Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Seroprevalence and risk factors for incidental leptospirosis in goats and sheep raised in a multispecies system in the Cerrado of Piauí, Brazil

Kassiele Barros Fernandes
UFPI: Universidade Federal do Piaui
Gustavo de Oliveira Alves Pinto
UFRPE: Universidade Federal Rural de Pernambuco
Eduarda Faria Raymundo
UFRPE: Universidade Federal Rural de Pernambuco
Márcia Paula Oliveira Farias
UFPI: Universidade Federal do Piaui
David Germano Gonçalves Schwarz
UFPI: Universidade Federal do Piaui
Fábio Sandro dos Santos
UDESC: Universidade do Estado de Santa Catarina
Rinaldo Aparecido Mota
rinaldo.mota@ufrpe.br
UFRPE: Universidade Federal Rural de Pernambuco https://orcid.org/0000-0002-2844-5509
Raylson Pereira de Oliveira
UFPI: Universidade Federal do Piaui

Research Article

Keywords: Leptospira spp., Icterohaemorrhagiae, Small Ruminants, Microscopic Agglutination Test

Posted Date: June 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9918555/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Abstract

Leptospirosis is an important zoonosis that can affect the productivity of small-ruminant herds. This study aimed to determine the seroprevalence of antibodies against spp. and investigate associated risk factors in goats and sheep raised in a multispecies production system in the Cerrado region of Piauí State, northeastern Brazil. A total of 287 animals (144 goats and 143 sheep) from nine farms were evaluated. Serum samples were tested using the Microscopic Agglutination Test (MAT) with a panel of 32 spp. serovars. The overall seroprevalence was 29.96% (86/287; 95% CI: 24.7–35.3). Seroprevalence was 31.25% (45/144; 95% CI: 23.7–38.8) in goats and 28.67% (41/143; 95% CI: 21.3–36.1) in sheep. The predominant serogroup in goats was Icterohaemorrhagiae (63.6%), whereas Bataviae (28.6%) and Louisiana (28.6%) were the most frequent serogroups in sheep. In the multivariable analysis, the implementation of quarantine measures was independently associated with seropositivity (OR = 2.11; 95% CI: 1.26–3.52; p = 0.004). These findings demonstrate the widespread circulation of spp. among small ruminants in the Cerrado region of Piauí State and highlight the need for further epidemiological and molecular investigations to support the development of effective prevention and control strategies.

1. Introduction

Leptospira spp. are spirochetes belonging to the family *Leptospira*ceae and are the etiological agents of leptospirosis, a widespread zoonotic disease affecting both humans and animals, particularly in tropical and subtropical regions. More than 250 pathogenic serovars and 24 pathogenic serogroups have currently been identified (Portela et al., 2024). Leptospirosis is considered an emerging infectious disease in humans, with a substantial increase in the number of reported cases and outbreaks in Southeast Asia and Latin America. Human infection most commonly occurs through occupational, recreational, or domestic exposure to the urine of infected animals, either by direct contact or indirectly through contaminated water or soil (Hajikolaei et al., 2022).

Leptospira spp. may be shed in the urine of infected sheep and goats, as occurs in other animal species, and transmitted through direct or indirect contact with infected animals or contaminated environments. Recent studies have reported that goats may play an important role in the epidemiology of leptospirosis, acting as asymptomatic carriers and shedders of *Leptospira* spp. (Hajikolaei et al., 2022). Furthermore, although considered an incidental pathogen in goats, *Leptospira noguchii* was associated with an abortion outbreak in this species (Aymée et al., 2022).

Leptospirosis in small ruminants is generally asymptomatic. However, it may impair the productivity of sheep and goats. In addition, the disease may occur in either acute or chronic forms, depending on the infecting serovar. The acute form is associated with evident clinical signs, whereas chronic infection is usually subclinical, making diagnosis more difficult and favoring bacterial persistence within herds (Viana et al., 2021).

Clinical manifestations associated with *Leptospira* infection in these animals include fever, abortion, stillbirth, agalactia, and fetal death. Lambs and kids, particularly those with poor health status, are more susceptible to infection and may develop fever, hemoglobinuria, and jaundice, which can ultimately result in death (Hajikolaei et al., 2007; Constable et al., 2017).

