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One Health drivers of zoonotic *Taenia solium* in rural districts of low and middle-income countries: A systematic review and meta-analysis.

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Systematic Review

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Abstract

Background

Infection with *Taenia solium* in humans and pigs continues to be a public health problem in rural districts of low and middle-income countries (LMICs). This is attributed to weak collaboration in surveillance, prevention, control and diagnosis among different sectors. Free-ranging pigs act as reservoirs of *T. solium*, increasing human infection risk through close contact, poor sanitation, and consumption of undercooked pork. This systematic and meta-analysis was aimed at estimating pooled prevalence of *T. solium* in human, porcine cysticercosis and identify their One health drivers in LMICs.

Methods

A systematic search of Medline/PubMed, Embase, CINAHL, Web of Science, Cochrane database, Global Health online, Scopus and African Journals Online. ClinicalTrials.gov, Google Scholar. Open Grey database, WHO reports, FAO/WHO/WOA, and government or NGO technical reports were searched for studies published in January 2015 onwards. The systematic review was registered under PROSPERO CRD 420251023448. Random effects meta-analysis using the Der Simonian–Laird method estimated pooled prevalence. Publication bias was assessed using funnel plots and Egger's regression test while subgroup and sensitivity analysis was used to explore heterogeneity.

Results

Fifty-nine studies meet the inclusion criteria for systematic review and 29 studies for meta-analysis. The pooled prevalence of porcine cysticercosis was 10.9% (95% CI: 5.1%-21.8%) based on 14 of fourteen studies involving 8,904 pigs. The pooled prevalence of human *T. solium* was 13% (95%CL 8.00%-20%) based on 15 studies including 25,184 participants. Most frequently studies reporting risk factors were poor sanitation and free-range pigs with each (41; 69.5%) follow by open defecation with (36; 61%), poor hygiene (26; 44.1%), poor knowledge (23; 39%), lack of meat inspection (20; 33.9%) and backyard slaughtering (17; 28.8%). Human, animal and environmental risk factors were consistently associated with transmission and highlighting the need for One health integrated interventions.

Conclusion

T. solium remains highly prevalent in endemic areas of LMICs. Strengthening One health surveillance, prevention, diagnosis and control strategies in human, animal and environmental sector is essential to reduce disease transmission and burden.

Background

Infection with the larvae of *Taenia solium* (*T*. *solium*) continues to be an important neglected zoonotic disease in many developing countries [1]. *T. solium* is prevalent in low and middle-income countries because of poor hygiene, lack of meat inspection of pig meat, rearing of free-range pigs, general economic hardships, poor knowledge about the parasite and consumption of undercooked pork meat, inappropriate pig husbandry practices [1–8]. The infection may be further contributed to by poor meat hygiene, consumption of contaminated water, and improper toilet use [9, 10].

In addition, the lack of affordable and easy-to-use diagnostics at a farm level hinders proper control of *T. solium* in endemic countries [11]. Furthermore, the research has shown that in most endemic areas, there is a lack of efficient control measures, reporting, monitoring and surveillance have been cited as a contribution to the spread of *T. solium* [8, 12]. It has been highlighted that without having water throughout the year, households without pit latrines, and open defecation are drivers of *T*. *solium* [6]. Additionally, *T. solium* infection spreads by inadequate abattoir sanitation, ignorance, keeping pigs for extended periods that increase with age, and a lack of knowledge about pig management [8]. Consequently, *T. solium* infection is responsible for severe health disorders such as seizures and death in humans, veterinary public health, economic impacts on smallholder farmers, and it poses a serious public health risk [8, 10].

The health impact of *T. solium* is substantial in endemic regions around the world, where neurocysticercosis is estimated to be responsible for about 30% of epilepsy [13]. *T. solium* cysticercosis/taeniasis (TSCT) continues to be a neglected zoonotic disease in many developing countries and is the global number one parasitic foodborne disease as ranked by the WHO [1, 10].

However, the parasite is responsible for severe health disorders such as seizures and death in humans, cysticercosis in pigs, and it poses a serious public health risk [8, 14]. The infection of *T. solium* is appearing on the World Health Organisation (WHO) list of neglected tropical diseases (NTD) [7].

This review will also contribute to the Sustainable Development Goals (SDGS) that align with and support the One Health Approach. The Sustainable Development Goals 3, which is Good Health and Well-being, Sustainable Development Goal 6, which is clean water and sanitation, and finally Sustainable Development Goal 11, which is sustainable cities and communities [15–18].

To bridge the gap in the prevention and control of *T. solium.* There is a need to do a systematic review and meta-analyses that will provide evidence on One Health drivers of *T. solium* transmission in rural districts of low and middle-income countries. To our knowledge, a lot of systematic reviews for *T. solium* have been conducted in humans and pigs, but there is no systematic review for One Health Spectrum that involves both human, animal and environmental drivers of *T. solium*.

Methods

Search strategy and eligibility criteria

For this systematic review and meta-analysis, we searched the Medline/PubMed, Embase, CINAHL, Web of Science Core, Cochrane database, Global Health online, Scopus and African Journals Online, ClinicalTrials.gov, Google Scholar, Open Grey database, WHO reports, FAO/WHO/WOAH, and government or NGO technical reports. To ensure literature saturation, the reference lists of the included studies were scanned to identify and capture other relevant studies and Google scholar was used to identify and screen studies citing them. There were no studies that need to be translated from other languages to English language.

The search was limited to human, pig and the environment in rural areas of low- and middle-income countries. The search strategy was developed based on the outcomes of interest including prevalence, One Health risk factors associated with human *T. solium* and porcine cysticercosis. The search strategy was developed in collaboration with Malawi University Science and Technology librarian specializing in health sciences. The complete comprehensive search strategy search strings using relevant keywords, MeSH terms, and Boolean operators “AND” and “OR” is provided in supplemental materials (Supplement 1).

We included cohort (retrospective and prospective) studies, longitudinal studies, clinical trials, cross-sectional studies, case-control studies and ecological studies in rural districts of low and middle-income countries explored the outcomes of interest (prevalence, risk factors associated with human *Taenia solium* all age group of study participant and porcine cysticercosis in rural areas. We excluded the following types of studies due to the lack of relevance to our research question, or due to their limitations in allowing us to identify risk factors for *T. solium* and porcine cysticercosis. Studies conducted in urban settings of low and middle-income countries or high-income countries were excluded in this review. In additional studies focusing only on *Taenia saginata* and *Taenia asiatica* were also not included in the systematic review and meta-analysis. Studies conducted before 2015 and those that do not contain primary results were also excluded in this review such as systematic reviews and meta-analysis, as case report, case series, that do not report absolute population and unpublished articles. Studies lacking extractable quantitative or qualitative one health drivers and interventions. We followed the Preferred Reporting Items for Systematic Review and Meta-Analysis guidelines (PRISMA-P) [19]. while conducting this systematic review and meta-analysis. The protocol is registered and published with Prospero with registration number (CRD42O251023448).

Because most studies reported the presence of potential transmission-related factors through field observations or questionnaires without estimating odd ratios, relative risks, or providing sufficient data to calculate effect estimate, quantitative meta-analysis of risks factors was not feasible. Therefore, reported factors were summarized descriptively according to their frequency of reporting and classified within the One Health domains (human, animal and environment). Univariable meta-regression analyses were performed to investigate whether publication years, region, country, study, and diagnostic method explained between-study heterogeneity.

Data extraction

Data extraction was done by (MC and MP) independently screened the titles and abstracts of studies according to the inclusion criteria in the Covidence [20]. Any disagreements were resolved by discussion and consensus. In cases of further disagreement, a third reviewer (HK) holding a casting vote was consulted. The full-text review then occurred, and each reviewer independently screened the full texts against the inclusion and exclusion criteria, with disagreements resolved by consensus or discussion with a third reviewer (HK), if necessary. Two MC and MP extracted data independently in pre pilot excel sheet and then full extracted in Covidence and the later exporting to excel.

