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Host-Specific And Seasonal Variations In Prevalence And Intensity Of Strongyloides Spp. Infections In Free-Ranging Herbivores Of Girnar Wildlife Sanctuary, India

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Abstract

This study investigates host-specific and seasonal patterns of Strongyloides spp. infections in free-ranging herbivores (Axis axis, Boselaphus tragocamelus, and Rusa unicolor) at Girnar Wildlife Sanctuary, India, using coprological and statistical analyses. From 135 fecal samples collected across monsoon, summer, and winter in 2023, prevalence ranged from 9.1% (A. axis in winter) to 70.0% (B. tragocamelus in winter), with 47.4% showing zero eggs per gram (EPG), indicating significant uninfected proportions. Logistic regression modelled infection presence/absence, revealing 2.63–2.79 higher odds for R. unicolor and B. tragocamelus compared to A. axis ($p < 0.05$), with robust fit (Hosmer-Lemeshow $p = 0.679$, McFadden's $R^2 = 0.049$). Seasonal effects were non-significant, suggesting host traits dominate over climatic drivers. Intensity, measured as EPG, peaked at 900.0 (IQR = 200.0–1350.0) in R. unicolor during monsoon and 3000 in B. tragocamelus during winter, with Kruskal-Wallis tests confirming host ($\chi^2 = 21.30$, $p < 0.001$) and host-season interactions ($\chi^2 = 29.24$, $p < 0.001$) as significant, but not season alone ($p = 0.238$). Dunn's post-hoc tests identified A. axis as having lower EPG than R. unicolor ($p < 0.001$) and B. tragocamelus ($p = 0.017$). A supplementary Poisson model indicated reduced winter rates (rate ratio = 0.414, $p = 0.010$), likely due to lower larval viability. These findings align with regional studies linking monsoon humidity to transmission peaks and highlight host-specific vulnerabilities, possibly tied to foraging or immunity. Implications include targeted deworming during monsoon for R. unicolor and winter for B. tragocamelus, with future research recommended for molecular diagnostics and immune profiling to enhance conservation strategies in semi-arid ecosystems.

Key words: *Strongyloides spp. infection, Herbivore parasitism, Seasonal prevalence, Girnar Wildlife Sanctuary, Host-specific intensity*

INTRODUCTION

Parasites significantly influence the regulation of host populations within natural environments; thus, understanding parasitic infections in wildlife is a vital consideration for ecosystem health (Van Wyk and Boomker 2011). Several parasite infections resulted in gradual population declines or manifest as severe clinical symptoms and mortality (Waal 2000). Subsequently, disease may impact conservation efforts, serving as a resulting threat in the fragility of wildlife hosts, sometimes leading to severe population declines (de Castro and Bolker 2005; Blehert et al. 2009). Endoparasites, such as Strongyles, are notable due to their widespread presence in ruminant gastrointestinal tract and their potential to cause severe health impacts, including anaemia, weight loss, reduced growth, and mortality. (Mbaya et al. 2008; Alvarado Rybak et al. 2016). In natural prey, strongyle infections may compromise survival rates, which could affect population dynamics and predator-prey relationships (Thieltges et al. 2024). Despite their relevance to ecology and veterinary healthcare, little is known about Strongyle infections in free-ranging herbivores, particularly in semi-arid environments.

In India human-induced land use changes have led to an increase in the diversity of parasites in natural habitats and the possibility of parasites spreading from livestock to wildlife (Chakraborty et al. 2019). Gujarat's Girnar Wildlife Sanctuary (GWS) is a significant habitat in the western part of India, home to diverse ungulate populations that serve as the primary prey for endangered Asiatic lions (Singh 2017). Seasonal fluctuations are crucial in semi-arid areas, and host-specific characteristics (such as immune responses and habitat use) and climatic variables also affect parasite-host interactions (Plowright et al. 2016; Becker and Hall 2014). The monsoon season, characterized by high humidity and moderate temperatures, facilitates parasite transmission, while dry seasons may limit it. Despite the ecological significance of GWS, little is known about the seasonal and host-specific patterns of Strongyle infections in its herbivore populations.

