Journal of Animal & Plant Sciences, 35(3): 2025, Page: 819-827
ISSN (print): 1018-7081; ISSN (online): 2309-8694
https://doi.org/10.36899/JAPS.2025.3.0070

BEHAVIORAL DYNAMICS OF CAPTIVE BLUE BULLS (*Boselaphus tragocamelus*): IMPACTS OF SEASONALITY, GENDER, AND VISITOR INTERACTION ON WELFARE AND MANAGEMENT STRATEGIES

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ABSTRACT

The Blue bull (*Boselaphus tragocamelus*), an endangered species in Pakistan, faces challenges in captivity due to limited research on behavioral dynamics and the impact of visitor interactions. This study examines seasonal and visitor-induced variations in the activity budgets of captive Blue bulls across four zoological facilities in Punjab, Pakistan, over a year. Detailed behavioral observations were conducted, capturing feeding, resting, social, and reproductive activities. Visitor density and behaviors were recorded to assess their influence on animal welfare. Results revealed distinct seasonal patterns, with increased feeding and drinking during autumn and heightened social and reproductive behaviors in winter. Visitor presence significantly altered behavior, with higher visitor numbers correlating with increased activity and social interactions but reduced resting times. These findings emphasize the critical need for season-specific enrichment and strategic visitor management to enhance animal welfare. This study provides actionable insights for optimizing zoo management practices and advancing conservation efforts for this endangered species.

Keywords: captive blue bull, behavioral ecology, seasonal behavior, animal welfare, Visitor effects

Published first online May 17, 2025 Published final June 26, 2025

INTRODUCTION

The Blue bull, or Nilgai (*Boselaphus tragocamelus*), is the largest Asian antelope and a keystone species in the grassland ecosystems of the Indian subcontinent. In Pakistan, it is classified as endangered due to habitat loss, poaching, and human-wildlife conflict (IUCN, 2023). The establishment of protected areas and natural reserves is an ideal conservation strategy; however, it faces significant challenges in Pakistan, where limited land availability, increasing human encroachment, and insufficient governmental resources hinder the effective creation and management of such areas (Khan *et al.,* 2022). As a result, conservation efforts increasingly rely on captive management. However, captivity presents its own challenges, including restricted space, environmental monotony, and frequent human interactions, all of which can significantly alter natural behaviors and impact overall well-being (Bono *et al.,* 2016). Behavioral patterns in captivity are shaped by seasonal variations and visitor presence, both crucial to animal welfare. Seasonal changes in temperature, photoperiod, and resource availability influence activity budgets, even in controlled zoo environments (Giannetto *et al.,* 2022; Deniz *et al.,* 2024). Studies on ungulates highlight the role of natural cycles in regulating behavior, with disruptions leading to stress and maladaptive responses (Aragona *et al.,* 2023). Research on zoo-housed species further emphasizes the need for adaptive management to mitigate seasonal impacts on welfare (Razal *et al.,* 2017).

Visitor presence represents another key variable affecting the behavior of captive animals. While moderate visitor interactions can act as environmental enrichment, encouraging activity and engagement, high visitor density or intrusive behavior often leads to stress, characterized by heightened vigilance, reduced resting periods, and increased aggression (D'Cruze *et al.,* 2019). Despite the recognized influence of seasonal and visitor-induced stressors on captive ungulates, limited research exists on their combined effects on the welfare of Blue bulls, highlighting a critical knowledge gap. To address these challenges, zoos have implemented enrichment programs and adaptive visitor management strategies to promote animal welfare. Behavioral enrichment, such as seasonal variation in diets enhancing enclosure complexity, and introducing interactive stimuli, has proven effective in reducing stress and encouraging natural behaviors (Bono *et al.,* 2016; Kleiman *et al.,* 2021). Similarly, designated visitor-free zones or scheduled interactive periods allow animals to retreat from stimuli, balancing welfare needs with educational goals (Sherwen and Hemsworth, 2019). However, in Pakistan, a lack of region-specific data on the behavioral ecology of captive Blue bulls limits the effectiveness of these practices. This study investigates the behavioral patterns of captive Blue bulls across four zoological facilities in Punjab, Pakistan, over a 12-month period. By examining the dual impacts of seasonal changes and visitor density, we aim to identify patterns in feeding, resting, social, and reproductive activities.

