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Original Article
Livestock Diseases

Prevalence of bovine tuberculosis: A systematic review and meta-analysis[1]

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ABSTRACT.- Bezerra Neto P.S., Medeiros G.B., Morais D.A., Limeira C.H., Higino S.S.S., Araújo F.R., Azevedo S.S. & Alves C.J. 2024. **Prevalence of bovine tuberculosis: A systematic review and meta-analysis.** *Pesquisa Veterinária Brasileira 44:e07390, 2024.* Departamento de Medicina Veterinária, Universidade Federal de Campina Grande, Av. Universitária s/n, Santa Cecília, Patos, PB 58708-110, Brazil. E-mail: clebertja@uol.com.br

Bovine tuberculosis is a zoonotic disease with global distribution. This study aimed to describe its prevalence in cattle through a systematic review and meta-analysis of studies conducted all around the world. The research consisted of a systematic literature review following the precepts of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology. Cross-sectional studies that described the prevalence of the disease using the diagnostic method through an intradermal test with bovine and avian purified protein derivative (PPD) were selected. Identifying articles was performed in the PubMed, ScienceDirect, Scopus, and Web of Science databases. Of the total number of studies found (n=1,839), 60 met all criteria and were included in this review. The overall prevalence was 3.27% (2.11–5.05%) for animals and 18.09% (11.20–27.90%) for herds. Analysis of risk factors for tuberculosis in cattle was found or performed in 50 studies. The heterogeneity identified among the works included was expected, given the differences in research design, year of publication, and the number of animals sampled. It is necessary to evaluate the insertion of new *ante mortem* diagnostic tests into control and eradication programs, which, combined with allergic tests, may identify the largest number of animals that presented an actual positive for the disease.

INDEX TERMS: *Mycobacterium bovis*, tuberculosis, prevalence, systematic review.

RESUMO.- [**Prevalência da tuberculose bovina: uma revisão sistemática e meta-análise.**] A tuberculose bovina é uma doença zoonótica com distribuição global. O objetivo do presente trabalho foi descrever a prevalência da enfermidade em bovinos através de uma revisão sistemática e meta-análise em estudos realizados no mundo. A pesquisa consistiu em uma revisão sistemática de literatura seguindo os preceitos da metodologia “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” (PRISMA). Estudos transversais que descreveram a prevalência da enfermidade utilizando o método de diagnóstico através da prova intradérmica com derivado proteico purificado (PPD) bovino e aviário foram selecionados. O processo de identificação dos artigos foi desenvolvido nas bases de dados PubMed, ScienceDirect, Scopus e Web of Science. Do total de estudos encontrados (n=1.839), 60 atenderam a todos os critérios e foram incluídos na presente revisão. A prevalência geral encontrada foi de 3,27% (2,11–5,05%) para animais e 18,09% (11,20–27,90%) para rebanhos. Análises de fatores de riscos para a tuberculose em bovinos foi encontrada ou realizada em 50 estudos. A heterogeneidade identificada entre os trabalhos incluídos nesta revisão era esperada tendo em vista as diferenças relacionadas aos desenhos de pesquisa, anos de publicação dos estudos e a quantidade de animais amostrados. É necessária a avaliação da introdução de novos testes de diagnóstico *ante-mortem* aos programas de controle e erradicação que, combinados com os testes alérgicos, possam identificar o maior número de animais verdadeiramente positivos para a enfermidade.

TERMOS DE INDEXAÇÃO: *Mycobacterium bovis*, tuberculose, prevalência, revisão sistemática.

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INTRODUCTION

Bovine tuberculosis (BTB) is a zoonotic disease that causes economic losses in cattle breeding and has direct impacts on public health in developed and developing countries. Caused by a member of the *Mycobacterium tuberculosis* complex, mainly *Mycobacterium bovis*, the microorganism adapts to cattle as a host but also causes the disease in other animal species, including some of the wild type (FAO et al. 2017).

Presenting worldwide distribution but with a significant reduction or elimination in developed countries (Kemal et al. 2019), bovine tuberculosis is on the list of notifiable diseases of the World Organization for Animal Health (WOAH). Intergovernmental organizations, as well as other entities, have adopted the One Health approach to discuss the challenges of the animal, human, and environmental health interface more comprehensively (Olea-Popelka et al. 2017).

In cattle, many cases are asymptomatic, making its control difficult. When present, clinical signs vary from cough and dyspnea in the respiratory form to diarrhea and constipation when the digestive system is involved (Dametto et al. 2020).

The delayed-type hypersensitivity skin test is the standard method for detecting the disease in cattle. It consists of measuring skin thickness, injecting tuberculin intradermally, and measuring any subsequent swelling at the injection site 72 hours later. The comparative cervical test (CCT), using bovine and avian tuberculin, has moderate to high sensitivity (68–95%) and high specificity (96–99%) (Ghebremariam et al. 2016), being important for differentiating between infection by *M. bovis* and environmental mycobacteria.

Outbreaks of the disease in cattle can generate large economic costs for society, as they can affect international trade of animals and animal products, generate productivity losses (e.g., reduced production of milk and meat, and reduced fertility), require costly measures due to restrictions in animal markets, trigger large control and eradication programs, and increase human health costs (Dejene et al. 2016).

In Brazil, for example, only 14 Federative Units conducted studies to characterize the epidemiological situation of the disease, finding levels of prevalence varying from 0.0009% to 1.6% (Bahiense et al. 2016, Belchior et al. 2016, Dias et al. 2016, Galvis et al. 2016, Guedes et al. 2016, Lima et al. 2016, Néspoli et al. 2016, Queiroz et al. 2016, Ribeiro et al. 2016, Rocha et al. 2016, Silva et al. 2016, Veloso et al. 2016, Vendrame et al. 2016, Ferreira Neto et al. 2020).