Two independently reviewers extract data on key variable such first author, year of publication, country, hypothesis/ aim, study design, number of participants, study settings, risk factors and prevalence associated with human *Taenia solium* infection and porcine cysticercosis. Extracted data was cross-checked for consistency and discrepancies were resolved through discussion. To asses risk of bias in the included studies, we used a modified Critical Appraisal Skills Programme (CASP) checklist for cross-sectional studies and the Newcastle-Ottawa scale (NOS) for cohort and case-control studies (supplementary) [21].

The CASP checklist used in this systematic review assessed seven domains: (i) Study population/participant recruitment appropriateness, (ii) eligibility criteria, (iii) Validity of *Taenia solium* diagnosis or outcome measurement and (iv) Completeness of reporting of One Health outcomes and risk factors, (v) Measurement of One Health exposures, (vi) Statistical analysis, (vii) Risk of selection bias. The methodological quality and risk of bias of the included observational studies were assessed using the Newcastle–Ottawa Scale (NOS) [22].

The methodological quality and risk of bias of the included observation studies were assessed using the NOS quality instrument score which was awarded a star (corresponding to the points) for each area. It assesses the study’s area of selection (maximum of 5 points), comparability (maximum of 2 points), and out comes (maximum of 3 points). After summing the star points, the studies were classified into three categories: good (7–10 points), moderate (5–6 points), and poor (0–4 points). The risk of bias assessment was performed by MC and MP, and any disagreements were resolved by consensus. For randomized controlled trial Cochrane RoB 2 tool, and for non- non-randomized studies using ROBINS-1 were used [23].

Table 1

Characteristics of included studies The main characteristic of the 59-study included in the study are presented in the table below

Authors, publication year	Region	Country	Study design	Study Population	Human Sample Size	Human Cases	Human Prevalence	Pig Sample Size	Pig Case	Pig Prevalence	Outcome
Kabululu et al. 2020 [24]	**East Africa**	**Tanzania**	**Cross-sectional**	**Humans and Pigs**	**0**	**0**	**0**	**282**	**26**	**9.2**	**Porcine cysticercos prevalence**
Ng-Nguyen et al. 2018 [26]	Southeast Asia	Vietnam	Cross - Sectional	humans and Pigs	342	17	4.97	1281	12	0.94	Human cysticercosi exposure, Porcine cysticercosi exposure
Carabin et al. 2015[27]	West Africa	Burkina Faso	Cross-sectional	Humans	3609	120	3.3	0	0	0	Active human cysticercosi infection
Thys et al. 2015 [28]	Southern Africa	Zambia	Cross-sectional	Humans	172	0	0	0	0	0	Community perceptions and sanitation practices
VanDamme et al. 2022 [29]	Southern Africa	Zambia	Observational Studies	Pigs	0	0	0	48	0	0	Pig movement patterns around households

Table 1
(continued)

Authors, publication year	Region	Country	Study design	Study Population	Human Sample Size	Human Cases	Human Prevalence	Pig Sample Size	Pig Case	Pig Prevalence	Outcome

Table 1 **(continued)**

Ngowi et al. 2017[30]	**West Africa**	**Burkina Faso**	**Cross-sectional**	**Humans**	**4773**	**0**	**0**	**0**	**0**	**0**	**Reduction in transmission and prevalence of *Taenia solium* infection**
Ng-Nguyen et al. 2018 [31]	Southeast Asia	Vietnam	Community-based cross-sectional	Humans	339	17	5	0	0	0	*T. solium* cysticerci exposure
Kungu et al. 2017 [32]	East Africa	Uganda	Cross-sectional	Humans and Pigs	1096	690	63	1185	144	12.2	Seroprevalence of porcine *Taenia solium* cysticercosis in pigs.
Madinga et al. 2017[33]	Central Africa	DR Congo	Cross-sectional baseline survey	Humans and Pigs	4751	1112	23.4	338	154	45.6	Seroprevalence of porcine *Taenia solium* cysticercosis and risk factors associated with infection in pigs
Mucavele et al. 2025 [34]	Southern Africa	Mozambique	Cross-sectional	Humans	6295	606	9.6	0	0	0	human cysticercosis (CC) seropositivity

Table 1 **(continued)**

Adikwu et al. 2025 [35]	**West Africa**	**Nigeria**	**Cross-sectional**	**Humans and Pigs**	**100**	**21**	**21**	**2176**	**24**	**1.1**	**Porcine *Taenia solium* cysticercosis**
Uwibambe et al.2024 [36]	East Africa	Rwanda	Longitudinal cohort study	Humans	206	0	0	0	0	0	Change in CHWs' knowledge of *Taenia solium*
Wilson et al. 2023 [37]	East Africa	Tanzania	Cross-sectional	Pigs	0	0	0	692	67	9.7	Porcine cysticercosis
Mananjara et al.2023 [38]	Southern Africa	Madagascar	Cross-sectional	Pigs	0	0	0	104	37	35.6	Porcine cysticercosis
Zulu et al. 2023 [39]	Southern Africa	Zambia	Community-based cross-sectional study	Humans	2762	241	8.7	0	0	0	Confirmed hyperendemic taeniasis *T. solium*
Makingi et al. 2023 [40]	East Africa	Tanzania	A cluster-randomised control trial	Humans	872	12	1.4	0	0	0	Knowledge about *Taenia solium* (TSTC) Preventive practices Prevalence and incidence of human cysticercosis (HCC)

Table 1 **(continued)**

Mulilo et al. 2023 [41]	**East Africa**	**Tanzania**	**Cross-sectional**	**Humans**	**150**	**0**	**0**	**0**	**0**	**0**	**Humans *Taenia solium***
Chege et al. 2023[42]	East Africa	Kenya	comparative cross-sectional design	Humans and Pigs	251	44	17.5	370	14	3.8	Porcine cysticercosis is strongly linked to poor sanitation, free-ranging pig systems, and low knowledge of transmission
Dahourou et al. 2022 [43]	West Africa	Burkina Faso	Cross-sectional	Pigs	0	0	0	373	205	54.9	Porcine cysticercosis
Nyangi et al. 2022 [10]	East Africa	Tanzania	Cross-sectional	Humans	480	0	0	0	0	0	Knowledge, attitudes and practices regarding *Taenia solium*
Moller et al. 2022 [44]	East Africa	Tanzania	Qualitative observation	Humans	64	0	0	0	0	0	Potential *Taenia solium* transmission risk factors associated with pork handling, cooking, and consumption practices.

Table 1 **(continued)**

Keller et al. 2022 [45]	**Southern Africa**	**Malawi**	**Cross sectional**	**Humans**	**127**	**5**	**4**	**0**	**0**	**0**	**Prevalence of neurocysticercosis (NCC) among people with epilepsy (PWE).**
Wilson et al. 2022	East Africa	Tanzania	Cross-sectional	Pigs	0	0	0	692	67	9.7	Risk factors for PCC seropositivity
Ngwili et al. 2022 [46]	East Africa	Uganda	Cross-sectional	Humans	264	0	0	0	0	0	Poor knowledge and awareness of *T. solium* transmission and control
Rahantamalala et al.2022 [47]	Southern Africa	Madagascar	Cross-sectional prevalence study	Humans	459	57	12.4	0	0	0	Exposure to *T. solium* (EITB/ELISA), active cysticercosis (Ag-ELISA), and associated risk factors.
Ngwili et al. 2022 [48]	East Africa	Uganda	Cross-sectional	Pigs	0	0	0	293	14	4.8	Porcine cysticercosis
Mlowe et al. 2022 [49]	East Africa	Tanzania	Cross-sectional	Humans	260	0	0	0	0	0	Knowledge, diagnostic capacity, and meat inspection practices related to *Taenia solium*