MATERIALS AND METHODS

Ethical Considerations: The study was conducted following ethical guidelines for captive animal research, with approval granted by the Punjab Wildlife and Parks Department (Ethical approval ref No: 242-43/DD/WS/2022, dated August 30, 2022). All observations prioritized animal welfare by minimizing disturbance and avoiding intrusive methods.

Study Area and Subjects: The study was carried out in four zoological facilities in Punjab, Pakistan: Lahore Zoo, Safari Zoo, Kamalia Zoo, and Gatwala Breeding Center. Lahore Zoo is the largest and most well-known zoo in Lahore, Punjab, Pakistan, covering an area of 25 acres. Safari Zoo, also located in Lahore, Punjab, spans 242 acres and offers a more natural habitat for wildlife. Kamalia Zoo, situated in Toba Tek Singh, covers 15 acres and serves as a smaller yet significant wildlife facility. Gatwala Wildlife Park and Breeding Center is a major conservation site in Gatwala, Faisalabad, Punjab, Pakistan, near Khurrianwala. It spans over 100 km², serving as a crucial breeding and preservation facility for native wildlife species. These facilities were selected to represent diverse environmental conditions, visitor densities, and enclosure characteristics. Variables such as enclosure size, vegetation density, and water availability were documented for each facility (Table 1).

Table 1: Characteristics of zoological facilities housing blue bull in Punjab, Pakistan

Captive site	Location	Altitude (m)	Latitude	Longitude	Total Area (Acres)	Size (Acres) For Blue	Number of Blue bull	Sex Ratio (M:F)	Other Species Present	Environmental Conditions	Design Features
Lahore Zoo	Lahore	217	31.33367	74.19471	25	0.188	12	3:9	Hog deer	Humid, Temperate	Natural vegetation, shades
Safari Zoo	Lahore	203	31.23001	74.12922	242	10.7	18	4:14	Mouflon Sheep, Zebra	Tropical, High Humidity	Open terrain, water points
Gatwala Breeding Center	Faisalabad	204	31.29159	73.13014	37	8.3	20	6:14	Hog Deer, Spotted Deer	Arid, High temperature	Mixed vegetation, shelters
Kamalia Zoo	Toba Take Singh	151	30.42802	72.40482	15	0.59	10	3:7	Blackbuck, Mouflon sheep	Temperate, Moderate	Limited vegetation, shade

A total of 40 Blue bulls, including 10 males and 30 females, were observed. The male-to-female ratio (1:3) aligned with typical captive housing practices to minimize aggression. Individuals from different age groups were included to account for behavioral variations across life stages. Age classification was based on body size and dentition: juveniles (6–12 months), subadults (1–3 years), and adults (≥3 years) (Bono *et al.,* 2016). To ensure consistency in behavioral assessments, animals with chronic health issues or injuries were excluded. The sample size (n = 40), distributed across multiple facilities, enhanced the reliability and generalizability of the findings.

Behavioral Observations: Observations were conducted systematically over 12 months (September 2022 to August 2023), encompassing all four seasons. Data were collected fortnightly at each site, resulting in 48 sessions per facility. Observations were conducted during three periods morning (5:00-11:00 AM), midday (11:00 AM-

1:00 PM), and evening (5:00-6:00 PM) to capture potential diurnal variations. Each session lasted two hours, with behaviors recorded every 10 minutes using a standardized ethogram. Observers were trained to ensure consistency in identifying and recording behaviors. A team of four trained observers, including wildlife biologists and postgraduate students specializing in animal behavior, conducted all observations**.** To minimize observer bias, each observer rotated across facilities, and inter-observer reliability was maintained above 0.80 using Cohen's kappa statistic.

Observation Protocol: Two methods were used for behavioral data collection:

Focal Animal Sampling: Detailed observations were conducted on 12 focal individuals (3 males and 9 females per facility) during each session to record individual behaviors.

Scan Sampling: Group behaviors were recorded at five-minute intervals to capture overall activity budgets.