MATERIALS AND METHODS

Study Area

The research was carried out in the 180 km² Girnar Wildlife Sanctuary (GWS), which was created in 2008 as a vital habitat for the Asiatic lion *(Panthera leo persica)* in western Gujarat, India. The sanctuary is located in a semi-arid biogeographic zone and contains tropical dry deciduous and scrub forests (Rodgers and Panwar 1988). A dry summer (March–June), a cooler winter (December–February), and a monsoon season (June–September, 80–100 cm rainfall) are all aspects of the climate that affect ecological processes and the spread of parasites.

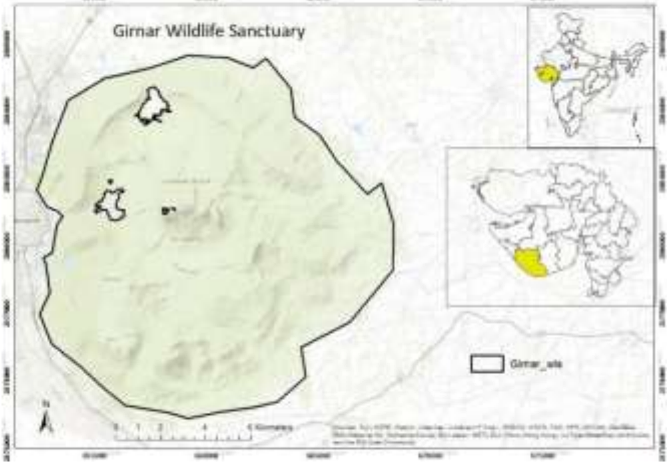


Figure 1: Showing study area at Girnar Wildlife Sanctuary in Gujarat India.

Sample Collection and analysis

A total of 135 fecal samples were taken from three herbivore species: Bluebull (*B. tragocamelus*, n=40), spotted deer (A. axis, n=56), and sambar (*R. unicolor*, n=39) during the monsoon (July–September 2023), summer (March–June 2023), and winter (December 2023–February 2024). A 1 × 1 km grid system created in ArcGIS v10.8.2 (Desktop GIS software. (n.d.). Esri.com.) was used in a random sampling design. To guarantee habitat diversity, pellet samples were taken every 200 meters along trails in five randomly chosen grids. Fecal samples were preserved in 10% formalin and analyzed using sedimentation and direct smear techniques. For sedimentation, 3 g of fecal matter was mixed with 50 ml of distilled water and Methylene Blue, settled in test tubes, and examined under 400× magnification (Tagesu 2018). Direct iodine (Lugol's iodine) and saline smears were used to detect gastrointestinal parasites, with slides prepared and observed under a microscope (Foreyt, 2013). *Strongyloides spp.* eggs were identified based on morphometric characteristics.

Statistical Analysis

All statistical calculations were conducted using R version 4.4.1. Prevalence of *Strongyloides spp.* infection was calculated as the proportion of positive samples per host species included *Axis axis*, *Boselaphus tragocamelus*, *Rusa unicolor* with various season. Prevalence was expressed as a percentage (Bush et al. 1997;), computed as:

$$P = \left(\frac{Number\ of\ positive\ samplesTotal\ sampless}{Total\ Samples}\right) \times 100$$

Moreover, we also adopted a logistic regression model to fit the binary outcome of infection status (Absent/Present) as a function of host and season by a binomial family with logit link through glm (Hosmer et al. 2013; Zuur et al. 2010; Hara and Kotze 2010; Warton 2015). The model was specified as:

$$logit(Pi) = \beta 0 + \beta 1 Host\ Species \dots i + \beta 2 Season \dots i$$

where Pi is the probability of infection for the $i_{..th}$ observations, $\beta 0$ is the intercept, $\beta 1$ denotes the effect of host species, and $\beta 2$ is effect of season. *A. axis* and monsoon were sorted as reference (intercept) categories. Hosmer-Lemeshow goodness-of-fit test (hoslem.test from ResourceSelection) (Sólymos and Lele 2016), McFadden's pseudo-R^2 (pR2 from pscl) (Long 1997), and residual diagnostics including deviance residuals (residuals) (Davison and Snell 1991), standardized residuals (rstandard) (Fox and Weisberg 2011), Q-Q plot of deviance residuals, and Cook's distance (cooks.distance, hatvalues) were assessed for the model evaluation,

