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Comparative acoustic analysis of bovine vocalizations and herding songs: implications for human–animal communication under grazing conditions

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Article

Keywords: Acoustics, herding songs, acoustic analysis, MIR, vocal communication, bovine vocalizations

Posted Date: March 8th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9002598/v1

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Additional Declarations: No competing interests reported.

Abstract

Communication has been a key part of cattle management across distinct cultures; however, there is limited information about the relationship between herding songs and bovine vocalizations over time. This study compared the acoustic features of bovine vocalizations (Bos taurus and Bos indicus) with those of herding songs using Bioacoustics and Music Information Retrieval (MIR). Similarities and differences were identified by principal component analysis (PCA). Results showed notable differences in both the timing and frequency-related acoustic parameters between cattle vocalizations and herding songs. Herding songs had longer durations, while bovine vocalizations were shorter in comparison. In the spectral range, songs showed higher frequencies (> 2500 Hz), whereas vocalizations ranged from 1115.67 to 1797.66 Hz. Cluster analysis revealed two distinct acoustic groups: one with Bos taurus and Bos indicus vocalizations and another with herding songs, characterized by greater spectral variability and a higher proportion of high-frequency components. These findings offer a quantitative look at the acoustic connection between bovine vocalizations and grazing songs, providing insights into interspecies communication and potential applications for livestock management based on acoustic signals.

Introduction

The vocalizations of cattle, expressed through mooing or bellowing, play a fundamental role in intraspecific communication, the maintenance of social bonds, and the expression of emotional states (Watts & Stookey, 2000). These vocal emissions result from vocal cord vibrations produced through the interaction of complex physiological systems, including the respiratory, digestive, musculoskeletal, and cardiovascular systems (Gavojdian et al. 2024; Yoshihara & Oya, 2021). For this reason, the vocalizations can provide information about both physiological and emotional states (Boissy et al. 2007; Whitham & Miller, 2024). Bovine vocalizations have been integrated into diverse human sound expressions that facilitate cattle management and constitute part of the intangible cultural heritage. For example, the “Grito de Monte” (GMS) is traditionally used to guide and manage cattle in grazing areas; the “Canto de Vaquería” (CVS) helps calm and manage grazing animals; and “Cabestreo” (CS) consists of rhythmic melodies used to lead cattle. The “Vela song” (VS) refers to the songs used during the night watch of livestock (Ministry of Culture, 2013), and the “Kulning” (KS) is a traditional Scandinavian high-pitched song with similar functions (Nikolsky, 2020). These expressions have been recognized for their importance in human–cattle relationships and form part of the cultural heritage of different regions.

The study of bovine vocalizations and herding songs is essential for understanding behavioral and emotional responses in animals, as these acoustic expressions can reflect affective states and interactions with the environment. Recent studies have explored the relationship between vocalizations and emotions in various species, including pigs. For instance, our group has evaluated behavioral responses during regrouping in pigs exposed to musical stimulation (Álvarez et al. 2023). In addition, we have evaluated the way music modulates emotional states in pigs (Zapata et al. 2022). The study of animal vocalizations and human cultural expressions, such as herding songs, provides key tools for

assessing and improving animal welfare. Laurijs et al. (2021) highlighted that vocalizations in farm animals can serve as indicators of positive emotional states, making them useful for welfare assessment. Similarly, Hutchins (2023) documented how Mongolian herders use specific songs to encourage surrogate mothers to adopt orphaned offspring, illustrating the practical impact of these practices on herd management. The integration of these perspectives enables the development of more effective management strategies grounded in a deeper understanding of animal communication and its relationship to human sound stimuli. Previous studies have analyzed equine and swine vocalizations in relation to stress levels, social interactions, and responses to environmental changes (Briefer et al. 2015; Tallet et al. 2013).

In cattle, this approach has not been addressed from acoustic and cultural perspectives, and there remains limited knowledge of the impact of herding songs on physiological, behavioral, and emotional responses. The objective of this study was to compare the acoustic characteristics of bovine vocalizations in different emission contexts with those of herding songs, to identify key patterns that may serve as a reference for the development of sound stimuli adapted to the species.

Materials and Methods

Study design and population

A descriptive–comparative study was designed to analyze both bovine (n=50) and human (n=80) vocalizations. The traditional Colombian herding songs and Kulning were taken from open-access music platforms. While Cattle vocalizations were recorded from Bos taurus and Bos indicus cows during management practices.

Ethical statement

Permission to conduct the study was obtained from herds and livestock processing plants, which authorized the recording of cattle vocalizations. This study has the ethical endorsement of the Institutional Committee for the Care and Use of Animals (CICUA) of the institution, Visión de las Americas University, in Medellín, Colombia, as stated in Act 59 of May 25, 2023. Vocalizations recording of the animals was performed in accordance with the principles of respect, autonomy, beneficence, and non-maleficence for biomedical ethics (Beauchamp 2001) and the regulations for the use of live animals in experiments of the Colombian Government statute for the protection of animals (Law 044 of 2009).

Traditional grazing songs and animal vocalization selection and recording

The recordings of the cattle vocalizations were made using a Zoom H6 recorder equipped with a shotgun microphone, 1 meter from the pen. It is important to note that a 30-minute habituation process was conducted with the cattle and the person who obtained the recordings. The selection criteria for vocalizations included clear emission, absence of overlapping background noise, and representativeness of the behavioral context. The recordings of bovine vocalizations were made in four specific contexts: 1)

Bos Indicus Grazing cows (GI); 2) *Bos Taurus* Grazing cows (GT); 3) *Bos Indicus* cows in barn before slaughter (IBS). 4) *Bos Taurus* cows in barn before slaughter (TBS).

Human vocalizations were extracted from different herding songs. Eight categories of traditional grazing songs from different regions of the country were included: Grito de Monte (MON) and Canto de Vaquería (VAQ) from the Atlantic Region; Cabestreo (CAB), Vela (VEL), Llamado (LLAM), Ordeño (ORD), and Silbos (SIL) from the Orinoco Region. Kulning songs (K) were selected as a non-Colombian grazing song (as a control). Traditional Colombian songs and Kulning were obtained from documented recordings available taken from open-access music platforms. The inclusion criteria were based on traditional use for cattle management, clear sound quality, and representativeness within the cultural repertoire.

Data Processing

Audacity software 3.5.1 was used for songs and vocalization extraction. The extraction includes the selection of a recording segment that contains the vocalizations of interest. Recordings were converted to .wav format and displayed in spectrograms for preliminary inspection. Band filters and noise reduction were applied to improve audio quality and eliminate interference. The bioacoustics analysis was performed with Raven software (version 1.6; Cornell Lab of Ornithology, Ithaca, NY, USA).

The following bioacoustics parameters were including in the analysis according to Yang (2019): Start time (s): Exact moment when a vocalization begins within the recording; End time (s): Time at which the vocalization ends, allowing its duration to be calculated; Maximum frequency (Hz): Highest frequency value reached in the vocalization; Frequency at 5% (Hz): Frequency below which 5% of the total energy of the vocalization is found; Frequency at 95% (Hz): Frequency below which 95% of the total energy of the vocalization is found; Peak frequency (Hz): Frequency with the highest amplitude within the vocalization; Time at 5% (s): Time at which 5% of the total energy of the vocalization has been accumulated; and Time at 95% (s): Time at which 95% of the total energy of the vocalization has been accumulated.