A pilot study refined data collection techniques and standardized the ethogram to align with best practices in ungulate behavior research. Observer schedules were rotated across facilities to minimize individual bias. Temperature, humidity, and weather conditions were recorded during each observation session using calibrated instruments. A Hanna Instruments (HI9565 thermo-hygrometer) was used to record temperature and humidity. A Davis Vantage Vue weather station (USA) recorded real-time atmospheric conditions, including wind speed and precipitation. Binoculars (Nikon Monarch 8x42, Japan) allowed observations from a distance to prevent behavioral disturbances. A digital decibel meter (Extech 407730, USA) measured noise levels near enclosures. Geographic coordinates of study sites were confirmed using a Garmin eTrex 32x GPS device (USA). A Casio HS-80TW-1E handheld stopwatch (Japan) was used for precise timing of observations, while real-time data were digitized using Samsung Galaxy Tab A8 tablets (South Korea) to minimize transcription errors. Seasonal categories were defined as follows: Autumn: September–November, Winter: December–February, Spring: March–May, Summer: June–August.

Visitor density was categorized into low (0-50 visitors/day), medium (51-100 visitors/day), and high (101+ visitors/day). Noise levels near enclosures were measured using a decibel meter (Extech 407730, USA) and visitor behaviors (e.g., shouting, feeding animals) were documented. To isolate the impact of visitor presence, observations were conducted on weekdays to avoid high-traffic periods such as weekends and holidays. Behavioral changes during high-visitor hours were compared with low-visitor periods to assess visitor influence.

Data were meticulously recorded on standardized forms and digitized for analysis. Redundant entries and ambiguous observations were excluded during data cleaning. Automated data validation scripts in R (version 4.1.0) flagged inconsistencies, which were then reviewed manually by independent observers to ensure accuracy.

Behavioral Categories: Behaviors were classified into six primary domains based on a refined ethogram. These categories included: feeding (ingestion of food or vegetation within the enclosure), resting (lying down or standing still without active movement), locomotion (walking, running, or pacing within the enclosure), social interactions (grooming, playing, or agonistic behaviors), reproductive activities (tail-pasting, flehmen response, or courtship behaviors), and vigilance (standing alert with an elevated head, scanning the surroundings). To maintain consistency while ensuring behavioral diversity, infrequently observed behaviors were incorporated into broader classifications.

Statistical Analysis: Behavioral data were analyzed using R (version 4.1.0). One-way ANOVA and Tukey's post hoc tests were applied to evaluate significant differences in behaviors across seasons. To assess differences between the four zoological facilities, a two-way ANOVA was conducted, with facility and season as fixed factors. Post hoc pairwise comparisons were performed using Tukey's HSD test to identify significant differences in behavioral patterns among facilities. Linear regression models were used to assess the relationship between visitor density and behavior frequencies. Mixed-effects models (LME) were applied, incorporating individual animals and facilities as random effects to account for repeated measures and site-specific influences.

RESULTS

A total of 40 Blue bulls (*B. tragocamelus*) were observed over 12 months across four zoological facilities. Behavioral patterns were categorized into six domains: feeding, resting, locomotion, social interactions, reproductive activities, and vigilance. Significant variation was observed across seasons, visitor densities, genders, and facilities.

Seasonal Variations in Behavior: Seasonal differences significantly influenced the activity budgets of captive Blue bulls (*B. tragocamelus*) (Table 2). Feeding activity peaked in autumn (mean = 41.2% ± 4.3) compared to summer (28.5% ± 3.8), reflecting increased vegetation availability (ANOVA: $F(3, 156) = 12.56$, $p < 0.001$). Resting was most frequent in summer (52.8% ± 5.6) and least in winter (32.1% ± 4.7; $F(3, 156) = 10.34$, $p < 0.001$), likely driven by thermoregulatory needs.

Reproductive behaviors, such as tail-pasting and flehmen responses, were concentrated in winter (mean = 3.4/hr ± 1.2; Tukey's post hoc, $p < 0.05$), coinciding with the breeding season.

Table 2: Seasonal variations in behavioral patterns of captive blue bulls.