For further comparison, a Poisson regression model with a log-link function was fitted to aggregated positive sample counts using glm, incorporating an offset term for total samples as:

$$log(\mu i) = \beta 0 + \beta 1 Host\ Species \ldots i + \beta 2 Season \ldots i$$

Where, $\beta 0$ is the intercept, $\beta 1$ and $\beta 2$ are the coefficients for host species and season, respectively, and μi is the projected number of positive samples for the *i*...th host-season combination. The reference pair for host species and season were established as the *Axis axis* and the monsoon. The Akaike Information Criterion (AIC) and pseudo-R2 metrics (McFadden's and Nagelkerke's R2) (McFadden 1987; Nagelkerke 1991) were adopted to evaluate the model fit. Model assumptions were estimated using residual plots, and overall model suitability was assessed using a chi-squared goodness-of-fit test.

Infection intensity was quantified as eggs per gram (EPG) of *Strongyloides spp.* Due to the non-normal distribution of EPG data, non-parametric Kruskal-Wallis tests were conducted using kruskal.test (Hollander and Wolfe 1973) to compare EPG across host species, seasons, and their interaction (created via interaction and mutate from dplyr). Post-hoc pairwise comparisons were performed using Dunn's test with Bonferroni correction (dunn.test) (Benjamini and Yekutieli 2001). A contingency table of host species and season was analyzed using a chi-squared test of independence (chisq.test), supplemented by Fisher's exact test (fisher.test) (Agresti 2002) for low expected cell counts (<5). Summary statistics for EPG (n, median, IQR, min, max) were computed using dplyr's group_by and summarise with quantile.

A significance level of $p < 0.05$ was used in all analyses. ggplot2 was employed to generate data visualizations, like box-jitter plots of EPG by host-season combinations (using geom_boxplot, geom_jitter, stat_summary, and coord_flip) and bar graphs of prevalence and predicted probability (with 95% confidence intervals via predict and geom_errorbar).

RESULT

Prevalence of Strongyloid Infection

Strongyloides spp. infection prevalence varies by host species and season, as shown in Figure 1 and summarized in Table 1. Among the three host species examined, *Boselaphus tragocamelus* exhibited the highest overall prevalence, ranging from 56.2% in the monsoon season to 70.0% in winter. In contrast, *Axis axis* showed the lowest prevalence, with rates of 50.0% in monsoon, 34.8% in summer, and 9.1% in winter. *Rusa unicolor* was present at intermediate rates throughout the monsoon season (60.0%), summer (62.5%), and winter (50.0%). The total number of samples for each host-season combination ranged from 8 (*R. unicolor* in winter) to 23 (*A. axis* in summer), indicating comparatively small sample sizes. The total number of positive samples showed a similar pattern, with *A. axis* having the lowest number in winter (1 out of 11) and *B. tragocamelus* having the largest number in winter (7 out of 10).

Table 1. Prevalence (%) of *Strongyloid spp.* Infection by Host Species and Season in Girnar Wildlife Sanctuary.

\\$^{a}$ Data from 135 fecal samples collected from free-ranging ungulates; prevalence calculated as (Positive Samples / Total Samples) × 100. ^{b} Rounded to two decimal places where applicable; $P < 0.05$ for host-species effect (logistic regression).

