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Prevalence of *Toxoplasma gondii* in Domestic animals in Sudan: A Systematic Review and Meta-Analysis

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Abstract

This study is aimed to estimate the pooled prevalence of *Toxoplasma gondii* infection in domestic animals in Sudan. This search included all published and unpublished studies written in Arabic and English before May 25, 2021. Databases namely Scopus, Web of Science, PubMed, MEDLINE, direct Google search, Google Scholar, world cat log, OpenGrey, OATD, and universities websites were used to retrieve published articles. Out of 650 screened studies, 27 articles with a total of 9926 animals were eligible for this meta-analysis. Data synthesis and statistical analysis were conducted by STATA software version 16. The pooled prevalence of overall *T. gondii* infections in the domestic animals, males, and females in Sudan was 38% (with CI 32%–45%), 36% (CI 25%–46%), and 38% (CI 28%–47%), respectively. Of these, the chicken had the highest prevalence of 80%, followed by sheep of 45%, goat of 41%, camel of 40%, cattle of 31%, horse of 31%, stray cats of 30%, and donkeys with the lowest prevalence of 16%. In this study, the reported pooled prevalence of *T. gondii* infections in Sudan was higher compared with other countries. The interpretation of these findings should take into consideration the presence of substantial heterogeneity between the included studies.

Keywords: Domestic animals, meta-analysis, prevalence, Sudan, *Toxoplasma gondii*

Introduction

Toxoplasma gondii (*T. gondii*) is an obligate intracellular parasite, that causes a worldwide zoonotic disease called toxoplasmosis (Dubey, 2010). This protozoan parasite infects almost all species of warm-blooded animals despite the only known definitive host of the parasite being the domestic cats (Dubey, 2010; Hill et al., 2005). Humans mainly become infected following the ingestion of undercooked meat from domestic animals harboring tissue cyst or by accidental ingestion of contaminated food, water, or soil with infected cat's feces (Aguirre et al., 2019; Dabritz & Conrad, 2010; Dubey, 2016; Hill et al., 2005).

Worldwide, the average prevalence of *T. gondii* in humans and animals is 30% and 35.5%, respectively; hence, the disease is considered a major public health concern in many countries around the globe (Foroutan-Rad et al., 2016; Gebremedhin & Tadesse, 2015; Tonouhewa et al., 2017). Interestingly, most infected animals do not show any clinical signs (Asymptomatic form). However, the infection is accompanied by clinical signs including neonatal death, mummification, and reproductive failure when the immune response of the host cannot stop the spread of the parasite (Symptomatic form) (Dubey, 2010; Hill et al., 2005). Studies found that the symptomatic form of *T. gondii* infection is associated with huge economic loss. For example, Uruguay alone recorded a 1.4–4.68 million US $ loss related to sheep abortions in 1 year (Aguirre et al., 2019; Dubey, 2016; Freyre et al., 1999; Stelzer et al., 2019). Economic loss resulting from this infection will likely have a huge implication in Sudan whose economy relies mainly on livestock revenues (Babiker et al., 2011).

Usually, the detection of the parasite in both asymptomatic and symptomatic animals has been done using one of the following tests: enzyme-linked immunosorbent assay (ELISA), latex agglutination test (LAT), indirect hemagglutination assay (IHA), McMaster method, and polymerase chain reaction (PCR). Of all these tests, PCR is considered to be the most accurate test. All these tests have high sensitivity and specificity indexes; hence, they can reveal the load and also the type of parasite (Bahnass et al., 2015; Mohammed, et al., 2021; Tonkal, 2008; Tonkin, 2020).

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In Sudan, studies showed that food-borne diseases such as toxoplasmosis are very common; this may be due to some unique feeding habits in Sudan like the consumption of raw meat such as camel liver and sheep offal "Elmaraara" (Abdelnabi et al., 2016; FAO & WHO, 2013). Therefore, the risk of occurrence of toxoplasmosis as a zoonotic disease in Sudan had rapidly increased. Different studies on the prevalence of *T. gondii* infection in animals in Sudan showed different results with a widely varied prevalence from 0.6% in some animals to 67% in other animals (Elamin et al., 1992; Hind & Hayfa, 2017). Based on that there is a need to critically appraise the available literature to make a pool estimation of the prevalence of *T. gondii* infections in animals in Sudan as this will be helpful to provide the necessary information that can assist decision-makers in toxoplasmosis treatment, control, and eradication programs. Thus, this study is aimed to estimate the pooled prevalence of *T. gondii* infections among animals in Sudan.

Methods

Eligibility Criteria

(1) All cross-sectional studies; (2) studies done on Sudanese domestic animals; (3) those published in Arabic or English; (4) those that reported the prevalence of *T. gondii*; (5), and studies in which positive cases *of T. gondii* were detected in naturally infected animals using the standard diagnostics methods (serological and coprology) were eligible for this study. Moreover, studies were not eligible for this study (1) if they were reviews, letters, editorials, and human studies and (2) if the full text was not available and had been requested from the author(s) through email but no feedback was received after 2 weeks.

Information Sources

The current comprehensive study was conducted according to the guideline of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021), and the relevant information was retrieved from the following databases: Scopus, Web of Science, PubMed, MEDLINE, direct Google search, Google Scholar, world cat log, OpenGrey, OATD, and universities websites. All those databases were searched from their inception to May 25, 2021, for animal studies published in English and/or Arabic.

Search Strategy

The Boolean search terms (AND, OR, NOT) were used to develop the research strategy. The final search strategy included the use of title/abstract related to ((Toxoplasma) AND ((prevalence) OR (epidemiology) OR (frequency)) AND ((cats) OR (cattle) OR (sheep) OR (goats) OR (camels) OR (donkeys) OR (horses) OR (pigs) OR (dogs) OR (rabbits) OR (chicken)) AND Sudan) taken from the study questions. Non-electronic sources were used combined with direct Google search, Google Scholar, world cat log, OpenGrey, OATD, and university websites. In addition, a manual search was done by the investigators for the gray literature and unpublished thesis/papers.

Selection Process

Firstly, all retrieved articles were exported to the EndNote X9 citation manager to check for duplication, and then the duplicated articles were excluded from the study. Screening and evaluations of the remaining studies by a careful reading of the title and abstract were done independently by two authors (AAA and MA). Each study that mentioned the outcomes of the review (prevalence of the animal toxoplasmosis/Sudan) in their titles and abstracts was considered for further evaluation based on the objectives, methods, and key findings. The quality of the relevant studies against the checklist of Joanna Briggs Institute quality assessment tools was evaluated by AAA and MA independently. Any discrepancy in the study findings was resolved by discussion between the two authors (AAA and MA) or by asking a third reviewer if consensus could not be reached. The selection process of the studies is presented using the PRISMA statement flow diagram (Figure 1).

Data Collection Process

Following the selection process of all appropriate articles for this systematic review and meta-analysis study, the relevant data were extracted using a Microsoft Word 2016 data extraction template by two authors (AAA and MA) independently.