Behavior	Autumn (% Time ± SD)	Winter (% Time ± SD)	Spring (% Time ± SD)	Summer (% Time ± SD)	Statistical Test
Feeding	41.2 ± 4.3	35.1 ± 3.8	29.7 ± 3.6	28.5 ± 3.8	$F(3, 156) = 12.56, p < 0.001$
Resting	35.3 ± 4.7	32.1 ± 4.7	45.8 ± 5.2	52.8 ± 5.6	$F(3, 156) = 10.34, p < 0.001$
Reproductive Activity	-	3.4/hr ± 1.2	-	-	Tukey's post hoc, $p < 0.05$
Locomotion	12.6 ± 3.5	15.2 ± 3.8	14.5 ± 3.7	10.1 ± 3.4	$F(3, 156) = 5.89, p < 0.05$

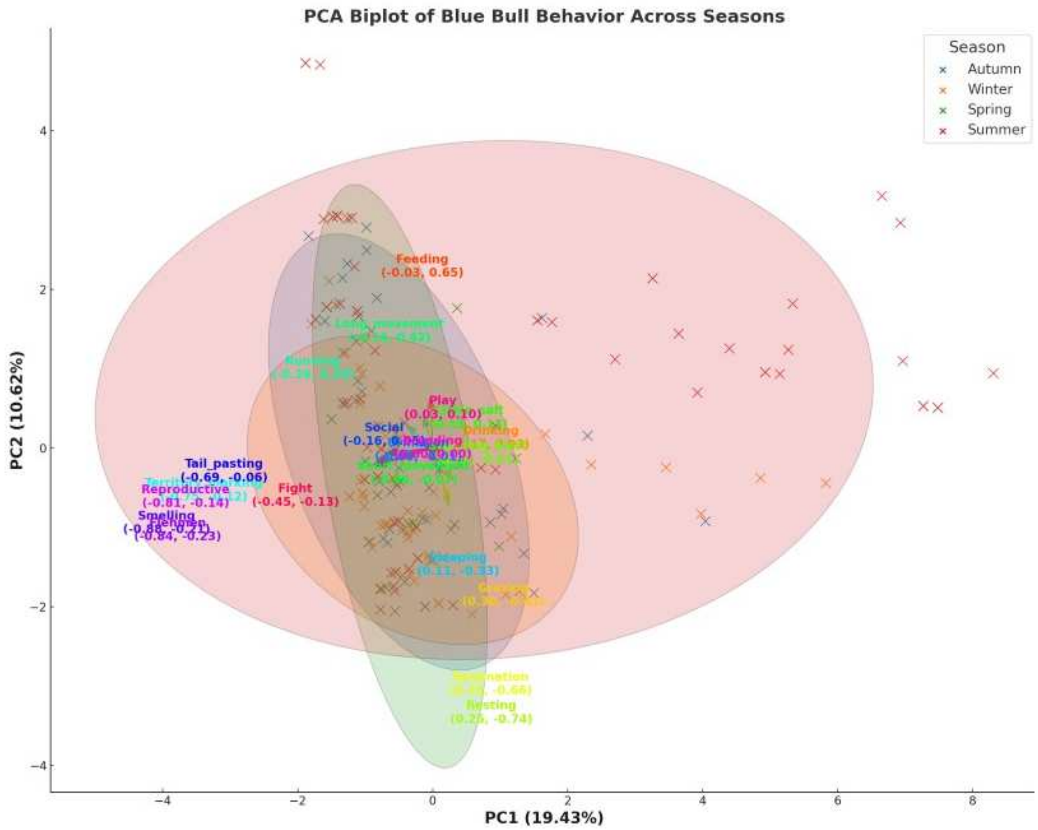

Figure 1: Principal Component Analysis (PCA) bi-plot of seasonal behavioral patterns: **PCA bi-plot showing seasonal clustering of Blue bull behaviors. Ellipses represent behavior groupings across autumn, winter, spring, and summer. Clear separation indicates season-specific patterns.**

The PCA bi-plot (Figure 1) further highlights seasonal behavioral patterns. Feeding and drinking behaviors dominated autumn, as reflected in the tight clustering within the red ellipse. Winter behaviors such as tail-pasting and flehmen responses clustered in the blue ellipse, indicating a seasonal shift toward reproductive activity. Overlapping regions for behaviors like resting and rumination suggest their occurrence across all seasons, while the minimal overlap of ellipses emphasizes distinct seasonal patterns.

