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Behavioral and adaptive evaluation of lactating Costeño con Cuernos and Gyrolando cows under tropical dry forest conditions (Colombia)

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ABSTRACT

Heat stress is one of the main challenges for cattle production in tropical regions, as it affects both animal welfare and productive efficiency. This study aimed to characterize the behavior of Costeño con Cuernos (CCC) and Gyrolando cattle under tropical dry forest conditions in Colombia, assessing their behavioral responses across different time periods and microclimatic conditions. The research was conducted in a silvopastoral system at the Motilonia Research Center of Agrosavia, located at an altitude of 106 m a.s.l., with a multiyear average temperature of 29.4 °C and an average relative humidity of 70%. Twelve lactating cows (six CCC and six Gyrolando) were observed from July to September 2023, and 20 behavioral variables, along with bioclimatic indicators such as the temperature–humidity index, were recorded. Data were analyzed using multiple correspondence analysis and hierarchical clustering. Results revealed two behavioral clusters: Cluster 1 (adverse climatic conditions) grouped animals that were more active during the hottest hours (12:00–14:00), with increased grazing activity and reduced resting behavior. This cluster consisted mainly of CCC cows. Cluster 2 (moderate climatic conditions) was characterized by predominant lying rumination, shaded resting, and lower overall activity, primarily involving Gyrolando cows. It is concluded that the native CCC breed exhibits more adaptive behavioral patterns under hot environmental conditions, underscoring its potential value for sustainable cattle production systems. The integration of multivariate tools and environmental monitoring allows the identification of management strategies aimed at improving animal welfare and productivity under extreme climatic conditions.

Keywords: animal welfare, adaptation, heat stress, microclimate**.**

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Evaluación comportamental y adaptativa de vacas en lactancia Costeño con Cuernos y Gyrolando bajo condiciones de bosque seco tropical (Colombia)

RESUMEN

El estrés por calor es uno de los principales desafíos para la producción bovina en regiones tropicales, afectando el bienestar animal y la eficiencia productiva. Este estudio tuvo como objetivo caracterizar el comportamiento de bovinos de las razas Costeño con Cuernos (CCC) y Gyrolando en condiciones de bosque seco tropical en Colombia, evaluando su respuesta comportamental ante diferentes rangos horarios y condiciones microclimáticas. La investigación se realizó en un sistema silvopastoril del centro de investigación Motilonia de Agrosavia a una altitud de 106 m s. n. m. con temperatura promedio multianual de 29,4 °C y humedad relativa promedio del 70%. Se observaron 12 vacas en lactancia (6 CCC y 6 Gyrolando) durante los meses de julio a septiembre de 2023, registrando 20 variables comportamentales e indicadores bioclimáticos como índice temperatura-humedad. Los datos fueron analizados mediante análisis factorial de múltiples correspondencias y clasificación jerárquica. Los resultados revelaron dos clústeres de comportamiento: clúster 1 (condiciones climáticas adversas) agrupó animales más activos durante las horas de mayor calor (12:00–14:00), con mayor pastoreo y menor descanso. Este grupo estuvo compuesto principalmente por la raza CCC. El clúster 2 (condiciones climáticas moderadas) presentó mayor rumia echado, descanso en sombra y menor actividad general, predominando la raza Gyrolando. Se concluye que la raza criolla CCC muestra actividades comportamentales más adaptativas en ambientes calurosos, lo que podría reforzar su valor en sistemas ganaderos sostenibles. La integración de herramientas multivariantes y monitoreo ambiental permite identificar estrategias de manejo orientadas al bienestar animal y la productividad bajo condiciones climáticas extremas.

Palabras clave: bienestar animal, adaptación, estrés por calor, microclima.

INTRODUCTION

The agricultural sector faces growing challenges associated with climate change, particularly in tropical regions where both the intensity and duration of heat waves are projected to increase (Masson-Delmotte *et al.*, 2019). This phenomenon threatens the sustainability of production systems, food security, and animal welfare, as it alters environmental conditions through anthropogenic activities (Bernabucci, 2019). Within this context, improving the thermal comfort of grazing animals has become a priority to ensure their health, productivity, and welfare (Islam *et al.*, 2021b).