Despite the recognized importance of leptospirosis in small ruminants, information regarding its occurrence and associated risk factors in multispecies production systems in the Cerrado region of Piauí State remains limited.

Therefore, this study aimed to determine the seroprevalence of antibodies against *Leptospira* spp. and investigate associated risk factors associated with infection in goats and sheep raised in a multispecies production system in the Cerrado region of Piauí State, northeastern Brazil.

2. Materials and Methods

2.1. Study area and sampling

Rural properties engaged in goat and sheep farming were selected and evaluated in four municipalities of the Chapada das Mangabeiras region (Bom Jesus, Redenção do Gurguéia, Monte Alegre, and Santa Luz), located in the Cerrado biome of Piauí State, northeastern Brazil (Fig. 1).

The sample size was calculated using the formula for simple random sampling in prevalence studies (Thrusfield, 2007). An expected prevalence of 50% was adopted to maximize the sample size, considering a desired absolute precision of 6% and a 95% confidence level (Z = 1.96). The minimum required sample size was calculated using the following formula:

$$n = \frac{Z^2 . P(1 - P)}{d^2}$$

where n is the required sample size, Z is the value of the standard normal distribution corresponding to the desired confidence level (1.96 for 95% confidence), P is the expected prevalence, and d is the desired absolute precision.

Based on these parameters, a total of 287 animals (144 goats and 143 sheep) from nine farms located in four municipalities were sampled. The inclusion criteria were the co-rearing of goats and sheep and the absence of vaccination against leptospirosis. Farms were selected by convenience sampling based on their eligibility for maintaining a multispecies production system. The distribution of sampled animals by municipality is presented in Table 1.

Table 1
Distribution of goats and sheep sampled on farms located in municipalities of the Cerrado region of Piauí State, Brazil.

Municipality	Farm	Goats (n)	Sheep (n)	Total (n)	Total (%)
Bom Jesus	P1	10	10	20	6.97
	P2	19	16	35	12.20
	P3	19	30	49	17.07
	P4	14	19	33	11.50
Redenção do Gurgueia	P5	4	5	9	3.14
	P6	15	25	40	13.94
Monte Alegre	P7	25	11	36	12.54
Santa Luz	P8	18	11	29	10.10
	P9	20	16	36	12.54
Total		**144**	**143**	**287**	**100**

2.2. Biological sample collection

Blood samples were collected by jugular venipuncture and placed into vacuum tubes without anticoagulant, which were properly identified. During transportation, the samples were maintained under refrigeration in labeled insulated containers. Subsequently, the samples were centrifuged at 10,000 × g for 5 min to obtain serum. The serum samples were then transferred to labeled microtubes and stored at − 20°C until serological analysis.

2.3. Microscopic Agglutination Test

The Microscopic Agglutination Test (MAT) was performed for the serological diagnosis of leptospirosis according to WOAH recommendations (WOAH, 2024). A panel of 32 *Leptospira* spp. serovars was used as antigens: Australis, Bratislava, Autumnalis, Butembo, Castellonis, Celledoni, Bataviae, Canicola, Djasiman, Guaricurus, Whitcombi, Cynopteri, Grippotyphosa, Hebdomadis, Copenhageni, Icterohaemorrhagiae, Javanica, Louisiana, Mini, Panama, RGA, Pomona, Pyrogenes, Hardjo (Hardjobovis), Hardjo (Hardjoprajitno), Wolffi, Shermani, Tarassovi, Verdun, Andamana, Patoc, and Sentot.

Serum samples were initially screened at a dilution of 1:100, the cutoff recommended by OMSA. Samples showing 50% or greater agglutination were considered positive and subsequently titrated by testing a series of two-fold serial dilutions. For samples reactive to more than one serogroup, the serogroup with the highest antibody titer was considered the presumptive infecting serogroup. Samples presenting identical titers for more than one serogroup were excluded from the analysis of the most frequent serogroup but were included in the overall prevalence calculation (Silva et al., 2021).

2.4. Risk factor analysis

Epidemiological questionnaires were administered on all farms to assess potential risk factors associated with leptospirosis. Information was collected regarding the history of reproductive disorders, vaccination protocols

against other pathogens, animal access to flooded areas, implementation of quarantine measures, and production system characteristics.

