor y humedad atmosférica de diferentes grupos raciales de ganado bovino. **Revista de Medicina Veterinaria y Zootecnia de Córdoba,** v. 16, n. 1, p. 2302-2309, 2011.

FERNANDEZ-NOVO, A.; PÉREZ-GARNELO, S. S.; VILLAGRÁ, A.; PÉREZ-VILLALOBOS, N.; ASTIZ, S. The effect of stress on reproduction and reproductive technologies in beef cattle—A review. **Animals**, v. 10, 2096, 2020.

GAUGHAN, J. B.; GOODWIN, P. J.; SCHOORL, T. A.; YOUNG, B. A.; IMBEAH, M.; MADER, T. L.; HALL, A. Shade preferences of lactating Holstein–Friesian cows. **Australian Journal of Experimental Agriculture**, v. 38, n. 1, p. 17-21, 1998.

GERALDO, Ana Carina Alves Pereira de Mira. **Termotolerância em fêmeas bovinas: abordagens celular e fisiológica**. Tese (Doutorado em Qualidade e Produtividade Animal) – Faculdade de Zootecnia e Engenharia de Alimentos, Universidade de São Paulo. Pirassununga, 93p. 2013.

GIRO, A.; PEZZOPANE, J. R. M.; JUNIOR, W. B.; DE FARIA PEDROSO, A.; LEMES, A. P.; BOTTA, D.; ROMANELLO, N.; DO NASCIMENTO BARRETO, A.; GARCIA, A. R. Behavior and body surface temperature of beef cattle in integrated crop-livestock systems with or without tree shading. **Science of the Total Environment**, v. 684, p. 587–596, 2019.

HAMMOND, A. C.; OLSON, T. A.; CHASE JR, C. C.; BOWERS, E. J.; RANDEL, R. D.; MURPHY, C. N.; VOGT, D. W.; TEWOLDE, A. Heat tolerance in two tropically adapted Bos taurus breeds, Senepol and Romosinuano, compared with Brahman, Angus, and Hereford cattle in Florida. **Journal of Animal Science,** v. 74, p. 295–303, 1996.

HASSAN, F.; NAWAZ, A.; REHMAN, M. S.; ALI, M. A.; DILKSHAD, S. M. R.; YANG, C. Prospects of HSP70 as a genetic marker for thermo-tolerance and immuno-modulation in animals under climate change scenario. **Animal Nutrition,** v. 5, n. 4, p. 340-350, 2019.

HOLM, D. E.; THOMPSON, P. N.; IRONS, P. C. The value of reproductive tract scoring as a predictor of fertility and production outcomes in beef heifers. **Journal of Animal Science,** v. 87, p. 1934-1940, 2009.

IBGE, 2022. **Agricultural Production [WWW Document]. Instituto Brasileiro de Geografia e Estatística.** Disponível em: <https://www.ibge.gov.br/explica/producao-agropecuaria/bovinos>. Acesso em: 17 out. 2023.

IBGE, 2022. Indicadores IBGE – Estatística da Produção Pecuária. Disponível em: <https://ftp.ibge.gov.br/Producao_Pecuaria/Fasciculo_Indicadores_IBGE/abate-leite-couro-ovos_202201caderno.pdf>. Acesso em: 05 jan. 2023.

IBGE, 2023. Rebanho de bovinos (bois e vacas). Disponível em: <https://www.ibge.gov.br/explica/producao-agropecuaria/bovinos/br>. Acesso em: 19 jun. 2025.

JOO, S. S.; LEE, S. J.; PARK, D. S.; KIM, D. H.; GU, B. H.; PARK, Y. J.; RIM, C. Y.; KIM, K.; KIM, E. T. Changes in Blood Metabolites and Immune Cells in Holstein and Jersey Dairy Cows by Heat Stress. **Animals,** v. 11, n. 4, p. 974, 2021.

KAUFMAN, J. D.; SAXTON, A. M.; RÍUS, A. G. Relationships among temperature-humidity index with rectal, udder surface, and vaginal temperatures in lactating dairy cows experiencing heat stress. **Journal of Dairy Science**, v. 101, n. 7, p. 6424-6429, 2018.

LOWMAN, B. G.; SCOTT, N. A.; SOMERVILLE, S. H. Condition Scoring of Cattle. East of Scotland College of Agriculture. **Animal Production, Advisory and Development Department Edinburgh: Edinburgh School of Agriculture Bulletin,** n. 6., 1976.