Extraction of acoustic parameters

For the vocalization acoustic analysis, the Musical Information Retrieval (MIR) technique was used. According to MIR technique described by Alvarez et al. (2023) and Zapata et al. (2023), the following parameters were analyzed: Spectral centroid (Hz): Indicates the point where most of the energy of the frequency spectrum is concentrated; Amplitude (dB): Represents the intensity or volume of the sound; Zero crossings (ZCR): Number of times the audio signal crosses the zero axis, indicating spectral variability; High-frequency content (Hz): Proportion of energy present in the higher frequencies of the signal; Dissonance (Hz): Measure of perceived inharmonicity in the audio signal; Highest value (Hz): Frequency with the highest magnitude in the spectrum.

Statistical analysis

To evaluate acoustic and bioacoustics differences between the different vocalizations and contexts, a one-way Analysis of Variance (ANOVA) was performed for the parameters obtained from the Riven

software (Begin Time, End Time, High Frequency, Frequency 5%, Frequency 95%, Peak Frequency, Time 5% and Time 95%) and the parameters extracted by the MIR technique [Amplitude (amp), Dissonance (ds), Highest Value (Hg), Centroid (c), Zero Crossing Rate (zc) and High Frequency Content (hfc)]. The Bonferroni post-hoc test was used to identify specific contrasts between bovine vocalizations (GT, TBS, GI, IBS) and herding songs (MON, VAQ, K, CAB, LLAM, ORD, SIL, VEL). Bartlett's test was used to verify the homogeneity of variances, ensuring the validity of the ANOVA assumptions. Additionally, a Principal Component Analysis (PCA) allowed us to reduce the dimensionality of the data and identify underlying patterns in the variability of the acoustic characteristics.

Results

Bioacoustics parameters

The vocalizations grazing songs span a broader spectrum and longer duration; the ORD, SIL, and VEL had higher values ($p<0.05$) in predominant energy frequencies and onset/termination time, while bovine vocalizations exhibited shorter durations and lower dominant frequencies (Figure 1). Each shaded cell in the matrix indicates significant differences between pairs of contexts, with shades of gray that may represent different levels of statistical significance. A heterogeneous distribution of differences is observed, suggesting that some acoustic parameters vary differentially between vocalizations and songs.

Acoustic parameters

The analysis of the acoustic parameters extracted from the MIR technique showed significant differences between bovine vocalizations and herding songs (Figure 2). The vocalizations presented lower values for Amp, Hg, and Hfc, while the herding songs showed higher values for Sd, c, and Ds. The results show consistent differences between both types of sound emission, with vocalizations characterized by lower amplitude and a more restricted spectral range, while songs exhibit greater spectral variability and a wider use of higher frequencies.

The Amplitude (Figure 3) was lower in vocalizations, with the minimum value for GI (Amp=0.0165) and the maximum value (Amp=0.0924) for GT. In songs, values ranged from 0.0589 in milking to 0.1774 in calling, reflecting greater acoustic intensity in the latter. The spectral deviation (Figure 3) was lowest for GT (2110.9 Hz) and highest for LLAM (3817.1 Hz). For the highest value (Figure 3), the lowest value ranged between 3.8 kHz and 24.2 kHz for GI and GT, and the highest values were between 13.5 kHz (ORD) and 53.6 kHz (LLAM). The spectral centroid (Figure 4) was consistently lower in bovine vocalizations, ranging from 631.8 Hz (IBS) to 809.9 Hz (GI), compared with songs, which ranged from 886.4 Hz (KUL) to 2440.4 Hz (SIL). Spectral dissonance (Figure 4) was also higher in songs, reaching a maximum of 35.54 for CAB, in contrast with lower values for VAQ (Ds=0.1959) and GT (Ds=0.4199). For zero crossings (Figure 4), vocalizations showed lower values, between 0.0272 (IBS) and 0.0517 (GT), whereas SIL reached 0.1062. The high-frequency content (Figure 4) was lower in vocalizations, with

values between 62.993 Hz (GI) and 67.148 Hz (TBS), while songs exhibited the highest values, reaching up to 690.754 Hz for MON.

Principal component analysis (PCA)

The PCA analysis facilitated the identification of relationships and similarities between vocalizations and songs, as well as the distribution of acoustic variables and contexts. Figure 5 displays clustering patterns among different types of vocalizations and songs. The GT and GI vocalizations clustered closely based on the principal components, indicating that both bovine species share similar acoustic features in grazing contexts. Likewise, TBS and IBS vocalizations also showed a pattern of similarity, though these were positioned slightly further apart than those associated with grazing. TBS and IBS remained within the same cluster as GT and GI, suggesting that bovine species maintain a common set of acoustic traits (Figure 6). Herding songs were spread across the principal components, indicating greater acoustic variability among them. Notably, some songs (e.g., KUL and CAB) grouped in PCA but exhibited significant differences in specific acoustic parameters in the ANOVA correlation matrix (Figure 1 - 2). Other songs, such as SIL and MON, are also clearly separated from vocalizations, highlighting differences between these sound types. Specifically, MON showed a distinct separation along the first major axis, emphasizing a unique acoustic feature that distinguishes it from both vocalizations and other herding songs. Therefore, while bovine vocalizations tend to cluster more closely and consistently —suggesting shared acoustic traits across species and contexts—Herding songs demonstrate greater variation and differentiation in their components, reflecting their acoustic diversity and specificity.

Discussion

This study provides novel evidence of the acoustic relationships between bovine vocalizations and herding songs, revealing both divergences and convergences in their Spectro-temporal characteristics. Herding songs demonstrated greater duration and spectral variability, particularly at higher frequencies, reflecting their functional role in ensuring audibility across long distances during cattle management. By contrast, bovine vocalizations were shorter and more restricted in frequency, consistent with their primary role in intraspecific communication, emotional expression, and maintenance of social cohesion. Despite the differences between vocalizations and songs, similarities in frequency peaks, temporal segmentation, and spectral energy distribution were also identified, suggesting that bovines can perceive certain songs as familiar stimuli. In addition, the differences in timbre and variability within each context indicate that not all songs generate the same effect on animals. These observations highlight the potential to optimize the use of acoustic stimuli derived from traditional songs by tailoring their characteristics to elicit specific responses in cattle, whether for animal mobilization, welfare practices, or facilitating milking interactions. Our findings are consistent with previous studies showing that human and animal vocalizations can differ considerably in frequency, duration, and other acoustic attributes (Oswald et al. 2022, Linn & Scheumann, M. 2021). Variability in these parameters may reflect each species' adaptation to its respective ecological and social contexts, in which vocalizations play specific roles in communication (Whitham & Miller, 2024; Debracque et al., 2023). Previous studies evaluated the

temporal-spectral characteristics of music using a music-informatics approach to assess their effects on emotional responses in pigs (Zapata et al. 2023). Our study employed similar techniques by analyzing acoustic characteristics related to timbre, tonality, sound dynamics, and spectro-temporal structure.