Cattle, as homeothermic species, possess physiological, metabolic, and behavioral mechanisms that enable them to maintain body temperature within normal ranges (Giro *et al.*, 2019). However, when heat accumulation exceeds the animal's capacity for dissipation, heat stress occurs—a condition that adversely affects productive parameters such as weight gain, fertility, milk yield, and meat quality, while also

compromising animal welfare (Collier *et al.*, 2019; Summer *et al.*, 2019). Behavioral and physiological responses to heat stress include increased respiratory rate, panting, elevated body temperature, reduced feed intake, and shade-seeking behavior, among others (Islam *et al.*, 2021b). Beyond physiological impacts, the economic repercussions are substantial, with estimated losses reaching hundreds of millions of dollars annually in the global meat and dairy industries (Kim *et al.*, 2021).

In recent years, research aimed at mitigating heat stress has gained importance in response to global warming and growing concerns about animal welfare. Numerous studies have evaluated heat resilience in livestock species by integrating behavioral aspects, thermoregulatory physiology, productive performance, and climate-based indices. In addition, genomic tools have been employed to identify genes associated with thermal adaptation and to assess the genetic potential of heat-tolerant breeds. Research has also extended to natural environments that encompass diverse feeding systems, ranging from monospecific pastures to silvopastoral systems. The latter have become particularly relevant due to their ability to improve the microclimate through shade provision and thermal regulation, thereby enhancing animal comfort and productive efficiency, especially during the dry season (Ripamonti *et al.*, 2025). These advances have contributed to the development of climate change mitigation strategies aimed at optimizing productivity and animal welfare in accordance with available resources (Barragán *et al.*, 2017; Bernabucci, 2019; Brennan *et al.*, 2021; Passamonti *et al.*, 2021).

Conventional livestock production systems often prioritize high-yielding breeds, which generally exhibit lower resilience to heat stress, thereby compromising performance and threatening the sustainability of cattle production in warm climates. In contrast, locally adapted breeds such as the Costeño con Cuernos (CCC) have developed remarkable heat tolerance as a result of long-term evolution under tropical conditions. However, this adaptive capacity can be influenced by physiological, metabolic, and phenotypic traits, including coat color. Foreign breeds such as the Gyrolando, depending on their genetic composition, may display higher productivity but tend to be more sensitive to extreme temperature conditions. These differences highlight the importance of conserving, identifying, and utilizing genotypes that combine heat tolerance with desirable productive traits, ensuring functionality in heterogeneous grazing environments (Carmickle *et al.*, 2022; Negri *et al.*, 2023; Pires *et al.*, 2019).

To analyze the relationship between animal behavior, environmental variables, and grazing conditions, multivariate statistical tools such as Factorial Analysis of Mixed Data (FAMD) are employed. This exploratory technique allows the simultaneous analysis of categorical and continuous variables, facilitating the identification of patterns, relationships among observations, and homogeneous groupings within mixed datasets (Husson *et al.*, 2024). The objective of the present study was to characterize the behavioral activities of Costeño con Cuernos (CCC) and Gyrolando cattle under tropical dry forest conditions in Colombia, assessing their behavioral responses across different time intervals and microclimatic conditions.

MATERIALS AND METHODS

Study site

The study was conducted at the Motilonia Research Center of the Colombian Corporation for Agricultural Research (Agrosavia), located in the municipality of Agustín Codazzi, Cesar Department, Colombia (geographical coordinates: 10°00'08.05" N; 73°14'50.76" W). The region is classified as a tropical dry forest (Bs-T) according to the Holdridge life zone system (Holdridge, 1978) and lies at an altitude of 106 m a.s.l. The climate is characterized by a multiyear average temperature of 29.4 °C, with thermal extremes of 34.2 °C (maximum) and 22.7 °C (minimum), an average relative humidity of 70%, and an annual mean precipitation of 1580 mm. Rainfall distribution is bimodal, with peaks occurring in May (209.0 mm) and October (268.8 mm) (Zuluaga *et al.*, 2025).