2.5. Statistical analysis

Descriptive statistical analysis was performed to calculate the absolute and relative frequencies of the serological results. To identify risk factors associated with the presence of anti-*Leptospira* spp. antibodies, a univariate analysis was initially conducted using Pearson's chi-square test or Fisher's exact test, as appropriate. Variables with p-values < 0.20 were considered eligible for inclusion in the logistic regression model. Serological status was used as the dependent variable, and the results were expressed as odds ratios (OR) with 95% confidence intervals (95% CI). The proportion of animals seropositive by MAT was calculated with 95% confidence intervals using the Wilson method. All statistical analyses were performed using Epi Info™ software, version 7.2.3.0.

3. Results

3.1. Seroprevalence and distribution of anti-*Leptospira* spp. serogroups

The overall seroprevalence, regardless of species, was 29.96% (86/287; 95% CI: 24.7–35.3). Among goats, 31.25% (45/144; 95% CI: 23.7–38.8) of the animals were seropositive, with the highest seroprevalence observed on Farm 7 (76.0%; 19/25) and Farm 3 (68.4%; 13/19). Among sheep, 28.67% (41/143; 95% CI: 21.3–36.1) were seropositive, with the highest frequencies observed on Farm 3 (43.33%; 13/30) and Farm 5 (40.0%; 2/5). The results for the remaining farms are presented in figure 2.

After excluding seropositive animals that showed cross-reactions with identical antibody titers against multiple serogroups, 33 goats remained for serogroup analysis. The most frequent serogroups were Icterohaemorrhagiae (63.6%; 21/33) and Semaranga (12.1%; 4/33). Among sheep, 28 animals remained after applying the same criterion, with Bataviae (28.6%; 8/28) and Louisiana (28.6%; 8/28) being the predominant serogroups (Table 2).

Table 2. Distribution of *Leptospira* spp. serogroups identified by the Microscopic Agglutination Test (MAT) in goats (n = 144) and sheep (n = 143) raised in a multispecies production system in Piauí State, Brazil.

Serogroup	N positive samples		Reactive (%)		Total	
	Goats	Sheep	Goats	Sheep	Goats (144)	Sheep (143)
Autumnalis	-	2	-	7,1%	-	1,4%
Bataviae	2	8	6,1%	28,6%	1,4%	5,6%
Celledoni	-	3	-	10,7%	-	2,1%
Hebdomadis	-	1	-	3,6%	-	0,7%
Icterohaemorrhagiae	21	2	63,6%	7,1%	14,6%	1,4%
Javanica	-	1	-	3,6%	-	0,7%
Louisiana	2	8	6,1%	28,6%	1,4%	5,6%
Semaranga	4	3	12,1%	10,7%	2,7%	2,1%
Sejroe	3	-	9,1%	-	2,1%	-
Pyrogenes	1	-	3,0%	-	0,7%	-
Total	33	28	100	100	22,9%	19,6 %

Regarding antibody titers, of the 287 samples analyzed by MAT, 61 showed serological reactions with antibody titers equal to or greater than 1:100 and did not present cross-reactions. Antibody titers ranged from 1:100 to 1:800. The highest titer (1:800) was observed mainly for the Bataviae serogroup, detected in two goats and four sheep, followed by the Semaranga serogroup, detected in one goat and one sheep (Table 3).

Table 3. Distribution of anti-*Leptospira* spp. antibody titers according to serogroup in seropositive small ruminants from the Cerrado region of Piauí State, Brazil.

Serogroup	Antibody titers								
	100		200		400		800		Total (%)
	Goats	Sheep	Goats	Sheep	Goats	Sheep	Goats	Sheep	
Autumnalis	-	1	-	-	-	1	-	-	2 (2,32)
Bataviae	-	1	-	2	-	1	2	4	10 (11,62)
Celledoni	-	3	-	-	-	-	-	-	3 (3,49)
Hebdomadis	-	-	-	1	-	-	-	-	1 (1,16)
Icterohaemorrhagiae	17	1	4	1	-	-	-	-	23 (26,74)
Javanica	-	1	-	-	-	-	-	-	1 (1,16)
Louisiana	2	8	-	-	-	-	-	-	10 (11,62)
Pyrogenes	1	-	-	-	-	-	-	-	1 (1,16)
Semaranga	-	-	3	2	-	-	1	1	7 (8,13)
Sejroe	3	-	-	-	-	-	-	-	3 (3,49)

3.2. Epidemiological questionnaire

Regarding the variables assessed through the epidemiological questionnaire, a history of reproductive disorders was reported on 5 of the 9 farms (55.56%). Vaccination protocols against other pathogens were adopted on 3 farms (33.33%). Animals had access to flooded areas on 6 farms (66.67%), while quarantine measures for newly introduced animals were implemented on 3 farms (33.33%). Extensive production systems were observed on all farms evaluated (9/9; 100%).