Research and surveys on the prevalence of bovine tuberculosis around the world are few and restricted to certain states or areas. The objective of this research was to describe the prevalence of bovine tuberculosis through a systematic review with meta-analysis in studies conducted all around the world.

MATERIALS AND METHODS

The research consisted of a systematic literature review following the precepts of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology (Moher et al. 2009). Cross-sectional studies that described the prevalence of the disease using the diagnostic method through the intradermal test with bovine and avian purified protein derivative (PPD) were selected. There were no restrictions on the year, language, or country where the work was conducted or published.

The types of publications included were complete and original articles published in indexed journals that addressed issues related to the following criteria: (I) prevalence of bovine tuberculosis and/or (II) diagnosis of the disease through the CCT test. Possible factors described in the studies associated with the *Mycobacterium bovis* infection were also analyzed. The exclusion criteria were: (I) literature reviews, research notes and editorials; (II) experimental tests; (III) diagnosis of the disease using a test other than the Comparative Cervical Test; and (IV) other types of publications that did not meet the inclusion criteria.

Following the establishment of the inclusion criteria, articles were identified on the PubMed, ScienceDirect, Scopus, and Web of Science databases. The following combination of English search terms was used: (bovine OR cattle) AND (tuberculosis OR *M. bovis*) AND (tuberculinization OR tuberculin) AND (prevalence). Citations of the studies identified, containing title and abstract, were saved in BibTex format and exported to a bibliographic manager (Mendeley®) for later selection. Data on risk factors were extracted from studies and included in the form of tag clouds. When possible and necessary, words with the same meaning were combined to present the same structure in different studies. The search was performed on August 18, 2023. Researchers P.S.B.N., D.A.M., and C.H.L. have read titles, abstracts, and full articles.

For the meta-analyses, we used the random effects model to estimate the combined prevalence of bovine tuberculosis at the individual and herd levels, using quantitative data (number of animals and herds tested and that tested positive) from the primary studies, dividing them into subgroups according to the continent where the research was conducted. The heterogeneity between studies was verified by Cochran's Q test and quantified by Higgins and Thompson's I^2 test. Visual analysis of the inverted funnel plot and the application of Egger's test were used to verify the presence of publication bias. The analyses were performed using the R statistical program, version 3.5.1 (R Core Team 2020), using the meta-statistical package (Balduzzi et al. 2019), and the wordcloud2 package was used to create the tag cloud (Lang & Chien 2018).

RESULTS

In Figure 1, we can observe the primary results found in the searched databases. Of the total number of studies found (n=1,839), 60 met all the criteria and were included in this review (Table 1). The overall prevalence found in the meta-analysis of the 60 studies was 3.27% (2.11–5.05%) for animals and 18.09% (11.20–27.90%) for herds, with high heterogeneity between studies in both situations. The articles included were published from 1993 to 2023.

The primary studies were divided into subgroups according to the continent where the research was conducted to identify possible causes of the heterogeneity found in the meta-analyses: Africa (n=39), South America (n=16), and Asia (n=5). On the African continent, Nigeria, Ethiopia, Ghana, Cameroon, Malawi, Niger, Tanzania, Eritrea, Egypt, Uganda, Mozambique, and Zambia published studies on the prevalence of bovine tuberculosis. In South America, studies were conducted in Brazil and Ecuador. In Asia, they occurred in Bangladesh, India, and Pakistan. Several works from other continents had their research excluded for not using the intradermal test with bovine and avian purified protein derivative (PPD) for diagnosing tuberculosis. In these studies, the diagnosis was performed through microbiological culture, polymerase