Table 1 **(continued)**

Mukendi et al. 2021[50]	**Central Africa**	**DR Congo**	**cross-sectional**	**Humans**	**340**	**43**	**12.6**	**0**	**0**	**0**	**Prevalence of *Taenia solium* antigen positivity (active cysticercosis)**
Mubanga et al. 2021[51]	Southern Africa	Zambia	Pospective diagnostic accuracy study	Humans	1254	13	1	0	0	0	TS POC T-positive taeniasis
AcostaSoto et al. 2021 [52]	East Africa	Rwanda	Cross-sectional school-based survey	Humans	572	76	13.3	0	0	0	human taeniasis
Vaernewyck et al. 2020 [53]	Southern Africa	Zambia	Cross-sectional study	Humans	47	0	0	0	0	0	Improvement in knowledge of *Taenia solium* transmission, prevention, porcine cysticercosis, human cysticercosis, neurocysticercosis and taeniasis. participants

Table 1 **(continued)**

Ramiandrasoa et al. 2020 [54]	**Southern Africa**	**Madagascar**	**Cross-sectional**	**Humans**	**960**	**0**	**0**	**0**	**0**	**0**	**Effect of annual praziquantel MDA on human taeniasis prevalence and treatment coverage/safety**
Mwabonimana et al. 2020 [55]	East Africa	Kenya	cross-sectional	Humans	280	0	0	0		0	Awareness, attitudes and perceptions regarding *Taenia solium*, porcine cysticercosis, and pork safety
Maganira etal. 2019[56]	East Africa	Tanzania	Cross-sectional	Pigs	0	0	0	447	77	17	Porcine cysticercosis
Dahourou et al. 2019 [57]	West Africa	Burkina Faso	Cross-sectional	Humans	320	0	0	0	0	0	Poor knowledge and high-risk sanitation and pig-rearing practices
Poudel et al. 2019 [58]	South Asia	Nepal	Longitudinal intervention study	Pigs	0	0	0	110	32	29.1	Vaccination and oxfendazole treatment in pigs can effectively interrupt transmission of *Taenia solium*.

Table 1 **(continued)**

Authors, publication year	Region	Country	Study design	Study Population	Human Sample Size	Human Cases	Human Prevalence	Pig Sample Size	Pig Case	Pig Prevalence	Outcome
Sahlu et al. 2019 [59]	**West Africa**	**Burkina Faso**	**Case-control**	**Humans**	**3392**	**106**	**3.1**	**0**	**0**	**0**	**Seropositi cysticerca antigens.**
Kabululu et al. 2018 [60]	**East Africa**	**Tanzania**	**Cross-sectional**	**Pigs**	**0**	**0**	**0**	**482**	**60**	**12**	**Porcine cysticerco**
Trevisan et al. 2018 [61]	Southern Africa	Mozambique	Cross-sectional	Pigs	0	0	0	661	84	12.7	Health bur economic and preval porcine cysticerco
Hobbs et al. 2018 [62]	Southern Africa	Zambia	Cross-sectional	Humans	166	0	0	0	0	0	human neurocysti
Adenuga et al. 2018 [63]	Southeast Asia	Cambodia	Cross-sectional	Pigs	0	0	0	620	29	4.7	seropreval porcine Ta spp. cystic and assoc risk factor
Dermauw et al. 2018 [64]	West Africa	Burkina Faso	Prospective cohort study	Humans	2211	66	3	0	0	0	human cysticerco
Sah et al. 2017 [65]	South Asia	Nepal	C	Pigs	0	0	0	110	32	29	Porcine cysticerco

Table 1 **(continued)**

Madinga et al. 2017 [66]	**Central Africa**	**DR Congo**	**Cross sectional**	**Humans**	**330**	**80**	**24.2**	**0**	**0**	**0**	**Prevalence *T. solium* taeniasis/cysticercosis and identification of associated risk factors.**
Assane et al. 2017 [67]	Southern Africa	Mozambique	Cross-sectional	Humans	1723	249	15.5	0	0	0	Human cysticercosis.
Okello et al. 2016 [68]	Southeast Asia	Lao PDR	Cross sectional	Humans	121	37	30.6	0	9	0	Prevalence of human taeniasis.
Wardrop et al. 2015 [69]	East Africa	Kenya	Cross-sectional	Humans and pigs	2092	139	6.6	93	16	17.2	Prevalence of human and porcine cysticercosis
Braae et al. 2015 [70]	East Africa	Tanzania	Case Control	Humans	93	0	0	0	0	0	Risk factors for porcine cysticercosis
Mwidunda et al. 2015 [71]	East Africa	Tanzania	Cluster randomised controlled trial	Humans	2063	0	0	0	0	0	Improvement in knowledge and attitudes towards *Taenia solium* taeniasis/cysticercosis

Data synthesis and Statistical analysis

The extracted data were reported as study level summary estimate, and qualitative and quantitative techniques were used to synthesise them. The primary outcome were risk factors, knowledge of prevention and prevalence of human *T. Solium* and porcine cysticercosis associated with One health drivers. All estimates were expressed as proportions with Restricted maximum likelihood (REML) 95% confidence interval (CI) and presented in forest plots using a random-effect meta-analysis. Heterogeneity was assed using Higgins I^2 statistic, Cochran's Q test and τ^2 (tau-squared). We set a stringent I^2 threshold of 75 to 100% as indicative of significant heterogeneity, but were also assess this heterogeneity through the CLs and localization on the forest plot [23]. The calculated pooled prevalence and 95% Confidence interval (CI) was done for meta-analysis using the proper statistical techniques.

Results

A total of 15,197 records were identified through a comprehensive data search were identified. Following title and abstract screening and full-text eligibility assessment, 59 studies met the inclusion criteria and were included in the systematic review. Most studies were conducted in East Africa (22, 37.3%), followed by southern Africa (19, 32.2%) and West Africa (9, 15.3%). Few studies were from Southeast Asia (4, 6.8%), Central Africa (3, 5.1%), and South Asia (2, 3.4%), indicating that the available evidence on the One Health drivers of *Taenia solium* transmission was predominantly derived from sub-Saharan Africa.

At the country level, Tanzania contributes the largest of studies for humans *T. solium* and porcine cysticercosis in rural areas (13,22.0%) [6, 10, 73–75, 24, 37, 40, 41, 44, 49, 56, 71],

followed by Zambia (11,18.6%) [25, 28, 78, 29, 39, 51, 53, 62, 72, 76, 77] and Burkina Faso (7, 11.9%) [27, 30, 43, 57, 59, 64, 79], Uganda (n = 4, 6.8%) [32, 46, 48, 80] and Mozambique (n = 4, 6.8%) [34, 61, 67, 81], while DR Congo (n = 3,5.1%)[33, 50, 66], Madagascar (n = 3,5.1%) [38, 47, 54] and Kenya (n = 3,5.1%) [42, 55, 69], each contributed 3. Vietnam (n = 2,3.4%), [26, 31] studies, Nigeria (n = 2, 3.4%) [35, 82], Rwanda (n = 2,3.4%)[36, 52], and Nepal (n = 2,3.4%) [58, 65] each had 2 studies, whereas Lao PDR (n = 1,1.7%) [83] Malawi (n = 1, 1.7%) [45], and Cambodia (n = 1, 1.7%) [63] each contributed one study. These findings indicate that research on One health drivers of *Taenia solium* risk factors in rural areas of low and middle-income countries has been concentrated predominantly in East and Southern Africa, with comparatively fewer studies conducted in Central Africa and Asia. This uneven geographical distribution suggests the need for additional research in underrepresented endemic.