The investigators contacted the authors of any study that did not report the aforementioned data (via email) to obtain the original data, and if after 2 weeks the missing data were still not obtained, a sensitivity analysis was carried out to check the impact of the missing data on the result and then to decide whether to seek to further information or not. The extraction template contains author/s name, study year, method of detecting the parasite, location of the study, the host animal, sample size, and the prevalence of *T. gondii* in overall males and females (Table 1). The data extraction accuracy was verified by comparing the data extraction results from the two investigators (AAA and MA) who independently extracted the data in a randomly selected subset of papers (30% of the total).

Data Items

The main outcome of this study was the prevalence of domestic animal toxoplasmosis in Sudan, and it was measured by the direct report from the individual studies. To quantify the outcome, the investigators considered studies that reported the prevalence of toxoplasmosis in their statistics. The result was interpreted by the proportions of the animal population which had a positive result for *T. gondii* from the total animal population studied.

Study Risk of Bias Assessment

Inclusion criteria were appraised for all retrieved articles by using their title and abstract first, and then, a full text was screened to check the quality of each study before the final selection. The following were the quality assessment criteria for the studies in the current review: (1) the diagnosis of *T. gondii* was done after performing the appropriate diagnostic tests (serological or coprology), and (2) the sample was representative of the population.

To minimize the risk of bias, two strategies were followed: (1) a comprehensive search for all electronic and non-electronic databases and (2) a critical appraisal tool (Joanna Briggs Institute Quality Assessment Tool) was used by two investigators (AAA and MA) independently to critically appraise the included studies, and studies with a score $\geq$ 60% were included.

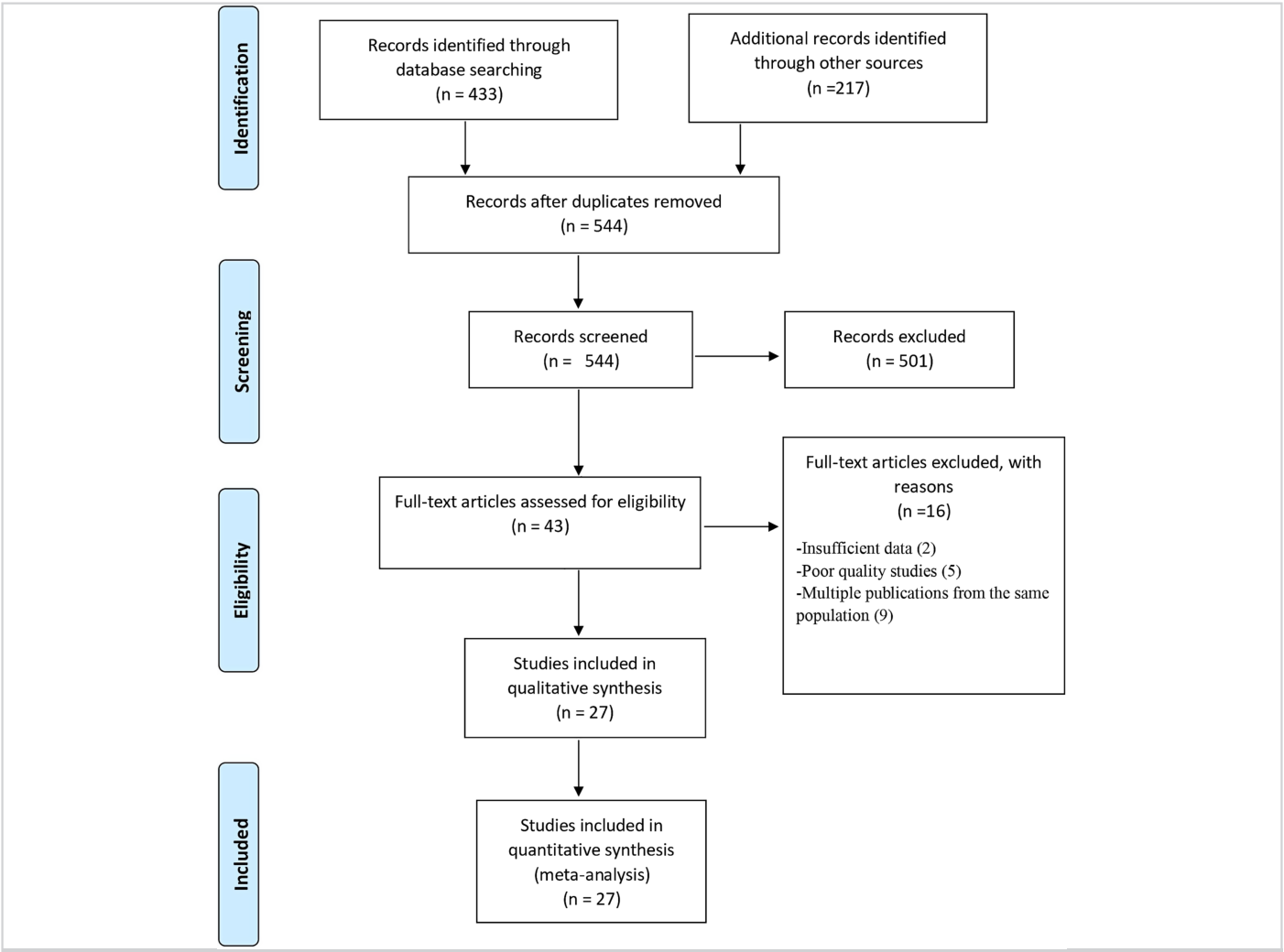

Figure 1.
Flow Diagram of the Studies Included in the Meta-Analysis.

Effect Measures
In light of the study objectives, the proportion of animal toxoplasmosis was used to synthesize and present the results for the analysis.

Synthesis Methods
Statistical software for data science (STATA) software version 16 was used to synthesize and analyze the meta-analysis data. The recommendation of the I^2 statistics (an I^2 of 75/100% and above suggesting considerable heterogeneity) as described by Higgins et al. (2003) was used to perform this meta-analysis. The effect size, with a 95% CI and standard error (SE), was used to calculate the result of this study. The effect size of this study was the prevalence of *T. gondii* (proportion), and it was calculated using the binomial distribution, while the SE, was calculated using the sample size (*n*) and the proportion of *T. gondii* (*p*) and applied it one SE formula: = sqrt [*p* (1−*p*)/*n*).

The potential publication bias was checked using a funnel plot and Egger's regression test, and it was assumed to be significant if the *p*-values were less than .10. Sensitivity analysis was applied to check the potential source of heterogeneity and possible source of bias. The studies were excluded from the final review if (1) the study has missing data, and (2) if it has a high risk of bias (studies with a score less than 60%). The study results were reported according to the PRISMA guidelines, and the findings of the included studies were first presented using a narrative synthesis and followed by a meta-analysis chart.