Experimental design

Variables associated with heat stress and behavioral activities were evaluated in two cattle breeds under the conditions of a silvopastoral system containing scattered native tree species characteristic of the Caribbean region, including *Albizia niopoides* (Spruce ex Benth.) Burkart (Fabaceae), *Albizia saman* (Jacq.) Merr. (Fabaceae), *Cecropia peltata* (Ruiz ex Klotzsch) (Urticaceae), *Cordia alba* (Jacq.) Roem. & Schult. (Cordiaceae), *Guazuma ulmifolia* (Lam.) (Malvaceae), *Maclura tinctoria* (L.) D. Don ex Steud. (Moraceae), and *Spondias mombin* (Jacq.) (Anacardiaceae). A total of twelve (12) lactating cows—six Gyrolando and six Costeño con Cuernos (CCC)—were included, all in the mid-lactation stage (second third).

Variable measurement

Bioclimatic indices

Ambient temperature (Ta, °C) and relative humidity (RH, %) were recorded every 30 minutes using two data loggers (RHT10, Extech FLIR, Boston, Massachusetts, USA) installed 1 m above ground level in both shaded areas (under trees) and sun-exposed zones. Based on these measurements, the temperature–humidity index (THI) was calculated as an indicator of environmental heat stress level, following the equation proposed by Lemal *et al.* (2024):

$$THI = [(1.8 \times T) + 32] - \{(0.55 - 0.0055 \times RH) \times [(1.8 \times T) - 26]\}$$

Interpretation of the THI was performed according to the scale described by Yan *et al.* (2022):

- Mild stress: 68 ≤ THI < 72
- Moderate stress: 72 ≤ THI < 79
- Severe stress: 80 ≤ THI < 89
- Extreme stress: 90 ≤ THI < 99
- Lethal: ≥ 99 THI

Behavioral patterns

Behavioral observations were conducted over three consecutive days in July, August, and September 2023. A simplified ethogram previously validated for grazing systems (Barragán *et al.*, 2017; Broom D., 2021; Martin & Bateson, 2007)) was applied and adapted to the specific conditions of the tropical dry forest (table 1).

Each behavioral activity was recorded using the focal sampling technique, consisting of direct observation sessions of 5 minutes per animal, repeated every 15 minutes between 09:00 and 16:00 h (Barragán *et al.*, 2017). The observations were subsequently grouped into three time

TABLE 1. Ethogram for the evaluation of behaviors in cattle under tropical dry forest conditions

Category	Behavioral activities	Definition
Feeding	Grazing under shade	Forage consumption while standing under tree cover.
	Grazing without shade	Forage consumption while standing in areas exposed to sunlight.
	Browsing	Consumption of leaves, branches or fruits from shrubs or trees.
	Water intake	Drinking water from troughs.
	Salt intake	Ingestion of mineral salts from salt licks.
Resting and ruminating	Standing rest under shade	Animal standing still under tree cover.
	Standing rest under sun	Animal standing still, exposed to sunlight.
	Lying rest under shade	Animal lying down, inactive, under tree cover.
	Lying rest under sun	Animal lying down, inactive, exposed to sunlight.
	Lying rumination	Chewing the ruminal bolus while lying down.
	Standing rumination	Chewing the ruminal bolus while standing.
	Sleeping	Eyes closed, inactive, with evident body relaxation.
Locomotion	Walking	Movement without feeding or direct social interaction.
Social interactions	Suckling	Calf suckling milk from the mother.
	Grooming	Licking or cleaning between individuals.
	Mounting	Mounting behavior (reproductive or social).
	Aggressive behavior	Pushing, headbutting, or charging other animals.
Physiological and others	Scratching	Use of objects (trees, fences) or limbs to rub the body.
	Urinating	Excretion of urine.
	Defecating	Excretion of feces.

Source: Adapted from Barragán *et al.* (2017); Broom D (2021); Martin & Bateson (2007).

intervals (09:00–12:00, 12:00–14:00, and 14:00–16:00) for comparative analysis.

Behavioral assessment was conducted by six observers previously familiarized with the animals through their routine handling of the cattle used in this study. Each observer was assigned to specific individuals to minimize both inter- and

intra-observer variability (Moller *et al.*, 2024). An eight-day habituation period was implemented, during which the personnel entered the grazing area daily with the cattle to reduce potential biases caused by environmental disturbance. This approach is recommended for welfare and efficiency assessments in extensive production systems (Barragán *et al.*, 2017; Martin & Bateson, 2007). Data were recorded using standardized forms that included the following fields: date, animal identification number, observer, behavioral activity, observation time, and duration of the activity. Subsequently, the percentage of time and frequency of each behavioral activity were calculated relative to the total observation time.