Behavioral Differences Across Zoological Facilities: To compare behaviors across captive sites results revealed that resting was significantly higher in Safari Zoo (48.1% ± 5.4) compared to Kamalia Zoo (35.6% ± 4.9; $p < 0.01$), likely due to differences in enclosure size and visitor exposure (Table 3). Locomotion was lowest in Lahore Zoo (11.3% ± 3.2) compared to Gatwala Breeding Center (16.7% ± 3.8; $p < 0.05$), possibly due to more space in Gatwala. Feeding behavior showed no significant variation across sites ($p > 0.05$), suggesting uniform feeding conditions (Table 3).

Behavioral Changes Due to Visitor Density: Visitor density significantly influenced the behavior of Blue bulls (Table 4). High visitor densities (101+ visitors) were associated with increased vigilance (12.8% ± 2.4 compared to 8.1% under low density; F(2, 156) = 6.78, $p < 0.01$) and pacing (7.9% ± 1.6 vs. 3.2% ± 1.1; r = 0.62, $p < 0.001$). Feeding decreased significantly with higher visitor densities (χ^2 = 14.34, $p < 0.01$), while resting declined from 45.5% ± 5.2 in low-density conditions to 35.6% ± 4.5 in high-density conditions (F(2, 156) = 8.21, $p < 0.01$).

Gender and Seasonal Interactions: Significant gender-season interactions were observed (Figure 2). Males exhibited pronounced reproductive behaviors during winter, while females showed steady feeding and social activity across seasons. Female resting peaked during summer (58.3% ± 3.4) compared to winter (31.7% ± 2.9; $p < 0.01$), highlighting thermoregulatory strategies.

Table 3: Behavioral Differences Across Four Zoological Facilities.

Behavior	Lahore Zoo (% ± SD)	Safari Zoo (% ± SD)	Gatwala Breeding Center (% ± SD)	Kamalia Zoo (% ± SD)	Statistical Test
Feeding	35.2 ± 4.1	36.5 ± 3.8	37.1 ± 4.0	34.8 ± 3.7	F(3, 156) = 2.34, p = 0.12
Resting	39.5 ± 4.8	48.1 ± 5.4	41.3 ± 4.5	35.6 ± 4.9	F(3, 156) = 9.78, p < 0.01
Locomotion	11.3 ± 3.2	13.8 ± 3.5	16.7 ± 3.8	14.9 ± 3.6	F(3, 156) = 6.45, p < 0.05
Vigilance	8.9 ± 2.1	9.3 ± 2.4	7.8 ± 2.2	8.1 ± 2.3	F(3, 156) = 1.89, p = 0.09

Table 4: Behavioral changes under visitor density.

Behavior	Low Density (0-50 Visitors)	Medium Density (51-100 Visitors)	High Density (101+ Visitors)	Statistical Test
Feeding	38.2 ± 4.1	34.6 ± 3.9	30.2 ± 3.5	χ^2 = 14.34, p < 0.01
Resting	45.5 ± 5.2	40.1 ± 4.8	35.6 ± 4.5	F(2, 156) = 8.21, p < 0.01
Vigilance	8.1 ± 2.4	10.5 ± 2.6	12.8 ± 2.4	F(2, 156) = 6.78, p < 0.01
Pacing (Agitation)	3.2 ± 1.1	5.8 ± 1.3	7.9 ± 1.6	r = 0.62, p < 0.001