Results

Study Selection
As shown in Figure 1, a total of 650 articles were identified through the major electronic and non-electronic databases and other relevant sources. A total of 106 articles were removed due to duplication while 544 studies were kept for further critical screening. From these studies, 501 were excluded after they went through a very careful screening according to their titles and abstracts. From the remaining 43 articles, 16 of them were excluded due to inconsistency

Table 1.
Main Characteristics of Studies Included in the Meta-Analysis

					Sample Size			Prevalence%		
No	**Authors**	**Method**	**Location**	**Host**	**Overall**	**Male**	**Female**	**Overall**	**Male**	**Female**
1.	Zain Eldin et al. (1985)	IHA	Kordofan and central regions	Camel	204	NR	NR	54	NR	NR
				Cattle	175	NR	NR	40	NR	NR
				Sheep	576	NR	NR	34	NR	NR
				Goat	134	NR	NR	63	NR	NR
2.	Abbas et al. (1987)	LAT	Gezira	Camel	95	55	40	12	7	18
3.	Elamin et al. (1992)	LAT	Khartoum	Camel	482	244	238	67	29.1	22.7
4.	Ishag (2003)	LAT	*AL-Butana plain and North Kordofan	Camel	588	238	346	61.7	60	63
5.	Khalil et al (2007)	LAT	AL-Butana plain, North Kordofan, and South Kordofan	Camel	153	NR	NR	22.2	NR	NR
6.	Siddig (2009)	IMMM	Red sea	Cat	100	NR	NR	34	NR	NR
7.	Khalil & Elrayah (2011)	LAT	Khartoum	Camel	70	NR	NR	20	NR	NR
				Cattle	50	NR	NR	32	NR	NR
				Sheep	80	NR	NR	57.5	NR	NR
8.	Ali (2012)	**ELISA, LAT	Khartoum	Cattle	200	NR	NR	18	NR	NR
				Sheep	200	NR	NR	11	NR	NR
9.	El Bashier et al. (2012)	LAT	Gezira	Camel	100	16	84	44	37.4	45.2
10.	Elfahal et al. (2013)	ELISA	Khartoum and Gezira	Cattle	181	13	168	44.8	30.8	11.9
11.	Ahmed et al. (2013)	LAT	Khartoum	Horse	100	NR	NR	38	NR	NR
				Donkey	105	NR	NR	27.6	NR	NR
12.	Elmubarak & Saad (2014)	LAT	Khartoum	Cat	50	17	33	24	23.5	24.2
13.	Ibrahim et al. (2014)	ELISA	Khartoum	Cattle	744	NR	NR	49.9	NR	NR
14.	Ishag et al. (2014b)	ELISA	Khartoum	Horse	405	272	133	6.3	6.3	6.2
15.	Ishag et al. (2014a)	LAT	River Nile, Gadarif, Sennar, Blue Nile, and Kordofan	Camel	278	NR	NR	56.5	61.4	52.8
16.	Medani & Kamil (2014)	ELISA	Khartoum	Cattle	235	NR	NR	11.9	NR	NR
				Sheep	305	NR	NR	40.9	NR	NR
17.	Ibrahim et al. (2015)	ELISA	Khartoum	Cattle	1216	NR	NR	40.9	NR	NR
				Camel	61	NR	NR	54.1	NR	NR
				Sheep	100	NR	NR	75	NR	NR
				Goat	100	NR	NR	64	NR	NR
18.	Abbas (2016)	LAT	Khartoum	Goat	100	17	83	29	29.4	28.4
19.	Atail et al. (2017)	ELISA, LAT	Gadarif	Sheep	200	108	92	57.5	49.5	54.9
				Goat	200	108	92	46.5	49.5	54.9
20.	Hind & Hayfa (2017)	ELISA	Khartoum	Chicken	336	7	329	0.59	0	0.61
21.	Hussien et al. (2017)	LAT	River Nile, Khartoum, and Sennar	Chicken	58	NR	NR	100	NR	NR
22.	Jiomaa et al. (2017)	ELISA, LAT	Gadarif	Camel	300	161	139	49.7	47.7	52.3
23.	Damour (2018)	ELISA+LAT	Gadarif	Cattle	300	122	178	41.3	40.7	59.35
24.	Lazim et al. (2018)	LAT	River Nile	Cattle	96	NR	NR	6.2	NR	NR
				Sheep	34	NR	NR	26.5	NR	NR
				Goat	61	NR	NR	27.9	NR	NR

25.	Abdelbaset et al. (2020)	LAT	West Kordofan and Blue Nile	Camel	45	NR	NR	13.3	NR	NR
				Cattle	75	NR	NR	44	NR	NR
				Sheep	36	NR	NR	61	NR	NR
				Goat	136	NR	NR	15.4	NR	NR
				Donkey	100	NR	NR	6	NR	NR
26.	Said (2020)	LAT	Khartoum	Cattel	162	55	107	14.8	7.3	18.7
27.	Mohammed et al. (2021)	LAT	*AL-Butana plain	Camel	600	109	491	30	27.5	30.5

Note: NR = not reported; ELISA = enzyme-linked immunosorbent assay; LAT = latex agglutination test; IMMM = improved modified McMaster method; IHA = indirect hemagglutination assay.
*AL-Butana plain included five states (Gadarif state, Gezira state, Kassala state, River Nile state, and Khartoum state); **ELISA and LAT were used for human population the LAT was used for animals.

with the study inclusion criteria. Finally, 27 studies that fulfilled the eligibility criteria, involving 9926 animals, were included for the systematic review and meta-analysis. To calculate the pooled prevalence of toxoplasmosis, any individual study from the 27 studies that reported the prevalence of toxoplasmosis for more than one animal species was divided and dealt with any prevalence individually which gave us in the end 45 studies derived from the original 27 studies.

Study Characteristics

Twenty-seven studies were included in the quantitative analysis (21 were peer-reviewed studies and the remaining 6 were university theses). The overall prevalence of *T. gondii* in the domestic animals in Sudan was reported in all included studies, and the association between the animal gender and *T. gondii* prevalence was reported in 16 studies. Meanwhile, the prevalence of *T. gondii* in camels, cattle, sheep, goats, horses, donkeys, chickens, and cats was reported in 12, 11, 8, 6, 2, 2, 2, and 2 studies, respectively. All included studies were cross-sectional studies. The most frequent study areas in the included studies were Khartoum state (13), followed by Kordofan states (5), Gezira state and Gadarif state (4), then Al-Butana plain (3) and River Nile (2), and lastly, Sennar state, red sea state, and the Blue Nile state by just one study. Of all available diagnostic tests for *T. gondii* parasite, only four were mentioned in the included studies: (1) latex agglutination test (LAT) 19 times (2) enzyme-linked immunosorbent assay test 10 times, (3) the indirect hemagglutination assay test 1 time, and (4) the improved modified McMaster method test. Table 1 showed the detailed characteristics of all included studies.

