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Ingestive Behavior of Dairy Cattle in Two Contrasting Tropical Production Systems in Colombia

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ABSTRACT

In dairy cattle, ingestive behavior is influenced by environmental, nutritional, and management factors. The objective of the study was to describe the ingestive behavior and productive performance of dairy cows in two contrasting dairy production systems in Colombia: a lowland system at 941 m above sea level (a.s.l.) with Lucerna cows, and a highland system at 2500 m a.s.l. with Holstein cows. The temperature-humidity index (THI), forage and water intake, as well as behavioral patterns, were monitored under each system. In the lowland system, the THI values exceeded 85 during afternoon hours, reaching emergency levels; however, Lucerna cows exhibited no clinical signs of heat stress, suggesting thermal resilience. In the highland region, THI remained within the alert range (72-79). Dry matter intake (DMI) as a percentage of body weight was 2.42% in the lowland system and 1.68% in the highland system. Feed efficiency was lower in the lowland system (69.56%) than in the highland system (96.67%). Milk yield per unit of metabolic body weight ($BW^{0.75}$) was 0.119 kg/kg $BW^{0.75}$ in the lowland system and 0.206 kg/kg $BW^{0.75}$ in the highland system. Water intake per 100 kg of body weight was 13.31 L in the lowland system and 16.12 L in the highland system. Forage quality was superior in the highland system, with greater crude protein levels and lower fiber content. Both systems showed metabolizable energy deficits, which increased when accounting for energy expenditures associated with walking. These findings underscore the critical need to tailor management strategies to the unique environmental and nutritional conditions of each production system, thereby enhancing animal welfare and optimizing productivity.

***Keywords:** animal welfare; bovine behavior; feed efficiency; milk production; thermal stress*

INTRODUCTION

Dairy production in Colombia spreads over a wide diversity of altitudes and climates, from the warm tropics of the lowlands to the cold highland areas, which is in line with other countries (Alvarado *et al*., 2021; Muñoz *et al*., 2020). Amid these diverse climates, cattle have unique challenges to meet: they change their ingestive behavior with temperature, humidity, and forage quantity (Llonch *et al*., 2018; Chen *et al*., 2024); these behaviors represent a key measure of animal welfare, efficiency of feed use, and levels of production.

Ingestive behavior, which comprises forage ingestion, rumination, and resting time, is particularly related to forage quality, shade availability, and microclimatic conditions (Boval & Sauvant, 2019; Reis *et al*., 2021). Knowing these behavioral responses to environmental and management conditions allows us to predict and influence feeding patterns in diverse production situations, being important for the overall efficiency of milk production, optimizing use of forage resources, and facilitating the design of facilities that reduce their negative impact on the environment and maximize economic efficiency (de Oliveira, 2021; Uribe *et al*., 2025).

Although ingestive behavior has been demonstrated as highly relevant for dairy production, the extent to which it varies between tropical lowland and highland systems has yet to be systematically investigated. This knowledge gap is particularly important in Colombia, where spatial heterogeneity in climate, altitude, and landscape features creates highly diverse production conditions among regions (Montoya *et al*., 2023; Durana *et al*., 2023). Addressing this gap is essential for developing dairy management strategies adapted to different microclimatic and forage-specific challenges.

The objective of this study was to provide a comprehensive and detailed characterization of ingestive behavior and productive performance in dairy cattle across lowland and highland production systems. Understanding these behavioral and productive traits is essential for developing management strategies tailored to the specific requirements of each production system to optimize animal welfare and productivity. We assessed ingestive behavior patterns (grazing, rumination, and resting), forage and water intake, milk yield, feed efficiency, cows' energy-protein balance, and walking distance.

MATERIALS AND METHODS

Study Locations

The first study was conducted in the lowland system (Hacienda Lucerna farm), located in the municipality of Bugalagrande, Valle del Cauca department (Colombia), at an altitude of 941 m a.s.l. The region has an average annual temperature of 26.3 °C and a relative humidity of 66.5%, under the characteristic conditions of the Tropical Dry Forest (b-ST; Holdridge, 1967). The evaluated system was an intensive silvopastoral system, characterized by a high density of *Leucaena leucocephala* Lam. Cv Cunningham (>8000 shrubs per hectare), associated with "star grass" (*Cynodon plectostachyus* K. Schum. Pilg). Forty-four Lucerna cows were managed under a rotational grazing system, utilizing daily strips of approximately 1200 m², with a rotation cycle of 43 days and a one-day occupation period, providing each animal with approximately 60 m² daily. Nutritional management incorporated supplementation during milking, conducted mechanically twice daily, with each cow receiving 2.19 kg of rice bran and 2.25 kg of cassava bran per day.

The second evaluation was conducted in the highland system (La Jacoba farm), located in the municipality of La Unión, Antioquia department (Colombia), at an altitude of 2,500 m a.s.l., with an average annual temperature of 17 °C and a relative humidity of 80%, under the characteristic conditions of the Lower Montane Humid Forest (bmh-MB; Holdridge, 1967). The rotational grazing system consisted of a "kikuyu" grass (*Cenchrus clandestinus*) monoculture, with 48 Holstein cows managed in daily strips of approximately 4,358 m² (90.8 m²/animal/d) using an electric mobile fence. The rotation cycle was 33 days, with a one-day occupation per strip. Nutritional management included 5 kg of commercial concentrate per cow, provided during milking twice a day.