Logistic Regression Analysis

The probability of *Strongyloides spp.* infection (presence/absence) as a function of host species and season was modelled using logistic regression, using the monsoon and *A. axis* as reference (intercept) groups (Table 2). The model coefficients indicated that both *R. unicolor* (β = 0.967, odds ratio [OR] = 2.630, 95% CI: 1.130–6.120, z = 2.240, p = 0.025) and *B. tragocamelus* (β = 1.025, OR = 2.790, 95% CI: 1.200–6.480, z = 2.377, p = 0.017) exhibited significantly elevated probabilities of infection relative to *A. axis*. Seasonal effects were not significant: summer (β = -0.220, OR = 0.800, 95% CI: 0.370–1.750, z = -0.547, p = 0.584) and winter (β = -0.608, OR = 0.540, 95% CI: 0.210–1.390, z = -1.260, p = 0.207) exhibited no substantial variation over monsoon season. Predicted probabilities from the model, with 95% confidence intervals, are depicted in Figure 2, confirming the host species differences. For instance, *A. axis* had the lowest predicted likelihood in winter (~9.0%, CI: ~1.0–25.0%), whereas *B. tragocamelus* had the greatest (roughly 70.0%, CI: ~55.0–82.0%). The model demonstrated good calibration (Hosmer-Lemeshow test: $\chi^2 = 3.135$, df = 5, p = 0.679; Table 3) and a low explanatory power (McFadden's Pseudo $R^2 = 0.049$), which is expected for ecological data with substantial ecological variability. The residual deviation was 178.03 on 130 degrees of freedom (AIC = 188.03), while the null deviance was 187.14 on 134 degrees of freedom.

Table 2. Logistic Regression Coefficients for *Strongyloides spp.* Infection Probability

Term	**Estimate**	**Std. Error[b]**	***z*-value**	**Odds Ratio**	**95% CI Low**	**95% CI Up**	***P*-value[b]**
(Intercept)	-0.386	0.352	-1.094	0.680	0.336	1.350	0.274
R. unicolor	0.967	0.423	2.286	2.630	1.140	6.240	0.025*
B. tragocamelus	1.020	0.418	2.439	2.790	1.210	6.610	0.017*
Summer	-0.220	0.409	-0.538	0.803	0.363	1.760	0.584
Winter	-0.608	0.442	-1.376	0.545	0.208	1.390	0.208

[a] Reference categories: *A. axis* (host) and monsoon (season); model fitted with binomial logit link on n = 135 samples (AIC = 188.03). [b] $P < 0.05$ indicated with *; Std. Error and *z*-values estimated from 95% CI where Excel data misaligned; McFadden's Pseudo $R^2 = 0.049$ (Table 3). *Significant host effects indicate higher infection odds in *R. unicolor* and B. tragocamelus.

Residual diagnostics validated the adequacy of the model (Supplementary Figure 1). The deviation residuals vs. fitted values showed random scatter around zero, suggesting neither non-linearity nor systematic patterns. The standardized deviation residuals showed no significant outliers, with most falling within ±2. The deviance residuals' Q-Q plot, which nearly matched the reference line, verified the approaching normality. Cook's distance revealed that there were few significant observations (threshold: 4/135 = 0.0296), and none of them went above this threshold, suggesting that the data was resistant to individual observations.

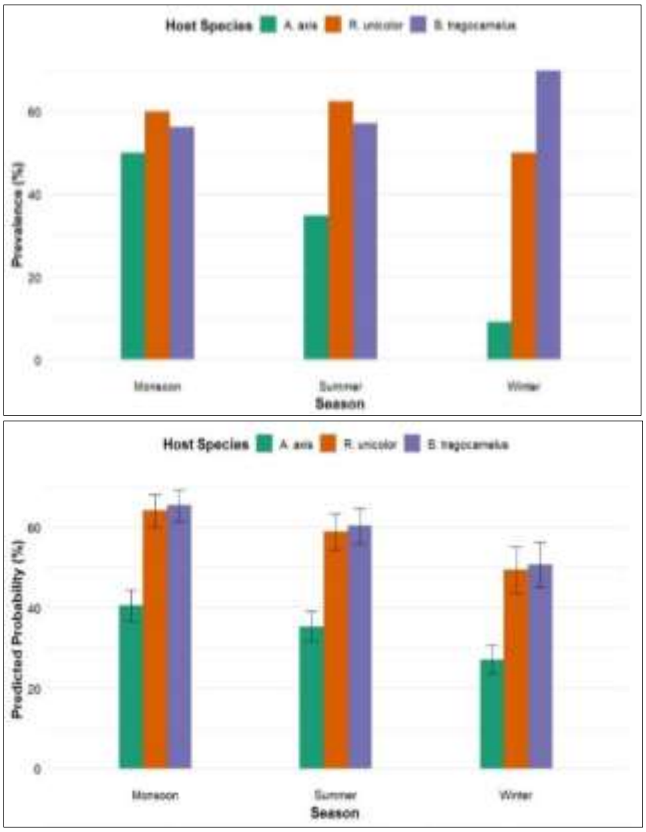
Table 3. Goodness-of-Fit Metrics for the Logistic Regression Model[a]