Statistical analysis

Initially, a descriptive analysis was conducted, followed by an analysis of variance (ANOVA) to evaluate environmental variables (temperature, humidity, and THI), comparing sensor locations (sun and shade) and time intervals (09:00–12:00, 12:00–14:00, and 14:00–16:00).

Subsequently, a Factorial Analysis of Mixed Data (FAMD) was performed to reduce the dimensionality of the dataset, which included 20 behavioral variables and the supplementary variables temperature–humidity index (THI), breed (Costeño con Cuernos—CCC and Gyrolando), and time interval (09:00–12:00, 12:00–14:00, and 14:00–16:00). This technique integrates categorical and quantitative variables, facilitating the visualization of patterns and associations among observations. In addition, a Student's *t*-test was applied to compare the means of environmental variables (temperature and humidity) and THI according to sensor location (sun and shade) and time interval.

Based on the FAMD results, a hierarchical cluster analysis (HCA) was conducted to identify homogeneous groups of individuals, using Euclidean distance as the dissimilarity metric and Ward's linkage method, which optimizes cluster formation by minimizing within-group variance. The optimal number of clusters was determined using the Elbow method, which evaluates inertia (explained variability) and identifies the point where the rate of decrease becomes less pronounced. Data processing and analysis were performed using the statistical software R v4.5.1 (R Core Team, 2025), employing the *FactoMineR* package (Lê *et al.*, 2008) for FAMD execution and *factoextra* (Kassambara & Mundt, 2020) for visualization and interpretation of the results.

RESULTS

Climatic data and environmental indices

Table 2 presents the adjusted mean values of temperature, relative humidity, and temperature–humidity index (THI) according to sensor location and time interval. In sun-exposed areas, the THI averaged 89 ± 2.4 (95% CI: 85–91), corresponding to a *severe* level of heat stress. In contrast, under natural shade, the average temperature decreased, resulting in a THI of 85 ± 1.2 (95% CI: 83–87), which is classified as *moderate* heat stress.

Behavioral patterns in cattle

Figure 1 shows the distribution of behavioral activities observed in Gyrolando and Costeño con Cuernos (CCC) cows across three-time intervals (09:00–12:00, 12:00–14:00, and 14:00–16:00). Ethological variables were grouped into five

main categories—feeding, resting and rumination, locomotion, social interactions, and physiological behaviors—each encompassing specific behavioral activities (table 1).

The Factorial Analysis of Mixed Data (FAMD) reduced the dimensionality of the 23 behavioral variables, identifying multivariate patterns that explained 70.7% of the total variability across the first 13

TABLE 2. Average values of the temperature-humidity index (THI), temperature, and humidity obtained from datalogger sensors placed under sun and natural shade in scattered-tree pastures during the evaluation period

	Temperature (°C)		**Humidity (%)**		**THI**	
Location	$\bar{x}$ ± S.E.	L.L. – U.L.	$\bar{x}$ ± S.E.	L.L. – U.L.	$\bar{x}$ ± S.E.	L.L. – U.L.
Sun	39.9 ± 0.7[a]	38.4 – 41.4	43.0 ± 1.2b	40.6 – 45.3	89 ± 2.4[a]	85 – 91
Shade	33.5 ± 0.9b	31.8 – 35.3	62.5 ± 1.4[a]	59.7 – 65.2	85 ± 1.2b	83 – 87
Time range	$\bar{x}$ ± S.E.	L.L. – U.L.	$\bar{x}$ ± S.E.	L.L. – U.L.	$\bar{x}$ ± S.E.	L.L. – U.L.
9 – 12	35.9 ± 0.8[a]	34.2 – 37.6	56.7 ± 1.4[a]	54.0 – 59.4	86.7 ± 0.9[a]	84.9 – 88.4
12 – 14	37.8 ± 1.1[a]	35.7 – 40.0	49.3 ± 1.7b	45.9 – 52.7	87.7 ± 1.1[a]	85.5 – 89.9
14–16	36.4 ± 1.1[a]	34.3 – 38.5	52.1 ± 1.7ab	48.7 – 55.5	86.8 ± 1.1a	84.6 – 89.0

Adjusted mean ($\bar{x}$); standard error (S.E.); lower and upper limits of the 95% confidence interval (L.L., U.L.). Different letters within the same column and category indicate statistically significant differences ($p < 0.05$).