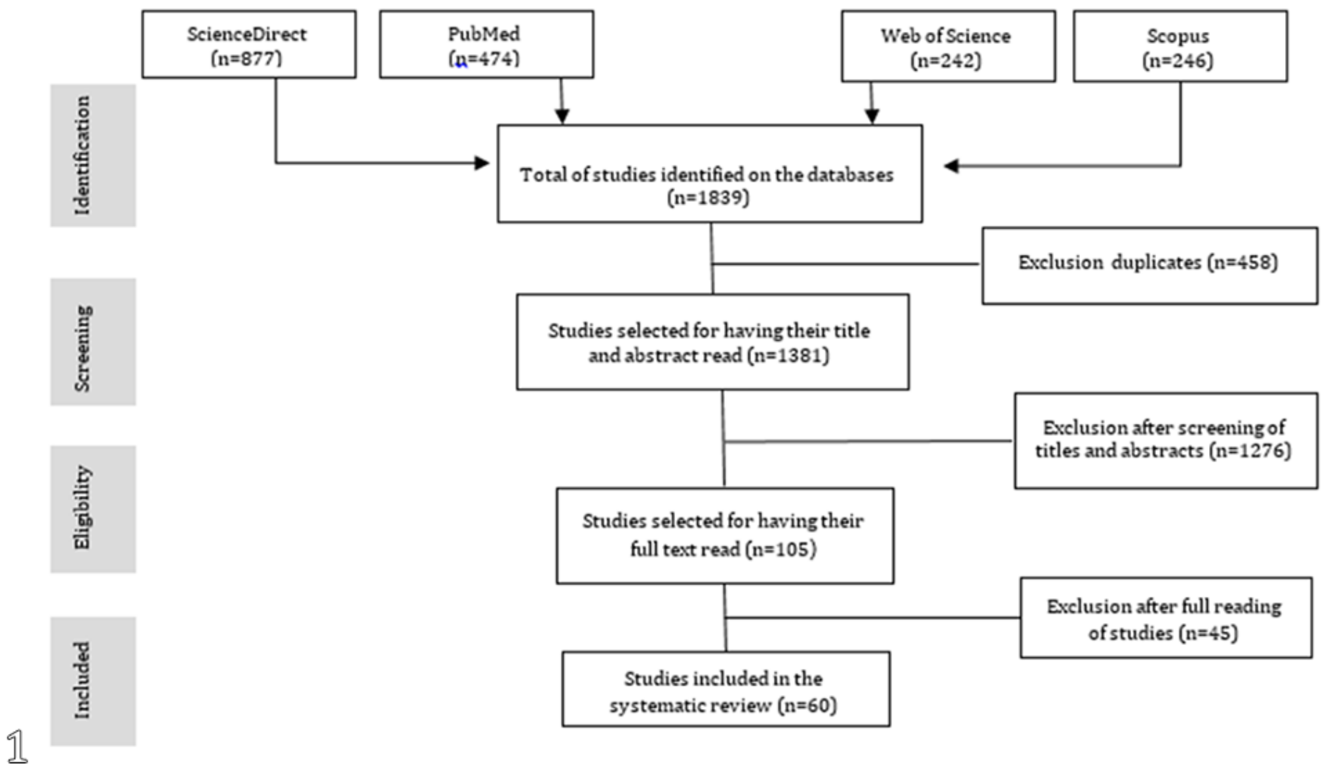

Fig.1. Flowchart of the search and selection process of primary studies included in the systematic review.

Table 1. Summary of the main characteristics of the 60 studies included in the meta-analysis regarding the prevalence of tuberculosis in cattle

References	Country	Continent	Prevalence for animals			Prevalence for herds			Associated risk factor
			Number of animals tested	Number of positive animals	Prevalence % (CI 95%)	Number of herds tested	Number of positive herds	Prevalence % (CI 95%)	
Abubakar et al. (2013)	Nigeria	Africa	967	139	14.37 (12.22–16.75)				Age
Akinseye et al. (2017)	Nigeria	Africa	515	60	11.65 (9.01–14.74)	45	21	46.67 (31.66–62.13)	Age, sex, herd size
Almaw et al. (2021)	Ethiopia	Africa	5,675	1,776	31.29 (30.08–32.51)	299	180	60.20 (54.40–65.79)	Herd size, age, cases of bovine tuberculosis on the property, breed
Asante-Poku et al. (2014)	Ghana	Africa	685	17	2.48 (1.45–3.94)				Age, herd size, agricultural practices, pasture sharing, other species
Awah-Ndukum et al. (2012)	Cameroon	Africa	2,853	121	4.24 (3.5–5.05)	61	38	62.30 (48.96–74.39)	Age, sex, herd size
Barbieri et al. (2016)	Brazil	South America	31,832	188	0.59 (0.51–0.68)	2,182	93	4.26 (3.45–5.20)	Herd size, acquisition of animals, type of exploitation
Bahiense et al. (2016)	Brazil	South America	18,810	24	0.13 (0.08–0.19)	1,305	19	1.46 (0.88–2.26)	Age, herd size, type of exploitation
Bedard et al. (1993)	Malawi	Africa	3,481	134	3.85 (3.24–4.54)				
Bonsu et al. (2000)	Ghana	Africa	1,200	166	13.83 (11.93–15.92)				

References	Country	Continent	Prevalence for animals			Prevalence for herds			Associated risk factor
			Number of animals tested	Number of positive animals	Prevalence % (CI 95%)	Number of herds tested	Number of positive herds	Prevalence % (CI 95%)	
Boukary et al. (2011)	Niger	Africa	393	14	3.56 (1.96–5.91)				Animals presenting cough
Dejene et al. (2016)	Ethiopia	Africa	2,550	140	5.49 (4.64–6.45)	102	47	46.08 (36.16–56.23)	Herd size, other species, type of exploitation
Dias et al. (2016)	Brazil	South America	2,723	55	2.02 (1.53–2.62)	1,743	169	9.70 (8.35–11.18)	Type of exploitation, herd size, milking type, pasture sharing
Dinka & Duressa (2011)	Ethiopia	Africa	625	76	12.16 (9.70–14.98)				Age, race
Duguma et al. (2016)	Ethiopia	Africa	554	21	3.79 (2.36–5.74)				Age, origin of animals
Durnez et al. (2009)	Tanzania	Africa	728	18	2.47 (1.47–3.88)	49	7	14.29 (5.94–27.24)	Herd size, pasture sharing, water source
Ferreira Neto et al. (2020)	Brazil	South America	11,926	1	0.008 (0.0002–0.047)	757	1	0.132 (0.003–0.73)	
Fetene & Kebede (2009)	Ethiopia	Africa	1207	117	9.69 (8.08–11.50)	75	41	54.67 (42.75–66.21)	
Firdessa et al. (2012)	Ethiopia	Africa	2,956	886	29.97 (28.32–31.66)	88	44	50.00 (39.15–60.85)	Age, property size
Galvis et al. (2016)	Brazil	South America	7,699	72	0.94 (0.73–1.18)	637	48	7.54 (5.61–9.87)	Herd size, type of milking
Ghebremariam et al. (2016)	Eritrea	Africa	15,354	1,736	11.31 (10.81–11.82)	3,149	545	17.31 (16.00–18.68)	Climate differences, proximity to dairy farms
Ghebremariam et al. (2018)	Eritrea	Africa	1,077	13	1.21 (0.64–2.06)	413	13	3.15 (1.69–5.32)	Water source
Guedes et al. (2016)	Brazil	South America	17,121	19	0.11 (0.07–0.17)	938	12	1.28 (0.66–2.22)	Technified dairy farm
Gumi et al. (2011)	Ethiopia	Africa	473	26	5.50 (3.62–7.95)	31	13	41.95 (24.55–60.92)	Age, water source
Gumi et al. (2012)	Ethiopia	Africa	421	10	2.38 (1.15–4.33)	28	4	14.29 (4.03–32.67)	
Habitu et al. (2018)	Ethiopia	Africa	1,357	59	4.35 (3.33–5.57)	310	50	16.13 (12.21–20.71)	Other species, acquisition of animals
Hamed et al. (2021)	Egypt	Africa	5,323	89	1.67 (1.34–2.05)	16	11	68.75 (41.33–88.98)	Cases of bovine tuberculosis on the property and neighboring properties, management, other species, purchase of new animals, herd size
Ibrahim et al. (2010)	Nigeria	Africa	922	10	1.09 (0.52–1.99)	22	10	45.46 (24.39–67.79)	Herd size, share of breeding animals
Inangolet et al. (2008)	Uganda	Africa	1,470	19	1.29 (0.78–2.01)				
Islam et al. (2020)	Bangladesh	Asia	1,865	210	11.26 (9.86–12.78)	79	36	45.57 (34.31–57.17)	Age, sex, property size