Among the 59 included studies, 37 (62.7%) investigated human populations only, 14 (23.7%) investigated pigs only, and 7 (11.9%) included both humans and pigs. Human data were available from 44 studies, including 51,179 participants; 37 human-only studies contributed 41,463 participants, while 7 integrated human–pig studies contributed 9,716 participants highlighting limited application to one health approach to *T. solium* research. Porcine data were available from 21 studies involving 10,566 pigs, of which 14 pig-only studies examined 5,074 pigs and 7 integrated human–pig studies examined 5,492 pigs. Most of the evidence comes from the human's sectors and a small proportion from animal sector. All the analyses were carried out using the free software R programme and Studio software version 4.6.1 with the metafor [84] *meta* [85] dmetar [84] packages.

Table 2: **Risk factors, studies reporting and domain**

The table below explain risk factor and One health risk domain for human *T. solium* and porcine cysticercosis

Risk factor	No. of studies	Percentage (%)	One Health domain
Poor hygiene	41	70.7	Human
Pork consumption	36	62.1	Human
Poor knowledge	26	44.8	Human
Free-range pig keeping	41	70.7	Animal
Backyard slaughtering	23	39.7	Animal
Lack of meat inspection	19	32.8	Animal
Pig ownership	13	22.4	Animal
Poor sanitation	20	34.5	Environmental
Open defecation	17	29.3	Environmental
Lack of latrine	14	24.1	Environmental
Unsafe water	6	10.3	Environmental

Table 2 Risk factors and One health domain

Risk factors associated with *Taenia solium* transmission were reported across the human, animal, and environmental One Health domains. The frequency of reported risk factors among the included studies is presented in Fig. 2.

Poor sanitation and free-range pig keeping were the most frequently reported risk factors, each identified in 41 (69.5%) studies, followed by open defecation reported in 36 (61.0%) studies. Human-related factors included poor hygiene (26; 44.1%) and poor knowledge (23; 39.0%), while animal-related factors included lack of meat inspection (20; 33.9%) and backyard slaughtering (17; 28.8%).

Meta-analysis

In addition to systematic review meta-analysis was performed in order to assess the effect of the variable of interest on the main outcome variables, prevalence and risk factors of humans *T. solium* and porcine cysticercosis. Meta-analyses were conducted separately for human and porcine prevalence because human *Taenia solium* infection and porcine cysticercosis represent distinct epidemiological outcomes measured in different host populations.

Meta-analysis of Porcine Cysticercosis from 14 studies

Among 14 studies involving 8,904 pigs, the pooled prevalence of porcine cysticercosis was 11% (95% CI: 5%–22%) under a random-effects model with Hartung-Knapp adjustment. Prevalence estimates ranged from 1.1% to 55.0%, with considerable heterogeneity was observe among studies (I^2 = 98.7%, τ^2 = 2.0234, Q = 1002.49, p < 0.0001).

The subgroup analysis based on geographical region

The subgroup analysis revealed a statistically significant disparity in the prevalence of porcine cysticercosis shown that geographic region demonstrated significant differences in the pooled prevalence of porcine cysticercosis across regions (Q = 90.09, p < 0.0001). Among the region studies in East Africa demonstrated the lowest rates of pooled prevalence 10% (95% CI: 6%–17%), 7% (95% CI: 0%–97%) in West Africa, 3% (95% CI: 0%–99%) in Southeast Asia, and 22% (95% CI: 0%–100%) in Southern Africa. Single studies from Central Africa and South Asia reported prevalences of 46% and 29%, respectively. Although pooled prevalence differed significantly across regions, Considerable heterogeneity remained within most regional subgroups (I^2 = 86.7%–99.6%), suggesting that geographic region explained only part of the observed variability between studies.

Subgroup-analysis based on Country

The subgroup analysis revealed a statistically significant disparity in the prevalence based on country. Analysis by country demonstrated significant differences in the pooled prevalence of porcine cysticercosis across countries (Q = 603.14, p < 0.001). Tanzania had a pooled prevalence of 12% (95% CI: 5%–7%), while Uganda of prevalences of 8% and Nigeria had lower pooled 2%. Considerable within-country heterogeneity was observed for Tanzania (I^2 = 88.1%), Uganda (I^2 = 91.9%), and Nigeria (I^2 = 90.8%), the Higgins and Thompson's I^2 statistics showed high heterogeneity in Uganda and Nigeria. Within-country heterogeneity could not be assessed for countries represented by a single study, and the corresponding subgroup estimates should therefore be interpreted cautiously.

Subgroup-analysis by publication period

The variation of prevalence by publication period demonstrated statistically significant differences in the pooled prevalence of porcine cysticercosis (Q = 6.47, p = 0.039). The pooled prevalence was 27% (95% CI: 4%–78%) among studies published during 2015–2017, 6% (95% CI: 2%–16.0%) for studies published during 2018–2021, and 12% (95% CI: 1%–58%) for studies published during 2022–2025. Nevertheless, considerable heterogeneity persisted within all publication periods (I^2 = 96.4%–99.3%), indicating that publication period explained only part of the between-study variability.

Meta-regression

Meta-regression analysis identified country as a significant moderator of porcine cysticercosis prevalence (QM test, p = 0.034), explaining 83.8% of the between-study heterogeneity. This suggests that geographical differences may contribute substantially to the variation in reported prevalence estimates. Other investigated moderators, including publication year, study design, diagnostic method, and region, were not statistically significant contributors to heterogeneity. However, diagnostic method accounted for approximately 49.6% of the explained heterogeneity, suggesting that differences in diagnostic approaches may also influence prevalence estimates.

Because of considerable heterogeneity was observed in the random-effects meta-analysis (I^2 = 98.7%, p < 0.001), mixed-effects meta-regression analysis were conducted to investigate potential sources of between study variability.

Publication bias was assessed using funnel plots and the regression-based test of Egger at P < 0.05. Overall visual inspection suggests asymmetrical in the distribution of study estimate around the pool effect, this indicating publication bias (Fig. 4). However, a formal Egger linear regression test was not statistically significant (t = − 2.04, p = 0.064). evidence of small study effects or publication bias and the substantial between-study heterogeneity (I^2 = 98.7%).

Forest plot showing prevalence of humans Cysticercosis from 15 studies

The meta-analysis included 15 studies comprising a total of 25,184 participants. Individual study sample sizes ranged from 127 participants to 6,295 participants. The meta-analysis humans *Solium* infection showed the Higgins and Thompson's I^2 statistics showed high heterogeneity among the included studies (I^2 = 99.4%, 95% CI: 99.2%–99.5%; Cochran's Q = 2188.74, p < 0.001), indicating that nearly all of the observed variability in prevalence estimate resulted from true difference between studies rather than sampling error.

The estimated between-study variance was substantial (τ^2 = 0.94, 95% CI: 0.49%–2.41%), supporting the use of a random-effects model. This indicates that the substantial variation in prevalence rates across the studies is due to true underlying differences in factors like geographical location, diagnostic approaches, and study characteristics. Due to high level of heterogeneity, a random-effect model was used to calculate the pooled estimate. This model yielded an overall pooled prevalence of 13% (95%CL 8% − 20%). This estimate provides statistical average of human *T. solium* infection across included studies provide a wider variability. The forest plot analysis reinforces the conclusion that prevalence is highly dependent on the population being studied, with geographical location and diagnostic methods much high burden of disease (Figures.5).

To explore potential sources of heterogeneity subgroup analysis were conducted confirming robustness of the pooled prevalence estimates.

Subgroup analysis based on diagnostic methods

The burden of humans *T. solium* by diagnostic method revealed significant differences in pooled prevalence estimates (Q = 1,693.62, p < 0.001). Subgroup analysis by diagnostic method showed that the pooled prevalence ranged from 5.6% (95% CI: 1.4–19.6%) among four studies using the B158/B60 Ag-ELISA. Other pooled estimates were 14.2% (95% CI: 3.7–41.6%) for Copro-Ag ELISA with three studies, 9.7% (95% CI: 7.1–13.3%) for B158C11A10 ELISA with two studies. The results showed heterogeneity persist among the studies with different diagnostic methods.