Significantly higher amplitudes were observed in grazing songs—particularly in MON and VAQ—suggesting a functional role in cattle management practices. In acoustics, sound amplitude is directly related to intensity and to its capacity to propagate through open spaces or uneven terrain (Zahorik & Kelly, 2007; Locher et al., 2018). From a bioacoustic perspective, this property is critical for long-distance communication, enabling signals to overcome ambient noise and echoes (Somervuo et al. 2023). In noisy or extensive environments, such as grazing areas, higher amplitude enhances the effectiveness of vocal communication (Bradbury & Vehrencamp, 2011). Spectral analysis further revealed that the elevated centroid in herding songs reflects a greater concentration of energy in higher frequencies, facilitating propagation over distance. From an auditory perception standpoint, sounds with higher spectral centroids are perceived as higher-pitched, which improves their localization and recognition in open environments (Allen et al. 2018; Kolarik et al. 2016). In contrast, bovine vocalizations had lower centroids, with energy concentrated in the mid and low frequencies. This feature provides tonal richness and enhances the cattle's attention, facilitating their response to the call. This phenomenon is particularly noticeable in cowherding, where harmonic variations allow attention to be captured under different acoustic conditions, a fundamental feature in long-distance communication (Krause & Farina, 2016).

The higher (Hg) values observed in herding songs highlight an acoustic design optimized for sound projection. Higher frequencies are more direct and undergo less attenuation in open environments (Spiousas et al. 2016). In contrast, bovine vocalizations, characterized by lower frequencies, propagate more effectively through vegetation and physical obstacles, thereby optimizing communication within grasslands and pastures (de la Torre et al. 2015; Gavojdian et al. 2024). This contrast suggests an adaptive fit between the sound type and the environmental context in which it is produced. Analysis of dissonance (Ds) revealed a homogeneous range across both emission types, except for CAB, which exhibited an exceptionally high value. This elevated CAB dissonance may serve as a specific function, possibly related to attraction techniques or the induction of emotions in the cow through rougher, more dissonant tonal structures. These differences indicate that herding songs and vocalizations are acoustically optimized for management purposes, whereas bovine vocalizations primarily respond to immediate communicative needs between animals (Fishbein et al. 2021; Ciborowska et al. 2021; Gavojdian et al. 2024).

Zero-crossing values reflect the frequency at which a sound wave changes polarity and are associated with the temporal fluctuation of the signal (Yurin et al. 2024; Takeuchi & Saito, 2023). The vocalizations of herding songs show a higher number of zero crossings, particularly for SIL and MON. This finding implies a more unstable, variable structure than vocalizations, which is associated with greater richness in high-frequency components and rapid phase changes (Coutinho & Schuller, 2017; Vellema et al., 2019). This instability can be beneficial in open environments, where signal variability improves

projection and perceptibility under different acoustic conditions (Wang et al. 2019; Fishbein et al. 2021). In contrast, bovine vocalizations present low and consistent values in zero crossings, suggesting a stable and homogeneous acoustic signal. Stability in vocalizations can favor signal clarity and intelligibility in controlled environments, where communicative precision is crucial (Chopra et al. 2020). This stability reflects fewer rapid fluctuations and a more defined carrier frequency, thereby facilitating accurate signal perception during short-distance interactions (Green et al. 2019).

The results on high-frequency content reflect the acoustic distinctions between herding songs vocalizations, and bovine vocalizations. Songs exhibited elevated, fluctuating high-frequency values, indicative of an acoustic design optimized to maximize propagation range. High frequencies are less susceptible to absorption by terrain and environmental objects (Hannah & Hunt, 2007), enabling calls to travel more effectively in open spaces, reach greater distances, maintain contact with animals, and facilitate communication across large areas. In contrast, bovine vocalizations recorded in pastoral contexts, such as GT and GI, displayed lower and more homogeneous high-frequency content. The reduction of high frequencies suggests a signal optimized for short-range communication, where projecting sound across large distances is less essential (Martin et al. 2017). Moreover, this stability may enhance the efficiency of close interactions by concentrating acoustic energy within frequency ranges that favor direct perception rather than long-distance transmission. The results indicate that most herding songs' vocalizations—except for ORD and KUL—are acoustically structured to maximize propagation and capture attention over long distances, reflecting their functional adaptation to grazing environments. Conversely, bovine vocalizations, with lower amplitudes, centroids, and spectral dispersion, are adapted for short-range communication, maintaining sonic coherence that reinforces social bonds within a more restricted spatial context. From an evolutionary perspective, the acoustic differences reflect the adaptations of the animal communication system to different contexts. While vocalizations are simpler and more stereotyped, allowing for the rapid transmission of relevant information (Gavojdian et al. 2024), songs have evolved to be more versatile and elaborate, meeting the demands of complex and social environments. This functional divergence highlights the importance of adapting vocal output according to the needs of the environment and the communicative purpose.

Principal component analysis (PCA) and data clustering revealed a notable separation between two large groups: vocalizations and songs, which is consistent with their functions and contexts in animal husbandry, as explained above. In the biplot, vocalizations cluster primarily along the directions of components such as "Amp," "Hg," and "Hfc," which are associated with a more stable and controlled signal. This pattern could respond to the need for precise, consistent communication in close interactions, where animals require clear signals to coordinate behavior in controlled environments, such as barns or herds. On the other hand, herding songs' vocalizations, grouped under variables such as "zc," "ds," and "c," show greater variability in frequency and zero crossings, indicating a less stable, more adaptable signal, suited to open environments. This suggests that songs are optimized for projection over wide spaces, serving as long-distance communication, which is critical for field management activities, such as dairy herding or calling cattle over large areas. While highly relevant for human–animal communication and relationships, the grazing songs must be understood as signals with specific

functions, such as herding and cattle handling, which implies maintaining animals in an active state. These findings are further supported by analyses conducted using Music Information Retrieval (MIR), which revealed acoustic convergence in the vocalizations of Bos indicus and Bos taurus during grazing. This suggests that such vocalizations may be shaped by the social and environmental dynamics of these animals (Whitham & Miller, 2024). The overlap in certain bioacoustics parameters across different emission contexts may reflect evolutionary adaptations for communication under similar ecological conditions, such as grazing (Whitham & Miller, 2024; Green et al., 2021). In the case of cattle in non-grazing contexts —e.g., animals awaiting slaughter—vocalizations are also clustered in a pattern that may reflect a specific social condition. This observation is consistent with the theory of social conditioning, which proposes that animals can develop distinct acoustic responses shaped by their prior experiences (Hoeschele et al. 2023; Whitham & Miller, 2024).