Results of Synthesis

The results of this meta-analytical study showed that the included studies had a pooled sample size of 9926 animals. Among these studies, the heterogeneity was high with a p-value $< .00001$, and I^2 of 99.09%. Therefore, the random effect model was applied for the analysis, and finally, the pooled proportion of *T. gondii* in Sudanese domestic animals was 38% with a CI of 32%–45% (Figure 2). The pooled prevalence of *T. gondii* in male and female domestic animals in Sudan from 16 studies was 36% (with CI 25%–46%) (Figure 3) and 38% (with CI 28%–47%) (Figure 4), respectively. Also, the random effect model was applied in this analysis because the heterogeneity was substantially high with p-value $< .00001$ and I^2 98.1% and p-value $< .00001$ and I^2 97.09%, for males and females, respectively. The risk of publication bias in the included studies is presented in funnel plots (Figure 5).

The Pooled Prevalence of *T. gondii* Infection in Different Animal Species in Sudan

The pooled prevalence of *T. gondii* in different domestic animals in Sudan is shown in Table 2. From all animal species included in this study, the highest pooled prevalence of *T. gondii* was found in chickens, and the lowest pooled prevalence of *T. gondii* was found in donkeys.

Discussion

T. gondii is a zoonotic disease, and it has a huge negative impact on the health and economic sectors, especially in endemic and developing countries including Sudan. Studies showed that many animal species were examined for the presence of *T. gondii* in Sudan to understand the epidemiology of the disease nationally; despite that there is a lack of published data on the status of *T. gondii* infections in stray cats, horses, donkeys, chickens, dogs, rabbits, and other domestic birds in Sudan.

In the current comprehensive study, the overall prevalence of *T. gondii* infection in Sudan was relatively higher (38%) compared with reports in Ethiopia (35.5%), Algeria (25.46%), Nigeria (20.70%), and China (23.7%) (Dong et al., 2018; Gebremedhin & Tadesse, 2015; Karshima et al., 2020; Ouchetati et al., 2020). In Sudan, animal gender is one of the most reported risk factors related to *T. gondii* infections in domestic animals. In consistence with the above, this present study observed a higher prevalence of *T. gondii* infections in females compared with males. A similar trend was observed in findings from Ethiopia, Algeria, and Nigeria (Gebremedhin & Tadesse, 2015; Karshima et al., 2020; Ouchetati et al., 2020). However, in contrast with the previous results, camel and horse males had a higher prevalence of *T. gondii* infections compared with females. This difference in the results may be due to the difference in the study population (production systems, herd size, and animals age), the climate of the study area, absence of routine treatment for definitive hosts; sample size, sampling procedure, and diagnostics method (Table 2) (Bahnass et al., 2015; Dubey et al., 1995; El Bissati et al., 2018; Stelzer et al., 2019).

Findings from this present study showed that meat animals including chicken, sheep, goat, camel, and cattle had a high prevalence of *T. gondii* infection compared with other domestic animals in Sudan (Horses, donkey, and cats). This may indicate that the main source of human *T. gondii* infections in Sudan is

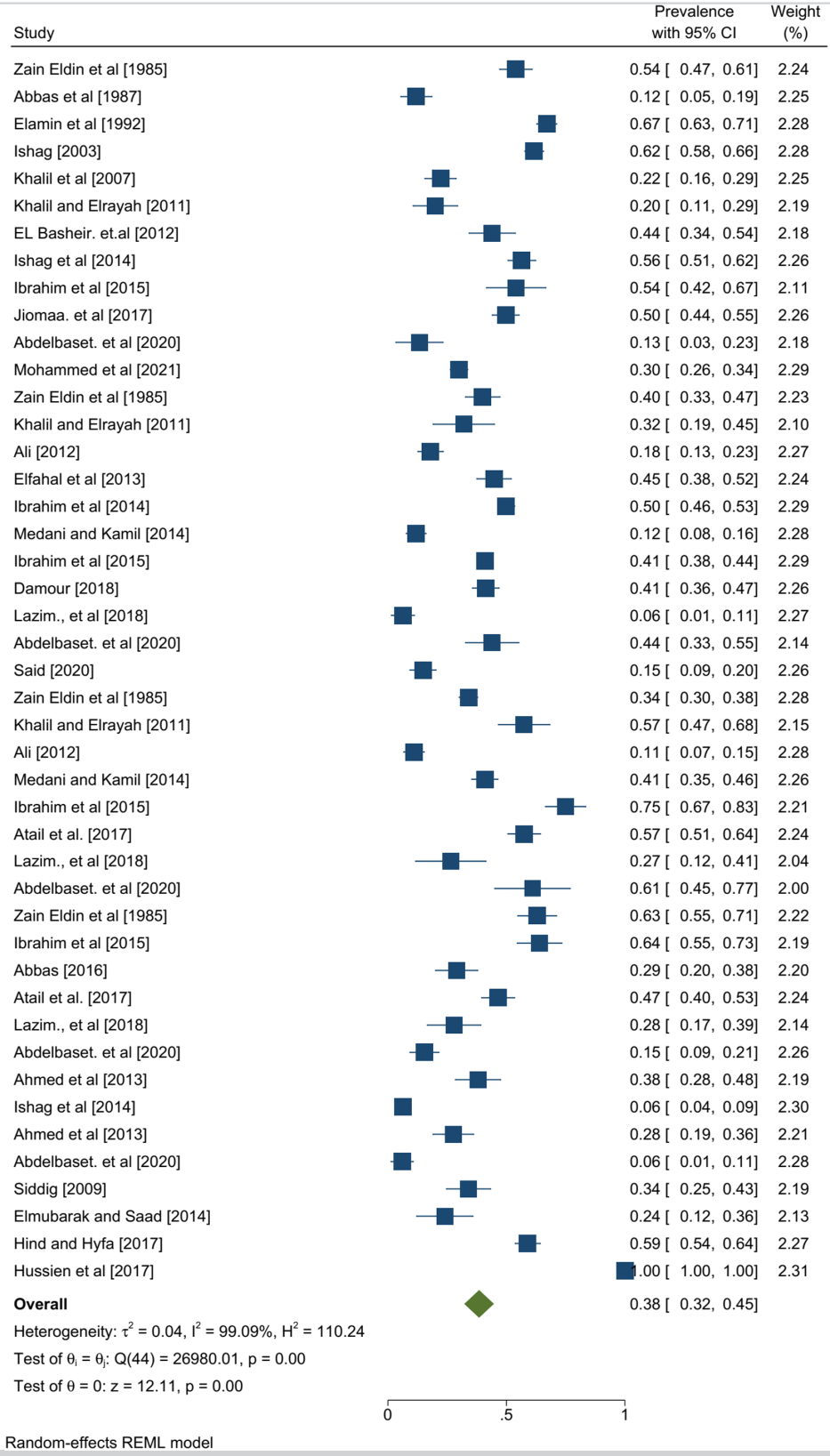

Figure 2.
Forest Plot (Random-Effects Model) for the Pooled Prevalence of Toxoplasma gondii in Domestic Animals in Sudan.