MACEDO, G. G.; COSTA E SILVA, E. V.; PINHO, R. O.; ASSUMPÇÃO, T. I.; JACOMINI, J. O.; SANTOS, R. M.; MARTINS, L. F. O estresse por calor diminui a fertilidade de fêmeas bovinas por afetar o desenvolvimento oocitário e o embrionário. **Revista Brasileira de Reprodução Animal**, v. 35, n. 2, p. 80-85, 2014.

MAIA, A. S. C.; SILVA, R. G.; BERTIPAGLIA, E. C. A. Características do pelame de vacas Holandesas em ambiente tropical: Um estudo genético e adaptativo. **Revista Brasileira de Zootecnia**, v. 32, p. 843–853, 2003.

MARTELLO, L. S.; SAVASTANO JR, H.; SILVA, S. L.; TITTO, E. A. L. Respostas fisiológicas e produtivas de vacas holandesas em lactação submetidas a diferentes ambientes. **Revista Brasileira de Zootecnia,** v. 33, p. 181-191, 2004.

MATEESCU, R.; HANSEN, P.; DIKMEN, S. Finding the genetic basis for thermotolerance in beef cattle. **Florida Cattlemen Journal,** fev. 2017. Disponível em: <https://www.ralucamateescu.com/beef-cattle-thermotolerance>. Acesso em: 08 jan. 2023.

MCFARLAND, D. **Animal behaviour: psychobiology, ethology and Evolution**. 3 ed. [S.I.]: Prentice Hall, p. 259-307. 1999.

MONTANHOLI, Y. R.; NICHOLAS, E. O.; KENDALL, C. S.; SCHENKEL, F. S.; MCBRIDE, B. W.; MILLER, S. P. Application of infrared thermography as an indicator of heat and methane production and its use in the study of skin temperature in response to physiological events in dairy cattle (Bos taurus). **Journal of Thermal Biology,** v. 33, p. 468–475, 2008.

MOURA, Gustavo André Bernado. **Equilíbrio Térmico de Bovinos Cruzados (Angus vs Nelore) em ambiente tropical**. Dissertação (Mestrado em Zootecnia) – Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista. Jaboticabal, 69p. 2019.

NARDONE, A.; RONCHI, B.; LACETERA, N.; BERNABUCCI, U. Climatic effects on productive traits in livestock. **Veterinary Research Communications**, v. 30, n. 1, p. 75-81, 2006.

NATURA. Sumário de Touros Brangus e Angus 2019/2020. 2019. Disponível em: <https://gensys.com.br/wp-content/uploads/2019/08/sumario-NATURA-2019.pdf>. Acesso em: 05 mai. 2021.

NOAA (National Oceanic and Atmospheric Administration). **Livestock hot weather stress.** US dept. Commerce natl. Weather serv. Central reg. In: Reg. Operations Man. Lett. C-31–36. NOAA, Washington, DC. 1976.

NOVO, A. F.; GARNELO, S. S. P.; VILLAGRÁ, A.; VILLALOBOS, N. P.; ASTIZ, S. The Effect of Stress on Reproduction and Reproductive Technologies in Beef Cattle—A Review. **Animals,** v. 10, p. 2096, 2020.

ONU, 2022. Nações Unidas. Acesso em: 09 de agosto de 2022. Disponível em: <https://news.un.org>. Acesso em: 05 mai. 2021.

ORTIZ-URIARTE, B.; ROSA-PADILLA, N.; LÓPEZ-LÓPEZ, R.; CURBELO-RODRÍGUEZ, J.; NEGRÓN-PÉREZ, V.; ORTIZ-COLÓN, G. The Slick Holstein as an alternative to cope with heat stress in tropical dairy operations. **Archivos Latinoamericanos de Producción Animal,** v. 28, n. 3-4, p. 145-153, 2020.

PENG, D.; CHEN, S.; LI, G.; CHEN, J.; WANG, J.; GU, X. Infrared thermography measured body surface temperature and its relationship with rectal temperature in dairy cows under different temperature-humidity indexes. **International Journal of Biometeorology,** v. 63, n. 3, p. 327-336, 2019.

PINHEIRO, J.; BATES, D.; TEAM, R. C. Linear and Nonlinear Mixed Effects Models. **R Package Version**, v. 3., p.1-162, 2023.

PIRES, B. V.; STAFUZZA, N. B.; LIMA, S.; NEGRÃO, J. A.; PAZ, C. C. P. Differential expression of heat shock protein genes associated with heat stress in Nelore and Caracu beef cattle. **Livestock Science,** v. 230, 103839, 2019.

POLSKY, L.; VON KEYSERLINGK, M. A. G. Invited review: Effects of heat stress on dairy cattle welfare. **Journal of Dairy Science,** v. 100, n. 11, p. 8645-8657, 2017.