Subgroup analysis based on country

The critical distinction was observed when analysing prevalence-based country setting country. The 15 prevalence studies demonstrated significant variation in human *T. solium* infection across countries (Q = 2118.78, p < 0.001). The pooled prevalence ranged from 3% in Burkina Faso to 63% in Uganda. The highest prevalence was reported in Uganda (63%; 95% CI: 60.1%–65.8%), while lower prevalence estimates were observed in Vietnam (3.5%; 95% CI: 2.0%–6.1%), Burkina Faso (3.3%; 95% CI: 2.8%–4.0%), and Malawi (4%; 95% CI: 1%–9%). Overall heterogeneity remained high (I^2 = 99.4%), suggesting substantial differences in transmission contexts, diagnostic approaches, and study characteristics. The forest plot reveals notable prevalence between geographical region likely due to variation in diagnostic criteria, study populations, and environmental conditions. The high heterogeneity (I^2 = 99.4%) observed in both meta-analysis underscores significant variation in study methodologies and population characteristics.

Subgroup analysis based on publication period

When the infections were differentiated by publication period, the analysis showed an overall taeniasis of pooled prevalence estimates of was notably higher of studies published between period of 2015 and 2017 with 18% (95% CI: 5.2%–45.9%), 7% (95% CI: 0.0%–99.9%) for studies published between 2018 and 2021, and 11.3% (95% CI: 7.3%–17.1%) for studies published between 2022 and 2025. However, there was no statistically significant difference in prevalence between publication periods (Q = 1.46, p = 0.4823). High residual heterogeneity persisted within all publication-period subgroups (I^2 = 85.6%–99.7%).

The subgroup analysis demonstrated variation in prevalence across countries and regions. This was supported by the meta-regression, which identified country as a significant source of between-study heterogeneity. However, the findings shown that several countries were represented by only one study. Furthermore, diagnostic method and study design were not significant moderators, suggesting that they did not account for the observed variability in prevalence estimates.

Meta-regression of Human T. solium

Univariable meta-regression was performed to explore whether publication years, region, country, study design, and diagnostic method explained between-study heterogeneity. Among the evaluated moderators, only country was significantly associated with the prevalence estimates (F = 32.09, p = 0.002), whereas diagnostic method (F = 2.63, p = 0.150) and study design (F = 0.34, p = 0.898) were not significant moderators. The country model explained 96.9% of the between-study heterogeneity, although this finding should be interpreted cautiously because most countries were represented by a single study.

Meta-regression analysis was performed to assess whether publication year influenced the pooled prevalence of human taeniasis. Univariable meta-regression showed publication year was not significantly associated with prevalence (β = −0.0144, 95% CI: −0.1830 to 0.1542; p = 0.8562). The moderator explained none of the between-study heterogeneity (R^2 = 0%), and considerable residual heterogeneity remained (I^2 = 99.29%; QE = 1832.67, p < 0.001).

Publication bias (Reporting bias)

Publication bias was assessed using funnel plots and the regression-based test of Egger at P < 0.05. Overall visual inspection suggests asymmetrical in the distribution of study estimate around the pooled effect, this indicating publication bias (Fig. 6). However, a formal Egger linear regression test was not statistically significant (t = − 0.82, p = 0.428), evidence of small study effects or publication bias and the substantial between-study heterogeneity (I^2 = 99.4%).

Leave-one-out sensitivity analysis

Leave-one-out-sensitivity analysis demonstrated that the pooled prevalence estimate was robust to the exclusion of individual studies. The overall pooled prevalence was 12.74% (95% CI: 7.79%–20.14%), while the leave-one-out estimates ranged from 10.97% to 13.99%. The lowest pooled prevalence was observed after excluding Kungu et al. (2017), (2017) (10.97%; 95% CI: 7.49%–15.80%), whereas the highest was observed after excluding Carabin et al. (2015) (13.99%; 95% CI: 8.66%–21.82%). Heterogeneity remained extremely high across all leave-one-out analyses (I^2 = 98.5%–99.4%). These findings suggest that no individual study substantially influenced the overall pooled prevalence estimate, although substantial between-study heterogeneity persisted.

Discussion

This systematic and meta-analysis is the first kind and presents the most comprehensive assessment of One health drives of *T. solium* in rural and middle-income countries. The current review showed that the prevalence of human *T. solium* and porcine cysticercosis in low and middle-income countries is clearly high and is associated with risk factors such as free-range pig keeping, pork sanitation, open defecation, poor hygiene, poor knowledge, lack of meat inspection, poor consumption, backyard slaughtering, lack of latrine, unsafe water and pig ownership. The findings are in consistence with previous findings from previous studies showing that poor sanitation, free-range husbandry, and inadequate meat inspection facilitate transmission of *T .solium* endemic settings [28, 86].

The findings demonstrate that transmission of *T. solium* is driven by interconnection by human, animal and environmental factors support supporting the One health approach in controlling the disease. Human behaviours such poor hygiene and limited knowledge of the disease interact with animal related factors such free-range pig keeping and inadequate meat inspection facilitate with the environmental contamination with parasite eggs. These findings indicate that intervention targeting one component are unlikely achieve sustainable control.

The current, meta-analysis identifies high variability between countries of porcine cysticercosis prevalence ranged from Vietnam, 1% (95% CI: 0.1%–2.0%) to Burkina Faso (55%; 95% CI: 50%–60%) and humans *T. solium* of Burkina Faso (3.3%; 95% CI: 2.8%–4.0%) to Uganda (63.0%; 95% CI: 60.1%–65.8%) respectively. Burkina Faso is identified as the lowest with prevalence human *T. solium* while Uganda with highest human prevalence *T. solium.*

The findings highlight the important role of multiple One Health related risks in the epidemiology of human *T. solium* infection and porcine cysticercosis. The overall pooled prevalence based on the included studies for human *T. solium* was 13% (95%CL 8.00%-20%). In Africa, the reported prevalence of *T. solium* taeniasis ranges from 0% to 17.25%, while the seroprevalence of human cysticercosis ranges from 0.68% to 34.5%. [87–89]. In addition the East and Southern Africa general population countries prevalence is reported up to 19.7% [90]. The One health drivers of prevalence of *T. solium* not well reported in low and middle-income countries. A Global Meta-analysis of general population reported high prevalence of *T .solium* is high prevalence compared to current review [91].

Furthermore, our meta-analysis found comparable pooled prevalence reported in a previous meta-analysis of studies conducted among the general population in India [92].

The similarity, *T. solium* prevalence suggests that *T. solium* remains an important public health concern in endemic settings [47, 77, 92]. However, the differences in geographical context, study population, diagnostic methods and transmission dynamics should be considered when interpreting these findings [89, 90, 93, 94].

The sources of variations might include the inclusion of studies that employed diagnostic techniques with a huge disparity in sensitivity and specificity. Subgroup analysis by diagnostic method showed that the pooled prevalence ranged from 5.6% among studies using the B158/B60 Ag-ELISA to 65.0% among studies using the B158C11A10/B60H8A4 Ag-ELISA. In line with existing research, the current results are supported by previous meta-analysis [95]. However, the gold standard method for human cysticercosis diagnosis is Neuroimaging, Computed tomography (CT) scan, Magnetic Resonance imaging (MRI) [96].

This review clear show that most the studies of human *T. solium* in low settings have conducted in sub-Saharan Africa and these findings are supported by meta-analysis published in literature that most the studies have conducted in sub-Saharan Africa [90, 95].

