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Determinants of susceptibility and parasite burden of gastrointestinal helminths in small ruminants from a tropical semi-arid region

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Abstract

Gastrointestinal nematode infections constitute a major sanitary challenge in sheep and goat farming, particularly in semi-arid regions, where environmental conditions modulate the parasitic cycle. This cross-sectional study evaluated prevalence, infection intensity, and associated risk factors in 1,915 small ruminants from 95 properties, conducted between September 2023 and April 2024. Clinical examinations, FAMACHA© scoring, and fecal egg counts (EPG) were performed. Data were analyzed using Poisson regression with robust variance to estimate prevalence and negative binomial regression to assess infection intensity. Overall prevalence reached 72.4%. The ovine species (PR = 0.87) and better body condition scores (PR = 0.62) functioned as protective factors against infection, though without significant influence on parasitic load. Young animals showed greater susceptibility and higher infection intensity (RT = 1.50), positioning them as key disseminators. Mixed grazing with cattle increased prevalence but did not affect infection intensity. Regarding treatment practices, intensive quarterly deworming showed no statistical difference compared to no treatment ($p > 0.05$), suggesting compromised drug efficacy. Conversely, sporadic treatments administered at intervals exceeding 12 months were associated with lower parasitic loads (RT = 0.58), indicating potential benefits of reduced anthelmintic pressure.These findings reinforce that susceptibility to infection and regulation of parasitic burden are governed by distinct factors, highlighting the need for integrated strategies based on risk category management and selective treatments, aiming to mitigate anthelmintic resistance and support long-term productive sustainability.

Introduction

The rearing of small ruminants in the Brazilian Semi-arid region was, for a long time, considered an activity mainly aimed at the subsistence of rural populations, as it provides an accessible source of animal protein to low-income families (Ferreira et al., 2017). Although there is great potential for the expansion of small ruminant farming in the Northeast region, this activity still faces significant limitations, such as food scarcity during drought periods, inadequate sanitary management, and the high prevalence of infectious diseases, especially those of parasitic origin (Leite et al., 2021).

Considering the main sanitary challenges, the presence of helminthiasis stands out, which negatively impacts animal performance by reducing feed conversion, compromising the immune system, slowing growth, and influencing phenotypic characteristics. Gastrointestinal parasitosis constitutes one of the main obstacles to sheep and goat production, being caused by nematodes, cestodes, and protozoa that affect the digestive tract. Among them, *Haemonchus contortus* stands out for its high pathogenicity, as it is a hematophagous parasite that causes severe anemia, hypoproteinemia, and reduced weight gain (Besier et al., 2016). Other genera, such as *Trichostrongylus* and *Oesophagostomum*, also contribute to the loss of productivity and increased mortality, especially in extensive systems where there is no adequate support for the control and prevention of these and other diseases that can affect the herd (Mavrot et al., 2015; Meradi et al., 2019).

The pathogenesis of these infections involves multiple mechanisms, including blood-feeding, tissue damage, toxin release, and competition for nutrients. These processes trigger immune responses that can lead to chronic inflammation and impaired intestinal absorption (Besier et al., 2016; González-Garduño et al., 2021; Abosse et al., 2022). Clinically, the affected animals present pale mucous membranes, submandibular edema, apathy, loss of appetite, and delayed body development. The severity of the clinical picture depends on the parasitic load, the nutritional status, and the host's immunity. Young animals and lactating females are more susceptible due to lower immunological resistance (González-Garduño et al., 2021).

Additionally, producers face high costs with the acquisition of anthelmintics and negative economic effects resulting from the withdrawal period of these drugs, which negatively impacts the profitability of the properties (Fissiha and Kinde, 2021). Endoparasite infections, although often subclinical, can progress to severe manifestations in situations of high parasitic load, causing progressive weight loss, diarrhea, anemia, and even death, especially in juvenile animals (Juszczak et al., 2019). Mass infections by this and other parasites lead to reduced productivity and fertility rates and can cause animal mortality, particularly in young animals (Risa et al., 2024). In this context, the objective of this work was to determine the prevalence and factors associated with gastrointestinal helminth infections in small ruminants raised in a tropical semi-arid region, considering variables related to the host, management, and productive conditions, aiming to contribute information applicable to the development of sustainable control strategies.