References	Country	Continent	Prevalence for animals			Prevalence for herds			Associated risk factor
			Number of animals tested	Number of positive animals	Prevalence % (CI 95%)	Number of herds tested	Number of positive herds	Prevalence % (CI 95%)	
Islam et al. (2021)	Bangladesh	Asia	510	37	7.26 (5.16–9.86)				Herd size, other species, animal presenting cough
Javed et al. (2011)	Pakistan	Asia	1,751	133	7.60 (6.40–8.94)	11	11	100.00 (71.51–100.00)	Age, other species
Kader et al. (2023)	India	Asia	360	38	10.55 (7.57–14.19)	36	18	50 (32.92–67.07)	Age
Katale et al. (2013)	Tanzania	Africa	1,100	26	2.36 (1.55–3.44)	32	16	50.00 (31.89–68.11)	Age, herd size
Kazoora et al. (2014)	Uganda	Africa	525	11	2.10 (1.05–3.72)	63	9	14.29 (6.75–25.39)	Water source, acquisition of animals
Kazwala et al. (2001)	Tanzania	Africa	5,936	781	13.16 (12.31–14.04)	239	122	51.05 (44.52–57.55)	Age, sex
Kemal et al. (2019)	Ethiopia	Africa	315	64	20.32 (16.01–25.19)	43	22	51.16 (35.47–66.70)	Management
Khattak et al. (2016)	Pakistan	Asia	368	17	4.62 (2.71–7.29)				Age, herd size
Lima et al. (2016)	Brazil	South America	5,728	28	0.49 (0.32–0.71)	906	22	2.43 (1.53–3.65)	Herd size, pasture share, number of milking sessions
Lima et al. (2022)	Brazil	South America	74	1	1.35 (0.03–7.30)	10	1	10 (0.25–44.50)	
Mekonnen et al. (2019)	Ethiopia	Africa	2,754	142	5.16 (4.36–6.05)	174	39	22.41 (16.45–29.34)	Herd size, acquisition of animals, management
Moiane et al. (2014)	Mozambique	Africa	1,136	450	39.61 (36.76–42.53)				Age
Muma et al. (2013)	Zambia	Africa	459	22	4.79 (3.03–7.17)				Moisture
Munyeme et al. (2009)	Zambia	Africa	944	52	5.51 (4.14–7.16)				Age, other species
Mwakapuja et al. (2013)	Tanzania	Africa	1,288	48	3.73 (2.76–4.91)				
Néspoli et al. (2016)	Brazil	South America	28,878	23	0.08 (0.05–0.12)	1,133	12	1.06 (0.55–1.84)	Type of Exploitation
Proaño-Perez et al. (2009)	Ecuador	South America	2,022	143	7.07 (5.99–8.28)	20	11	55.00 (31.53–76.94)	Age, other species, herd size
Queiroz et al. (2016)	Brazil	South America	9,895	74	0.75 (0.59–0.94)	1,067	31	2.91 (1.98–4.10)	Age, type of exploitation, herd size
Regassa et al. (2010)	Ethiopia	Africa	413	48	11.62 (8.70–15.11)	39	19	48.72 (32.42–65.22)	Age, management
Ribeiro et al. (2016)	Brazil	South America	2,019	1	0.05 (0.0013–0.28)	278	1	0.36 (0.01–1.99)	
Rocha et al. (2016)	Brazil	South America	18,659	71	0.38 (0.30–0.48)	900	29	3.22 (2.17–4.60)	Number of milkings, technical dairy farm
Rodrigues et al. (2022)	Brazil	South America	17,210	82	0.47 (0.37–0.59)	1,757	46	2.61 (1.92–3.47)	Property size, type of exploitation and whey feeding