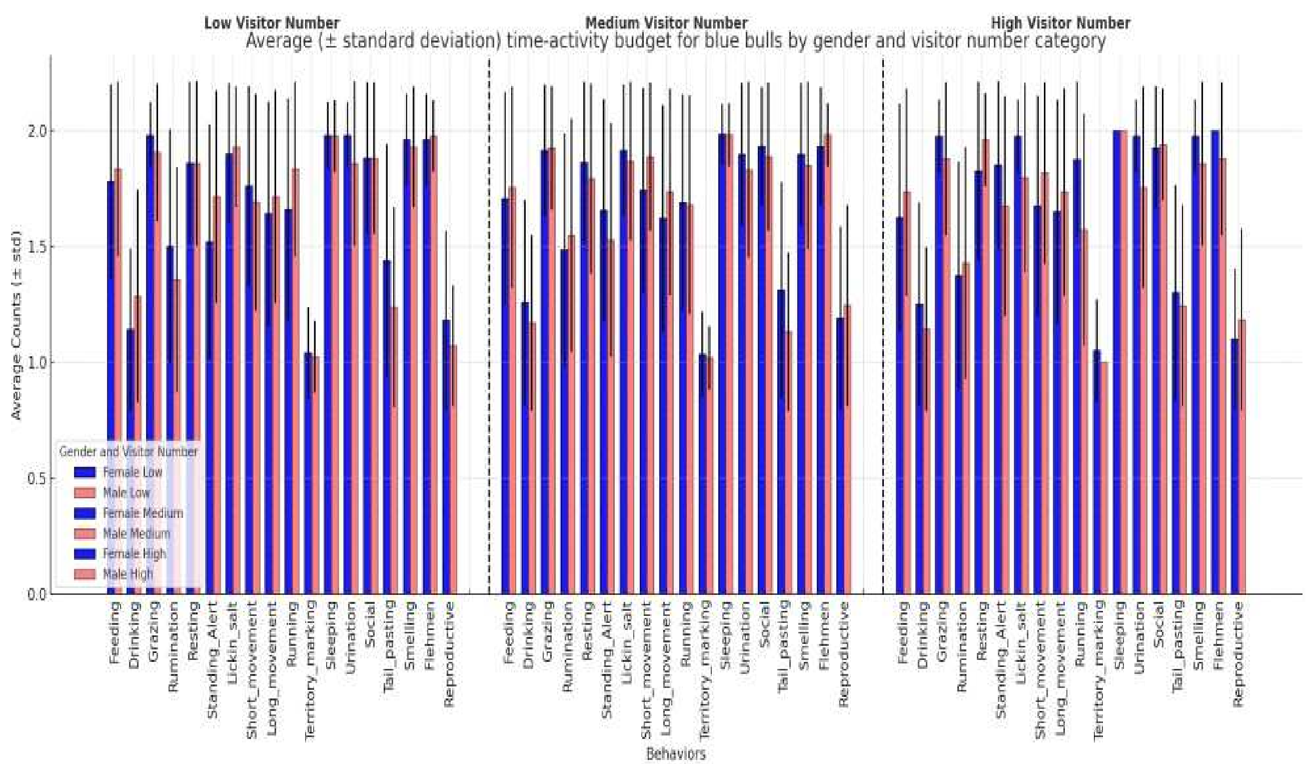

Figure 2: Gender-specific seasonal behavioral patterns: Gender-specific behavioral trends of Blue bulls across seasons. Males show seasonal spikes in reproductive behaviors, while females exhibit consistent feeding and social activity with seasonal resting variations.