Materials and Methods

Study Area

This study was conducted on 95 properties, distributed across four contiguous municipalities in the Brazilian Semi-Arid region (Barra, Ibotirama, Buritirama, and Xique-Xique), between September 2023 and April 2024 (Fig. 1). The study area has a semi-arid climate, with predominant Caatinga vegetation and rainy periods concentrated between November and March. The sampling method used to determine the prevalence of properties positive for helminthiasis was conducted in two stages. In the first, the properties were selected randomly. The number of properties to be sampled was calculated based on the following parameters: (i) expected prevalence of 50%, (ii) confidence level of 95%, and (iii) absolute error of 10%. The second stage consisted of determining the number of animals to be sampled per property. In each property, the number of animals selected was determined individually to detect the presence of the infection, using the following formula: n = [1-(1-p) d 1] x (N- d) + 1. Where: n = sample size; p = probability of detecting at least one positive animal; N = herd size; d = number of positive animals in the herd (Thrusfield, 2018). The probability of detecting at least one positive animal was 95% (p = 0.95), and the number of positive animals per herd (d) was calculated assuming an intraherd prevalence of 10%.

Clinical evaluation of the animals and sample collection

For this study, a clinical and physical assessment of the animals was conducted. The evaluation included checking weight, mucous membrane color, and body condition score (BCS). In addition, the FAMACHA method was used to assess the degree of anemia in the animals based on the color of the ocular mucosa. The fecal samples were collected directly from the rectal ampoule and stored in sterile containers, with identification of the animal and the property. All collected materials were stored in isothermal boxes until processing. All information was recorded on specific forms, according to the property visited.

Sample processing

The samples collected in the field were sent to the *Laboratório de Saúde Única (LASU)* at the *Universidade Federal do Oeste da Bahia (UFOB)* for processing. For the processing of fecal samples, two procedures were adopted: (i) individual evaluation of the samples using the eggs per gram of feces (EPG) counting technique, as described by Gordon and Whitlock (1939); and (ii) grouping of samples from each property for coproculture, as described by Roberts and O'Sullivan (1950). After 15 days of coproculture incubation, the larvae were collected and stored in 15 ml Falcon® tubes, properly labeled with the property of origin and the collection date. The identification of the larvae followed the procedure described by Van Wyk and Mayhew (2013).

Statistical analysis

The data analysis occurred in three stages: descriptive, bivariate, and multivariate. The initial processing was carried out using the jamovi software (v. 2.3.28), and the final modeling in the R environment (v. 4.5.1; R Core Team, 2025). In the descriptive phase, the qualitative variables were presented by absolute and relative frequencies. Due to the absence of normality (Shapiro-Wilk test), the intensity of the infection (EPG) was described by median and interquartile range (IQR). In the bivariate stage, the Pearson Chi-square test was used for the binary outcome and the Mann–Whitney U or Kruskal–Wallis tests for the continuous outcome. Variables with $p \leq 0.20$ were selected for the multivariate models, except for the FAMACHA© variable, which was excluded due to collinearity with BCS and its nature as a clinical indicator resulting from infection.

The multivariate analysis employed distinct Generalized Linear Models (GLM) for each outcome. For prevalence, Poisson Regression with robust variance was chosen, allowing for the direct estimation of the Prevalence Ratio (PR) and avoiding the overestimation of the measure associated with *Odds Ratio* in frequent outcomes. For intensity (EPG count), Negative Binomial Regression was used, selected based on the Akaike Information Criterion (AIC) after confirming excessive overdispersion in the data (deviance/degrees of freedom ratio $\gg 1$), ensuring the proper adjustment of the *Rate Ratio* (RR).