References	Country	Continent	Prevalence for animals			Prevalence for herds			Associated risk factor
			Number of animals tested	Number of positive animals	Prevalence % (CI 95%)	Number of herds tested	Number of positive herds	Prevalence % (CI 95%)	
Shitaye et al. (2006)	Ethiopia	Africa	2,098	443	21.12 (19.39–22.93)	85	41	48.24 (37.26–59.34)	
Silva et al. (2016)	Brazil	South America	16,045	63	0.39 (0.30–0.50)	1,419	33	2.33 (1.61–3.25)	Type of exploitation, size of property, type of milking
Swai & Schoonman (2012)	Tanzania	Africa	642	8	1.25 (0.54–2.44)	130	6	4.62 (1.71–9.78)	Property location
Tigre et al. (2012)	Ethiopia	Africa	384	82	21.35 (17.36–25.80)	35	17	48.57 (31.38–66.01)	Soil treatment, herd size
Tschopp et al. (2009)	Ethiopia	Africa	2,216	94	4.24 (3.44–5.16)	73	49	67.12 (55.13–77.67)	Acquisition of animals, other species
Tsegaye et al. (2010)	Ethiopia	Africa	1,132	386	34.10 (31.34–36.94)	56	30	53.57 (39.74–67.01)	Age, herd size
Tora et al. (2022)	Ethiopia	Africa	221	18	8.14 (4.89–12.56)	70			Age
Tulu et al. (2021)	Ethiopia	Africa	654	257	39.30 (35.53–43.16)	65	38	58.46 (45.57–70.56)	Breed, nutrition, management
Vendrame et al. (2016)	Brazil	South America	19,640	26	0.13 (0.09–0.19)	904	21	2.32 (1.44–3.53)	Acquisition of animals

chain reaction (PCR), interferon-gamma assay (IFN-γ), and enzyme-linked immunosorbent assay (ELISA).

The highest combined prevalence of the disease in cattle was in Asia (8.19%; CI 6.16–10.80%), although the region presents only five studies. With sixteen studies, South America had the lowest prevalence (0.36%; CI 0.18–0.75%) (Fig.2, Table 2).

In the visual evaluation of the funnel charts regarding prevalence studies for animals and herds (Fig.3 and 4), it was possible to observe evidence of asymmetry in the distribution of the points that represent the individual studies under the graph plotting area, which indicates possible publication bias. However, Egger's test did not prove that asymmetry is a consequence of this type of bias (p<0.05).

Regarding the prevalence for herds, with only three studies, the Asian continent presented very high numbers, thus presenting the highest prevalence (48.3%; CI 39.38–57.33%) and South America the lowest (2.99%; CI 1.57–5.6 %) (Fig.5, Table 3).

In addition to prevalence, risk factors for tuberculosis in cattle were analyzed in 50 studies, generating a tag cloud with the most significant ones (Fig.6). Several factors associated with the infection were described by the authors in their research and "age" was the most used one (27 studies). Other terms with high frequency were "herd size" (n=21), "other species" (n=9), "acquisition of animals" (n=7), and "type of exploitation" (n=5) (Table 1).

DISCUSSION

In this systematic review and meta-analysis, a total of 60 cross-sectional studies were considered, and they showed a prevalence of 3.27% (2.11–5.05%) for animals and 18.09% (11.20–27.90 %) for herds. Despite meeting the eligibility criteria, the selected studies do not share the same methodology, especially regarding the sampling system used in the surveys, which is one of the possible explanations for the high heterogeneity found in the meta-analyses, classified as methodological heterogeneity by Santos & Cunha (2013).

The use of non-random sampling in part of the studies may have directly influenced the results obtained, considering that this type of selection allows the determination of important epidemiological indicators. However, selecting the sampling units according to non-probabilistic criteria generalizes the results, influencing the prevalence (Ramalho et al. 2020).

When analyzing the subgroups according to the continent where the research was conducted, a higher prevalence for animals and herds was observed in Asia (8.19%; CI 6.16–10.80%/48.3%; CI 39.38–57.33%). On the other hand, South America, with 16 papers, fifteen of which were from Brazil, had the lowest prevalence (0.36%; CI 0.18–0.75%/2.99%; CI 1.57–5.6%). Many developed nations have reduced or eliminated tuberculosis from their cattle populations by implementing effective control strategies, including testing and culling infected animals, active surveillance, and restrictions on movement in affected areas (Tulu et al. 2021).

In Brazil, after two decades of implementation of the "Programa Nacional de Controle e Erradicação da Brucelose e da Tuberculose Animal" (National Program for the Control and Eradication of Brucellosis and Animal Tuberculosis – PNCEBT), it can be verified the effectiveness of the implemented actions with the reduction of the prevalence of the illnesses in cattle and buffaloes in some Federative Units, as is the case of Tocantins, with a very low prevalence (0.009%) for animals and 0.16% for herds (Ferreira Neto et al. 2020). Currently, the action strategy of the PNCEBT is based on classifying states