The differences between human vocalizations (herding songs) and bovine vocalizations can largely be attributed to the variation in the arrangement and structure of the vocal and phonatory apparatuses in these species. The human vocal apparatus is highly specialized in producing a wide range of sounds, including the complex tones and overtones characteristic of music (Zang 2016). This apparatus includes the larynx, vocal cords, oral cavity, and nasal and oral resonators, which allow for precise modulation of pitch, frequency, and sound quality (Zang 2016, Zang 2023). In contrast, the vocal apparatus of cattle is less complex and is primarily adapted for communication within their social group and for specific functions such as alertness or coordination during herding (Jung et al. 2021, Gavojdian et al. 2024). Cattle have a larynx and vocal system that produce sounds with a more limited range compared to humans. This is due to the difference in the structure of the vocal folds and resonators, which are optimized for low-frequency sounds and short-distance communication (Alipour et al. 2011; Gavojdian et al. 2024). These differences in vocal structure result in variations in acoustic parameters such as the fundamental frequency, amplitude, and timbre of vocalizations. While humans can produce a wide range of frequencies and modulations due to the complexity of their vocal apparatus, bovine vocalizations tend to be more uniform and less modulated (Linn & Scheumann, 2021; Hoeschele et al. 2023; Zhang, 2016). This reflects the adaptive specialization of each species for its respective communicative contexts.

The results of this study indicate that bovine vocalizations exhibit more consistent beginning and ending times compared with herding songs, suggesting greater regularity in communication. By contrast, the higher temporal variability observed in songs likely reflects stylistic diversity, which may hinder the development of musical stimuli with predictable and relaxing rhythms for cattle. Moreover, bovine vocalizations tend to contain fewer high-frequency components, an important consideration given cattle's limited sensitivity to higher frequencies. Consequently, music designed within the frequency range of bovine vocalizations is likely to be more comfortable for cows. Analysis of the 5th and 95th percentile frequency ranges further demonstrated that bovine vocalizations have a narrower and more specific acoustic spectrum, which may be advantageous for developing musical stimuli aligned with the animals' natural parameters, thereby creating a more predictable and harmonious auditory environment. In contrast, the broader range of herding songs could introduce variability that cattle may perceive as unsettling or less relaxing. Similarly, the lower peak frequencies of bovine vocalizations appear more

natural and less arousing. In contrast, the higher peak frequencies of pastoral calls may fall outside the optimal perceptual range for cattle. Finally, the greater consistency in acoustic event duration in bovine vocalizations is explained by reduced variability in onset and offset times at the 5th and 95th percentiles. This uniform pattern is beneficial for designing music with predictable durations, contributing to a more calming and less disruptive listening experience for cows, in contrast to the greater variability in pastoral calls, which could result in a less predictable and more stressful musical structure. In conclusion, the results suggest that bovine vocalizations present more uniform and predictable bioacoustics parameters compared to songs, which is crucial for the design of specific sound stimuli for cows, as it allows the music to be tailored to the natural acoustic patterns and auditory preferences of cows, resulting in a more pleasant listening experience.

Human vocalizations are designed to communicate effectively with other humans and not necessarily to resonate with the bovine auditory system in a way that promotes calm and tranquility (Talkington et al. 2012; Lange et al. 2020). Thus, herding songs, typically associated with traditional shepherd music, can have effects on animals due to specific factors in their structure and presentation that resonate with or direct specific animal behavior (Rosenberg & Lã., 2024). However, compared with bovine vocalizations, differences in acoustic parameters reveal why these songs can elicit a specific response from the animal, inducing an immediate response. Herding songs typically have a melodic and rhythmic structure that includes a range of frequencies and modulations designed to communicate in specific contexts, such as herding or communication in rural environments (Olczak et al. 2023). In contrast, bovine vocalizations, especially in positive contexts like grazing conditions, exhibit acoustic characteristics of intraspecific communication (Lange et al. 2020). These vocalizations tend to be in a lower frequency range and less modulated compared to human vocalizations. Cattle respond to frequencies and patterns that are aligned with their specific communicative and social needs, such as communicating in large groups during grazing or calling their young (Dimov & Marinov, 2023). Cattle's ability to process sounds depends on the compatibility of the emitted frequencies with their optimal hearing range. When sound stimuli are outside this range, the cattle's response may be limited or different from the expected response (e.g., increased arousal or stress rather). In the case of herding songs, these often include pitch modulations and variations in note duration, designed to capture human attention. However, cattle appear to respond more effectively to sounds with less tonal variability and greater stability, like the acoustic properties of their own natural vocalizations (Olczak et al. 2023). The high modulation and complexity of grazing music may not be suitable for bovine auditory perception, resulting in lower effectiveness in improving welfare (Lange et al. 2020). Herding songs are closely linked to cultural contexts and management situations that may not always hold direct relevance for cattle. By contrast, bovine vocalizations are intrinsically adapted to the animals’ natural and social environments, thereby facilitating more effective communication. Familiarity and positive associations with these vocalizations are likely to be more beneficial for animal welfare than sound stimuli primarily designed for human purposes.

Despite herding songs playing a significant role in the cultural tradition of cattle management, their acoustic structure differs considerably from that of bovine vocalizations. The acoustic parameters of

herding calls, designed to capture human attention and facilitate communication in rural contexts, are not specifically optimized to elicit cows' natural responses. The herding songs are typically used as tools to induce behaviors that express increased activity and alertness in animals, rather than being designed to generate spontaneous responses typical of their natural environment. This study provides a basis for developing welfare-oriented management strategies related to acoustic stimuli for cattle, demonstrating that bovine vocalizations—particularly those associated with grazing—represent a promising resource for designing species-specific music. The vocalizations exhibit acoustic characteristics that are closely aligned with the bovine auditory system and are finely tuned to their communicative and social needs. By operating within specific frequency ranges and structured acoustic patterns, bovine vocalizations may promote calmer behaviors and enhance animal welfare by resonating with sounds that cattle naturally perceive as relevant and comforting for the expression of their behavioral repertoire (Green et al. 2019; Fitch, 2010).

The response of cattle to sound stimuli is not the result of an innate predisposition, but rather a conditioning process in which animals learn to associate certain sounds with specific actions imparted by the herder. Therefore, the development of acoustic stimuli for livestock should be based on the natural vocalizations of the species, reflecting their grazing and social interaction contexts. The findings of this study suggest that some pastoral calls share acoustic parameters with bovine vocalizations associated with states of calm and group coordination, making them a potentially useful alternative in the design of auditory stimuli for cattle management. ORD songs, commonly used during milking, exhibit acoustic characteristics closer to bovine vocalizations, favoring states of receptivity and cooperation in the animals. These results support the hypothesis that grazing songs can play a relevant role in modulating bovine behavior. However, their application must respond to clearly defined objectives and conform to the species' natural vocalization frequencies and acoustic patterns. Thus, their integration into the creation of specific sound stimuli for cattle could contribute to inducing precise behavioral responses, optimizing both human-animal interaction and cattle welfare.

Declarations

Acknowledgements

The authors acknowledge the support received from the QUIRON Pathobiology Group and the Committee for the Development of Research – CODI of the University of Antioquia, Medellín, Colombia. The authors thank the Agricultural Research Corporation – AGROSAVIA, Business Development Department, and Obonuco Research Center Dairy Farming Project.

Funding.

This work was supported by the QUIRON Pathobiology Group, University of Antioquia, Medellín, Colombia, and the Committee for the Development of Research – CODI of the University of Antioquia, Medellín, Colombia. The work was additional supported by the Colombian Agricultural Research Corporation – AGROSAVIA and the Ministry of Science, Technology, and Innovation - MINCIENCIAS,

Government of Colombia, Grant Number 937 (Fundamental Research) as an objective within the macro-project "Design of a preventive model based on metabolic profile in the transition period to improve reproductive efficiency in grazing dairy cows in the high tropics.