Multicollinearity was ruled out by analyzing the Variance Inflation Factor (VIF < 5). The significance of the final associations was assessed using the Wald Test, adopting α = 5%. The computational routines used the *MASS packages* (negative binomial adjustment), *sandwich*, and *lmtest* (robust variance estimation).

Results

Descriptive Analysis: Characterization of the Population and Management

A total of 1915 small ruminants were evaluated, with the sample predominantly composed of goats, which represented 58.1% (n = 1113) of the total, compared to 41.9% (n = 802) of sheep. There was a predominance of females, accounting for 81.9% (n = 1569) of the animals. Regarding the age distribution, a well-distributed proportion among the categories (Young, Young Adult, and Adult) was observed. Due to the higher concentration of rural properties, the geographical distribution of the animals was concentrated in the municipality of Xique-Xique, which contributed 47.6% (n = 912) of the sample (Table 1).

Concerning the coloration of the ocular mucosa, assessed as an indicator of anemia using the FAMACHA© method in 1855 animals, it was observed that the majority were classified in grade 3 (66.3%), followed by grade 4 (24.0%). This distribution profile suggests the presence of anemia in a significant portion of the evaluated population (Table 1).

The herd management profile revealed the predominance of the semi-extensive breeding system, adopted in 90.4% (n = 1732) of the properties. Practices such as intercropping (1.6%) and cohabitation with cattle (3.1%) were infrequent. Regarding parasitic control, the most common deworming frequencies were semiannual (34.9%) and quarterly (31.2%). Regarding the hygiene of the facilities, the predominant practice consisted of physical scraping (98.4%), carried out mostly on a monthly basis (98.4%) (**Table S1**).

Factors Associated with Gastrointestinal Helminth Infection

The overall prevalence of gastrointestinal helminths in the studied population was 72.4% (n = 1386). The results of the coproculture demonstrated a significant predominance of *H. contortus* (64.5%), followed by a moderate presence of *Oesophagostomum* spp. (5.7%) and *Trichostrongylus* spp. (3.1%) in the analyzed properties. The bivariate analysis revealed that both intrinsic host factors and management practices were associated with the infection, as detailed in the prevalence (Table 2) and intensity (**Table 3**) analyzes.

Intrinsic factors, such as species, age group, and body condition, showed a strong association with the infection. The prevalence was significantly higher in goats (77.5%) than in sheep (65.2%; p < 0.001) (Table 2), a pattern that was maintained in the intensity analysis, in which the median EPG was also

higher in goats (**Table 3**). Age group was also a relevant factor, with adult animals showing lower prevalence and lower median EPG compared to younger groups (Tables 2 and 3).

The clinical scores demonstrated a clear association with parasitosis. A strong inverse relationship was observed with the BCS ($p < 0.001$), in which both the prevalence and the median of EPG consistently decreased with the improvement of body condition. In contrast, the relationship with the FAMACHA© score was direct ($p < 0.001$), where the highest prevalences and medians of EPG were found in animals with higher scores, indicative of anemia (Tables 2 and 3).

Among the management factors, the frequency of deworming was associated with both prevalence ($p = 0.025$) and infection intensity ($p < 0.001$), with animals that did not receive treatment showing the worst indicators. Interestingly, the coexistence with cattle was shown to be a risk factor for prevalence ($p = 0.026$) (Table 3), but did not demonstrate a significant association with the intensity of the infection in the bivariate analysis ($p = 0.272$) (**Table 3**).