Environmental Monitoring

Temperature and relative humidity were recorded every 20 minutes for 48 hours using thermohygrometers placed in the paddocks. The temperature-humidity index (THI) was calculated using the Kibler (1964) equation, and thermal stress levels were classified according to Wiersama (2005).

$$THI= (1.8 \times T° + 32) – (0.55 – 0.55 \times RH / 100) \times (1.8 \times T° – 26)$$

Where: THI denotes the temperature-humidity index, T is temperature in degrees Celsius, and RH is relative humidity in percentage.

Forage and Water Intake

Daily forage offered (kg DM/animal or kg DM/100 kg BW) was estimated using the comparative yield method (Haydock & Shaw, 1975), which relies on a visual scale with three forage availability levels (low, medium, and high). Forage was harvested 8 cm above ground level, and nine out of 25 randomly placed 0.25 m² frames per strip were weighed. For shrub biomass, the method was modified using a linear meter and cutting three shrubs 10 cm above the ground level. Available forage biomass was calculated as total biomass minus dead material. Daily forage intake (kg DM/animal or kg DM/100 kg BW) was estimated from the difference between forage offered and the remainder after grazing. Water intake was measured using flow meters at drinking stations, and water from feed was estimated based on dry matter intake and forage moisture content.

Feed Composition Analysis

A representative sample of the forages and feed supplements offered to animals was collected from each strip assigned for grazing. Samples were stored under refrigeration until transport to the laboratory, where they were dried in a forced-air oven at 65 °C for 72 h to determine dry matter (AOAC, 2019, Method 934.01). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined following the methodology described by Van Soest et al. (1991). Crude protein (CP) was determined by the Kjeldahl method (AOAC, 2019, Method 984.13). Ether extract (EE) was quantified by Soxhlet extraction (AOAC, 2019, Method 920.39). Ash was obtained by direct incineration in a muffle furnace (AOAC, 2019, Method 942.05). Finally, calcium and phosphorus concentrations were determined according to the official AOAC methods (2019, Methods 968.08 and 965.17, respectively). The nutritional composition of all feed sources is presented in Table 1.

Nutritional Balance and Walking Distance

Nutritional balance was estimated using the Cornell Net Carbohydrate and Protein System (CNCPS; Van Amburgh *et al*., 2015), based on field data on forage supply, feed composition, and animal productive and reproductive parameters. Two simulations were performed per system: one considering only baseline nutritional requirements and another including the energy cost of walking. To estimate walking distance, one animal per system was equipped with a GPS device (Oregon 650 Garmin) and a mobile phone running the STRAVA app, both mounted on a head collar. Georeferenced data were processed in QGIS (version 3.36.3) to calculate the total distance walked during the observation period.

Nutritional Balance and Walking Distance

Animal behavior was continuously monitored over 48 hours under grazing conditions. Observations

Table 1. Nutritional composition (percent of DM) of the feed sources included in the study

Variables	Nutrients							
	DM	NDF	ADF	CP	Fat	Ca	P	Ash
Lowland system								
Leucaena leucocephala	26.7	35.2	28.4	27.9	1.82	0.85	0.24	6.76
Cynodon plectostachyus	23.5	61.6	39.1	15.3	2.00	0.19	0.36	13.1
Rice bran	9.60	16.7	7.60	13.6	1.7	0.05	1.60	8.68
Cassava bran	13.8	26.1	20.9	2.2	1.2	0.32	0.03	3.81
Highland system								
Cenchrus clandestinus	13.9	53.4	26.1	23.7	3.04	0.39	0.49	11.3
Concentrate	87.4	22.8	10	15.3	5.6	0.71	0.52	5.98

Note: DM= dry matter, NDF= neutral detergent fiber, ADF= acid detergent fiber, CP= crude protein, Ca= calcium, and P= phosphorus.

were carried out by four trained researchers organized in alternating 12-hour shifts, using the scan sampling technique described by Setz (1991). Behavioral records were taken every 20 minutes, resulting in a total of 144 observations per farm. The recorded behaviors included forage intake (FI), standing rumination (RuS), lying rumination (RuL), standing rest (ReS), and lying rest (ReL). This information allowed for the quantification of time allocation to each activity and the identification of behavioral patterns associated with the animals' circadian rhythms.

Statistical Analysis

Since the initial conditions of each farm differed from the beginning, no direct comparisons were made between them. Although the results are presented together, the description and statistical analysis were carried out independently for each farm. Variables related to forage supply, forage intake, and water intake were analyzed using descriptive statistics (mean and standard deviation). To explore the association between behavioral activities and time of day, a chi-square test was applied, followed by a multiple correspondence analysis (MCA). Additionally, the Friedman test was used to assess significant differences among the recorded behaviors. This non-parametric alternative to two-way ANOVA is suitable for randomized complete block designs when parametric assumptions are not met. All analyses were performed in R (R Core Team, 2022).

RESULTS

Environmental Conditions

During the observation period, the THI in the lowland system exceeded 85 units between 13:00 and 17:00, reaching the emergency threshold. In contrast, in the highland system, THI values remained below 75 units (Figure 1), within the alert range. Cows in the lowland system showed no clinical signs of heat stress (respiratory rate <60 breaths/min, no panting or salivation), indicating a high level of thermal adaptation. These findings suggest that the risk thresholds proposed by Wiersama (2005) may require adjustment for this breed.

Forage and Water Intake

Data on forage supply and intake, nutritional composition, and water consumption are presented in Table 2. In the lowland system, dry matter intake as a percentage of body weight was higher, and forage composition reflected a greater fiber content. In the highland system, dry matter intake, feed efficiency, and available grazing area per animal were consistent with the agroecological conditions of the region. Forage in this system showed higher CP and lower NDF. Total water intake included both drinking water and water from feed and was associated with the productive characteristics observed in each system.