Meta-regression showed no significant association between publication year and the prevalence of human *Taenia solium* infection, suggesting that the observed heterogeneity was not explained by temporal trends. This indicates that differences in prevalence are more likely attributable to variations in geographical settings, study populations, diagnostic approaches, sample sizes, surveillance intensity, and One Health-related risk factors such as sanitation practices, pig management systems, meat inspection practices and other epidemiological factors than to change over time.

Leave-one-out-sensitivity analysis demonstrated that the pooled prevalence estimate was robust to the exclusion of individual studies. As excluding individual studies resulting in minor changes to the pooled estimate. This suggests that the finding was not driven by a single study. However, the persistently of heterogeneity across all analysis indicating that the observe variability likely reflecting the difference in study populations. geographical settings, diagnostical method and methodological characteristics rather than the influence of individual studies.

The subgroup analysis based on geographical region

We conducted three subgroup analysis for porcine cysticercosis by taking account that studies were conducted in different geographical region, country and publication year. Out of fourteen studies, the overall pooled prevalence based on the included studies for porcine cysticercosis was 11% (95% CI: 5%–22%) which is lower than the 17% (95% CI: 14%–20%) reported in an earlier previous meta-analysis [97, 98].

The discrepancy is likely due to differences in study selection, diagnostic methods, geographical representation, and the inclusion of more recent evidence in the current review. Unlike previous meta-analysis that synthesized evidence from diverse settings, the present review focused exclusively on rural settings, providing prevalence estimates that are more representative of communities where *T. solium* transmission is more likely to occur [91, 95, 97].

The present review includes more recently published studies reflecting in changes in disease epidemiology and the implementation of improve control measures in some settings. Secondly, the use of different statistical approach and random-effects model can also influence pooled prevalence estimates.

Unlike previous reviews, that focus both urban and rural areas, this current review exclusively focus on rural settings that are characteristic free-range pigs, poor sanitation, limited access to meat inspection and human, pig interaction of all which facilitate *T. solium* transmission. Consequently, the pooled prevalence observed in this review may better reflect the epidemiology of the disease in high-risk rural population rather than national averages.

The subgroup analysis of this meta-analysis with prevalence by region of Southern Africa of 22% (95% CI: 0%–99%) corroborate with a meta-analysis that show similar results [97]. However, this finding differs from that reported in the Eastern Africa region, where the pooled prevalence was 13% (95% CI: 11%–15%), compared with the much lower pooled prevalence of 10% (95% CI: 6%–17%) observed in our review [97]. The lower pooled prevalence observed in Esat Africa compared to previous report can be attributed in the studies included diagnostic method, study population, and local epidemiological conditions. In addition, the very wide confidence interval and high heterogeneity indicate substantial uncertainty in the pooled estimate. This is likely reflecting the limited number of studies and considerable variability between studies.

The significant region difference observed in this review are likely attribute to variation in pig production systems, sanitation infrastructure, socioeconomic condition, culture practices, access to veterinary and public health services, and implementation disease control programme. For example, religious, pork consumption, climate and environmental condition are expected to have greater contamination with *T. solium* eggs resulting increase transmission between humans and pigs.

Subgroup-analysis based on Country

The subgroup analysis revealed a statistically significant disparity in the prevalence based on country. Analysis by country demonstrated significant differences in the pooled prevalence of porcine cysticercosis across countries ($Q = 603.14$, $p < 0.001$). Tanzania had a pooled prevalence of 12% (95% CI: 5%–

27%), whereas Uganda of prevalences of 8%. The prevalence of Tanzania is comparable to that reported by Gulelat et al. [97], who estimated prevalence of 12% (95% CI: 9%–16%). Uganda has one of the largest pig population in Africa making pig production an important component of the country's livestock [99]. Although the pooled prevalence for Uganda was lower than the 15% (95% CI: 6%–26%) reported by Gulelat et al., the wider confidence interval in the present study indicate substantial uncertainty and overlaps with previous estimates.

Subgroup-analysis by publication period

The variation of prevalence by publication period demonstrated statistically significant differences in the pooled prevalence of porcine cysticercosis (Q = 6.47, p = 0.039). The pooled prevalence was 27% (95% CI: 4%–78%) among studies published during 2015–2017, 6% (95% CI: 2%–16%) for studies published during 2018–2021, and 12% (95% CI: 1%–58%) for studies published during 2022–2025. Nevertheless, considerable heterogeneity persisted within all publication periods (I^2 = 96.4%–99.3%), indicating that publication period explained only part of the between-study variability.

The pooled prevalence of porcine cysticercosis significantly across publication periods, suggesting temporal variation in disease occurrence. This variation may reflect differences in the implementation of control measures, including improvement in sanitation, pig confinement, meat inspection, and health education in some endemic region.

The evidence suggests that changes in diagnostic approach and the geographical distribution of studies conducted different periods may have contributed to the observed different rather than representing true decline or increase in disease burden. However, the persistently high heterogeneity within each publication period (I^2 >96%) indicate that publication year explain only a small proportion of the between-study variability. Other factors, such as geographical setting, pig production systems, study design, and diagnostic methods, are likely to have a greater influence on prevalence estimates, as has reported in previous systematic reviews and methodological guidance on meta-analysis [95].

Meta-regression

Because of substantial heterogeneity was observed in the random-effects meta-analysis (I^2 = 98.7%, p < 0.001), mixed-effects meta-regression analysis were conducted to investigate potential sources of between study variability. Meta-regression analysis identified country as a significant moderator of porcine cysticercosis prevalence (QM test, p = 0.034), explaining 83.8% of the between-study heterogeneity. This suggests that geographical differences may contribute substantially to the variation in reported prevalence estimates. Other investigated moderators, including publication year, study design, diagnostic method, and region, were not statistically significant contributors to heterogeneity. However, diagnostic method accounted for approximately 49.6% of the explained heterogeneity, suggesting that differences in diagnostic approaches may also influence prevalence estimates.

The findings have important implication for policy and diseases control programme in endemic countries. Integrated interventional that involve, human health, veterinary, environmental, and agriculture sector should be prioritised. Such intervention should include sanitation, improved use of household latrine, community health education, improve pig husbandly, strengthening meat inspection systems and enhance surveillance of both human taeniasis and porcine taeniasis. Coordinated of these interventions through One health framework is likely to be more effective than sector specific approach.

Future research should explore longitudinal and interventional studies to evaluated the effectiveness of One health strategies in rural endemic areas. Improve of reporting of risk factors and standardisation of diagnosis of methods would facilitate more robust comparison across studies and strengthening future meta-analysis.

Study Limitation

Some subgroup analyses were based on a small number of studies resulting in wide confidence intervals and reducing the precision of the subgroup estimates. Consequently, these findings should be interpreted with caution, and addition studies are needed to provide more robust region estimate.

Conclusion and recommendation

Responding to zoonotic *T. solium* and porcine cysticercosis threats requires multidisciplinary approach through policymakers, researchers, intersectoral and multidisciplinary collaboration, and local and international stakeholders to develop a comprehensive surveillance, screening, prevention and treatment. The pooled prevalence of porcine and *T. solium* indicating that the infection is relatively common in the study population. As consequences target population needs to be put in place in terms of awareness campaigns, mass drug administration and pig vaccination.

Declarations

Study Registration

The protocol has been registered with the Prospective Register of Systematic Reviews, Prospero registration number (CRD42O251023448).

Authors Contribution

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Competing Interests

The authors declare that they have no competing interests.