Metric	**Value**
Hosmer-Lemeshow p-value	0.679
McFadden's Pseudo R^2	0.049

[a] Based on deviance residuals; p > 0.05 indicates good calibration. [b] Null deviance = 187.14 (df = 134); residual deviance = 178.03 (df = 130). *Modest R^2 reflects ecological variability typical in wildlife data.

To investigate infection rates, a Poisson regression model was fitted to the total number of positive samples per host species and season, with an offset for all samples (results presented in supplemental Table S4). While no significant effects were found for host species or summer, the model showed a significant negative effect for winter ($\beta = -0.882$, rate ratio = 0.414, 95% CI: 0.211–0.811, z = -2.571, p = 0.010), indicating a lower infection rate relative to the monsoon reference season. Despite a residual deviation of 5.239 on 4 degrees of freedom (AIC = 48.704), the model's explanatory power was moderate (McFadden's Pseudo R2 = 0.181). However, considering the smaller sample size of 9 host-season groups in comparison to the 135 individual samples examined in the logistic regression, this method was deemed less appropriate for the primary analysis because of possible aggregation bias and lower statistical power.

Figure 2. Prevalence and Predicted Probabilities of *Strongyloides spp.* Infection by Host Species and Season



Combined plot showing observed prevalence (%) and predicted probabilities (%) of Strongyle spp. infection in A. axis, R. unicolor, and B. tragocamelus across monsoon, summer, and winter in Girnar Wildlife Sanctuary, 2025. Bars depict prevalence with 95% confidence intervals from binomial proportions, while an overlaid line or point plot displays predicted probabilities from the logistic regression model (Table 2) with 95% confidence intervals. Reference categories are A. axis and monsoon (n = 135 samples).

Infection Intensity of Strongyle Parasites

Strongyle spp. infection intensity, expressed as eggs per gram (EPG) in fecal samples, varied significantly among host species and seasons (Table 4). The EPG values of 135 samples, which ranged from 0 to 3000 (mean = 277.8, median = 100.0, IQR = 0–300), were examined. This indicates that parasite burdens in herbivore populations have a highly skewed distribution. A significant percentage of hosts were uninfected, as indicated by the 47.4% of samples with nil EPG, which is in line with prior reported prevalence patterns (Table 1). Unlike Boselaphus tragocamelus in winter (200.0, IQR = 125.0–300.0, range = 0–3000) and Rusa unicolor in summer (250.0, IQR = 0–750.0, range = 0–1400), the median EPG was highest in Rusa unicolor during the monsoon season (900.0, IQR = 200.0–1350.0, range = 0–1900). In contrast, *Axis axis* displayed consistently low median EPG across all seasons (0.0 in monsoon/summer/winter, with IQRs of 0–200/0–200/0–0, respectively; ranges = 0–600/400/300). Despite having intermediate medians (150.0–200.0), *B. tragocamelus* occasionally displayed significant burdens, as evidenced by its winter maximum (3000). Given that *R. unicolor* exhibits higher intensities during wetter times, which may be related to greater environmental transmission, these patterns point to host-specific vulnerability.

Significant variations in EPG intensity by host species ($\chi^2 = 21.30$, df = 2, $P < 0.001$) and the host-species × season interaction ($\chi^2 = 29.24$, df = 8, $P < 0.001$) were confirmed by Kruskal-Wallis tests, but not by season alone ($\chi^2 = 2.87$, df = 2, $P = 0.238$; Table 5). The host-species × season interaction ($\chi^2 = 29.24$, df = 8, $P < 0.001$) and host species ($\chi^2 = 21.30$, df = 2, $P < 0.001$) showed significant differences in EPG intensity, but not by season alone ($\chi^2 = 2.87$, df = 2, $P = 0.238$; Table 5).