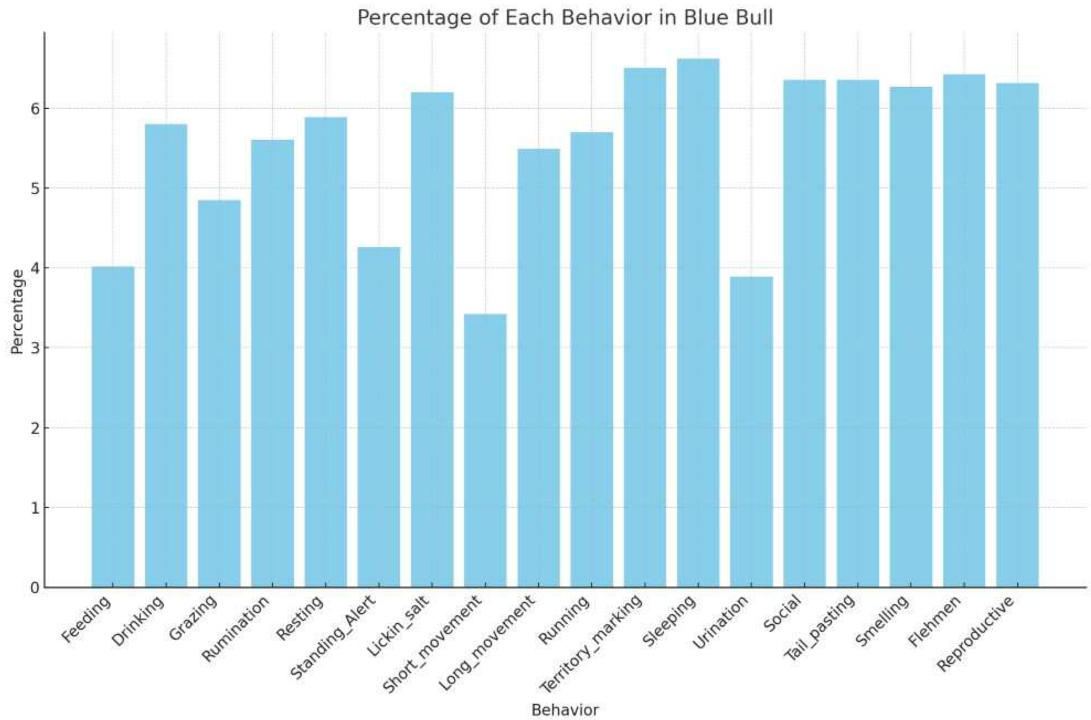

Figure 3: Behavioral variations across visitor densities. Percentage distribution of behaviors in captive Blue bulls. Maintenance behaviors such as grooming and resting dominate, while reproductive and feeding activities occur less frequently.

The bar graph in Figure 3 depicts these variations clearly, with feeding and resting showing a consistent decline as visitor density increases. While, vigilance and agitation (e.g., pacing) behaviors like pacing rise markedly, indicating heightened stress responses.

DISCUSSION

The findings provide valuable insights into the behavioral ecology of captive Blue bulls, highlighting the significant influences of seasonal changes, visitor density, and gender differences on their activity patterns. Seasonal variations revealed increased feeding activity during autumn, reflecting natural foraging behaviors driven by abundant vegetation availability. Similar patterns were observed in Blue bulls in zoological settings in India, where seasonal variations strongly influenced feeding behaviors (Quasin *et al.,* 2014). Our results align with other studies on ungulates, such as sambar deer (*Rusa unicolor*), where resource cycles drive seasonal behavioral changes (Smith *et al.,* 2024; Qiao *et al.,* 2024a). Elevated resting periods during summer are likely thermoregulatory strategies to manage heat stress, consistent with findings in species like Asian small-clawed otters, which increase resting during warmer periods (Morales-Betancourt, 2011). The concentration of reproductive behaviors in winter coincides with the breeding season, reinforcing the persistence of natural rhythms in captivity (Ali *et al.,* 2024). Reproductive behaviors concentrated in winter align with the species' natural breeding season, underscoring the persistence of inherent reproductive cycles even in captivity. This finding supports the importance of accommodating seasonal reproductive behaviors to improve welfare and promote naturalistic behaviors (Skovlund et al., 2021; Hao *et al.,* 2023a). The study by Cerutti *et al.* (2021) revealed significant differences in locomotor activity patterns between maned wolves and domestic dogs. Maned wolves exhibited a nocturnal rhythm, while dogs displayed a diurnal pattern, with a diurnality index of 0.29 and 0.93, respectively. In this study, a significant seasonal variation in locomotion was observed, with activity highest in winter and lowest in summer. This increase in movement during winter may be associated with heightened mate-searching behavior and competitive interactions among males, commonly observed during the breeding season in ungulates. Comparable findings have been reported in alpine musk deer (*Moschus sifanicus*), where males display increased movement during the rut season, whereas females show elevated locomotion during the pre-rut period (Meng *et al.,* 2008).

The observed behavioral variations among zoological facilities highlight the impact of enclosure design and management practices on animal welfare. While feeding and vigilance behaviors remained stable, significant differences in resting and locomotion suggest that environmental factors play a crucial role. Higher resting levels at Safari Zoo (~48%) and lower locomotion at Lahore Zoo (~11.3%) may be attributed to enclosure complexity, which has been shown to influence behavioral diversity and well-being in captive animals (de Azevedo *et al.,* 2023). Similarly, increased locomotion at Gatwala Breeding Center (~16.7%) may reflect an environment that better supports natural activity patterns, aligning with findings that enriched enclosures promote physical engagement and psychological health (Mason *et al.,* 2007).