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Note applicable

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Figures

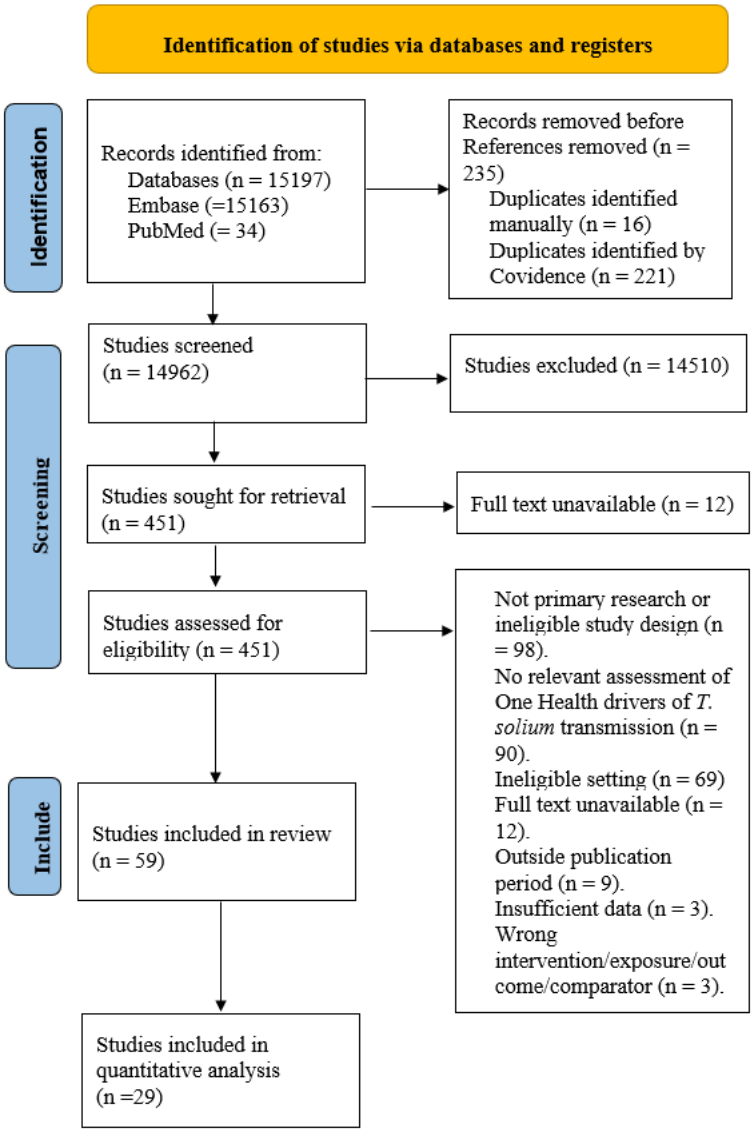


Figure 1

PRISMA flowchart of articles screening and selection

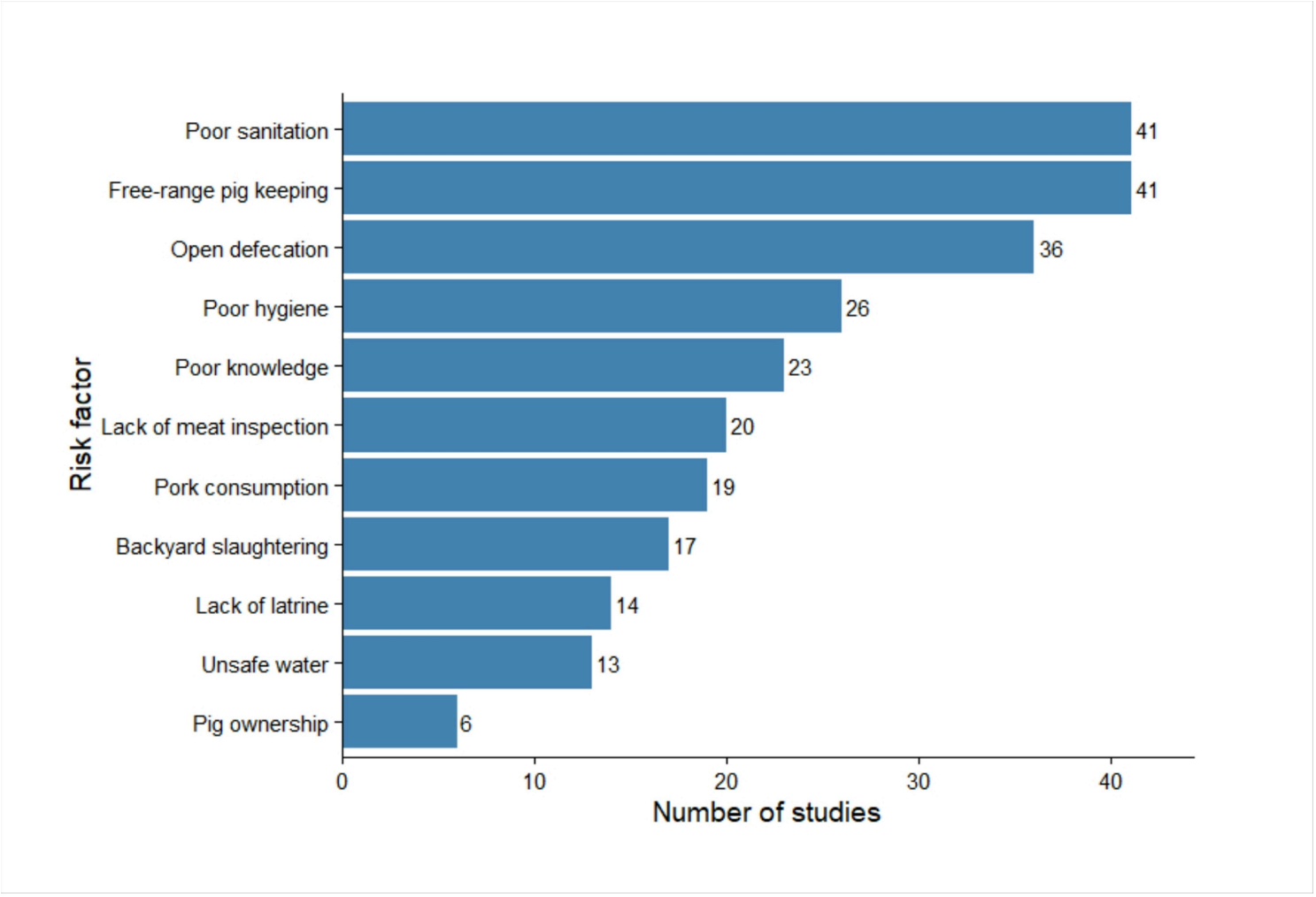


Figure 2

shows the frequency with which risk factors were reported across the included studies. Poor sanitation and free-range pig keeping were the most frequently reported risk factors (41 studies each), followed by open defecation (36 studies), poor hygiene (26 studies), and poor knowledge (23 studies).

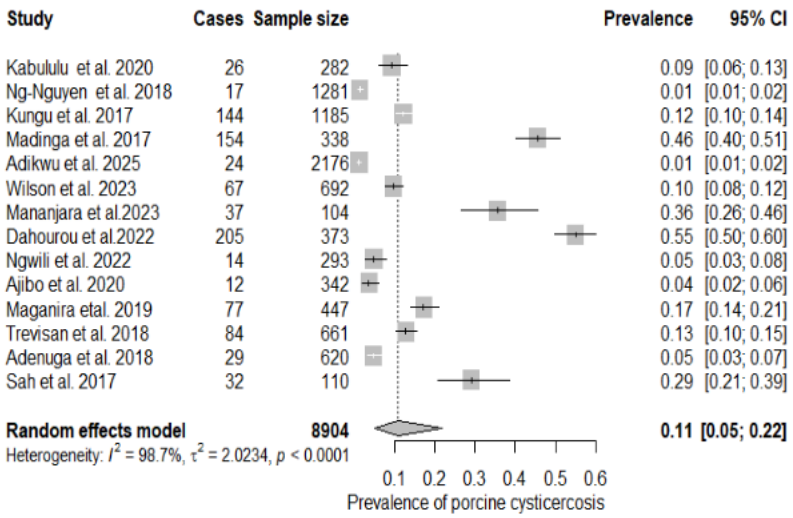


Figure 3

Forest plot showing a combine prevalence of Porcine Cysticercosis

Publication bias for porcine cysticercosis (Reporting bias)