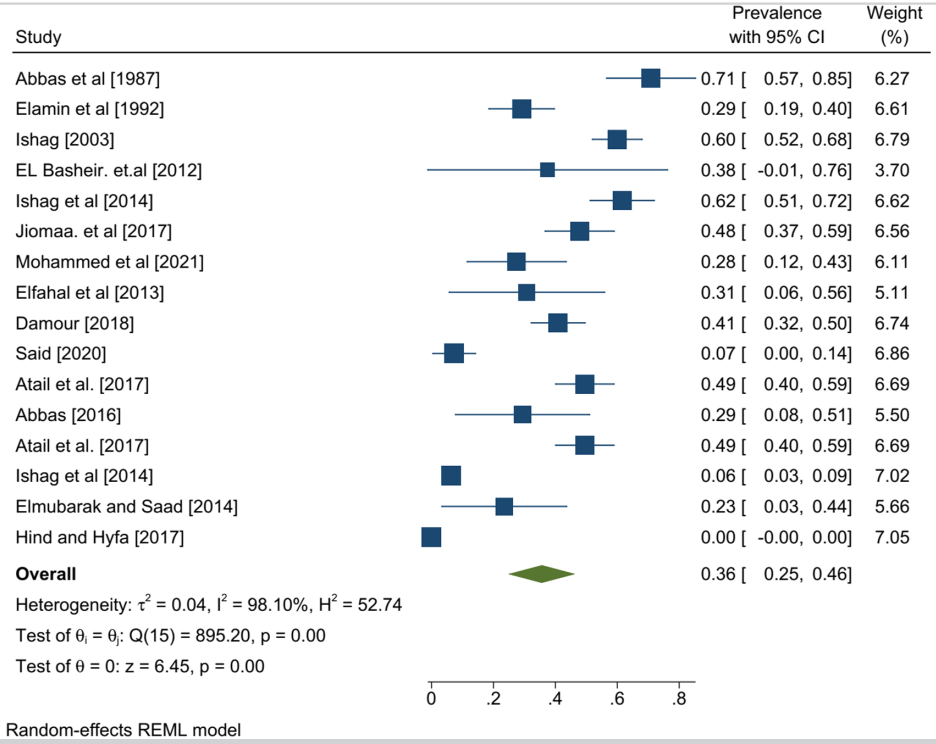

Figure 3.
Forest Plot (Random-Effects Model) for the Pooled Prevalence of Toxoplasma gondii in Male Domestic Animals in Sudan.

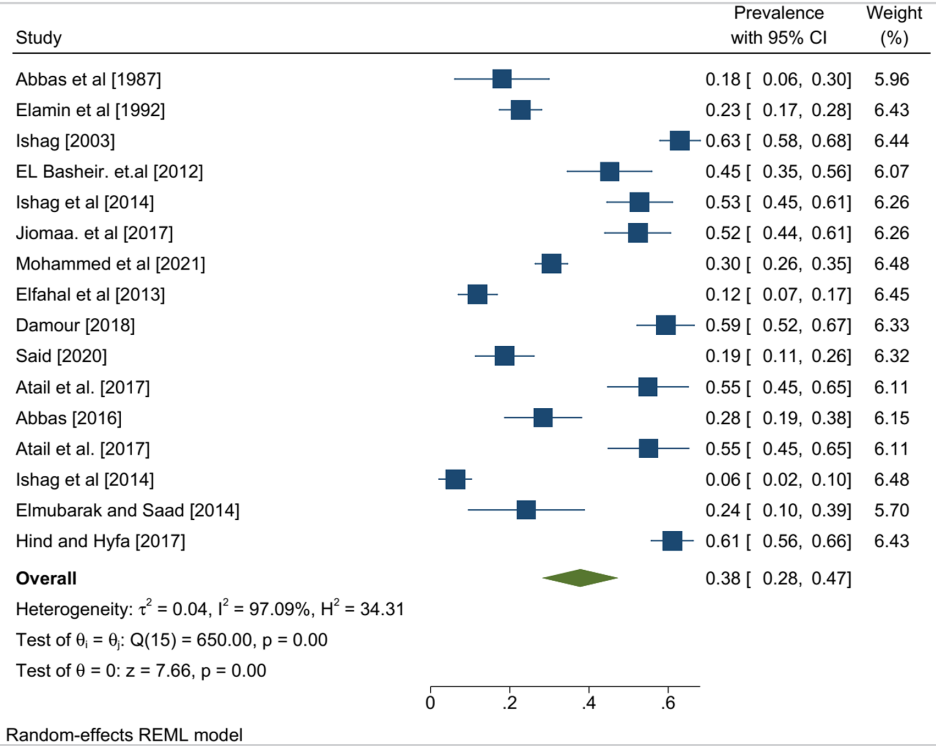

Figure 4.
Forest Plot (Random-Effects Model) for the Pooled Prevalence of Toxoplasma gondii in Female Domestic Animals in Sudan.

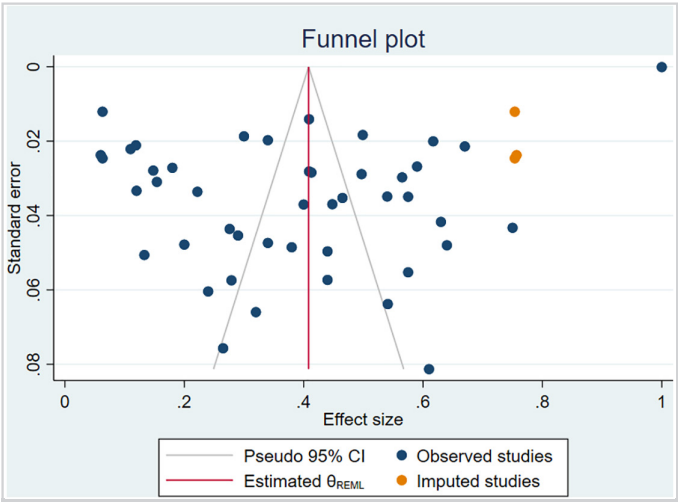

Figure 5.
Funnel Plot for Assessing Publication Bias in the Pooled Prevalence of Toxoplasma gondii in Domestic Animals in Sudan.