PROMEBO, 2018. **Manual do Usuário PROMEBO.** Acesso em: 11 de novembro de 2022. Disponível em: <https://angus.org.br/wp-content/uploads/2018/04/Man-ual-do-Usu%C3%A1rio-PROMEBO.pdf>. Acesso em: 05 mai. 2021.

RECCE, S.; HUBER, E.; NOTARO, U. S.; RODRÍGUEZ, F. M.; ORTEGA, H. H. REY, F.; SIGNORINI, M. L.; SALVETTI, N. R. Association between heat stress during intrauterine development and the calving-to-conception and calving-to-first-service intervals in Holstein cows. **Theriogenology,** v. 162, p. 95-104, 2021.

REYNOLDS, L. P.; FERRELL, C. L.; NIENABER, J. A.; FORD, S. P. Effects of chronic environmental heat stress on blood flow and nutrient uptake of the gravid bovine uterus and foetus. **Journal of Agricultural Science,** v. 104, p. 289–297, 1985.

ROSENKRANS, K. S. & HARDIN, D. K. Repeatability and accuracy of reproductive tract scoring to determine pubertal status in beef heifers. **Theriogenology**, v. 59, p. 1087–1092, 2003.

RUBIANO, G. A. G.; ARRIGONI, M. B.; MARTINS, C. L.; RODRIGUES, E.; GONÇALVES, H. C.; ANGERAMI, C. N. Desempenho, características de carcaça e qualidade da carne de bovinos superprecoces das raças Canchim, Nelore e seus mestiços. **Revista Brasileira de Zootecnia,** v. 38, n. 12, p. 2490-2498, 2009.

SÁNCHEZ-RODRÍGUEZ, H. L. Thermoregulatory and productive-related comparisons between wild type and slickhaired Puerto Rican Holstein cows. **The Journal of Agriculture of the University of Puerto Rico**, v. 103, n. 1, p. 69-86, 2019.

SARLO DAVILA, K. M.; HAMBLEN, H.; HANSEN, P. J.; DIKMEN, S.; OLTENACU, P. A.; MATEESCU, R. G. Genetic parameters for hair characteristics and core body temperature in a multibreed Brahman–Angus herd. **Journal of Animal Science,** v. 97, p. 3246–3252, 2019.

SCHIRMANN, K.; VON KEYSERLINGK, M. A. G.; WEARY, D. M.; VEIRA, D. M.; HEUWIESER, W. Validation of a system for monitoring rumination in dairy cows. **Journal of Dairy Science,** v. 92, p. 6052–6055, 2009.

SCHLEGER, A. V. & TURNER, H. G. Sweating rates of cattle in the field and their reaction to diurnal and seasonal changes. **Australian Journal of Agricultural Research**, v. 16, p 92-106, 1965.

SILANIKOVE, N. Effects of heat stress on the welfare of extensively managed domestic ruminants. **Livestock Production Science,** v. 67, p. 1-18, 2000.

SILVA, R. G. Estimativa do balanço térmico por radiação em vacas holandesas expostas ao sol e à sombra em ambiente tropical. **Revista Brasileira de Zootecnia,** v. 28, p. 1403-1411, 1999.

SILVA, R. G. **Introdução à bioclimatologia animal**. São Paulo: Nobel, p. 286, 2000.

SILVA, R. G.; JR SCALA, N. L.; TONHATI, H. Radiative Properties of the Skin and Haircoat of Cattle and Other Animals. **American Society of Agricultural Engineers**, v. 46, p. 913-918, 2003.

SMITH, B. I.; DONOVAN, G. A.; RISCO, C.; LITTELL, R.; YOUNG, C.; STANKER, L. H.; ELLIOT, J. Comparison of various antibiotic treatments for cows diagnosed with toxic puerperal metritis. **Journal of Dairy Science,** v. 81, n. 6, p. 1555-1562, 1998.

SOUZA, W.; BARBOSA, O. R.; MARQUES, J. A.; COSTA, M. A. T.; GASPARINO, E.; LIMBERGER, E. Microclimate in silvipastoral systems with eucalyptus in rank with different heights. **Revista Brasileira de Zootecnia,** v. 39, p. 685–694, 2010.

SPAROVEK, G.; DE JONG VAN LIER, Q.; DOURADO NETO, D. Computer assisted Koeppen climate classification: a case study for Brazil. **International Journal of Climatology,** v. 27, p. 257–266, 2007.

STEWART, R. E. Absorption of solar radiation by the hair of cattle. **Agriculture Engineering,** v. 34, p. 235–238, 1953.