Milk Production

Average milk yield was 12.4 ± 2.03 kg/animal/day in the lowland system and 25.33 ± 7.19 kg/animal/day in the highland system. When expressed per unit of metabolic body weight ($BW^{0.75}$), milk production was 0.119 kg/kg $BW^{0.75}$ in the lowland system and 0.206 kg/kg $BW^{0.75}$ in the highland system. Feed conversion efficiency, expressed as milk yield per kilogram of dry

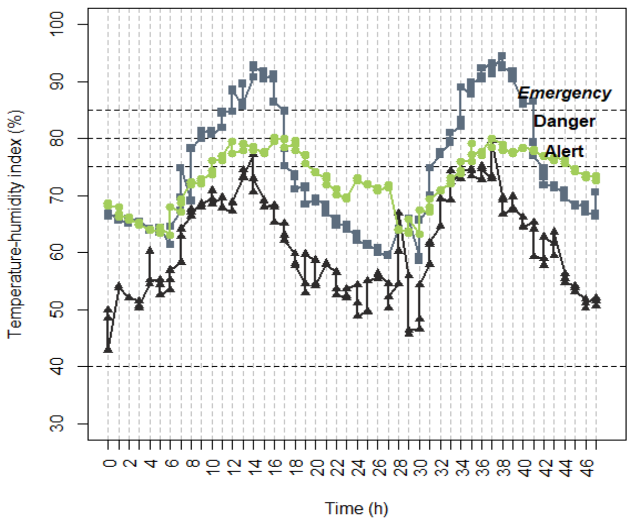

Figure 1. Temperature and relative humidity indexes (%) for the Lowland and Highland system dairy farms during the study. ■ Lowland system, ● Lowland system (under tree shade), ▲ Highland system.

Table 2. Means and standard deviations of the variables related to botanical composition, forage offer, forage intake, and production in tropical dairy production systems

	Type of production system	
	Lowland system	Highland system
Forage offered, kg fresh forage/m²		
Cenchrus clandestinus		2.49 ± 0.08
Cynodon plectostachyus	2.59 ± 1.35	
Leucaena leucocephala	0.68 ± 0.05	
General information on the grazing system		
Number of animals, head	44	48
Animal body weight, kg	475.3 ± 9.1	601.7 ± 6.10
Pasture regrowth period, d	45	35
Available area, m²/animal/d	59.98 ± 5.75	90.80 ± 30.74
Available area, m²/100 kg BW/d	12.62 ± 1.21	15.09 ± 5.11
Forage offer		
Fresh forage, kg/m²/d	3.27 ± 1.35	2.49 ± 0.08
Fresh forage, kg/animal/d	65.51 ± 3.81	75.21 ± 23.30
DM, kg/animal/d	15.97 ± 8.57	10.45 ± 3.24
Intake, kg/animal/d		
Fresh forage, yield method	45.87 ± 13.06	72.71 ± 22.45
DM, yield method	10.85 ± 3.07	10.10 ± 3.12
Fresh forage, CNCPS	46.70	71.94
DM, CNCPS	11.13	10.00
CP, yield method	1.73	2.39
CP, CNCPS	1.36	2.09
NDF, yield method	6.53	5.34
NDF, CNCPS	6.42	4.32
ADF, yield method	4.18	2.64
ADF, CNCPS	4.24	2.61
DM intake, % of liveweight	2.42 ± 0.69	1.68 ± 0.52
Intake efficiency, %	69.56 ± 15.90	96.67 ± 0.07
Supplement intake, kg/animal/d (DM)		
Concentrate		5.00
Rice bran	0.21	
Cassava bran	0.31	
CP	0.035	0.765
NDF	0.116	1.14
Fat	0.007	0.28
Water intake, L/animal/d		
Drinking water intake	63.25 ± 4.66	97.02 ± 7.28
Feed water intake	36.66 ± 9.99	62.61 ± 19.35
Total water intake	99.91 ± 3.35	159.63 ± 7.46
Production		
Milk, kg/cow/d	12.4 ± 2.03	25.33 ± 7.19
kg/Bw$^{0.75}$	0.119 ± 0.019	0.206 ± 0.058

Note: DM= dry matter, CP= crude protein, NDF= neutral detergent fiber, ADF= acid detergent fiber.

matter intake, was 0.78 in the lowland system and 1.68 in the highland system.

Energy Balance and Walking Distance

Tables 3 and 4 show the estimated nutritional balance according to the CNCPS model for farms located in lowland and highland systems, respectively. The nutritional evaluation indicated a metabolizable energy (ME) deficit in lowland and highland systems. In the lowland system, cows walked an average of 1,300 m per day (Figure 2B), resulting in an additional energy expenditure of 0.49 Mcal/day. This increased the ME deficit from −3.96 to −4.45 Mcal/day (Table 3), representing approximately 1.87% of the total ME requirement. In the highland system, cows walked an average of 3,440 m per day (Figure 3B), with an associated energy cost of 1.66 Mcal/day. This raised the ME deficit from −4.79 to −6.45 Mcal/day (Table 4), equivalent to 3.81% of daily ME requirements. Detailed values for protein, amino acids, and minerals are presented in Tables 3 and 4.