Author contributions.

All the authors contributed to the study conception and design. Conceptualization: PBC, JMZ, NAH, MBA, BR, and DVT; Data curation: PBC, MBA and DVT; Funding acquisition: DVT, JMZ, and BR; Investigation: PBC, JMZ, MBA, JGM, and BR; Methodology: DVT, BR; Project administration: BR, DVT; Resources: BR, DVT, JMZ, and BR; Supervision: DVT and BR; Visualization: PBC, MBA, NAH and DVT; Writing– original draft: PBC, JMZ; Writing– review & editing: BR, JGM and DVT. All the authors have read and agreed to the published version of the manuscript.

Competing interests.

The authors have no relevant financial or non-financial interests to disclose.

Data availability.

The datasets generated during the current study are available from the corresponding author upon reasonable request.

Ethical approval.

The present study has the ethical endorsement of the Institutional Committee for the Care and Use of Animals (CICUA) of the institution Visión de las Americas University in Medellín-Colombia, as stated in Act 59 of May 25, 2023.

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Figures

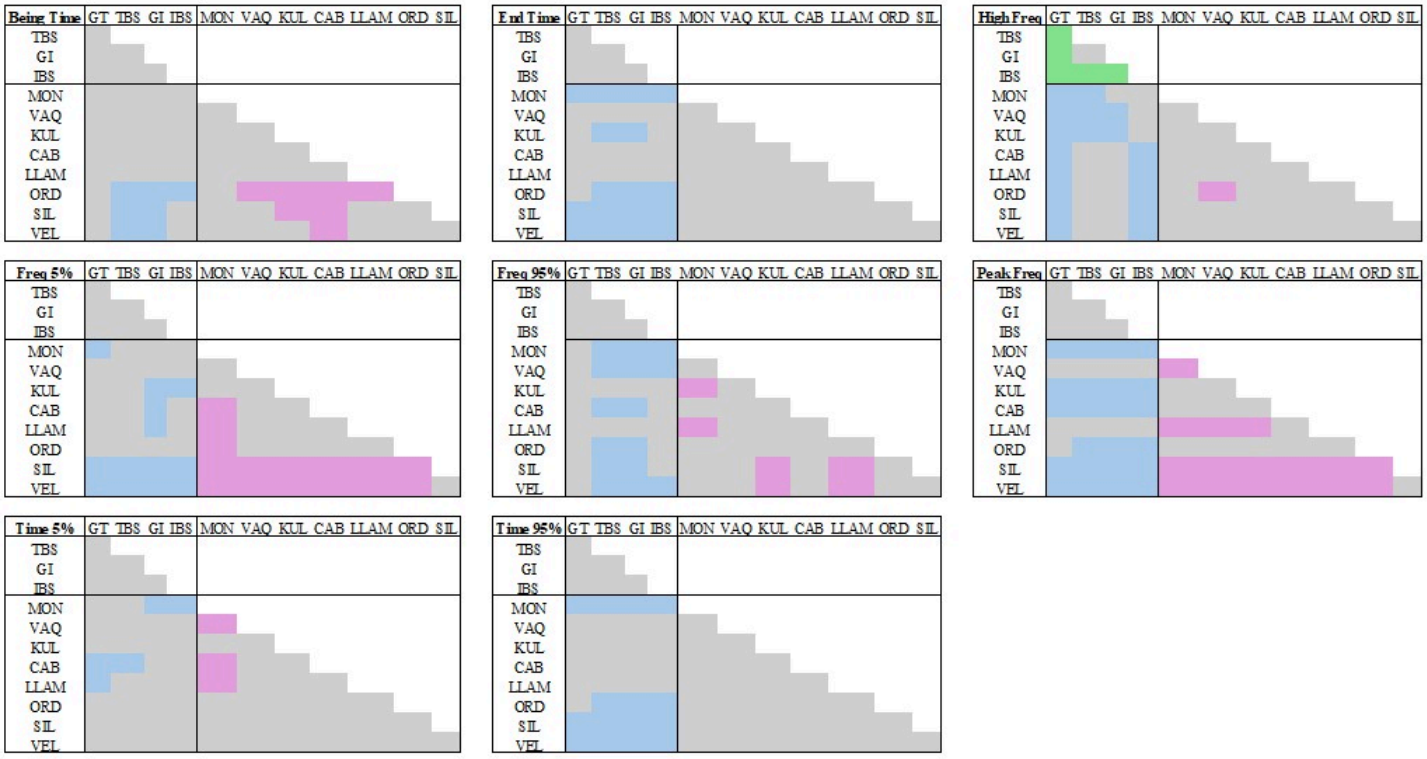


Figure 1

One-way Analysis of Variance (ANOVA) matrix for temporal and spectral bioacoustics parameters comparison between bovine vocalizations (n=130) recorded in different contexts (n=4) and herding songs (n=8) from Colombia.

Cow vocalizations: Bos Taurus Grazing cows (GT); Bos Indicus cows in barn before slaughter (TBS); Bos Indicus Grazing cows (GI); Bos Taurus cows in barn before slaughter (IBS). Herding songs: Grito de Monte (MON); Canto de Vaquería (VAQ); Kulning (KUL); Cabestreo (CAB); Llamado (LLAM); Ordeño (ORD); Silbos (SIL); Vela (VEL). The gray cells in the figures indicate that non-statistically significant differences were found. The green cells indicate significant differences between the contexts of cow vocalizations. The purple cells indicate significant differences between herding songs. The blue cells indicate significant differences between the contexts of cow vocalizations and herding songs.