3.3. Statistical analysis

In the univariate analysis, a significant association was observed between *Leptospira* spp. seropositivity and the implementation of quarantine measures ($p = 0.004$). The variables history of reproductive disorders, vaccination, and access to flooded areas were not significantly associated with seropositivity ($p > 0.05$).

Variables with p-values ≤ 0.20 in the univariate analysis were included in the multivariable logistic regression model. In the final model, the implementation of quarantine measures remained independently associated with seropositivity (OR = 2.11, 95% CI: 1.26–3.52; $p = 0.004$). The results of the statistical analysis are presented in Table 4.

Table 4. Association between epidemiological variables and seropositivity to *Leptospira* spp. in small ruminants from the Cerrado region of Piauí State, Brazil.

Variable	MAT				Univariate analysis (*p*-value)	Logistic Regression	
	Reactive		Non-reactive			OR (IC95%)	p-value
	A.F.	R.F (%)	A.F.	R.F. (%)			
History of reproductive disorders							
Yes	35	26.3	98	73.7	0.26	-	-
No	51	33.1	103	66.9			
Vaccination							
Yes	22	25.0	66	75.0	0.22	-	-
No	64	32.2	135	67.8			
Access to flooded áreas							
Yes	62	27.9	160	72.1	0.16	-	-
No	24	36.9	41	63.1			
Routine diagnostic testing							
Yes	7	21.2	26	78.8	0.24	-	-
No	79	31.1	175	68.9			
Quarantine of newly introduced animals							
Yes	46	39.3	71	60.7	0.004	2,11 (1.26-3.52)	0.004
No	40	23.5	130	76.5			

4. Discussion

To the best of our knowledge, this is the first study to investigate the seroprevalence of *Leptospira* spp. in small ruminants from the Cerrado region of Piauí State, northeastern Brazil. The overall seroprevalence was 29.96% (86/287), with similar frequencies observed in goats (31.25%) and sheep (28.67%). In addition, at least one seropositive animal was identified on every farm evaluated, indicating the widespread circulation of *Leptospira* spp. among small ruminants in the study area. These findings highlight leptospirosis as an important health concern for goat and sheep production in Piauí State.

Studies conducted in different regions of Piauí State have reported varying seroprevalence rates. In the Teresina microregion, seroprevalence rates of 40.5% in sheep and 34.6% in goats were reported, which are higher than those observed in the present study (Campos et al., 2017). In contrast, Santos et al. (2017) reported lower seroprevalence rates in the Serra das Confusões National Park, also located in Piauí State. These variations may be partially explained by climatic and environmental differences among the studied regions, since the occurrence

of leptospirosis is strongly influenced by factors such as temperature, humidity, and rainfall patterns (Mwachui et al., 2015).

Agglutinating antibodies against different *Leptospira* spp. serogroups were detected, with Icterohaemorrhagiae predominating in goats (63.6%) and Bataviae (28.6%) and Louisiana (28.6%) predominating in sheep. A similar predominance of Bataviae in sheep has previously been reported in Piauí State (Campos et al., 2017). In contrast, more recent studies conducted in northeastern Brazil identified Autumnalis as the most frequent serogroup in both sheep and goats (Silva et al., 2021; Viana et al., 2022). These differences likely reflect regional epidemiological and environmental characteristics that may influence the maintenance and transmission dynamics of distinct *Leptospira* spp. serogroups.

The Icterohaemorrhagiae serogroup, identified as the most prevalent in the present study, has been associated with outbreaks of acute leptospirosis in small ruminants. In addition, this serogroup is considered to be adapted to rodents, which act as important reservoirs of *Leptospira* spp. and can shed the bacteria through their urine (Ellis, 2015). Since all farms evaluated in this study employed extensive production systems, contact between animals and rodents cannot be ruled out and may have contributed to the dissemination of the pathogen within the herds.