Source: own elaboration.

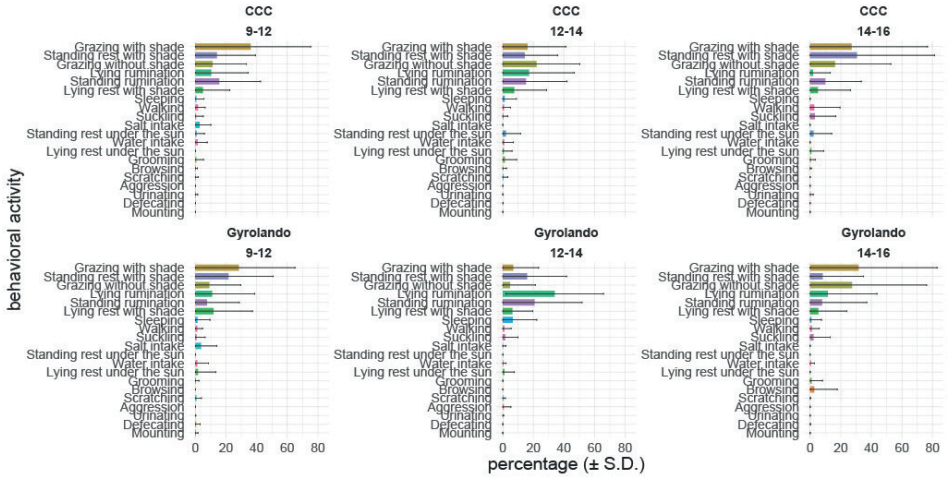

FIGURE 1. Percentage distribution of behavioral activities in lactating Costeño con Cuernos (CCC) and Gyrolando cows across three-time intervals (09:00–12:00, 12:00–14:00, and 14:00–16:00) between July and September in Agustín Codazzi, Colombia.

Source: own elaboration.

components. The hierarchical cluster analysis (HCA) based on these components grouped individuals into two distinct clusters with significant differences in activity patterns, suggesting differentiated behavioral responses influenced by environmental and physiological factors:

- **Cluster 1 (Adverse Climatic Conditions, ACC):** Comprised animals that were more active during the hottest hours, exhibiting longer grazing periods (even in unshaded areas), reduced resting time, greater salt intake, and higher THI levels.
- **Cluster 2 (Moderate Climatic Conditions, MCC):** Included animals showing energy-conserving behavioral patterns, characterized by increased shaded resting, lying rumination, and reduced activity during peak heat hours.

Figure 2 presents the Principal Component Analysis (PCA) applied to the defined clusters. A clear separation between clusters was observed, indicating that the variables included in the analysis effectively discriminated between the groups. Individuals located on the left side of the plot were associated with adverse climatic conditions (ACC), whereas those on the right corresponded to moderate climatic conditions (MCC).

Table 3 presents both the categorical and global means for the activities performed by individuals within each cluster that were statistically significant ($p < 0.01$). For the activity "grazing under shade," results indicate that animals in Cluster 1 spent more time grazing in shaded areas compared with those in Cluster 2. These results were compared with the global mean, representing the total time spent grazing under shade by all individuals (table 3). In other words, the categorical mean values illustrate behavioral differences between clusters, whereas the global mean reflects the overall average for all animals in the study.