Table 4: Summary statistics for *Strongyloides spp.* eggs per gram (EPG) by host species and season. Medians and IQRs are robust to skewness; zeros indicate uninfected samples (overall 47.4% zeros).

Host Species	Season	N	Median EPG	IQR (EPG)	Min EPG	Max EPG
A. axis	Monsoon	22	0.0	(0.0-200.0)	0.0	600
	Summer	23	0.0	(0.0-200.0)	0.0	400
	Winter	11	0.0	(0.0-0.0)	0.0	300
R. unicolor	Monsoon	15	900.0	(200.0-1350.0)	0.0	1900
	Summer	16	250.0	(0.0-750.0)	0.0	1400
	Winter	8	100.0	(0.0-425.0)	0.0	800
B. tragocamelus	Monsoon	16	200.0	(0.0-300.0)	0.0	700
	Summer	14	150.0	(0.0-275.0)	0.0	600
	Winter	10	200.0	(125.0-300.0)	0.0	3000

[a] Medians/IQRs robust to skewness (47.4% zeros overall); n = sample size. [b] Data from 135 fecal samples; Shapiro-Wilk tests confirmed non-normality in 7/9 groups ($P < 0.05$; Table S3). *Highest medians in R. unicolor-monsoon and B. tragocamelus-winter.

Several pairwise differences were identified using post-hoc Dunn's testing with Bonferroni adjustment (Table S2). In terms of host species, *A. axis* had a considerably lower EPG than *B. tragocamelus* ($Z = -2.54$, adjusted $P = 0.017$) and *R. unicolor* ($Z = -4.56$, adjusted $P < 0.001$), however there was no difference between *B. tragocamelus* and *R. unicolor* ($Z = -1.88$, adjusted $P = 0.089$). There were no significant pairwise seasonal differences (all adjusted $P > 0.19$). For the interaction, 6 of 36 comparisons were significant (adjusted $P \leq 0.025$): *R. unicolor*-monsoon exceeded all *A. axis* groups ($P < 0.001$ for each), reflecting pronounced intensity peaks in this combination. Other patterns, including the B. tragocamelus-winter vs. *A. axis* groups, came close to being significant (adjusted P = 0.146–0.724), but fell short of the cutoff, indicating more subtle impacts that need more research.

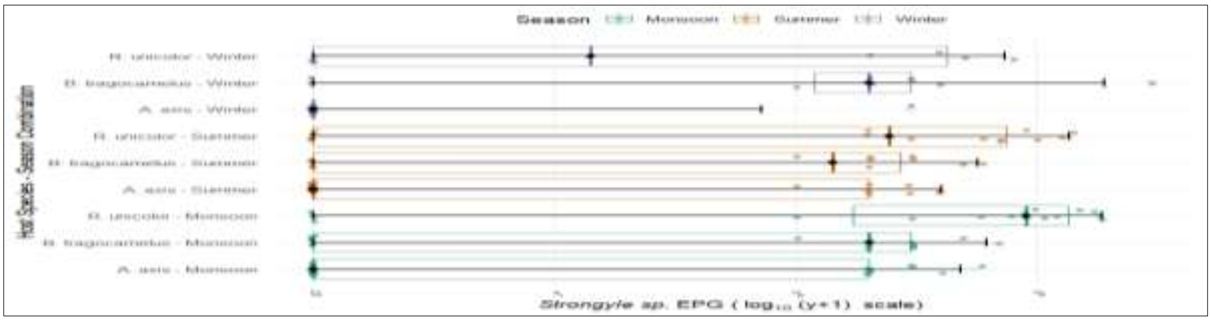
Table 5. Kruskal-Wallis Test Results for *Strongyloides spp.* EPG Intensity[a]

Test Factor	**χ^2**	**df**	***P*-value[b]**
Host Species	21.30	2	<0.001*
Season	2.87	2	0.238
Host Species × Season	29.24	8	<0.001*

[a] Omnibus tests for group differences in EPG (n = 135). [b] $P < 0.05$ indicated with *; justifies Dunn's tests (Table S2). *Interaction effect highlights host-season modulation.