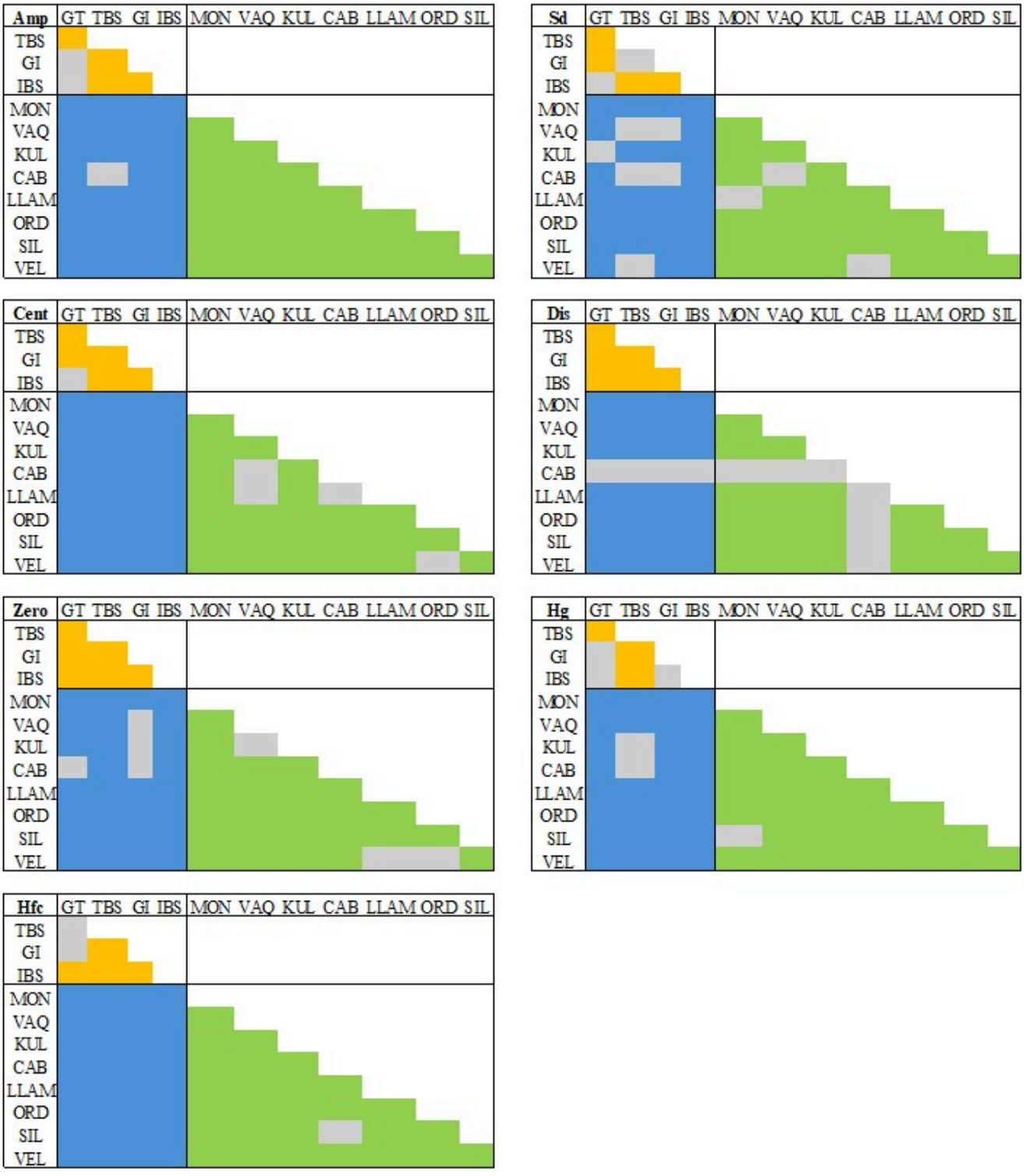


Figure 2

One-way Analysis of Variance (ANOVA) correlation matrix for acoustic parameters comparison between bovine vocalizations (n=130) recorded in different contexts (n=4) and herding songs (n=8) from Colombia.

Acoustic parameters: Amplitude (Amp); Spectral deviation (Sd); Highest (Hg); Centroid (Cent); Dissonance (Dis); Zero crossing (Zero); High frequency content (Hfc). Cow vocalizations: *Bos Taurus*Grazing cows (GT); *Bos Indicus* cows in barn before slaughter (TBS); *Bos Indicus* Grazing cows (GI); *Bos Taurus* cows in barn before slaughter (IBS). Herding songs: Grito de Monte (MON); Canto de Vaquería (VAQ); Kulning (KUL); Cabestreo (CAB); Llamado (LLAM); Ordeño (ORD); Silbos (SIL); Vela (VEL). The gray cells in the figures indicate that non-statistically significant differences were found. The yellow cells indicate significant differences between the contexts of cow vocalizations. The green cells indicate significant differences between herding songs. The blue cells indicate significant differences between the contexts of cow vocalizations and herding songs.

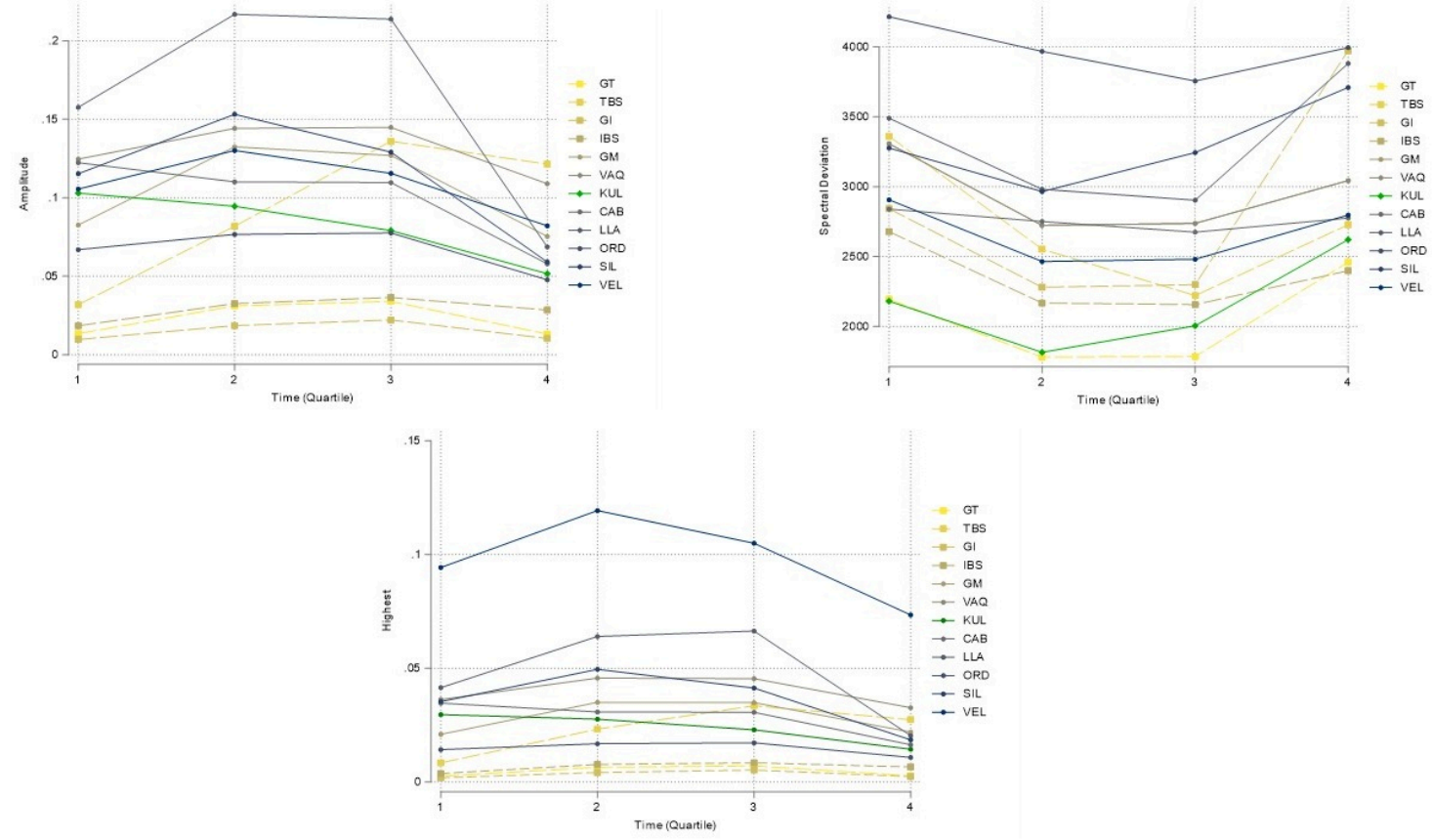


Figure 3

Acoustic parameters over time (Amplitude, Spectral deviation, Highest), in bovine vocalizations (n=130) recorded in different contexts (n=4) and herding songs (n=8) from Colombia**.**