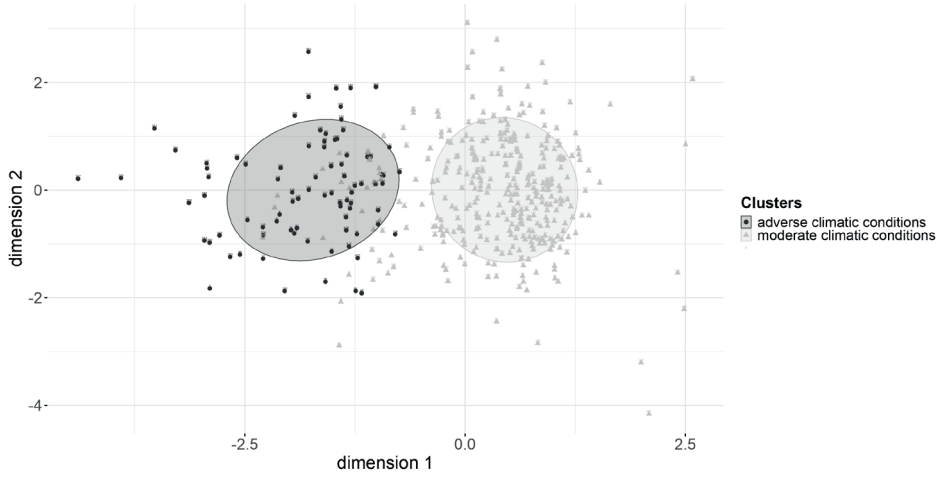

FIGURE 2. Hierarchical classification analysis of the first two dimensions according to the two defined clusters (adverse climatic conditions and moderate climatic conditions) in lactating cows of the horned coastal (CCC) and Gyrolando breeds.

Source: own elaboration.

TABLE 3. Average of the different activities performed by individuals per cluster and global mean

Behavioral activity	Category's		Overall mean
	Cluster 1 (ACC)	Cluster 2 (MCC)	
	$\bar{x}$ ± S. D.	$\bar{x}$ ± S. D.	$\bar{x}$ ± S. D.
Grazing under shade	28.53 ± 3.48	3.89 ± 1.17	21.14 ± 3.18
Grazing without shade	15.66 ± 2.74	4.91 ± 1.41	12.39 ± 2.46
Standing rest under shade	18.18 ± 2.91	8.78 ± 1.67	15.23 ± 2.63
Salt intake	1.74 ± 0.68	0.25 ± 0.21	1.28 ± 0.58
Lying rumination	2.15 ± 0.98	38.26 ± 3.42	12.75 ± 2.61
Lying rest under shade	1.72 ± 0.80	17.61 ± 2.91	6.37 ± 1.86
Sleeping	0.02 ± 0.00	5.43 ± 1.45	1.60 ± 0.82
Standing rumination	9.47 ± 2.15	18.07 ± 3.01	11.96 ± 2.46
Scratching	0.12 ± 0.12	0.67 ± 0.32	0.28 ± 0.20
Environmental index			
Temperature-humidity index	87.21 ± 1.86	84.81 ± 1.20	85.08 ± 1.70

Adverse climatic conditions (ACC); Moderate climatic conditions (MCC)*. Mean ($\bar{x}$) ± standard deviation (S.D.).

Source: own elaboration.

Table 4 presents the categorical variables most strongly associated with each cluster. The Cla/Mod metric represents the proportion of individuals within the cluster exhibiting a given characteristic, Mod/Cla indicates the percentage of individuals with that characteristic belonging to the cluster, and Global denotes the overall percentage of the population displaying the characteristic.

For instance, in Cluster 1, the Cla/Mod metric indicates that most individuals were active between 14:00 and 16:00 h, meaning that nearly all members of this cluster exhibited this characteristic. In contrast, the Mod/Cla metric shows that 39.6% of all animals active during this time period belonged to Cluster 1, suggesting that this behavior was not exclusive to that cluster but also occurred among individuals from other groups.

The detailed characterization of each cluster, based on the averages of significant behavioral activities (table 3) and the association with categorical variables (table 4), is summarized as follows:

TABLE 4. Behavioral activities of lactating cows of Costeño con Cuernos (CCC) and Gyrolando breeds, indicating for each cluster (1 and 2) the percentage of individuals within each cluster that exhibit the characteristic (Cla/Mod) and of individuals with the characteristic that belong to that cluster (Mod/Cla) by time range

Variable	Cla/Mod		Mod/Cla		Overall
	Cluster 1	Cluster 2	Cluster 1	Cluster 2	
Time range = 14–16	95,07	4,22	39,59	4,17	28,98
Breed = CCC	78,89	20,37	62,46	38,19	55,1
Time range = 12–14	75,96	22,6	46,33	32,64	42,45
Breed = Gyrolando	40,45	58,18	37,54	61,8	44,9
Time range = 9–12	34,28	65	14,08	63,19	28,57

Source: own elaboration.