Figure 3 confirms the Kruskal-Wallis interaction effect by visualizing EPG distributions on a log10(y+1) scale to account for zeros and skewness. In line with post-hoc findings, R. unicolor-monsoon and B. tragocamelus-winter displayed the widest spreads and highest values. Boxplots display medians and IQRs, with jittered dots emphasizing individual variation.

Figure 3. Distribution *Strongyloides spp.* Egg Per Gram (EPG) Intensity by Host Species and Season with Log10-Transformed Scale



Boxplot showing median, IQR, and range of Strongyloides spp. EPG for A. axis, R. unicolor, and B. tragocamelus across monsoon, summer, and winter in Girnar Wildlife Sanctuary, 2023-24, on a log10(y+1) scale. Medians/IQRs: A. axis (0.0/0–200 all seasons), R. unicolor (900.0/200.0–1350.0 monsoon; 250.0/0–750.0 summer; 200.0/0–300.0 winter), B. tragocamelus (150.0/0–300.0 monsoon; 200.0/0–500.0 summer; 200.0/125.0–300.0 winter, max 3000). Outliers as points; n = 135, 47.4% zeros. Overall, these findings suggest that the intensity of *Strongyloides spp.* infections varies depending on the host, with seasonal variation increasing burdens in *B. tragocamelus* during the winter and *R. unicolor* during the monsoon. These variations may be due to variations in the herbivore species' foraging habits, immune responses, or parasite life cycles.

DISCUSSION

The trends in the prevalence and intensity of *Strongyloides spp.* in *Axis axis*, *Boselaphus tragocamelus*, and *Rusa unicolor* at Girnar Wildlife Sanctuary highlight how host-specific characteristics and seasonal environmental cues play a crucial role in determining the dynamics of gastrointestinal nematodes in free ranging ungulates. Interspecific differences in foraging ecology, immune competence, and microhabitat utilization are likely the primary causes of variation in parasite exposure and susceptibility, as evidenced by the consistently low prevalence in *A. axis* (down to 9.1% in winter) compared to elevated rates in *B. tragocamelus* (70.0%) and *R. unicolor* (62.5%) during the same period (Singh et al. 2009) found that species-specific ecological traits correlate with differential parasite burdens in Indian wildlife. which supports the idea that gastrointestinal parasitism is influenced by foraging behaviors and habitat preferences in free-ranging herbivores. While *A. axis's* selective grazing in open microhabitats may lessen vulnerability by lowering larval density, browsing activities in cervids such as *R. unicolor* may enhance interaction with unhealthy foliage, raising exposure (Turner and Getz 2010). Likewise, immune modulation in bovids such as *B. tragocamelus* may impair defense and increase infection during resource-constrained winters (Hasegawa et al. 2025). Consistent with evidence depicting that browsing practices that increase interaction with morbid pasture often result in increased strongyle loads in cervids such as *R. unicolor* which align with finding on captive herbivores by (Naz et al. 2021), logistic regression analysis confirmed that *B. tragocamelus* and *R. unicolor* showed 2.8- and 2.6-fold higher odds of infection relative to A. axis, similar pattern observed on cattle by (Gupta, 2016). Further supporting this host-specific variation lies the logistic model's non-significant seasonal effects, which show that behavioral adaptations or genetic resistance to intrinsic factors dominate over extrinsic seasonal drivers in determining the likelihood of infection (Hawley et al. 2025).