Multivariate Regression Analysis

A combined analysis of Fig. 2 and Table 4 reveals distinct dynamics of susceptibility and parasitic load. Intrinsic host factors demonstrated important associations. The ovine species acts as a protective factor for prevalence (RP = 0.87; $p < 0.001$), although it did not show a statistically significant difference in infection intensity (RT = 0.87; $p = 0.191$) compared to goats. In contrast, the young age group appears as a risk factor both for prevalence (RP = 1.09; $p = 0.012$) and, more significantly, for the intensity of the infection (RT = 1.50; $p < 0.001$), indicating that young animals not only get infected more but also sustain higher egg counts. The body condition score (BCS) demonstrated a protective effect on prevalence at higher scores (BCS 3 and 4), but did not significantly influence the reduction of egg count (RT).

Among the management factors, cohabitation with cattle was confirmed as a factor associated with higher prevalence (RP = 1.18; $p = 0.006$), but it did not exert a significant influence on the intensity of the infection (RT). The frequency of deworming presented complex results: the treatment strategy with intervals longer than 12 months proved to be the most effective, acting as a protective factor for both prevalence (RP = 0.87) and, robustly, for intensity (RT = 0.58). Semiannual treatment was associated with a reduction in prevalence but not in egg counts, while quarterly deworming did not show a statistically significant association with any of the outcomes.

A central observation of this analysis is the distinction between the determinants of prevalence and intensity. Contrasting with the expectation of similar behavior between the outcomes, the data reveal distinct biological patterns: variables such as species and body condition primarily modulated susceptibility to infection (prevalence), while age and specific deworming strategies exerted a decisive impact on the magnitude of the egg counts (intensity).

Discussion

The present study revealed a high prevalence (72.4%) of gastrointestinal helminths in small ruminants in a semi-arid region of northeastern Brazil, a finding that, although expected for tropical ecosystems, reinforces the ongoing challenge that these parasitoses represent for local production (Ferreira et al., 2017; Leite et al., 2021). The multivariate analysis allowed for the identification of a clear epidemiological profile, in which intrinsic host factors and management practices proved to be determinants for infection. The understanding of these factors is fundamental for the development of more effective and sustainable control strategies for the region. The findings of the present study also contribute to the epidemiological understanding of helminthiases in semi-arid regions, where extreme environmental variables modulate the dynamics of infections (Vilela et al., 2021). The identification of consistent risk factors reinforces the idea that isolated interventions tend to be insufficient when disconnected from the local reality.

One of the most robust findings of the study was the confirmation of the greater susceptibility of goats compared to sheep. This difference between the species is widely documented in the literature and often associated with distinctions in grazing behavior and, crucially, in innate and acquired immune competence against helminths (Risa et al., 2024). Sheep, in general, demonstrate a greater ability to develop a protective immune response, especially against blood-feeding helminths like *H. contortus*, which is reflected in the lower prevalence observed. Our data showed that sheep are less infected (RP), but when they do get infected, they present a load equal to that of goats (RT). However, it is relevant to note that, although the prevalence was lower in sheep, the intensity of the infection (EPG) did not differ statistically between the infected species. This suggests that the advantage of sheep lies in their lower probability of infection (lower susceptibility), but once infected, the immune response does not seem sufficient to reduce egg excretion, which remains at levels similar to those of goats.

Age and body condition score (BCS) emerged as important modulators of infection, corroborating the literature. The higher prevalence in young animals (up to one year of age) is classically attributed to an immune system still in development, unable to efficiently control primary infections (Torres-Chable et al., 2020; Sajovitz et al., 2023). Our results expand this understanding by demonstrating that the impact of age is much more severe on intensity (RT = 1.50) than on prevalence (RP = 1.09). This characterizes young animals as the main "super-shedders" of the herd, acting as biological amplifiers of pasture contamination. This finding highlights the importance of directing prophylactic measures, such as pasture management and strategic deworming, toward the younger categories of the herd. Similarly, the strong inverse association between BCS and infection highlights the vicious cycle between malnutrition and parasitism. Animals with better nutritional status have more resources to mount a competent immune response, both to resist the establishment of the infection and to demonstrate resilience (maintaining production despite the infection) (Caroprese et al., 2015; Smith et al., 2018).