Cluster 1–ACC (animals more active in the afternoon under extreme/severe THI conditions):

- Displayed a higher proportion of grazing activity, both in shaded and unshaded areas.
- Showed increased salt consumption.
- Spent less time resting and ruminating while lying down.
- Recorded shorter sleeping periods.
- This cluster was strongly associated with afternoon hours, with most individuals active between 14:00–16:00 h, followed by the 12:00–14:00 h interval.
- The Costeño con Cuernos (CCC) breed predominated in this cluster.

Cluster 2–MCC (animals more active in the morning with longer resting and rumination periods):

- Exhibited lower grazing activity, both in shaded and unshaded areas.
- Spent a higher proportion of time ruminating, both lying and standing.
- Dedicated more time to resting, particularly while lying under shade.
- Recorded longer sleep durations.
- This cluster was mainly associated with the morning period (09:00–12:00 h), when most individuals were active.
- The Gyrolando breed was more frequent in this cluster.

DISCUSSION

The results revealed significant differences in microclimatic conditions between the evaluated locations. The higher temperature and temperature–humidity index (THI) recorded in sun-exposed areas reflect the direct impact of solar radiation on the animals' immediate environment, whereas shaded areas maintained lower temperatures and higher relative humidity. This pattern aligns with findings from studies on silvopastoral systems, where tree cover contributes to thermal mitigation and microclimatic stability, thereby reducing the heat load experienced by livestock (table 2).

Regarding temporal variation, both temperature and THI increased between 12:00 and 14:00 h, coinciding with the peak of daily solar radiation. Subsequently,

these values declined between 14:00 and 16:00 h, while relative humidity exhibited an inverse pattern. This diurnal trend is characteristic of tropical dry forest ecosystems, where the combination of high temperatures and low humidity at midday intensifies heat stress in grazing cattle. As reported by Yan *et al.* (2022), the THI values observed in this study fall within the severe stress threshold, potentially compromising animal welfare. In this context, shade plays a crucial role, as evidenced by an approximate 6 °C temperature reduction compared with unshaded conditions (table 2).

These findings highlight the strong influence of time of day and shade availability on the expression of cattle behavior, consistent with previous studies reporting circadian variations in activity patterns driven by microclimatic factors (Barragán *et al.*, 2017; Giro *et al.*, 2019; Barsotti *et al.*, 2024; Pezzopane *et al.*, 2019; Ripamonti *et al.*, 2025). The presence of scattered trees within grazing areas provides shade and enhances thermal comfort (Pezzopane *et al.*, 2019), serving as an effective strategy to mitigate heat stress even when physiological indicators—such as panting or elevated respiratory rate are affected. However, full recovery to normal physiological states may require additional time, depending on subsequent environmental conditions (Veissier *et al.*, 2018).

The main findings of this study indicate that bioclimatic indicators, including THI, exceeded the thermotolerance capacity of cattle in both Cluster 1 and Cluster 2, remaining within the severe heat stress range ($80 \leq THI < 90$) (table 3). Consequently, the evaluated animals were likely exposed to significant heat stress resulting from environmental factors, which can lead to behavioral alterations, reduced feed intake, panting, decreased rumination, and weight loss, among other effects (Islam *et al.*, 2021).

In Cluster 1, THI values remained within the severe to extreme range, and grazing occurred predominantly under shaded rather than unshaded conditions. When comparing breeds, CCC cattle exhibited higher activity levels than Gyrolando cows (tables 3 and 4). Similar findings have been reported by Barsotti *et al.* (2024) and Ripamonti *et al.* (2025), who documented the positive effects of tree shade on productive performance and animal welfare, including reduced heat discomfort, lower THI values during the dry season and peak temperature hours, and extended grazing activity in silvopastoral systems.