Ingestive Behavior

Multiple correspondence analysis revealed distinct behavioral patterns based on time of day and animal posture. In the lowland system, Dimension 1 explained

Table 3. Nutritional balance according to the Cornell net carbohydrate and protein system (CNCPS) model of the lowland system

Requirement	Lowland system (Walking)					
	ME (Mcal/d)	MP (g/d)	MET (g/d)	LYS (g/d)	Ca (g/d)	P (g/d)
Maintenance	11.63	560	11	34	0	0
Pregnancy	0.12	4	0	0	0	0
Lactation	12.95	612	11	37	15	12
Growth	1.49	39	1	2	1	1
Total requirement	26.19	1215	22	74	28	25
Total supply	21.74	870	15	48	9	29
Balance	-4.45	-346	-7	-26	-19	3
	Lowland system (No-walking scenario)					
Maintenance	11.13	560	11	34	0	0
Pregnancy	0.12	4	0	0	0	0
Lactation	12.95	612	11	37	15	12
Growth	1.49	39	1	2	1	1
Total requirement	25.69	1215	22	74	28	25
Total supply	21.74	870	15	48	9	29
Balance	-3.96	-346	-7	-26	-19	3

Note: ME= Metabolizable energy; MP= Metabolizable protein; Met= Methionine; Lys= Lysine; Ca= Calcium; P= Phosphorus.

Table 4. Nutritional balance according to the Cornell net carbohydrate and protein system (CNCPS) model of the highland system

	Highland system (Walking)					
Requirements	ME (Mcal/d)	MP (g/d)	MET (g/d)	LYS (g/d)	Ca (g/d)	P (g/d)
Maintenance	15.26	568	11	35	0	0
Pregnancy	0.14	5	0	0	0	0
Lactation	28.27	1288	23	78	31	25
Growth	0	0	0	0	0	0
Total Requirement	43.67	1861	34	113	46	41
Total supply	37.22	1917	32	99	75	75
Balance	-6.45	56	-1	-14	28	34
	Highland system (No-walking scenario)					
Maintenance	13.6	568	11	35	0	0
Pregnancy	0.14	5	0	0	0	0
Lactation	28.27	1288	23	78	31	25
Growth	0	0	0	0	0	0
Total Requirement	42.01	1861	34	113	46	41
Total supply	37.22	1917	32	99	75	75
Balance	-4.79	56	-1	-14	28	34

Note: ME= Metabolizable energy; MP= Metabolizable protein; Met= Methionine; Lys= Lysine; Ca= Calcium; P= Phosphorus.

63.8% of the variability and distinguished between standing and lying behaviors, while Dimension 2 (28.7%) was associated with periods of elevated THI, during which cows spent more time standing (Figure 2C). In the highland system, Dimension 1 (44.5%) also reflected postural differences, and Dimension 2 (38.6%) separated activities occurring in the paddock from those associated with milking (Figure 3C).

In both farms, forage intake followed a bimodal distribution, with peaks in the early morning (06:00–08:00; Figure 2A) and late afternoon (16:00–18:00; Figure 3A). Lying rumination and lying rest predominated during nighttime hours (19:00–03:00), while standing rest was more frequent around midday and during milking periods. Standing rumination was the least frequent activity and showed a more uniform distribution throughout the day.

The temporal distribution and daily duration of activities are summarized in Table 5. In the lowland system, cows spent an average of 7.4 hours on forage intake, followed by lying rumination (5.9 h) and standing rest (5.5 h). Lying rest and standing rumination were less frequent, with 3.0 and 2.2 hours, respectively. In the highland system, forage intake was slightly higher (7.9 h), with similar durations for lying rumination (5.4 h) and standing rest (4.2 h). Lying rest and standing rumination were recorded at 3.9 and 2.6 hours, respectively.

The Friedman test revealed significant differences in time allocation among behavioral categories of cows grazing in the lowland system ($p= 0.019$), with forage intake, lying rumination, and standing rest showing the highest average ranks. In the highland system, differences were not statistically significant ($p = 0.06$), although similar behavioral trends were observed.