From a productive standpoint, the high prevalence observed in this study can translate into a significant economic impact, given the reduction in weight gain, milk production, fertility, and feed conversion efficiency in parasitized animals. This scenario is especially critical in subsistence or low-technology

systems, where the herd represents a primary source of family income (Fthenakis and Papadopoulos, 2018).

Among the management practices, the coexistence with cattle and the absence of deworming stood out. The sharing of pastures with cattle, associated with an 18% increase in prevalence, likely elevates environmental contamination by infective larvae, increasing the infection pressure on small ruminants (Nascimento et al., 2021; Sands et al., 2024). According to D'Alexis et al. (2014), production systems with limited forage resources, and the presence of cattle in the same grazing area, can force small ruminants to graze closer to the ground, an area where the concentration of infective larvae is exponentially higher. This dynamic creates a conducive environment for the increase of gastrointestinal parasitic load, as most nematodes in the larval stage reside in the lower portion of the pasture (D'Alexis et al., 2014; Joly et al., 2022). Competition for food can lead to a subclinical nutritional deficit, compromising the immunity of these animals(Hoste et al., 2008; Smith et al., 2018).

Additionally, the study confirmed the unequivocal benefit of deworming but revealed important nuances regarding the frequency of treatment. The absence of treatment was consistently associated with the worst parasitological indicators. However, it was observed that intensive regimes (quarterly) did not differ statistically from the absence of treatment, while strategic or sporadic regimes (> 12 months) provided the greatest protection, reducing the estimated egg count by 42%. This challenges the notion that "more treatment is better." This result alerts to the ineffectiveness of fixed and frequent sanitary schedules in the region, which no longer seem to control parasitosis, possibly due to the selection of resistant parasites.

Considering the global context of anti-helminthic resistance, the results of this study gain additional importance. The failure observed in the quarterly regimen is a strong indication of established parasitic resistance. Anti-helminthic resistance arises mainly due to the selective pressure exerted by the repeated use of the same active ingredient, associated with the lack of efficacy monitoring and frequent underdosing (Fortes and Molento, 2013). Such a scenario necessitates a reevaluation of parasitic control strategies, seeking alternatives that minimize selective pressure on helminth populations and preserve the efficacy of available drugs (Gonçalves et al., 2018). The detection of resistance is crucial to alert producers about the need for adequate sanitary management and effective treatments, while the absence of monitoring significantly contributes to its emergence (Ng'etich et al., 2024).

The fact that management practices influence prevalence, with a magnitude similar to that of the use of anthelmintics, indicates that integrated interventions can reduce selective pressure and delay the emergence of resistant strains (Fissiha and Kinde, 2021; Ng'etich et al., 2024). The conventional control of gastrointestinal parasitic infections in small ruminants is predominantly based on the use of synthetic anthelmintics, such as benzimidazoles, imidazothiazoles, and macrocyclic lactones (Charlier et al., 2023).

A central finding of this study was the distinction between the determinants of prevalence and intensity of infection. Contrary to the expectation of a uniform behavior, the data revealed that variables such as

species and body condition primarily modulated susceptibility to infection (prevalence), while age and specific deworming strategies had a decisive impact on the magnitude of the egg counts (intensity). This pattern suggests that epidemiological control should be multifaceted: measures aimed at reducing prevalence (such as improving BCS and selecting adapted species) should be combined with strategies focused on reducing parasitic load in high-risk groups, notably young animals, to mitigate environmental contamination.

The robustness of the evidence presented in this study is supported by the extensive sampling and the rigor of the statistical modeling employed. Although the cross-sectional design restricts the establishment of definitive causal links, the consistency of the identified multivariate associations provides a solid epidemiological profile of helminthiases in the region.