The elevated activity observed under adverse thermal conditions likely reflects an interaction between nutritional demands, resource availability, and adaptive mechanisms to heat stress. The behavioral pattern of Cluster 1 animals showing increased grazing activity during the hottest hours (12:00–16:00 h)—indicates either enhanced heat tolerance or a behavioral drive to continue foraging and seeking water despite high thermal loads (Barragán *et al.*, 2017). This capacity to sustain grazing under stressful environmental conditions, particularly evident in the CCC breed that predominated in this cluster, holds significant implications for productivity and adaptive efficiency. As a creole or locally adapted breed, CCC cattle have evolved under tropical environments and consequently display superior thermotolerance compared with exotic breeds such as Gyrolando.

Conversely, the behavioral strategy observed in Cluster 2 characterized by reduced grazing activity and increased

resting and rumination in shaded areas during the hottest hours can be explained by thermophysiological mechanisms, since feed intake elevates internal body temperature (Islam *et al.*, 2021). Therefore, this pattern reflects an energy- and heat-conservation strategy adopted under severe heat stress conditions. The higher activity levels recorded during the cooler morning hours (09:00–12:00 h) are consistent with the natural circadian rhythm of cattle, which favors reduced activity and greater shade-seeking behavior during periods of elevated thermal load.

Rumination plays a key role in digestion and nutrient absorption and serves as a reliable behavioral indicator for detecting illness or heat stress, as its frequency typically declines under such conditions (da Silva Santos *et al.*, 2023). This trend was also evident in the present study, where animals in Cluster 2 spent approximately 38.3% of their time ruminating (Table 3). These results align with Maia *et al.* (2020), who found that Gyrolando cattle exposed to heat stress exhibited reduced dry matter intake and altered rumination behavior.

The higher proportion of Gyrolando cattle in Cluster 2 indicates that this breed spent more time resting and ruminating, particularly between 12:00 and 14:00 h (Table 4). This behavior reflects an adaptive response to thermal stress and a general tendency to reduce activity under severe climatic conditions (Barragán *et al.*, 2017). Negri *et al.* (2023) reported that breeds with a higher proportion of *Bos taurus* ancestry such as Gyrolando (7/8 H, or 87.5% Holstein) have a lower heat stress threshold and dissipate heat less efficiently than breeds adapted to hot climates. Nevertheless, within-breed variation exists, as composite genotypes such as ¼ H, ½ H, and 5/8 H (Gyr × Holstein) have demonstrated greater thermal resistance (Negri *et al.*, 2023).

When comparing breeds, CCC cattle exhibited greater tolerance to extreme heat, maintaining active behaviors such as grazing even during the hottest hours. This resilience may be attributed to genetic and morphophysiological traits typical of creole breeds, including lower metabolic heat production, protective pigmentation, and efficient heat dissipation mechanisms (Freitas Silveira *et al.*, 2021). In contrast, Gyrolando cattle, with a stronger European genetic background, markedly reduced activity during peak heat periods, favoring shaded resting and lying rumination behaviors. This pattern suggests a lower capacity for adaptation to tropical thermal environments (Maia *et al.*, 2020). Moreover, heat stress is not merely an acute condition but may exert chronic, long-term effects on cows (Becker & Stone, 2020).

Overall, these findings highlight the importance of promoting the use of heat-adapted breeds such as CCC in tropical dry forest systems, as well as ensuring continuous access to shade and fresh water during high-temperature periods—particularly for less heat-tolerant breeds such as Gyrolando. The reduction in grazing during critical hours may affect feed efficiency and productivity, underscoring the need for management strategies that optimize animal welfare and performance. Moreover, the analysis demonstrates that breed significantly influences heat tolerance, with genotypic differences reflected in preferences for shaded resting areas versus direct sun exposure.

CONCLUSIONS

The hierarchical cluster analysis identified two groups with distinct behavioral strategies in response to environmental

conditions. The Costeño con Cuernos (CCC) breed exhibited greater activity under extreme heat conditions. These results underscore the importance of implementing management strategies that enhance thermal regulation in cattle production systems, with implications for improving animal welfare, optimizing grazing schedules, and promoting the selection of animals with higher heat resilience.

CONFLICT OF INTEREST

The authors declare no conflict of interest related to this research.

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ETHICAL APPROVAL

This study did not require approval by an ethics committee, as animals were observed directly in their grazing areas without physical contact or experimental manipulation.

DECLARATION ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors declare that artificial intelligence was not used in the preparation of this manuscript.

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