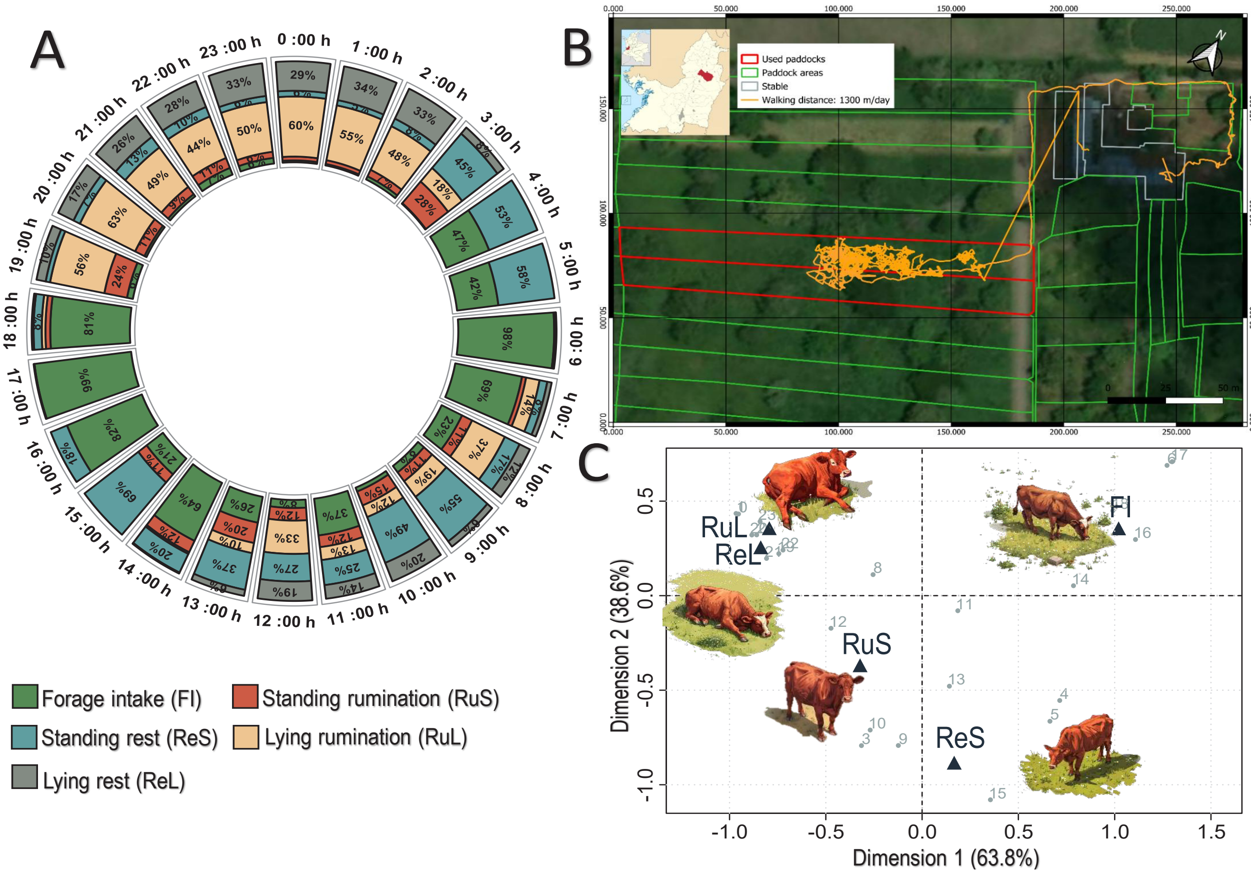

Figure 2. Ingestive and spatial dynamics of 44 Lucerna dairy cows in a lowland system. A) Ingestive behavior. B) Walking distance map. C) Correspondence analysis.

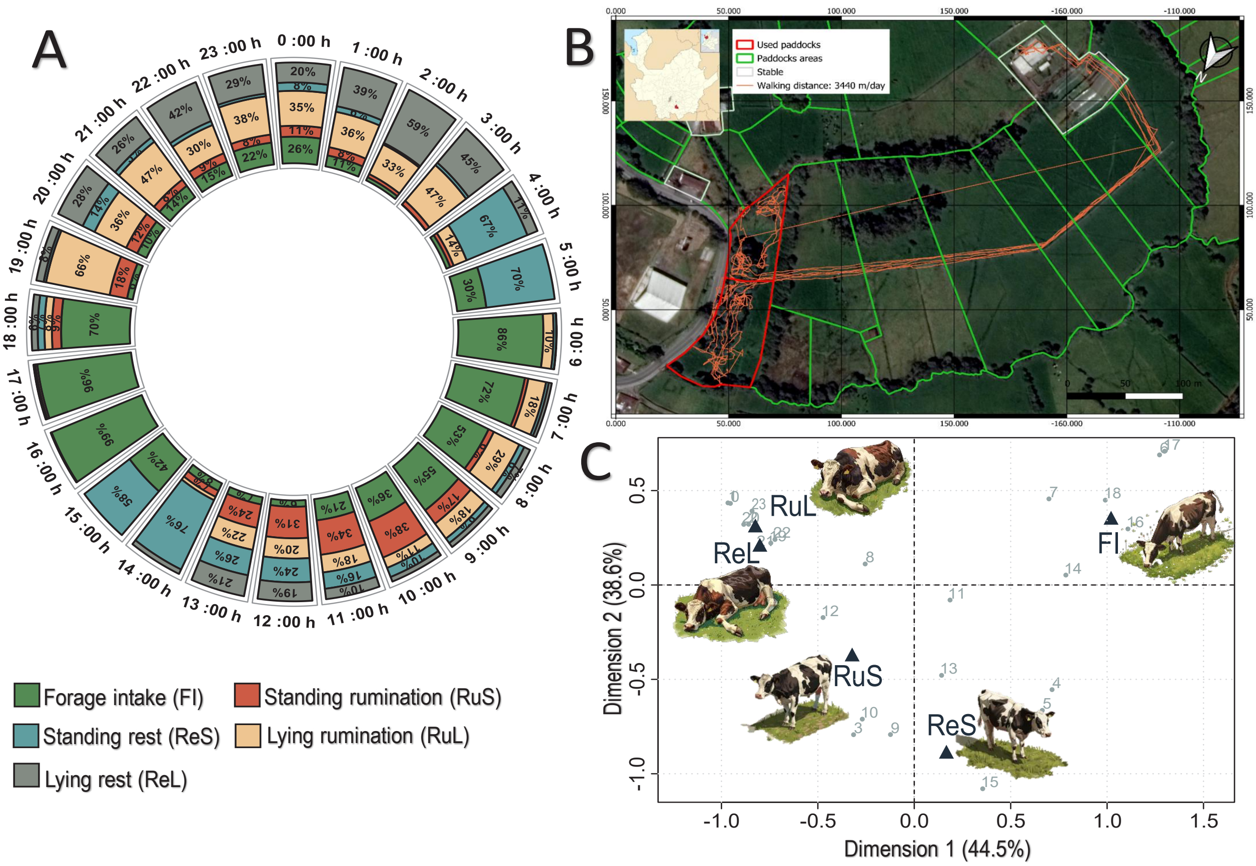

Figure 3. Ingestive and spatial dynamics of 48 Holstein dairy cows in a highland system. A) Ingestive behavior. B) Walking distance map. C) Correspondence analysis.