Despite the intrinsic limitations of cross-sectional design regarding causality, the reliability of the associations is ensured by the rigor of multivariate statistical modeling. Although the vast territorial extent and the absence of an updated animal census imposed a convenience sampling, which could suggest a selection bias, this condition was mitigated by the significant sample size and the statistical control of confounding variables. Thus, the multivariate adjustment ensured that the factors identified as significant operate independently of local variations or management practices, consolidating a representative and solid epidemiological profile for the Brazilian semi-arid region.

Conclusion

In conclusion, this study shows that the dynamics of helminth infections in small ruminants in a tropical semi-arid region of Brazil are governed by distinct determinants of susceptibility and parasitic load. Control strategies should be multifactorial, prioritizing the protection of the goat species and the rigorous sanitary management of young animals, identified here as the main amplifiers of environmental contamination. Crucially, the results highlight the ineffectiveness of frequent treatment regimes (quarterly), reinforcing the urgent need to replace fixed schedules with strategic or selective deworming, associated with improved nutritional support, to preserve the efficacy of the drugs and ensure the sustainability of production.

Declarations

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Declaration of conflicts of interest

The authors declare that there are no conflicts of interest.

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Author Contributions

All authors contributed to the study conception and design. **Mauricio dos Santos Conceição**: Conceptualization, Writing - Original Draft, Investigation, Data curation, Formal analysis; **Caliene Andrade Melo-Silva**: Conceptualization, Writing - Original Draft, Data curation, Formal analysis; **Lorena Braga de Souza:** Conceptualization, Methodology, Investigation; **Taiane Nogueira dos Santos**: Conceptualization, Methodology, Investigation; **Luanna Santos de Almeida e Santos**: Conceptualization, Methodology, Investigation; **Hélen Larissa da Cruz Oliveira**: Conceptualization, Methodology, Investigation; **Shaiane Ramos Campos**: Conceptualization, Methodology, Investigation; **Luana dos Santos Aquino**: Conceptualization, Methodology, Investigation; **Rosângela Soares Uzêda**: Conceptualization, Formal analysis, Validation, Writing - Review & Editing; **Jairo Torres Magalhães-Junior**: Project administration, Resources, Methodology, Supervision, Funding acquisition, Writing - Review & Editing.

Ethical Statements

This study was approved by the Animal Use Ethics Committee (CEUA), no. 0012-2023, and the Research Ethics Committee (CEP), CAAE 6.447.122, both linked to the *Universidade Federal do Oeste da Bahia*.

Data availability

The data used in this study are available upon request. The authors are committed to providing full access to the relevant data for interested researchers to promote transparency and reproducibility of the results.

Consent to participate

Not applicable

Use of artificial intelligence

The authors declare the assistance of artificial intelligence tools for the grammatical review, and translation of this manuscript.

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Tables

Tables are available in the Supplementary Files section.