Infection intensity, as measured by eggs per gram (EPG), reinforced these host-driven disparities, with *R. unicolor* displaying the highest median EPG during monsoon (900.0, IQR = 200.0–1350.0) and *B. tragocamelus* reaching a maximum of 3000 EPG in winter (Sengar et al. 2025). Seasonal modulation is dependent on host identity rather than a universal environmental effect, as the Kruskal-Wallis tests showed significant differences by host species ($\chi^2 = 21.30$, df = 2, $P < 0.001$) and host-season interaction ($\chi^2 = 29.24$, df = 8, $P < 0.001$), but not by season alone ($P = 0.238$) (Williams et al. 2023). The interaction revealed that *R. unicolor*-monsoon outperformed all *A. axis* groups ($P < 0.001$), while Dunn's post-hoc testing identified *A. axis* as having considerably lower EPG than *R. unicolor* ($P < 0.001$) and *B. tragocamelus* ($P = 0.017$) (Singh et al. 2009). These findings echo patterns in Indian ungulates, where Monsoon humidity increases the survival and transmission of larvae, causing intensity maxima in sensitive species (Gupta et al. 2009; Barmon et al. 2014). The skewed distribution characteristic of strongyle infections in which a subset of hosts experiences enormous burdens, possibly as a result of behavioral avoidance or acquired immunity is confirmed by the 47.4% prevalence of zero EPG samples (Lind 2005).

The modest explanatory power of the logistic model (McFadden's Pseudo $R^2 = 0.049$) and good calibration (Hosmer-Lemeshow $P = 0.679$) reflect the multifaceted nature of parasite-host interactions in natural systems, where unmeasured variables like host density or nutritional status contribute to residual variability (Tompkins et al. 2011). Random dispersion in deviance residuals and the absence of influential spots (Cook's distance < 0.0296) are examples of residual diagnostics that validate the model's robustness and its application in infection probability prediction (Zuur et al. 2009). Although its aggregated design restricts flexibility, the additional Poisson model confirmed a seasonal reduction in winter rates (rate ratio = 0.414, P = 0.010), most likely as a result of decreased larval viability in drier conditions (Corral and García 2014).

These findings directly affect the conservation of ungulates in semi-arid sanctuaries such as Girnar, where population health is at jeopardy from strongyle diseases due to climate variability (Singh et al. 2016). The host-season peaks indicate that, as shown in mixed-grazing systems, focused deworming or habitat management during the winter for *B. tragocamelus* and the monsoon for *R. unicolor* could lessen loads (Forteau et al. 2020). However, widespread anthelmintic resistance in strongyles necessitates integrated approaches, including rotational grazing to dilute infective larvae (Bellaw and Nielsen 2020). The coprological approach, which might understate prevalence because of sporadic egg shedding, is a study limitation (Hendrix and Robinson, 2022). To clarify resistance mechanisms in A. axis, future studies should include longitudinal immunological profiling and molecular diagnostics for species-level identification (Hawley and Altizer, 2011). By integrating these insights, management strategies can enhance resilience against parasitism, ensuring the sustainability of these keystone herbivores in changing ecosystems.

CONCLUSION

This study elucidates host-specific and seasonal dynamics of *Strongyloides spp.* infections in free-ranging herbivores at Girnar Wildlife Sanctuary, it found that *A. axis* demonstrated strong resistance throughout the seasons, while *B. tragocamelus* and *R. unicolor* were more vulnerable hosts, peaking in frequency and severity during the winter and monsoon, respectively. With robust diagnostics (Hosmer-Lemeshow p = 0.679, no influential points) and logistic regression highlighting enhanced chances (OR = 2.63–2.79) for *R. unicolor* and *B. tragocamelus* relative to *A. axis*, host features were highlighted as the main drivers over seasonality. These results highlight the necessity for focused treatments like rotational grazing to lessen burdens in the face of climate variability (Forteau et al., 2020) and are consistent with regional trends in Indian sanctuaries, where monsoon humidity increases transmission (Turner and Getz 2010). This study advocates for molecular diagnostics and immunological profiling in future endeavours to maintain biodiversity by combining coprological and statistical methods to establish a baseline for ungulate health monitoring and conservation in semi-arid ecosystems (Hawley & Altizer, 2011). Ultimately, understanding these interactions informs proactive management, ensuring the resilience to parasitic threats for herbivores in semi-arid habitat like Girnar wildlife sanctuary in India.

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Conflict of Interest

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

Author Contribution

Study design and concept: Sejal Vala; Nishith Dharaiya, Data collection: Sejal Vala, Identification: Sejal Vala and Vandip Chauhan, Statistical analysis: Sejal Vala and Vandip Chauhan, Manuscript writing-editing: Sejal Vala, Manuscript review: Nishith Dharaiya and Shreyas Bhatt.

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