Table 5. Temporal distribution and daily duration in hours and percentages of ingestive behavior in rotational grazing systems

Activity	Lowland system (Lucerna cows)			
	Hours	Mean ± SD	Median ± Range	Average Rank
Forage intake	7.4	0.309 ± 0.34	0.144 ± 0.98	2.87[a]
Lying rest	3.0	0.126 ± 0.12	0.088 ± 0.34	2.37[b]
Standing rest	5.5	0.230 ± 0.21	0.148 ± 0.68	3.42[a]
Lying rumination	5.9	0.245 ± 0.23	0.159 ± 0.63	3.69[a]
Standing rumination	2.2	0.091 ± 0.08	0.099 ± 0.28	2.65[b]
P-value				0.019
	Highland system (Holstein cows)			
Activity	Hours	Mean ± SD	Median ± Range	Average Rank
Forage intake	7.9	0.331 ± 0.31	0.216 ± 0.99	3.4
Lying rest	3.9	0.162 ± 0.17	0.090 ± 0.59	2.7
Standing rest	4.2	0.174 ± 0.24	0.056 ± 0.76	3.7
Lying rumination	5.4	0.226 ± 0.17	0.193 ± 0.66	2.5
Standing rumination	2.6	0.107 ± 0.11	0.078 ± 0.39	2.8
P-value				0.06

Note: Different letters within a column indicate significant differences between activities according to the Friedman test with Holm correction for multiple comparisons (α= 0.05).

DISCUSSION

This study offers a comprehensive analysis of ingestive behavior and productivity indicators in rotational grazing dairy systems located in diverse tropical environments, with variations by region, breed, and climate. It emphasizes how crucial management is to productivity and animal welfare. These variations were demonstrated through clear changes in the behavior and performance of the animals, illustrating how physiology and environment can impact production outcomes.

The cows in the lowland system showed no symptoms of discomfort, despite THI values being high enough to indicate heat stress. These findings suggest that the Lucerna breed exhibits high tolerance to elevated temperatures, which is consistent with Habimana *et al.* (2023) findings and emphasizes the need to reevaluate THI thresholds currently established for European breeds such as Holstein (Wiersama, 2005). Microclimatic variations within the same paddock were evident from THI records. Tree-covered areas largely remained within the alert range (Figure 1), significantly reducing exposure to thermal stress conditions (Ferreira *et al*., 2021), while unshaded areas experienced danger and even emergency levels for several hours each day. These results support the role of tree cover in reducing heat load and promoting thermoregulation, highlighting the significance of incorporating management practices like natural shade in tropical livestock systems (Thornton *et al*., 2022; Pérez *et al*., 2024).

Highland system conditions provided better thermal comfort, with milk production levels and forage intake patterns that matched those expected in specialized systems (Avellaneda *et al*., 2022; Enciso *et al*., 2021). Nevertheless, deficiencies in metabolizable energy (ME) were identified, mainly linked to energy requirements for walking long distances and moving over sloping terrain, which may impact animal productivity. Neave *et al*. (2021) reported that as walking distances increased, cows spent more time grazing and less time ruminating, likely due to increased energy demands from locomotion, resulting in reduced milk yield. Dickinson *et al*. (2021) and Antanaitis *et al*. (2024) also reported similar behavioral patterns.

Energy balance analysis revealed that the lowland system had a deficit of 1.87% of total requirements, while the highland system exhibited a deficit of 3.81%. Walking energy expenditure was 0.49 Mcal/day in the lowland system compared to 1.66 Mcal/day in the highland system. For Holstein cows in the highland system, the energy cost associated with walking was estimated at 0.48 Mcal/km based on an average daily walking distance of 3.4 km. In comparison, the National Research Council [NRC] (2001) model calculates an energy cost of 0.27 Mcal/km for a 600 kg animal. This discrepancy results from the model's failure to account for terrain slope; however, the NRC (2001) suggests increasing energy values by up to 50% for steep slopes, highlighting the significance of considering topography and walking distance in diet formulation (Gonçalves *et al*., 2024; Talmón *et al*., 2025).

Cynodon plectostachyus (NDF: 61.6%, ADF: 39.1%) constitutes the majority of the diet in the lowland system. Its high fiber content and low digestibility slow ruminal passage, limit voluntary intake, and prolong lying rumination time (average rank: 3.69). This pattern illustrates how forage quality affects cows' time allocation and digestive efficiency. Consistent with earlier research (Iqbal *et al*., 2023; Heublein *et al*., 2017), distinct circadian rhythms were observed, with increased grazing activity during cooler hours and predominantly rest and rumination at night. Due to the fibrous nature of the forage and the requirement for prolonged rumination periods, lying rumination was among the most frequent activities. Uribe *et al.* (2025) also reported similar behavioral patterns in cattle managed in Colombia's tropical regions. Incorporating legumes with lower NDF content, such as *Leucaena* *leucocephala*, and supplementing with highly digestible energy sources, including rice and cassava bran, can improve nutrient density, reduce fill effects, and enhance animal comfort and productivity (Chará *et al*., 2019; Gaviria *et al*., 2022).

The observed milk-to-water conversion efficiency (0.12 kg/L in the lowland system and 0.26 kg/L in the highland system) demonstrates how physiological and environmental factors influence water utilization in dairy production. While farm-to-farm comparisons were not the primary objective of this study, these values provide useful benchmarks for understanding system-specific dynamics. Furthermore, data on forage intake and supply confirm that the CNCPS model can be successfully applied in tropical environments (Van Amburgh *et al*., 2015), enhancing its utility for estimating nutrient intake in dairy cows under different management systems.