It is also important to note that all farms operated under a multispecies production system, in which goats and sheep shared the same environment. This management practice may facilitate the maintenance and transmission of *Leptospira* spp. among different animal species, increasing opportunities for exposure to and spread of the pathogen (Guzman-Barragan et al., 2021).

The predominance of the Icterohaemorrhagiae serogroup observed in the present study corroborates previous findings in small ruminants from other regions of Brazil (Alves et al., 2017; Viana et al., 2021). In Espírito Santo State, southeastern Brazil, Icterohaemorrhagiae was reported as the most frequent serovar in sheep (Cortizo et al., 2015). The authors considered this finding unexpected, as small ruminants are more commonly associated with the Hardjo serovar. In contrast, infections caused by the Icterohaemorrhagiae serogroup, as well as other incidental serogroups, have frequently been associated with leptospirosis outbreaks in small ruminants (Martins et al., 2012; Fang et al., 2014).

Leptospirosis is recognized as an important reproductive disease in livestock; however, its role in small-ruminant reproductive disorders remains incompletely understood. Nevertheless, the presence of *Leptospira* spp. DNA has been confirmed in the reproductive tract of sheep (Raymundo et al., 2026) and goats (Soares et al., 2021; Aymée et al., 2022), supporting the potential involvement of this pathogen in reproductive infections in these species.

In the present study, no significant association was observed between a history of reproductive disorders and seropositivity to *Leptospira* spp. However, this finding does not exclude the potential impact of leptospirosis on reproductive performance. Similar studies conducted in other regions of Brazil have highlighted the importance of leptospirosis as a potential cause of reproductive and productive losses in small ruminants (Cortizo et al., 2015).

The positive association observed between the implementation of quarantine measures and *Leptospira* spp. seropositivity should be interpreted with caution. Quarantine is a widely recommended biosecurity practice aimed at reducing the introduction of infectious agents into animal populations. Therefore, the observed association may reflect specific management characteristics of the evaluated farms, reverse causality, or

limitations inherent to the observational design of the present study rather than a direct effect of quarantine on infection risk.

Finally, only the MAT was used in the present investigation, which represents a limitation because serological results alone do not allow the identification of circulating *Leptospira* species or confirmation of active infection. Nevertheless, our findings reinforce the need for molecular studies in the region to identify the *Leptospira* species circulating among small-ruminant herds in Piauí State and to improve the understanding of the epidemiology of leptospirosis in this production system.

The results of this study demonstrate that *Leptospira* spp. infection is an important health challenge for goat and sheep production in the Cerrado region of Piauí State and may represent a potential public health concern. The high seroprevalence observed, together with the detection of different serogroups, particularly Icterohaemorrhagiae, Louisiana, and Bataviae, highlights the widespread circulation of *Leptospira* spp. among small ruminants in the region. These findings contribute to a better understanding of the epidemiology of leptospirosis in the Brazilian Cerrado and provide valuable information for the development of preventive and control measures aimed at reducing the impact of this infection on animal production and public health.

Statements and Declarations

6.1. Funding

This study was financially supported by the Instituto Nacional de Ciência e Tecnologia - Rede de Estudos Avançados em Doenças Negligenciadas no Contexto de Uma Só Saúde no Nordeste Brasileiro (INCT/NegliOne), Grant/Award Number #408531/2024-0.

6.2. Conflict of Interest

The authors declare that they have no conflicts of interest related to this study.

6.3. Ethical approval

This study was approved by the Animal Ethics Committee (CEUA) of the Federal University of Piauí (UFPI), Professor Cinobelina Elvas Campus (CPCE), Bom Jesus, Piauí, Brazil, under protocol number CEUA-BJ 007/2025.