Temporal evolution (represented in quartiles) of mean amplitude, spectral deviation, and highest in different bovine vocalizations and herding songs. The yellow color lines (–■–) correspond to *Bos*

*taurus*and *Bos Indicus* vocalizations: *Bos Taurus* Grazing cows (GT); *Bos Indicus* cows in barn before slaughter (TBS); *Bos Indicus* Grazing cows (GI); *Bos Taurus* cows in barn before slaughter (IBS). The blue and green color lines (–●–) correspond to Herding songs: Grito de Monte (MON); Canto de Vaquería (VAQ); Kulning (KUL); Cabestreo (CAB); Llamado (LLAM); Ordeño (ORD); Silbos (SIL); Vela (VEL).

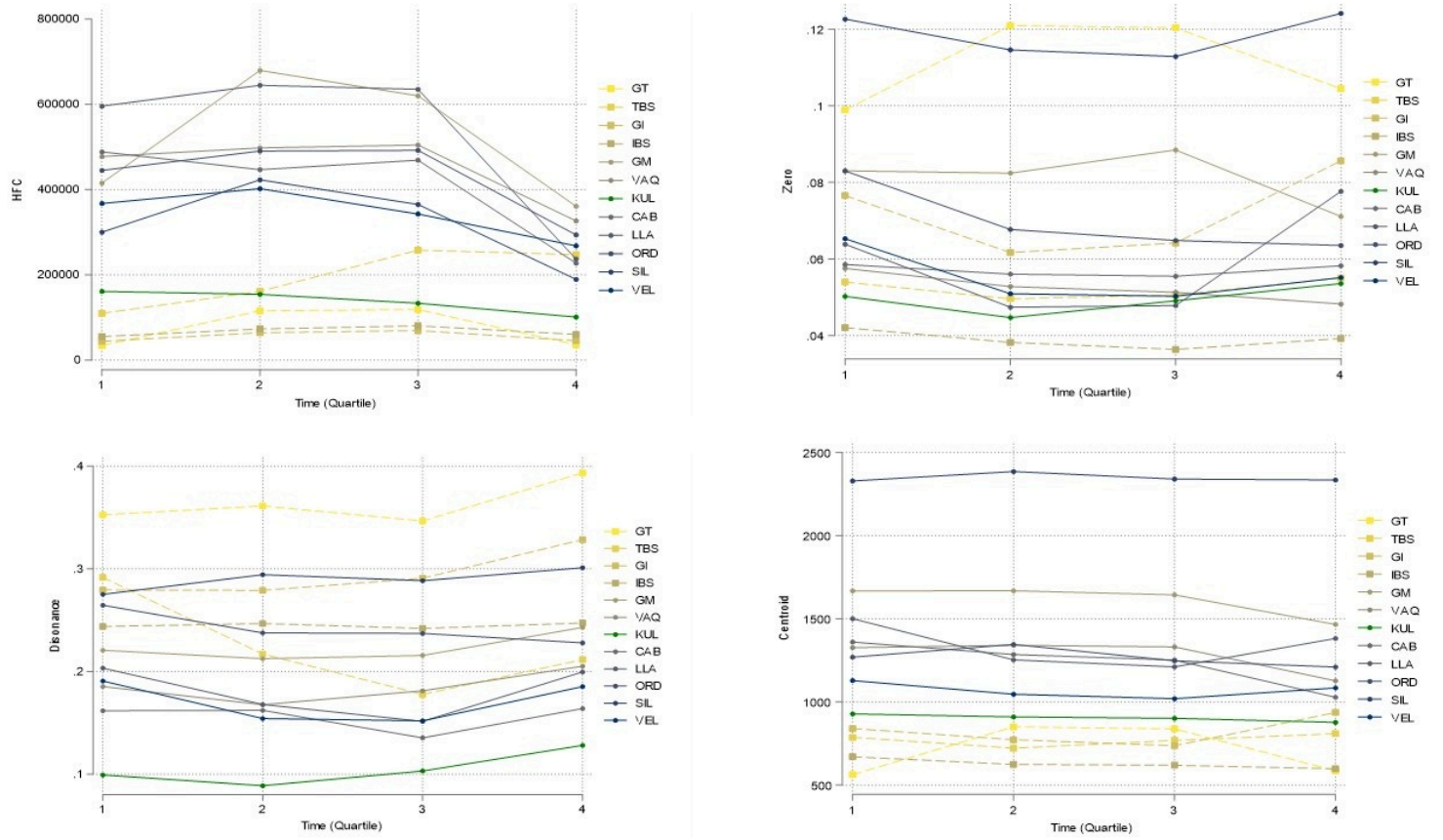


Figure 4

Acoustic parameters over time (Hfc, Zero crossing, Dissonance, Centroid), in bovine vocalizations (n=130) recorded in different contexts (n=4) and herding songs (n=8) from Colombia**.**

Temporal evolution (represented in quartiles) of high-frequency content, zero crossing, dissonance, and centroid in different bovine vocalizations and herding songs. The yellow color lines (–■–) correspond to *Bos taurus* and *Bos Indicus* vocalizations: *Bos Taurus* Grazing cows (GT); *Bos Indicus* cows in barn before slaughter (TBS); *Bos Indicus* Grazing cows (GI); *Bos Taurus* cows in barn before slaughter (IBS). The blue and green color lines (–●–) correspond to Herding songs: Grito de Monte (MON); Canto de Vaquería (VAQ); Kulning (KUL); Cabestreo (CAB); Llamado (LLAM); Ordeño (ORD); Silbos (SIL); Vela (VEL).