CONCLUSION

This study examined ingestive behavior and productive performance in lowland and highland dairy systems. The variations in grazing, rumination, resting patterns, walking distance, and energy-protein balance indicate unique behavioral strategies that develop as adaptive responses to the productive requirements and environmental limitations of each system. The nutritional deficiencies identified in both systems demonstrate that behavioral adaptation alone cannot maintain production without specific interventions. These findings establish a framework for incorporating behavioral profiling into precision management strategies, enabling producers to address system-specific constraints and enhance both animal welfare and productive efficiency in tropical dairy production.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author(s) used ChatGPT (OpenAI) to improve the readability and grammar of the manuscript, and MidJourney and Illustrae to create illustrative figures for visualization purposes. After using these tools/services, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the publication.

REFERENCES

Alvarado, V., Medrano, J., Haro, J., Castro, J., Dickhoefer, U., & Gómez, C. (2021). Enteric methane emissions from lactating dairy cows grazing cultivated and native pastures in the high Andes of Peru. Livestock Science, 243, 104385. https://doi.org/10.1016/j.livsci.2020.104385

Antanaitis, R., Džermeikaitė, K., Krištolaitytė, J., Girdauskaitė, A., Arlauskaitė, S., Tolkačiovaitė, K., & Baumgartner, W. (2024). The relation between milk lactose concentration and the rumination, feeding, and locomotion behavior of early-lactation dairy cows. Animals, 14(6), 836. https://doi.org/10.3390/ani14060836

AOAC International. (2019). Métodos oficiales de análisis de la AOAC Internacional (21st ed.). AOAC International.

Avellaneda, Y., Mancipe, E., & Vargas, J. (2022). Ingestive behavior and dry matter intake of dairy cattle grazing Kikuyu grass (*Cenchrus clandestinus*) pastures. Tropical Grasslands-Forrajes Tropicales, 10(3), 261-270. https://doi.org/10.17138/tgft(10)261-270

Boval, M., & Sauvant, D. (2019). Ingestive behaviour of grazing ruminants: meta-analysis of the components of bite mass. Animal Feed Science and Technology, 251, 96-111. https://doi.org/10.1016/j.anifeedsci.2019.03.002

Chará, J., Rivera, J., Barahona, R., Murgueitio, E., Calle, Z., & Giraldo, C. (2019). Intensive silvopastoral systems with *Leucaena leucocephala* in Latin America. Tropical Grasslands-Forrajes Tropicales, 7(4), 259-266. https://doi.org/10.17138/tgft(7)259-266

Chen, L., Thorup, V. M., Kudahl, A. B., & Østergaard, S. (2024). Effects of heat stress on feed intake, milk yield, milk composition, and feed efficiency in dairy cows: A meta-analysis. Journal of Dairy Science, 107(5), 3207-3218. https://doi.org/10.3168/jds.2023-24059

de Oliveira, C. C., de Almeida, R. G., Junior, N. K., Villela, S. D. J., Bungenstab, D. J., & Alves, F. V. (2021). Daytime ingestive behaviour of grazing heifers under tropical silvopastoral systems: Responses to shade and grazing management. Applied Animal Behaviour Science, 240, 105360. https://doi.org/10.1016/j.applanim.2021.105360

Dickinson, E. R., Stephens, P. A., Marks, N. J., Wilson, R. P., & Scantlebury, D. M. (2021). Behaviour, temperature and terrain slope impact estimates of energy expenditure using oxygen and dynamic body acceleration. Animal Biotelemetry, 9, 47. https://doi.org/10.1186/s40317-021-00269-5

Durana, C., Murgueitio, E., & Murgueitio, B. (2023). Sustainability of dairy farming in Colombia's High Andean region. Frontiers in Sustainable Food Systems, 7, 1223184. https://doi.org/10.3389/fsufs.2023.1223184

Enciso, K., Castillo, J., Albarracín, L. O., Campuzano, L. F., Sotelo, M., & Burkart, S. (2021). Avena sativa AV25-T (Altoandina) supplementation as alternative for Colombia's high-altitude dairy systems: an economic analysis. Frontiers in Sustainable Food Systems, 5, 758308. https://doi.org/10.3389/fsufs.2021.758308

Ferreira, H. C., Carvalho, C. C. S., Monção, F. P., Rocha Júnior, V. R., Ruas, J. R. M., da Costa, M. D., de Jesus, M. A., Magalhães Gonçalves, M. C., Mendes Rocha, H. C., Gomes Ribas, W. F., Delvaux Júnior, N. A., Alencar Chamone, J. M., & Sampaio Rigueira, J. P. (2021). Effect of shading strategies on intake, digestibility, respiratory rate, feeding behaviour, and performance of feedlot-finished Nellore bulls in the semi-arid region of Brazil. Italian Journal of Animal Science, 20(1), 1759-1769. https://doi.org/10.1080/1828051X.2021.1912662

Gaviria, X., Castro, J., Bolívar, D. M., Molina, I., Chirinda, N., Dickhoefer, U., Barahona, R., & Arango, J. (2022). The effects of two species of Leucaena on *in vitro* rumen fermentation, methane production and post-ruminal protein supply in diets based on Urochloa hybrid cv. Cayman. Agronomy, 12(3), 629. https://doi.org/10.3390/agronomy12030629

Gonçalves, P., Magalhães, J., & Corujo, D. (2024). Estimating the energy expenditure of grazing farm animals based on dynamic body acceleration. Animals, 14(15), 2140. https://doi.org/10.3390/ani14152140