6.4. Data availability

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

References

1. Alves JRA, Lima GMS, Silva JD, Costa DF, Santos FA, Higino SSS, Azevedo SS, Alves CJ (2017). Epidemiological characterization and risk factors associated with leptospirosis and brucellosis in small ruminants sold at animal fair in the Sertão Region of Pernambuco State, a semiarid Region of Northeastern Brazil. Semina Cienc Agrar 38(4), 1933–1946. https://doi.org/10.5433/1679-0359.2017v38n4p1933
2. Aymée L, Azevedo MIND, Melo JDSL, Balaro MFA, Martins GMS, Consalter A, Leite JDS, Carvalho CFA, Lilenbaum W (2022). *Leptospira noguchii* associated to reproductive disease in ruminants. Transboundary

and Emerg Dis 69, 3103–3108. https://doi.org/10.1111/tbed.14377

3. Campos ÂP, Miranda DFH, Rodrigues HWS, Lustosa MDSC, Martins GHC, Mineiro ALBB, Silva SMMS (2017). Seroprevalence and risk factors for leptospirosis in cattle, sheep, and goats at consorted rearing from the State of Piauí, northeastern Brazil. Trop Anim Health Prod 49, 899–907. https://doi.org/10.1007/s11250-017-1255-2
4. Constable PD, Hinchcliff KW, Done SH, Grünberg W (2017). Veterinary Medicine: A Textbook of the Diseases of Cattle, Horses, Sheep, Pigs and Goats. 11th ed. Elsevier, St. Louis
5. Cortizo P, Loureiro AP, Martins G, Rodrigues PR, Faria BP, Lilenbaum W, Deminicis BB (2015). Risk factors to incidental leptospirosis and its role on the reproduction of ewes and goats of Espírito Santo State, Brazil. Tropical Anim Health Prod 47, 231–235. https://doi.org/10.1007/s11250-014-0684-4
6. Ellis WA (2015). Animal leptospirosis. Curr Top Microbiol Immunol 387, 99–137. https://doi.org/10.1007/978-3-662-45059-8_6
7. Guzman-Barragan BL, Martínez-Rodríguez LC, Tobón-Torreglosa JC, Tafur-Gómez GA, (2022). Seroprevalence and risk factors for *Leptospira* spp. in small ruminants of semi-arid zone in northeastern Colombia. Tropical Anim Health Prod 54, 10. https://doi.org/10.1007/s11250-021-03019-0
8. Haji Hajikolaei MR, Ghorbanpour M, Keshavarzi-Yangabadi M, Abdollapour GR (2007). Seroprevalence of *Leptospira* infection in goats of Ahvaz. Iran J Vet Res 8(4), 93–96
9. Haji Hajikolaei MR, Rezaei S, Mashhadi ARG, Ghorbanpoor M (2022). The role of small ruminants in the epidemiology of leptospirosis. Scientific Reports 12, 2148. https://doi.org/10.1038/s41598-022-05767-x
10. Martins G, Brandão FZ, Hamond C, Medeiros MA, Lilenbaum W (2012). Diagnosis and control of an outbreak of leptospirosis in goats with reproductive failure. Vet J 193(2), 600–601. https://doi.org/10.1016/j.tvjl.2012.01.016
11. Mwachui MA, Crump L, Hartskeerl R, Zinsstag J, Hattendorf J (2015). Environmental and behavioural determinants of leptospirosis transmission: A systematic review. PLoS Negl Trop Dis 9(9), e0003843. https://doi.org/10.1371/journal.pntd.0003843
12. Raymundo EF, Pinto GOA, Silva GG, Santos AS, Pessoa RD, Correia DS, Batista AM, Samico-Fernandes EFT, Mota RA (2026). Molecular detection of *Leptospira* spp. in ovarian structures of naturally infected ruminants and its potential impact on reproductive function. Comp Immunol, Microbiol Infect Dis127, 102465. https://doi.org/10.1016/j.cimid.2026.102465
13. Santos LF, Guimarães MF, Souza GO, Silva IWG, Santos JR, Azevedo SS, Horta MC (2017). Seroepidemiological survey on *Leptospira* spp. infection in wild and domestic mammals in two distinct areas of the semi-arid region of northeastern Brazil. Trop Anim Health Prod 49, 1715–1722. https://doi.org/10.1007/s11250-017-1382-9
14. Silva JD, Viana MP, Calado LGLP, Lima AMC, Alves FSF, Pinheiro RR, Costa DF, Silva GCP, Azevedo SS, Alves CJ (2021). Cross-sectional survey for sheep leptospirosis in the northeast region of Brazil. Prev Vet Med 197, 105525. https://doi.org/10.1016/j.prevetmed.2021.105525
15. Soares RR, Barnabé NNC, Nogueira DB, Silva LSC, Araújo Júnior JP, Malossi CD, Ullmann LS, Costa DF, Silva MLCR, Higino SSS, Azevedo SS, Alves CJ (2021). Serological, molecular and bacteriological approaches for detecting *Leptospira* sp. carrier rams maintained in semiarid conditions. Acta Trop 213, 105759. https://doi.org/10.1016/j.actatropica.2020.105759
16. Thrusfield M (2007). Veterinary Epidemiology. 3rd ed. Blackwell Science Ltd., Oxford