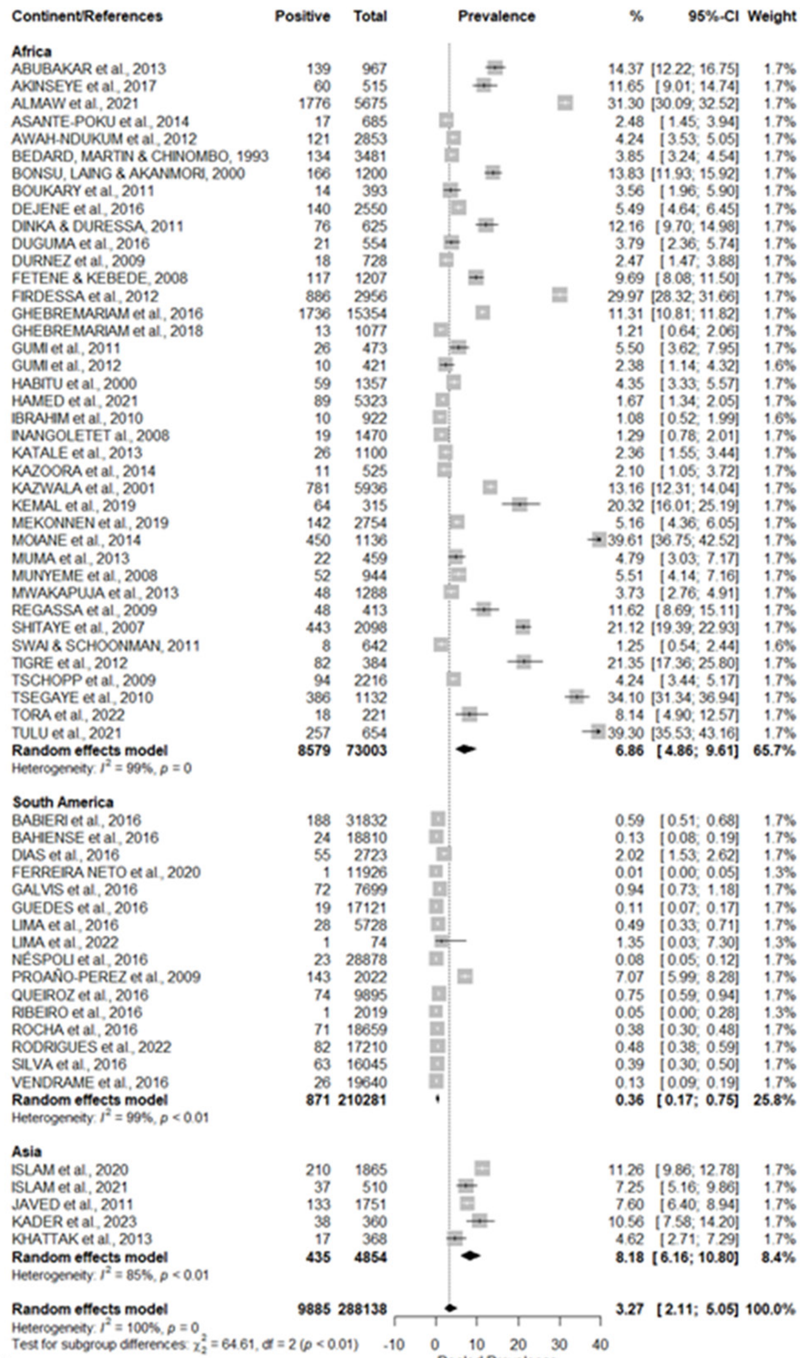

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Fig.2. Forest plot of the meta-analysis by continent subgroup, showing the prevalence per animal.

Table 2. Summary of the meta-analysis of the prevalence of tuberculosis for bovines by subgroup, according to the continent where the research was conducted

	Number of studies	Sampling	Number of positives	Combined prevalence (CI 95%)	Heterogeneity	
					p	I^2
Overall combined prevalence	60	288,138	9,885	3.27% (2.11–5.05%)	< 0.01	99.60%
Continent						
Africa	39	73,003	8,579	6.86% (4.86–9.61%)	< 0.01	99.3%
South America	16	210,281	871	0.36% (0.18–0.75%)	< 0.01	98.8%
Asia	5	4,854	435	8.19% (6.16–10.80%)	< 0.01	85.0%

in terms of the degree of risk for these diseases and on the application of animal health defense procedures suited to different realities (MAPA 2017).

We observed an asymmetry in both the visual evaluation of the funnel chart in the meta-analysis of prevalence for animals and herds (Fig.3 and 4). However, the result of Egger's test was not significant for the presence of publication bias ($p<0.05$). The observed asymmetry may not necessarily be a potential publication bias. According to Sibhat et al. (2017), the lack of symmetry around the inverted funnel plot is related to the number of reports of studies with low prevalence. It works with reduced sampling and is a consequence of the high heterogeneity between studies (Sterne et al. 2011).

Based on the results, the risk factors associated with the disease were mainly related to age, herd size, other species, acquisition of animals, and type of exploitation (beef, dairy, or mixed). In line with other studies, the prevalence of tuberculosis increased with the age of the animals and with the size of the herd, probably due to greater exposure to the agent over time and greater contact between susceptible hosts