derived from undercooked meat. The free-range chickens have the highest prevalence of *T. gondii* compared with other meat animals. A similar result was found in China (Dong et al., 2018), Algeria (Ouchetati et al., 2020), and Africa (Tonouhewa et al., 2017). However, in the United States, chickens have the second highest prevalence of *T. gondii* after goats (Guo et al., 2016). This high prevalence of *T. gondii* in chickens may be due to the feeding behaviors of the free-range chicken (Dal Bosco et al., 2014). After chicken, sheep were found to be the second most infected animals followed by the goat, camel, and cattle. Similar results were found in Ethiopia and Iran (Gebremedhin & Tadesse, 2015; Sharif et al., 2015). Meanwhile, in Algeria and China, goats had the highest prevalence of *T. gondii* followed by sheep and then cattle (Dong et al., 2018; Ouchetati et al., 2020) while the cattle and camel had the highest prevalence of *T. gondii* in Nigeria and Africa, respectively (Karshima et al., 2020; Tonouhewa et al., 2017). The difference in the prevalence of *T. gondii* among animals may be due to animals' feeding behaviors and husbandry methods (Dias e Silva & Abdalla Filho 2020). Although cats are definitive hosts of *T. gondii*, the prevalence of *T. gondii* in cats is 30% and this is relatively low compared to the prevalence of *T. gondii* observed in some other animals. Almost similar results were reported in Nigeria (29.58%) and Iran (33.6%) (Karshima et al., 2020; Rahimi et al., 2015). In contrast, a higher prevalence of *T. gondii* in cats was found in Algeria (70.31%), Ethiopia (87.72%), and Africa (51%) (Gebremedhin & Tadesse, 2015; Montazeri et al., 2020; Ouchetati et al., 2020). Meanwhile, a lower prevalence (20.3%) was found in China (Ding et al., 2017).

Table 2.
Summary Table of the Data from Included Studies Showing the Pooled Prevalence of Toxoplasma Gondii *Infection in Different Animal Species in Sudan Using the Random Effect Model*

Animal Species		Number of Studies	Pooled Sample Size	Pooled Prevalence % (95% CI)	Heterogeneity (I^2 %, *p*-value)
Camel	Overall	12	2976	40 (29–52)	97.6, $p < .001$
	Male	7	961	49 (36–62)	86.77, $p < .001$
	Female	7	1478	41 (28–53)	96.09, $p < .001$
Cattle	Overall	11	3434	31 (22–40)	97.27, $p < .001$
	Male	3	190	26 (4–47)	91.79, $p < .001$
	Female	3	453	30 (1–59)	98.36, $p < .001$
Sheep	Overall	8	1531	45 (30–60)	97.41, $p < .001$
	Male	1	108	50 (40–60)	-
	Female	1	92	55 (45–66)	-
Goat	Overall	6	731	41 (25–57)	95.78, $p < .001$
	Male	2	125	42 (23–61)	-
	Female	2	175	42 (16–68)	-
Horse	Overall	2	505	32 (20.24–43.79)	-
	Male	1	272	6.3 (3.6–9.8)	-
	Female	1	133	6.2 (2.6–11.5)	-
Donkey	Overall	2	205	16 (5–38)	-
Cat	Overall	2	150	30 (20–39)	-
	Male	1	17	24 (6.8–50)	-
	Female	1	33	24 (11–42)	-
Chicken	Overall	2	394	80 (39–100)	-
	Male	1	7	0	-
	Female	1	329	61 (55.6–66.4)	-

This present study observed lowest prevalence of *T. gondii* in horses and donkeys among all domestic animals in Sudan. This report is in agreement with findings in Algeria and Nigeria (Karshima et al., 2020; Ouchetati et al., 2020).

Despite the seriousness of *T. gondii* infection in Sudan as presented in this study, no data is available about the economic impact of the disease on the livestock sector and public health sector in the country; thus, a work needs to be done to cover the gap in this area. In addition, a collaborative effort and immediate action need to be taken from the policymakers and governments (federal and state government) to adopt a national wide epidemiological program to clarify the design of regional strategies and to guide the development of prevention and eradication programs in light of one health concept. Finally, with the help of the authorities, molecular diagnostic tools need to be adopted, particularly in public laboratories, to better understand and diagnose the disease (Li et al., 2020).

This is the first comprehensive quantitative meta-analysis summarizing available evidence to determine the pooled prevalence of *T. gondii* infections in animals in Sudan.

Strengths and Limitations

This study used extensive and comprehensive search strategies and included published, unpublished, and gray literature. The study also used a standardized tool to evaluate the methodological quality of the studies. Studies with abstracts were the only ones included. However, the limitations of the current study can be listed as the following: the absence of some data about the animal ages, breeds, and other potential risk factors in some studies, together with the relatively small sample size of some studies; the small number of studies for some species such as horses, donkeys, and chickens; and the use of different diagnostic tests in various studies. Thus, all the above-mentioned limitations may raise questions about their representativeness.

The results of this meta-analysis suggested that the pooled prevalence of *T. gondii* infections in Sudanese domestic animals is 38%, and the females were more susceptible to infection compared to males. The highest and lowest pooled prevalence of *T. gondii* was found in chickens and donkeys, respectively. The interpretation of these findings should take into consideration the presence of substantial heterogeneity among the included studies. Further studies need to be carried out to clarify the role of dogs and domestic birds in the epidemiology of the disease in Sudan.

Availability of Data, Code, and Other Materials

The data that support the review findings of this study are available upon submitting a reasonable request from the corresponding author.

Registration and Protocol

This review was developed base on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline. The review has been registered protocol by the International prospective register of systematic reviews (CRD42021256067) https://www.crd.york.ac.uk/Prospero/#recordDetails

Ethics Committee Approval: This study was carried out in strict accordance with the recommendations in the PRISMA guidelines. Ethics committee or institutional review board permission was not required since it is a systematic review and meta-analysis.

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References

Abbas, B., El Zubeir, A. E. A., & Yassin, T. T. M. (1987). Survey for certain zoonotic diseases in camels in Sudan. *Revue d'Elevage et de Medecine Veterinaire des Pays Tropicaux*, *40*(3), 231–233. [CrossRef]

Abbas, S. A. M. (2016). *Seroprevalence of Toxoplasma gondii infection in goats in Khartoum State, Sudan. MSc*. Sudan: University of Khartoum.

Abdelbaset, A. E., Mossaad, E., Ismail, A. A., Ibrahim, A. M., Xuan, X., Suganuma, K., ... & Igarashi, M. (2020). Seroprevalence of Toxoplasma gondii in Farm Animals in West Kordofan, and Blue Nile states, Sudan. *Journal of Protozoology Research*, *30*, 21–26. [CrossRef]

Abdelnabi, G., Hassan, S., Abdelgadir, A., & Elamin, E. (2016). Meat-borne parasites a health hazard concern in the Sudan: A review. *Animal and Veterinary Sciences*, *4*(6), 103–107. [CrossRef]

Aguirre, A. A., Longcore, T., Barbieri, M., Dabritz, H., Hill, D., Klein, P. N., Lepczyk, C., Lilly, E. L., McLeod, R., Milcarsky, J., Murphy, C. E., Su, C., VanWormer, E., Yolken, R., & Sizemore, G. C. (2019). The one health approach to toxoplasmosis: Epidemiology, control, and prevention strategies. *EcoHealth*, *16*(2), 378–390. [CrossRef]

Ahmed, S. M., Ibrahim, A. M., Alshafie, N. K., Mohammed, R. H., Ismail, A. A., & Angara, T. E. E. (2013). The first report on sero-prevalence of Toxoplasma gondii in working horses and donkeys in the Sudan. *Journal of Life Sciences*, *7*(12), 1284–1287.