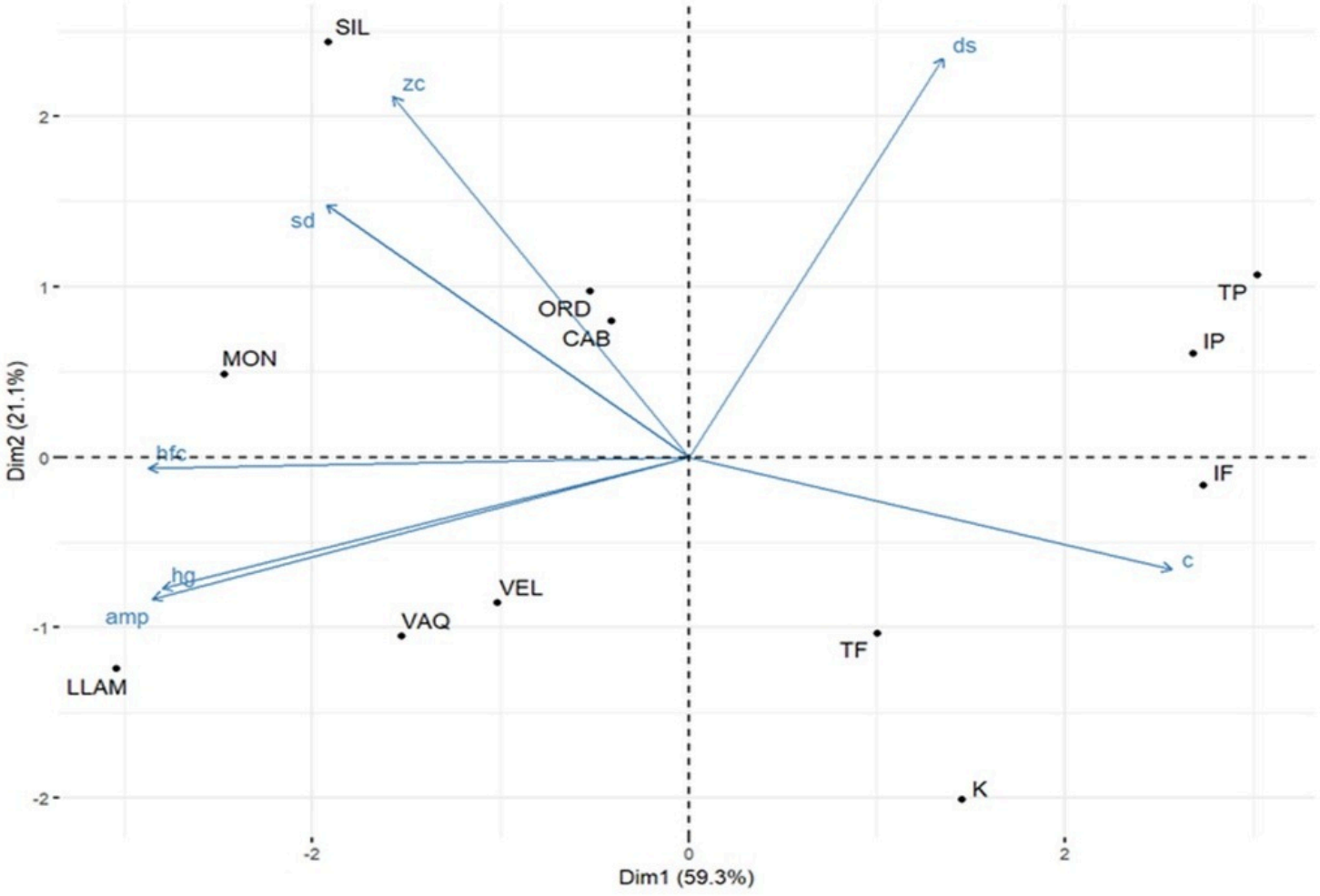


Figure 5

Biplot showing a principal component analysis (PCA) of bovine vocalizations (n=130) recorded in different contexts (n=4) and herding songs (n=8) from Colombia.

Biplot showing a principal component analysis (PCA) for the comparison of vocalizations and songs in different contexts (ORD, CAB, VEL, TF, among others). Dimensions 1 and 2 explain 59.3% and 21.1% of the variance, respectively. Arrows represent acoustic variables indicating their contribution and direction of influence on the distribution of the contexts. The dots indicate the relative positions of the contexts of emission of bovine vocalizations in the multivariate space, showing groupings and possible associations between specific contexts and certain variables.

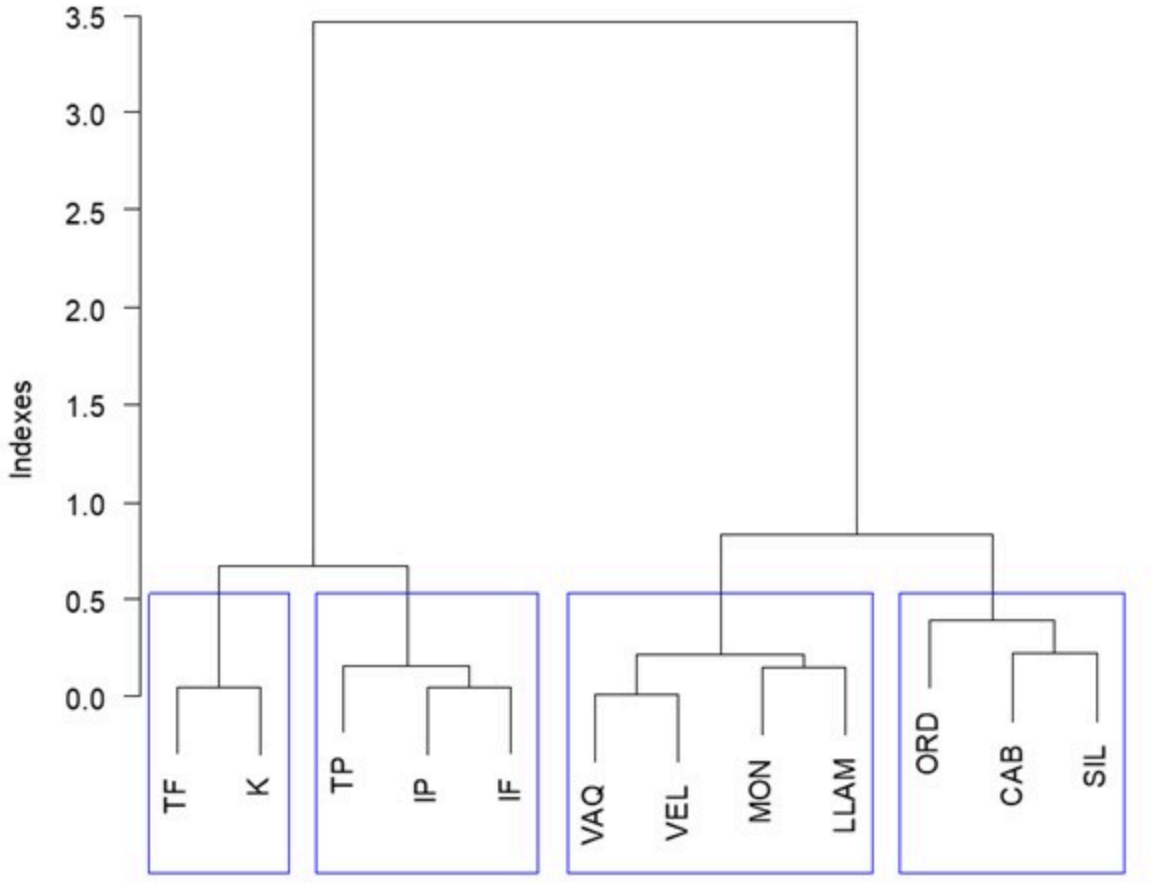


Figure 6

Dendrogram showing a cluster analysis between different bovine vocalizations (n=130) recorded in different contexts (n=4) and herding songs (n=8) using the complete linkage method.

Cluster analysis between different vocalizations and songs was performed using the complete linkage method. The vertical axis represents the distance or dissimilarity between the groups, while the horizontal axis includes the samples of vocalizations and songs evaluated. The blue boxes at the bottom indicate the groups resulting from the analysis, showing four main clusters. The hierarchical structure of the dendrogram allows us to observe how vocalizations and songs are progressively grouped into levels of greater similarity as they descend in the graph.