Figures

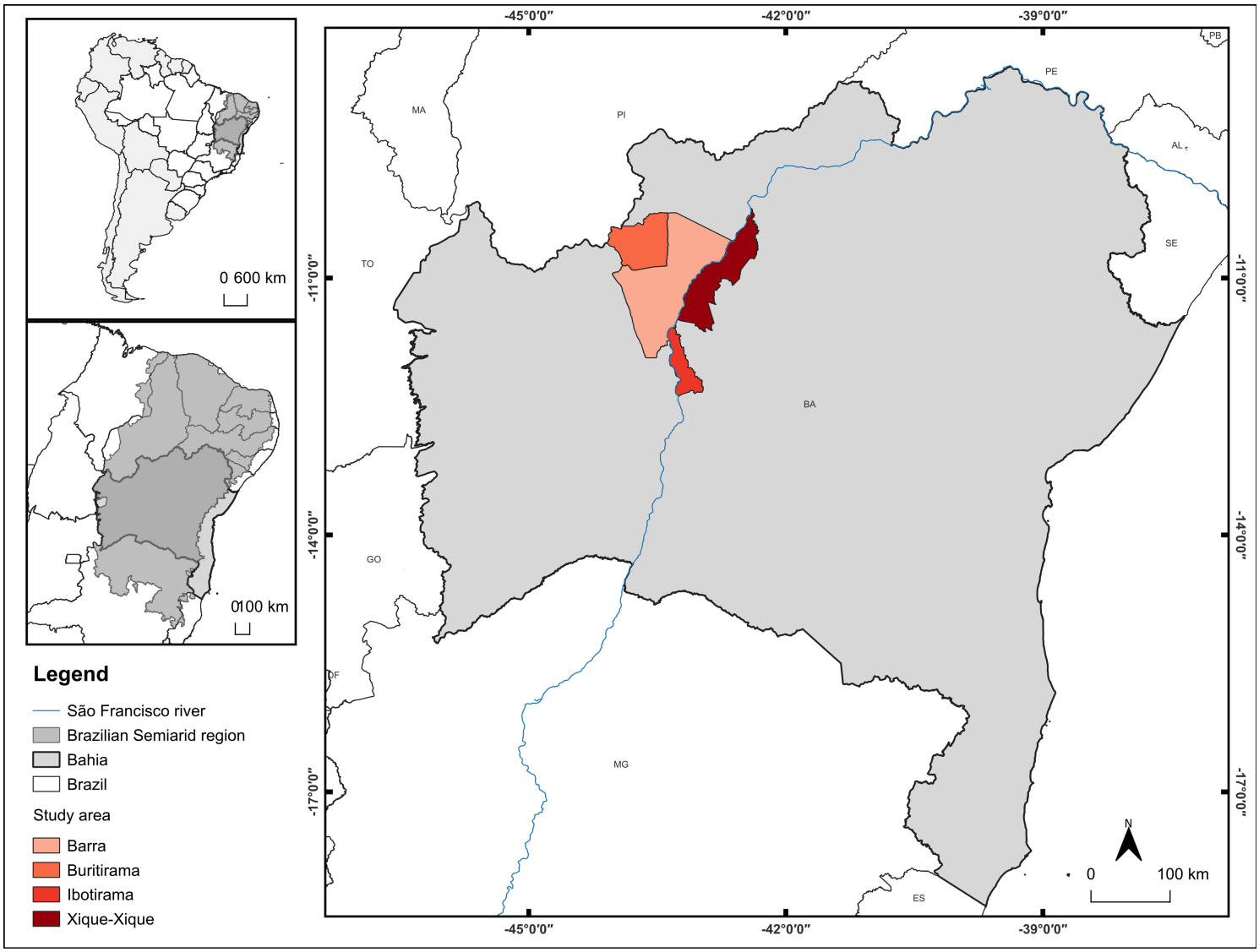


Figure 1

Geographic location of the study area in the semi-arid region of northeastern Brazil. Sampling was conducted in four municipalities in the state of Bahia (Barra, Buritirama, Ibotirama, and Xique-Xique),

highlighted in shades of red.