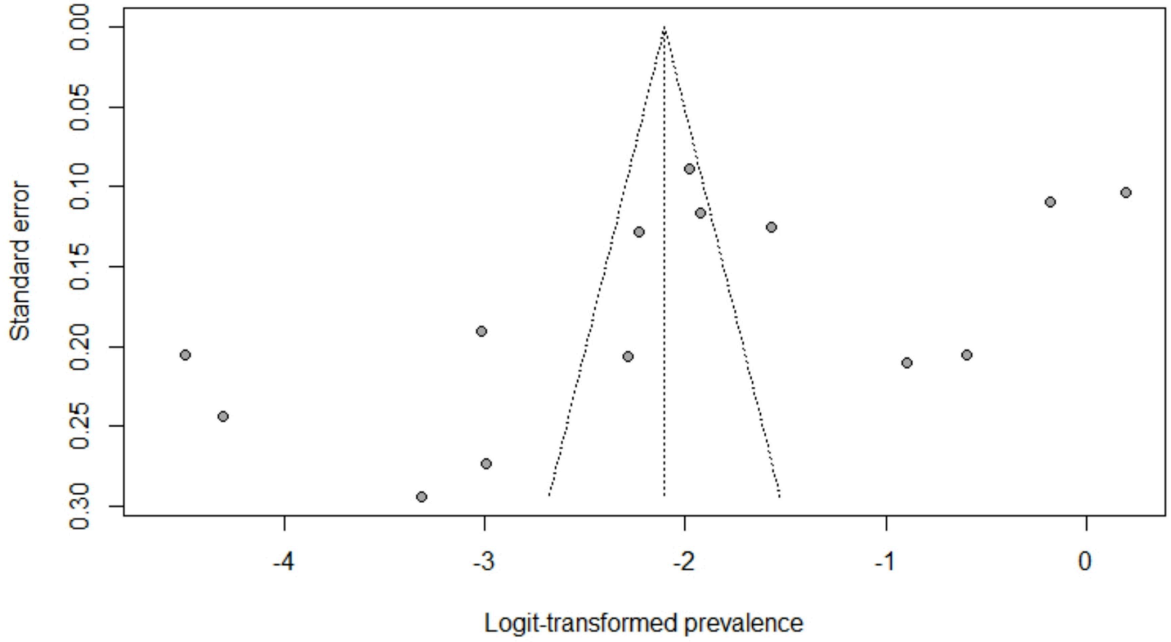


Figure 4

Publication bias (Reporting bias)

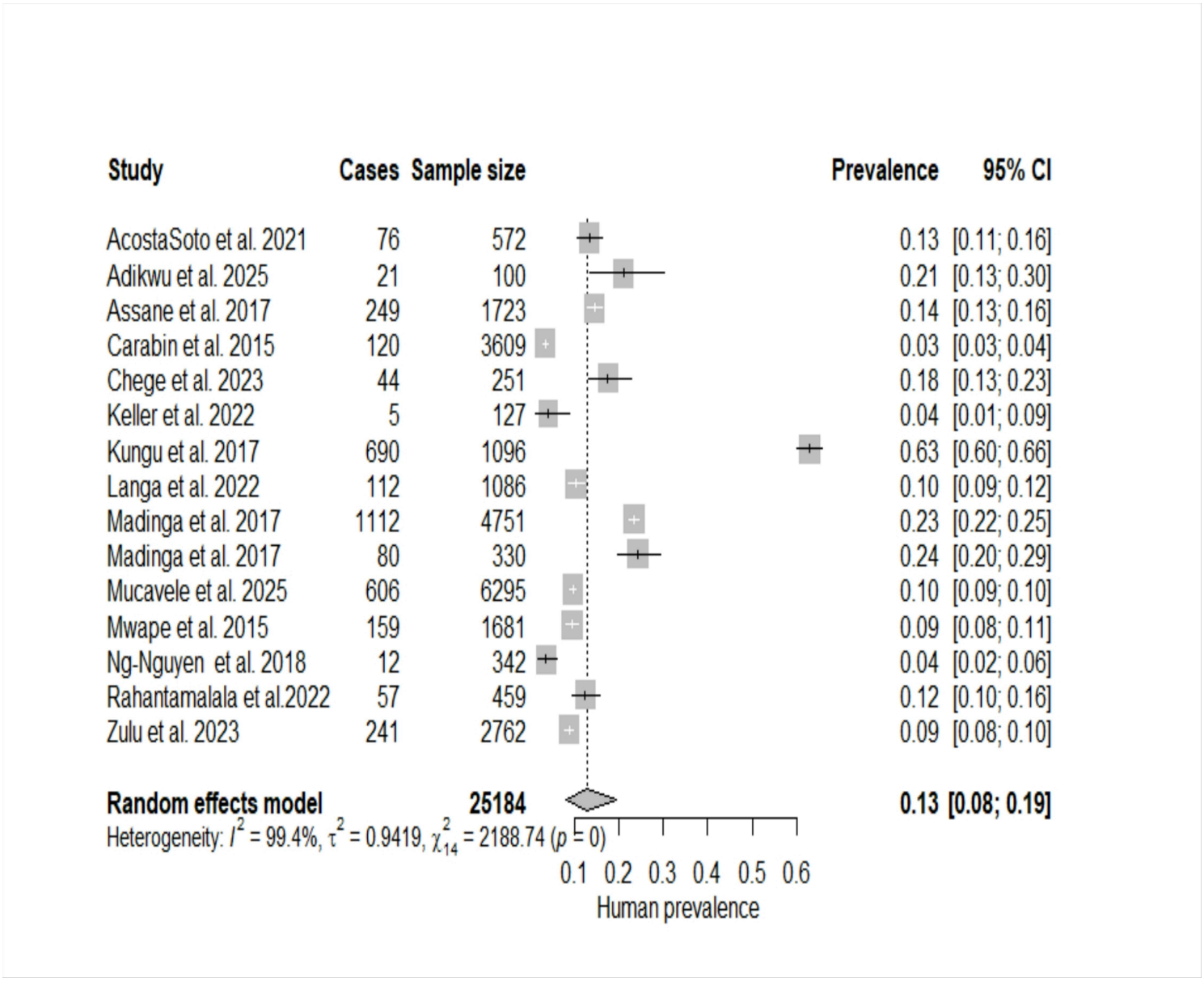


Figure 5

Forest plot showing prevalence of humans Cysticercosis from 15 studies

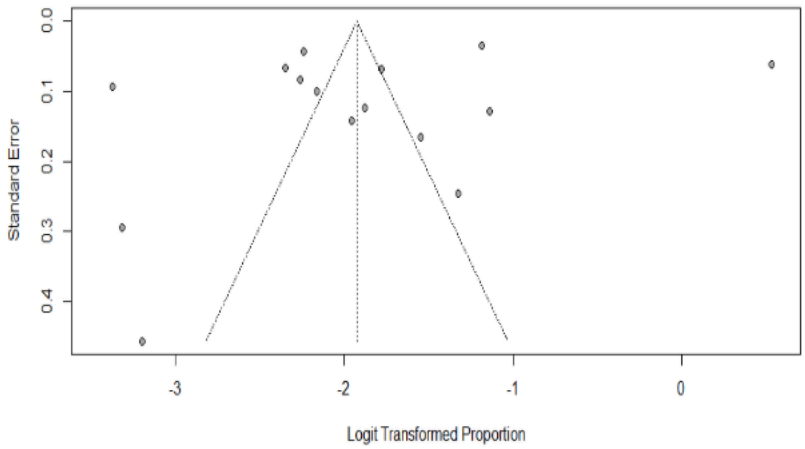


Figure 6

Legend not included with this version