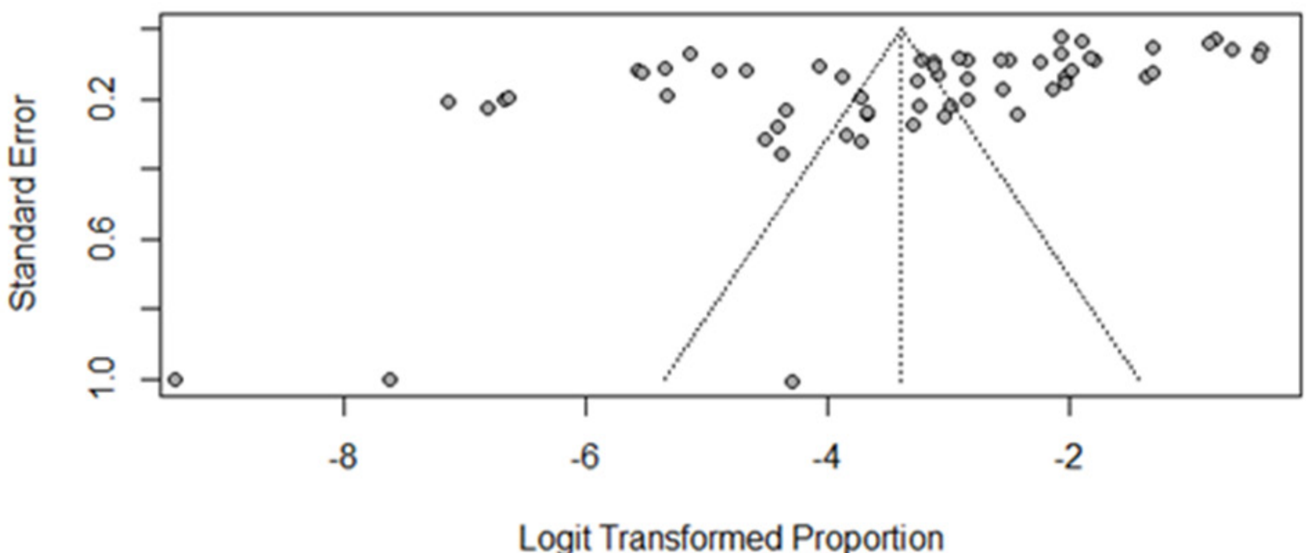

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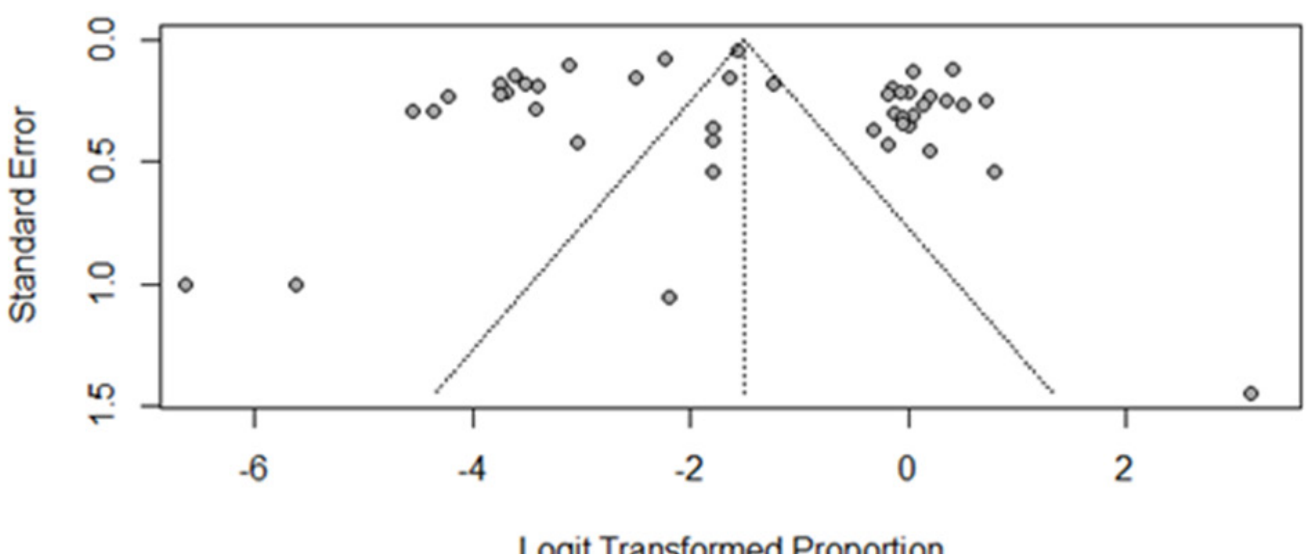
Fig.3. Funnel chart for verification of publication bias in studies on the prevalence of tuberculosis in cattle.



4

Fig.4. Funnel chart for verification of publication bias in studies on the prevalence of tuberculosis for herds