Ali, A. A. (2012). *Detection of the Rate of anti-Toxoplasma gondii antibodies among the Humans, Cattle and Sheep Population in Khartoum State using the latex Agglutination and ELISA Tests. MSc*. Sudan: University of Khartoum.

Atail, H. B., Ibrahaem, H. H., Shuaib, Y. A., Mohamed, A. K., Suliman, S. E., Idris, S. H., & Abdalla, M. A. (2017). Sero-prevalence of toxoplasmosis in sheep and goats in El-Gadarif state. *Journal of Advanced Veterinary and Animal Research*, *4*(2), 207–213. [CrossRef]

Babiker, B. I., Abdullah, A. M., & Al-Feel, M. A. (2011) Sudanese live sheep and mutton exports competitiveness. *Journal of the Saudi Society of Agricultural Sciences*, *10*(1), 25–32. [CrossRef]

Bahnass, M. M., El-Shahawy, I. S., & Fawzi, E. M. (2015). Comparative analysis of toxoplasmosis in farm animals by indirect hemagglutination assay and enzyme linked immunosorbent assay. *Alexandria Journal of Veterinary Sciences*, *46*, 15–19.

Dabritz, H. A., & Conrad, P. A. (2010). Cats and Toxoplasma: Implications for public health. *Zoonoses and Public Health*, *57*(1), 34–52. [CrossRef]

Dal Bosco, A., Mugnai, C., Rosati, A., Paoletti, A., Caporali, S., & Castellini, C. (2014). Effect of range enrichment on performance, behavior, and forage intake of free-range chickens. *Journal of Applied Poultry Research*, *23*(2), 137–145. [CrossRef]

Damour, N. M. A. (2018). *Sero-prevalence of toxoplasmosis in cattle in el-Gadarif State. MSc*. Sudan: Sudan University of Science & Technology.

Dias e Silva, T. P., & Abdalla Filho, A. L. (2020). Sheep and goat feeding behavior profile in grazing systems. *Acta Scientiarum. Animal Sciences*, *43*. [CrossRef]

Ding, H., Gao, Y. M., Deng, Y., Lamberton, P. H., & Lu, D. B. (2017). A systematic review and meta-analysis of the seroprevalence of Toxoplasma gondii in cats in mainland China. *Parasites and Vectors*, *10*(1), 27. [CrossRef]

Dong, H., Su, R., Lu, Y., Wang, M., Liu, J., Jian, F., & Yang, Y. (2018). Prevalence, risk factors, and genotypes of Toxoplasma gondii in food animals and humans (2000–2017) from China. *Frontiers in Microbiology*, *9*, 2108. [CrossRef]

Dubey, J. P. (2010). Toxoplazmosis of animals and humans (2nd ed.). *CRC Press*, Francis and Taylor Group, USA.

Dubey, J. P. (2016). *Toxoplasmosis of animals and humans*. Boca Raton: CRC press.

Dubey, J. P., Lappin, M. R., & Thulliez, P. (1995). Long-term antibody responses of cats fed Toxoplasma gondii tissue cysts. *Journal of Parasitology*, *81*(6), 887–893. [CrossRef]

El Bashier, H. M. E., Elias, S., & Abdel-Aziz, B. E. (2012). Serosurveillance of Toxoplasma gondii antibodies in camels at Tumbool slaughterhouse, central Sudan. Sudan. *Journal of Veterinary Research*, *27*, 65–67.

El Bissati, K., Levigne, P., Lykins, J., Adlaoui, E. B., Barkat, A., Berraho, A., Laboudi, M., El Mansouri, B., Ibrahimi, A., Rhajaoui, M., Quinn, F., Murugesan, M., Seghrouchni, F., Gómez-Marín, J. E., Peyron, F., & McLeod, R. (2018). Global initiative for congenital toxoplasmosis: An observational and international comparative clinical analysis. *Emerging Microbes and Infections*, *7*(1), 165. [CrossRef]

Elamin, E. A., Elias, S., Daugschies, A., & Rommel, M. (1992). Prevalence of Toxoplasma gondii antibodies in pastoral camels (Camelus dromedarius) in the Butana plains, mid-Eastern Sudan. *Veterinary Parasitology*, *43*(3–4), 171–175. [CrossRef]

Elfahal, A. M., Elhassan, A. M., Hussien, M. O., Enan, K. A., Musa, A. B., & El Hussein, A. M. (2013). Seroprevalence of Toxoplasma gondii in dairy cattle with reproductive problems in Sudan. *ISRN Veterinary Science*, *2013*, 895165. [CrossRef]

Elmubarak, S. I., & Saad, A. M. (2014). Seroprevalence of Toxoplasma gondii in stray cats (*Felis domesticus*) in Khartoum area. *Journal of Veterinary Medicine and Animal Production*, *5*(1), 36–41.

Food and Agriculture Organization, & World Health Organization (2013). *Food safety situation in Sudan. Prepared in honor of the 50th anniversary of the codex Alimentarius commission*.

Foroutan-Rad, M., Majidiani, H., Dalvand, S., Daryani, A., Kooti, W., Saki, J., Hedayati-Rad, F., & Ahmadpour, E. (2016). Toxoplasmosis in blood donors: A systematic review and meta-analysis. *Transfusion Medicine Reviews*, *30*(3), 116–122. [CrossRef]

Freyre, A., Bonino, J., Falcón, J., Castells, D., Correa, O., & Casaretto, A. (1999). The incidence and economic significance of ovine toxoplasmosis in Uruguay. *Veterinary Parasitology*, *81*(1), 85–88. [CrossRef]

Gebremedhin, E. Z., & Tadesse, G. (2015). A meta-analysis of the prevalence of Toxoplasma gondii in animals and humans in Ethiopia. *Parasites and Vectors*, *8*(1), 291. [CrossRef]

Guo, M., Mishra, A., Buchanan, R. L., Dubey, J. P., Hill, D. E., Gamble, H. R., Jones, J. L., & Pradhan, A. K. (2016). A systematic meta-analysis of Toxoplasma gondii prevalence in food animals in the United States. *Foodborne Pathogens and Disease*, *13*(3), 109–118. [CrossRef]

Higgins, J. P., Thompson, S. G., Deeks, J. J., & Altman, D. G. (2003). Measuring inconsistency in meta-analyses. *BMJ*, *327*(7414), 557–560. [CrossRef]

Hill, D. E., Chirukandoth, S., & Dubey, J. P. (2005). Biology and epidemiology of Toxoplasma gondii in man and animals. *Animal Health Research Reviews*, *6*(1), 41–61. [CrossRef]

Hind, A. A., & Hayfa, M. I. (2017). Prevalence of Toxoplasma gondii antibodies in chickens and pigeons in Khartoum State, Sudan. *Journal of Veterinary Medicine and Animal Production*, *8*(2), 112–122.