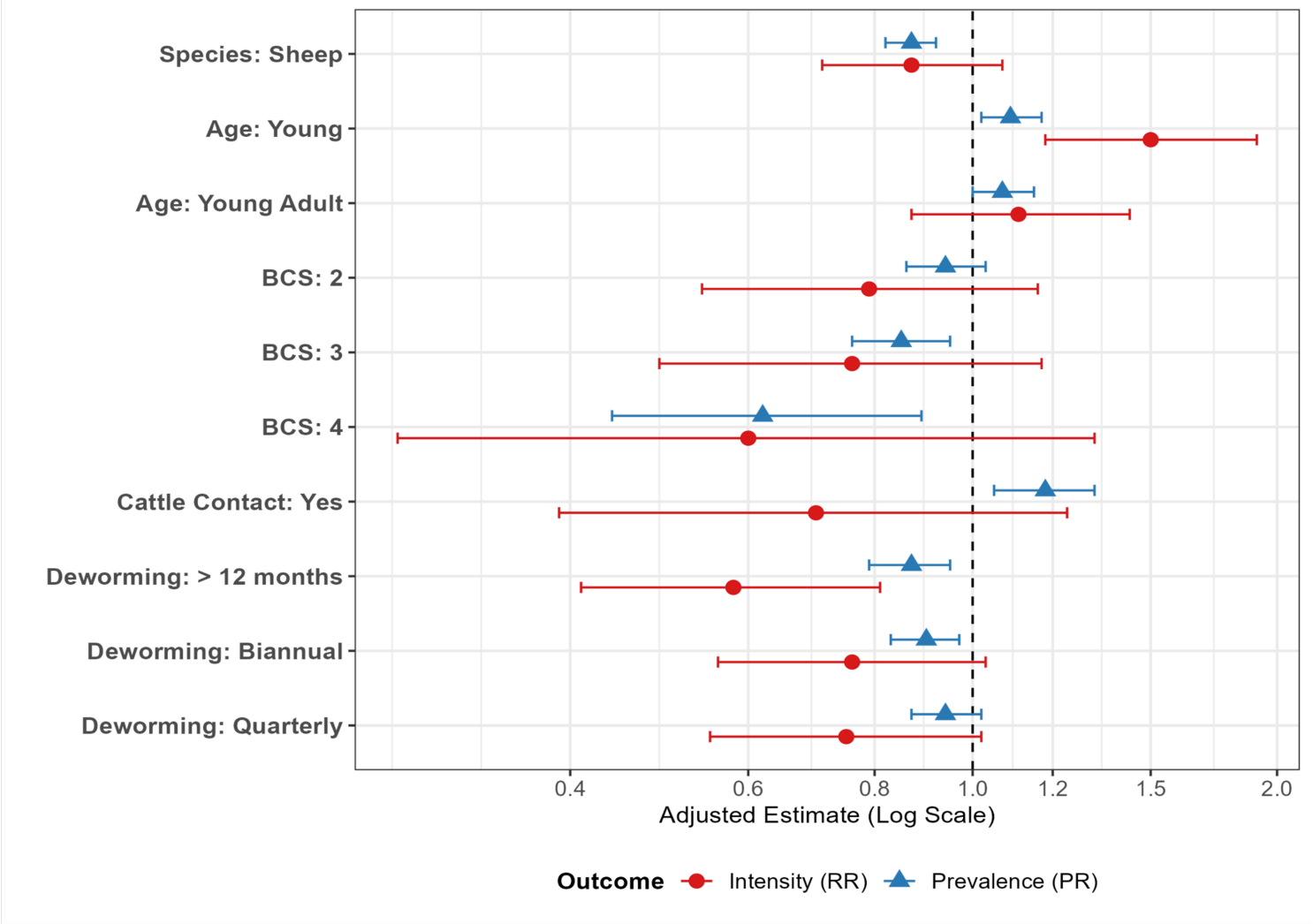


Figure 2

Forest plot of factors associated with the dynamics of gastrointestinal helminth infection in tropical semi-arid region. The estimates represent the Prevalence Ratios (PR; blue triangles) calculated via Poisson Regression with robust variance and the Rate Ratios (RR; red circles) calculated via Negative Binomial Regression. The horizontal lines indicate the 95% Confidence Intervals (CI), and the dashed vertical line indicates nullity (value 1.0). Values to the right of the null line indicate higher risk or an increase in egg counts (EPG), while values to the left indicate protection or reduction. The associations were calculated by comparing the exposed categories with their respective reference groups (denominators). Species: Sheep compared to Goats (Reference). Age: Young and Young Adults compared to Adults (Reference). BCS (Body Condition Score): Scores 2, 3, and 4 compared to Score 1 (Reference). Contact with Cattle: Presence of contact (Yes) compared to absence (Reference). Deworming: Quarterly, biannual, and more than 12 months frequencies compared to the absence of treatment (Reference).

Supplementary Files

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- Tables.docx
- Supplementarymaterial.docx