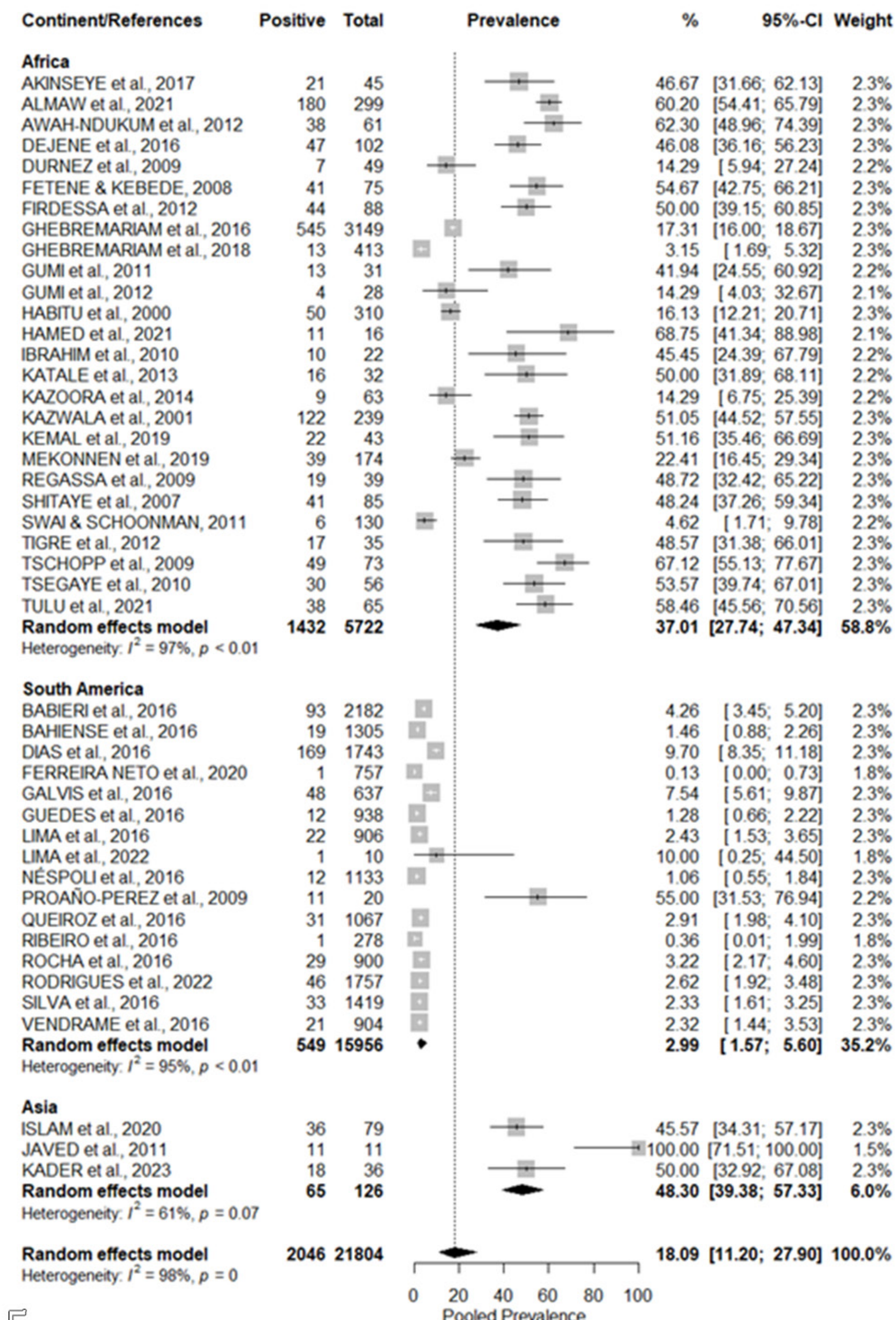


Fig.5. Forest plot of the meta-analysis by continent subgroup, prevalence by herd.

Table 3. Summary of the meta-analysis of the prevalence of tuberculosis for herds by subgroup according to the continent where the research was conducted

	Number of studies	Sampling	Number of positives	Combined prevalence (CI 95%)	Heterogeneity	
					p	I^2
Overall combined prevalence	45	21,804	2,046	18.09% (11.20–27.90%)	< 0.01	98.30%
Continent						
Africa	26	5,722	1,432	37.01% (27.74–47.33%)	< 0.01	96.7%
South America	16	15,956	549	2.99% (1.57–5.6%)	< 0.01	95.3%
Asia	3	126	65	48.3% (39.38–57.33%)	< 0.01	61.5%

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Fig.6. Tag cloud representing risk factors for bovine tuberculosis reported in 50 primary studies. The larger the words, the more frequent they are.

and infectious agents (Javed et al. 2011, Moiane et al. 2014, Dejene et al. 2016). The results also showed the presence of other species associated with the disease in cattle. Lima et al. (2021), for example, confirmed an outbreak of tuberculosis by *Mycobacterium bovis* in captive deer in the state of Rio Grande do Sul, Brazil, with the presence of suggestive lesions, confirming the transmission of the agent to other species. Regarding the type of exploitation, dairy herds proved to be more susceptible to infection since the animals are kept very close for milking (Ferreira Neto et al. 2016).

As in any other type of research, we identified limitations in our study. Although the World Organization for Animal Health considers delayed-type hypersensitive skin testing the standard method for detecting tuberculosis in cattle (WOAH 2018), it has an imperfect performance caused by cross-reactions and errors during the application of the tuberculin (Zhu et al. 2023). There is a possibility that infected animals will not react to the test, thus being possible sources of infection for other animals and/or humans. In some countries, new *ante mortem* diagnostic tests can be used as complementary to skin tests. In the European Union, the IFN-γ assay was formally recognized as a supplementary parallel test to allow detection of the maximum number of infected bovines in herds (De la Rua-Domenech et al. 2006).

In a study conducted in Taiwan, researchers observed that 29% of dairy cows that tested positive in the intradermal allergy test were subsequently found to be negative for tuberculosis based on necropsy, histopathological examination, and mycobacterial isolation results. It is believed that the other false-positive results in the test could be related to cross-reactions by nontuberculous mycobacteria (Lin et al. 2022). In Egypt, a high sensitivity was observed for detecting infected cases using the indirect ELISA assay for the qualitative detection of antibodies against *M. bovis* in serum. It could detect 80% of the cases presenting lesions of the disease in slaughterhouses, therefore considered promising for diagnosing the disease (Borham et al. 2021).

Several studies in different countries have suggested the risk of occupational exposure to *M. bovis* infection, especially for animal handlers who have close contact, slaughterhouse workers, veterinarians and their assistants (Devi et al. 2021). In Portugal, through regulation (UE) 2019/627, *post mortem* inspection requirements applied to cattle have been analyzed, essentially reducing handling and incisions in young cattle to reduce exposure to the agent (Gonçalves et al. 2022).

CONCLUSION

The heterogeneity identified among the works included in this review was expected, given the differences in their research design, year of publication, and the number of animals sampled. It is necessary to evaluate the introduction of new *ante mortem* diagnostic tests to the control and eradication programs, which, combined with allergic tests, can identify the greatest number of animals that presented a true positive for the disease.

Conflict of interest statement.- The authors declare that there are no conflicts of interest.

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