Visitor density was a significant environmental factor affecting behavior. High visitor densities correlated with increased vigilance and pacing behaviors while reducing feeding and resting times. Such behavioral shifts, often referred to as the visitor effect, suggest elevated stress levels in response to increased human presence (D'Cruze *et al.,* 2019; Qiao *et al.,* 2024b). Similar trends have been documented in zoo mammals, where higher visitor densities induced stress-related behaviors (Sherwen *et al.,* 2015). However, species-specific responses to visitor density have also been observed. For example, in bears, neither season nor visitor density significantly affected behavior, emphasizing the need for tailored management strategies based on species-specific needs (Bernstein-Kurtycz *et al.,* 2021). Gender-based differences in seasonal and visitor-induced behaviors highlight the importance of gender-specific management strategies. Males exhibited heightened reproductive behaviors in winter, while females demonstrated consistent feeding and social activities across seasons, with increased resting during summer. These patterns align with studies in other species, where gender influences responses to environmental variables, including visitor density (Barber *et al.,* 2020). Our findings also align with studies on other sexually dimorphic ungulates, such as red deer (*Cervus elaphus*), where male dominance-driven behaviors are influenced by enclosure conditions (Ruckstuhl and Neuhaus, 2002). Females' adaptability across seasons emphasizes the importance of mixed-gender housing in fostering natural group dynamics and reducing stress. Larger enclosures were associated with reduced aggression and greater behavioral diversity, highlighting the importance of enriched environments in promoting welfare. The Shannon Index of behavioral diversity was highest in Safari Zoo, which featured the largest enclosures and most complex habitats. Behavioral diversity, as a welfare indicator, is supported by recent findings that link environmental complexity with reduced stress and increased naturalistic behaviors (Smith *et al.,* 2024). Understanding these behavioral patterns has significant implications for improving captive management. Implementing environmental enrichments, such as visual barriers or controlled visitor interactions, can reduce stress-induced behaviors and promote natural activity patterns. Additionally, habitat modifications tailored to seasonal and gender-specific needs can further support the psychological and physiological well-being of captive animals (Sherwen and Hemsworth, 2019; Hao *et al.,* 2023b).

Conclusion: This study highlights the complex interplay of seasonal, gender-specific, and visitor-induced factors in shaping the behavior of captive Blue bulls. Seasonal variations were prominent, with feeding behaviors peaking in autumn, resting dominating in summer, and reproductive activities concentrated in winter. Gender-specific patterns revealed higher feeding and social behaviors in females, while males exhibited elevated aggression and locomotion, particularly in smaller enclosures. Visitor density and noise significantly influenced behavioral responses, with increased vigilance and pacing observed under high visitor conditions. The findings emphasize the importance of seasonally tailored enrichment programs, gender-sensitive housing strategies, and visitor management practices to promote welfare. Larger, enriched enclosures were associated with reduced aggression and increased behavioral diversity, underscoring their critical role in fostering naturalistic behaviors. These insights provide a framework for adaptive zoo management that aligns with the biological and ecological needs of captive Blue bulls. Future research should incorporate physiological measures, such as cortisol levels and heart rate variability, to complement behavioral observations and validate stress responses. Expanding the scope to include additional facilities and experimental manipulations of environmental factors would further enhance the generalizability of these findings. By addressing these aspects, zoological facilities can optimize management practices, contributing to the conservation of this endangered species and supporting broader efforts in captive animal welfare.

Acknowledgments: The authors extend their appreciation to the Researchers Supporting Project (RSPD2025R758), King Saud University, Riyadh, Saudi Arabia.

Conflict of interest: The authors declare no conflict of interest.

Data availability: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Funding: This work was funded by the Researchers Supporting Project (RSPD2025R758), King Saud University, Riyadh, Saudi Arabia.

Authors contributions: Hakim Bibi: conceptualization, writing, methodology, sampling, original draft preparation. Aima Iram Batool: supervision, review and editing, formal data analysis. Muhammad Fayyaz-Ur Rehman, Saira Naz and Syed Sikandar Habib: Statistical Analysis, review and editing. Misbah Sarwar and Mohamed Mohany: Data collection, Funding and Validation.

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