TEAM, R. C. **R: A language and environment for statistical computing.** R Foundation for Statistical Computing, Vienna, Austria. 2023.

TEIXEIRA, G. R.; MARTINS, O. A.; FIORUCI, B. A.; DE MELLO JÚNIOR, W.; PINHEIRO, P. F. F.; KREMER, R.; MARTINEZ, F. E. Respostas biológicas ao estresse. **Revista eletrônica de Veterinária PUBVET**, v. 3, n. 31, 2008.

THORNTON, P. K.; NELSON, G. C.; MAYBERRY, D.; HERRERO, M. Impacts of heat stress on global cattle production during the 21st century: a modelling study. **The Lancet Planetary Health,** v. 6, n. 3, p. e192-e201, 2022.

TITTO, E. A. L. Clima: Influência na produção de leite. Ambiência na produção de leite em clima quente. **Piracicaba: FEALQ**. 1998.

USDA, 2022. Maiores rebanhos e produtores mundiais de carne bovina: expectativa para 2022. Disponível em: <https://gestaopecuaria.com.br/maiores-rebanhos-e-produtores-mundiais-de-carne-bovina-expectativa-para-2022/>. Acesso em: 11 jan. 2023.

VALENTE, E. E. L.; CHIZZOTTI, M. L.; OLIVEIRA, C. V. R.; GALVÃO, M. C.; DOMINGUES, S. S.; RODRIGUES, A. C.; LADEIRA, M. M. Intake, physiological parameters and behavior of Angus and Nelore bulls subjected to heat stress. **Semina: Ciências Agrárias**, v. 36, n. 6, p. 4565-4574, 2015.

VASCONCELOS, J. L. M. **Manejo de vacas leiteiras para melhoria do desempenho reprodutivo durante períodos de estresse calórico – parte 2**. 2001.

WILSON, S. J.; KIRBY, C. J.; KOENIGSFELD, A. T.; KEISLER, D. H.; LUCY, M. C. Effects of controlled heat stress on ovarian function of dairy cattle. 2. Heifers. **Journal of Dairy Science,** v. 81, p. 2132–2138, 1998.

WRIGHT, S. A.; RAMOS, P.; JOHNSON, D. D.; SCHEFFLER, J. M.; ELZO, M. A.; MATEESCU, R. G.; BASS, A. L.; CARR, C. C.; SCHEFFLER, T. L. Brahman genetics influence muscle fiber properties, protein degradation, and tenderness in an Angus-Brahman multibreed herd. **Meat Science,** v. 135, p. 84–93, 2018.

Anexo

Anexo - Documento da Comissão de Ética e Experimentação Animal

PARECER Nº **134/2021/CEUA/REITORIA**
PROCESSO Nº 23110.020479/2021-91

Certificado

Certificamos que a proposta intitulada **"Comparação de parâmetros relacionados ao estresse térmico entre vacas de pelagem preta ou vermelha das raças Holandês e Angus"**, registrada com o nº 23110.020479/2021-91, sob a responsabilidade de **Rafael Gianella Mondadori** - que envolve a produção, manutenção ou utilização de animais pertencentes ao filo Chordata, subfilo Vertebrata (exceto humanos), para fins de pesquisa científica (ou ensino) – encontra-se de acordo com os preceitos da Lei nº 11.794, de 8 de outubro de 2008, do Decreto nº 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle de Experimentação Animal (CONCEA), e recebeu parecer **FAVORÁVEL** a sua execução pela Comissão de Ética no Uso de Animais, em reunião de 11 de novembro de 2021.

Finalidade	(x) Pesquisa ( ) Ensino
Vigência da autorização	Início = **01/12/2021** Término = **01/12/2024**
Espécie/linhagem/raça	*Bos taurus* / Holandês e Angus
Nº de animais	**26 Holandês e 316 Angus**
Idade	2 a 10 anos
Sexo	Fêmeas
Origem	Fazendas localizadas no Rio Grande do Sul

Código para cadastro nº **CEUA 020479/2021-91**

Priscila Marques Moura de Leon

Coordenadora da CEUA

Documento assinado eletronicamente por **PRISCILA MARQUES MOURA DE LEON**, **Professor do Magistério Superior/Adjunto**, em 11/11/2021, às 16:11, conforme horário oficial de Brasília, com fundamento no art. 4º, § 3º, do Decreto nº 10.543, de 13 de novembro de 2020.

A autenticidade deste documento pode ser conferida no site http://sei.ufpel.edu.br/sei/controlador_externo.php?acao=documento_conferir&id_orgao_acesso_externo=0, informando o código verificador **1495451** e o código CRC **E231E3F2**.