Habimana, V., Ekine-Dzivenu, C. C., Nguluma, A. S., Nziku, Z. C., Morota, G., Chenyambuga, S. W., & Mrode, R. (2023). Genes and models for estimating genetic parameters for heat tolerance in dairy cattle. Frontiers in Genetics, 14, 1127175. https://doi.org/10.3389/fgene.2023.1127175

Haydock, K. P., & Shaw, N. H. (1975). The comparative yield method for estimating dry matter yield of pasture. Australian Journal of Experimental Agriculture and Animal Husbandry, 15, 663–670. https://doi.org/10.1071/EA9750663

Heublein, C., Dohme-Meier, F., Südekum, K. H., Bruckmaier, R. M., Thanner, S., & Schori, F. (2017). Impact of cow strain and concentrate supplementation on grazing behaviour, milk yield and metabolic state of dairy cows in an organic pasture-based feeding system. Animal, 11(7), 1163-1173. https://doi.org/10.1017/S1751731116002639

Holdridge, L. R. (1967). Life zone ecology. Tropical Science Center.

Iqbal, M. W., Draganova, I., Henry Morel, P. C., & Todd Morris, S. (2023). Variations in the 24 h temporal patterns and time budgets of grazing, rumination, and idling behaviors in grazing dairy cows in a New Zealand system. Journal of Animal Science, 101, skad038. https://doi.org/10.1093/jas/skad038

Kibler, H. H. (1964). Thermal effects of various temperature-humidity combinations on Holstein cattle as measured by eight physiological responses. University of Missouri Agricultural Experiment Station Research Bulletin 862.

Llonch, P., Mainau, E., Ipharraguerre, I. R., Bargo, F., Tedó, G., Blanch, M., & Manteca, X. (2018). Chicken or the egg: the reciprocal association between feeding behavior and animal welfare and their impact on productivity in dairy cows. Frontiers in Veterinary Science, 5, 305. https://doi.org/10.3389/fvets.2018.00305

Montoya, S., Chará, J. D., Murgueitio, E., Correa-Londoño, G. A., & Barahona, R. (2023). Producción forrajera y consumo en ganaderías colombianas con diversos sistemas de pastoreo incluyendo sistemas silvopastoriles. Livestock Research for Rural Development, 35(7).

Muñoz, E. C., Andriamandroso, A. L., Blaise, Y., Ron, L., Montufar, C., Kinkela, P. M., Lebeau, F., & Bindelle, J. (2020). How do management practices and farm structure impact productive performances of dairy cattle in the province of Pichincha, Ecuador. Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS), 121(2), 233-241.

National Research Council. (2001). Nutrient requirements of dairy cattle (7th rev. ed.). National Academy Press.

Neave, H. W., Edwards, J. P., Thoday, H., Saunders, K., Zobel, G., & Webster, J. R. (2021). Do walking distance and time away from the paddock influence daily behaviour patterns and milk yield of grazing dairy cows?. Animals, 11(10), 2903. https://doi.org/10.3390/ani11102903

Pérez, V. M., López, S., Pérez, S., Pérez, P., Castillo, E., & Jarillo, J. (2024). Effect of tree shade on behavior and haircoat temperature of grazing dual-purpose cows in a hot and humid tropical environment. Agroforestry Systems, 98(1), 165-178. https://doi.org/10.1007/s10457-023-00897-1

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/

Reis, N. S., Ferreira, I. C., Mazocco, L. A., Souza, A. C. B., Pinho, G. A., da Fonseca Neto, Á. M., Malaquias, J. V., Macena, F. A., Muller, A. G., Martins, C. F., Balbino, L. C., & McManus, C. M. (2021). Shade modifies behavioral and physiological responses of low to medium production dairy cows at pasture in an integrated crop-livestock-forest system. Animals, 11(8), 2411. https://doi.org/10.3390/ani11082411

Setz, E. Z. F. (1991). Métodos de quantificação de comportamento de primatas em estudos de campo. A Primatologia No Brasil, 3, 411–435.

Talmón, D., Jasinsky, A., Marin, F., Menegazzi, G., Chilibroste, P., & Carriquiry, M. (2025). Estimation of the energy cost of activities in grazing dairy cows using the oxygen pulse–heart rate method. Journal of Dairy Science, 108(6), 5847-5859. https://doi.org/10.3168/jds.2024-25756

Thornton, P., Nelson, G., Mayberry, D., & Herrero, M. (2022). Impacts of heat stress on global cattle production during the 21st century: A modelling study. The Lancet Planetary Health, 6(3), e192–e201. https://doi.org/10.1016/S2542-5196(22)00002-X

Uribe, S. M., Orozco, J. D. C., Restrepo, E. M., Londoño, G. A. C., & Rosales, R. B. (2025). Effects of intensive silvopastoral systems on bovine ingestive behavior in three contrasting tropical regions. Journal of Animal Behaviour and Biometeorology, 13(2), 2025011. https://doi.org/10.31893/jabb.2025011

Van Amburgh, M. E., Collao-Saenz, E. A., Higgs, R. J., Ross, D. A., Recktenwald, E. B., Raffrenato, E., Chase, L. E., Overton, T. R., Mills, J. K., & Foskolos, A. (2015). The Cornell Net Carbohydrate and Protein System: Updates to the model and evaluation of version 6.5. Journal of Dairy Science, 98(9), 6361-6380. https://doi.org/10.3168/jds.2015-9378

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science, 74(10), 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Wiersama, F. (2005). Appendix 1: Temperature humidity index. In J. Moran (Ed.), Tropical dairy farming: Feeding management for the small holder dairy farmers in the humid tropics (p. 275). Landlinks Press.