17. Viana MP, Silva JD, Lima AMC, Alves FSF, Pinheiro RR, Calado LGLP, Costa DF, Higino SSS, Azevedo SS, Alves CJ (2021). Epidemiological survey for goat leptospirosis in two distinct biomes in Northeastern Brazil. Research, Society and Development 10(2), e5610212242. https://doi.org/10.33448/rsd-v10i2.12242
18. Viana MP, Silva JD, Lima AMC, Alves FSF, Pinheiro RR, Costa DF, Silva GCP, Calado LGLP, Azevedo SS, Alves CJ (2022). Epidemiological and geospatial characterization of goat leptospirosis in Northeast region of Brazil. Small Rumin Res 206, 106589. https://doi.org/10.1016/j.smallrumres.2021.106589
19. World Organisation for Animal Health (WOAH) (2024). Leptospirosis. In: Manual of Diagnostic Tests and Vaccines for Terrestrial Animals. 13th ed. WOAH, Paris, Chapter 3.1.12, pp. 1–14

Figures

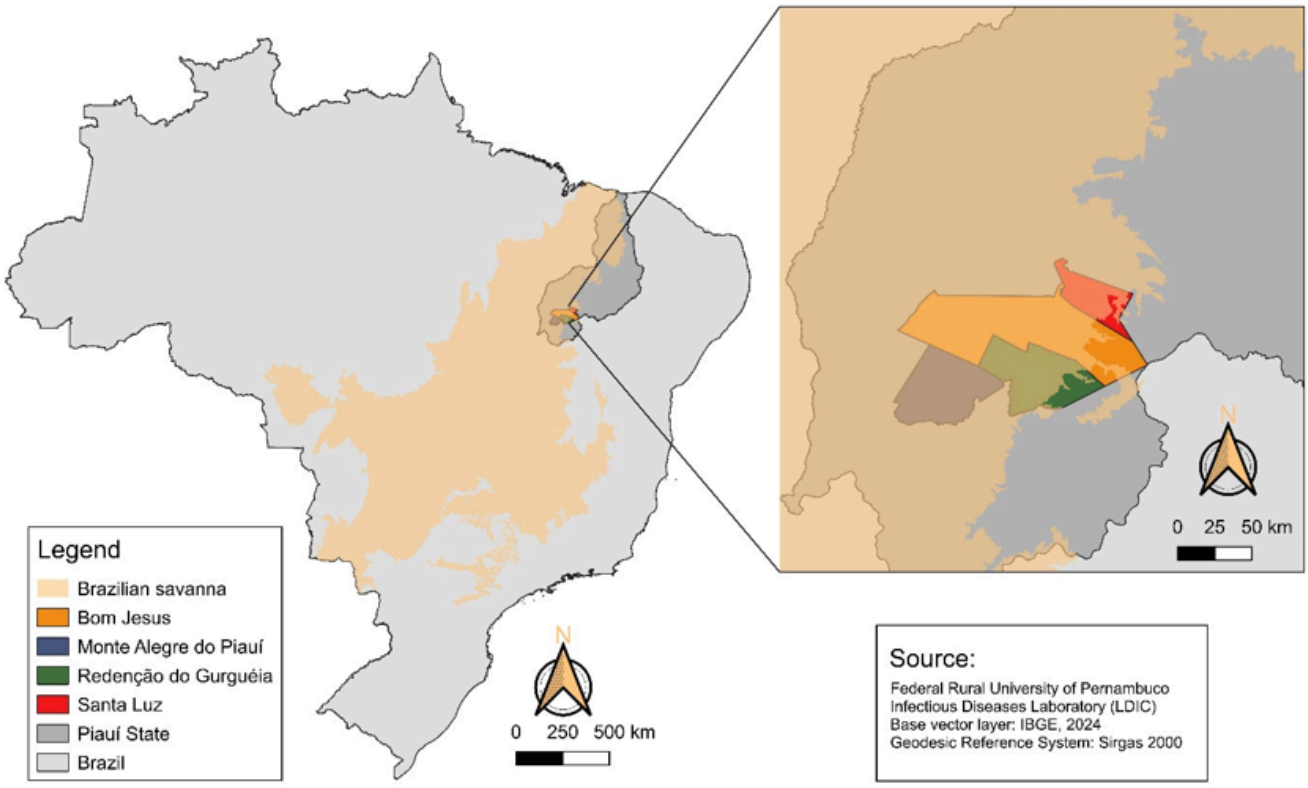


Figure 1

Geographic distribution of the municipalities included in the study area, highlighting the Cerrado biome.

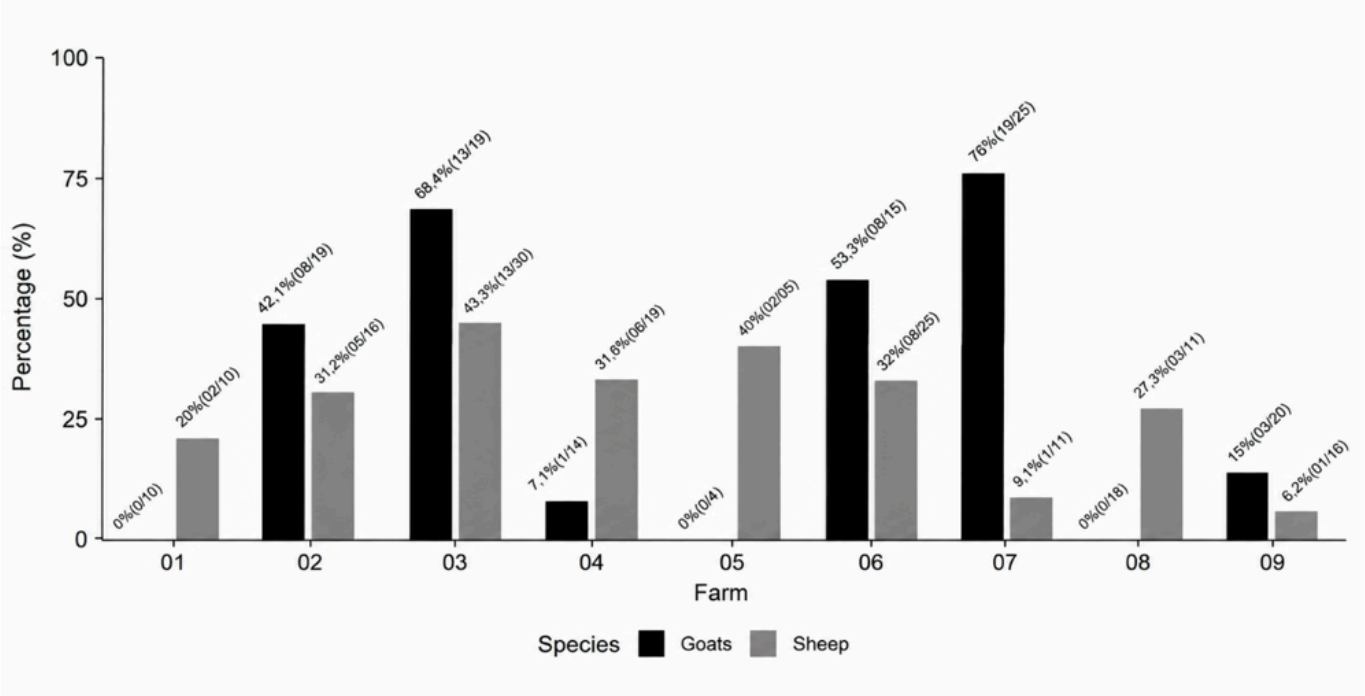


Figure 2

Seroprevalence of anti-*Leptospira* spp. antibodies in goats and sheep according to farm in the Cerrado region of Piauí State, Brazil.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Graphicalabstract.png