Hussien, M. O., Hassan Alfaki, S., & Mohamed El Hussein, A. R. (2017). Seroprevalence of Toxoplasma gondii in chickens (Gallus domesticus) in Sudan. *International Journal of Infection*, *4*(3), e40312. [CrossRef]

Ibrahim, A. M., Ismail, A. A., Angara, T. E. E., & Osman, O. M. (2014). Serological Survey on Toxoplasma gondii in Dairy Cows from the Sudan using ELISA. *Global Journal of Animal Science, Livestock Production and Animal Breeding*, *2*(3), 114–118.

Ibrahim, A. M., Ismail, A. A., & Angara, T. E. E. (2015). Analysis of risk factors associated with seroprevalence of Toxoplasma gondii in dairy animals from Khartoum State, Sudan. *Sudan Journal of Science and Technology*, *16*(1), 19–28.

Ishag, M. Y. (2003). *Studies on toxoplasma and sarcocystis from camels (Camelus dromedaries) in the Sudan. PhD*. Sudan: University of Khartoum.

Ishag, M. Y., Ali, Y. H., & Majid, A. M. (2014a). Toxoplasma gondii and Rotavirus associated with camel-calf diarrhea in Sudan. *Journal of Veterinary Medicine and Animal Production*, *5*(1), 20–28.

Ishag, M. Y., Majid, A. M., & Abuobeida, M. M. (2014b). Studies on toxoplasmosis in horses in Khartoum state-Sudan. *Journal of Veterinary Medicine and Animal Production*, *5*(1), 29–35.

Jiomaa, A. M. A., Abdalla, M. A., & Idris, S. H. (2017). Prevalence of camels toxoplasmosis in Gedarif State Eastern Sudan. 3rd International Scientific Conference of Camel Research and Production (ISCCRP). Khartoum-Sudan.

Karshima, S. N., Karshima, M. N., Karaye, G. P., & Oziegbe, S. D. (2020). Toxoplasma gondii infections in birds, companion, food and recreational animals in Nigeria: A systematic review and meta-analysis. *Veterinary Parasitology, Regional Studies and Reports*, *21*, 100418. [CrossRef]

Khalil, K. M., & Elrayah, I. E. (2011). Seroprevalence of Toxoplasma gondii antibodies in farm animals (camels, cattle, and sheep) in Sudan. *Journal of Veterinary Medicine and Animal Health*, *3*(3), 36–39. [CrossRef]

Khalil, K. M., Gadir, A. E. A., Rahman, M. M. A., Yassir, M., O., Ahmed, A. A., & Elrayah, I. E. (2007). Prevalence of Toxoplasma gondii antibodies in camels and their herders in three ecologically different areas in Sudan. *Journal of Camel Practice and Research*, *14*(1), 11–13.

Lazim, S. A. M., Ibrahim, A. M., & Ahmed, A. B. (2018). Seroprevalence of Toxoplasma gondii in cattle, Sheep and Goats from River Nile State, Sudan. *Multidisciplinary Advances in Veterinary Science*, *2*(2), 332–337.

Li, X., Ni, H. B., Ren, W. X., Jiang, J., Gong, Q. L., & Zhang, X. X. (2020). Seroprevalence of Toxoplasma gondii in horses: A global systematic review and meta-analysis. *Acta tropica*, *201*, 105222.[CrossRef]

Medani, M. Y. I., & Kamil, I. Y. (2014). Serosurvey of Toxoplasma gondii in sheep and cattle for human consumption in Khartoum slaughterhouses, Sudan. *International Journal of Infectious Diseases*, *21*, 157. [CrossRef]

Mohammed, M. S., Mohamed, M. A. A., Bala, A. E., & Abakar, A. D. (2021). Seroprevalence of toxoplasmosis among one-hampered camels (Camelus dromedarius) in AL Butana plain, Sudan. *International Journal of Veterinary Sciences and Animal Husbandry*, *6*(2), 04–08. [CrossRef]

Montazeri, M., Mikaeili Galeh, T. M., Moosazadeh, M., Sarvi, S., Dodangeh, S., Javidnia, J., Sharif, M., & Daryani, A. (2020). The global serological prevalence of Toxoplasma gondii in felids during the last five decades (1967–2017): A systematic review and meta-analysis. *Parasites and Vectors*, *13*(1), 82. [CrossRef]

Ouchetati, I., Ouchene, N., Khelifi-Ouchene, N. A., Khelifi, M., Dahmani, A., Haïf, A., Zeroual, F., & Benakhla, A. (2020). Prevalence of Toxoplasma gondii infection among animals in Algeria: A systematic review and meta-analysis. *Comparative Immunology, Microbiology and Infectious Diseases*, 101603. [CrossRef]

Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., et al. (2021). PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. *BMJ*, *372*, n160. [CrossRef]

Rahimi, M. T., Daryani, A., Sarvi, S., Shokri, A., Ahmadpour, E., Teshnizi, S. H., Mizani, A., & Sharif, M. (2015). Cats and Toxoplasma gondii: A systematic review and meta-analysis in Iran. *Onderstepoort Journal of Veterinary Research*, *82*(1), e1–e10. [CrossRef]

Said, S. N. M. (2020). *Sero-prevalence and risk factors associated with Toxoplasma gondii in cattle in Sharg Elnil and Omdurman localities, Khartoum State, Sudan. MSc*. Sudan: Sudan University of Science & Technology.

Sharif, M., Sarvi, Sh, Shokri, A., Hosseini Teshnizi, S. H., Rahimi, M. T., Mizani, A., Ahmadpour, E., & Daryani, A., & Daryani, A. (2015). Toxoplasma gondii infection among sheep and goats in Iran: A systematic review and meta-analysis. *Parasitology Research*, *114*(1), 1–16. [CrossRef]

Siddig, A. B. (2009). *Study on toxoplasmosis in humans and cats in the red sea statre, Sudan MSc*. Sudan: Sudan University of Science & Technology.

Stelzer, S., Basso, W., Benavides Silván, J. B., Ortega-Mora, L. M., Maksimov, P., Gethmann, J., Conraths, F. J., & Schares, G., & Schares, G. (2019). Toxoplasma gondii infection and toxoplasmosis in farm animals: Risk factors and economic impact. *Food and Waterborne Parasitology*, *15*, e00037. [CrossRef]

Tonkal, A. M. (2008). PCR versus ELISA in diagnosis of human toxoplasmosis in Jeddah, Saudi Arabia. *Journal of the Egyptian Society of Parasitology*, *38*(3), 707–714.

Tonkin, C. J. (2020). *Toxoplasma gondii methods and protocols*. Berlin: Springer.

Tonouhewa, A. B. N., Akpo, Y., Sessou, P., Adoligbe, C., Yessinou, E., Hounmanou, Y. G., Assogba, M. N., Youssao, I., & Farougou, S., Youssao, I., & Farougou, S. (2017). Toxoplasma gondii infection in meat animals from Africa: Systematic review and meta-analysis of sero-epidemiological studies. *Veterinary World*, *10*(2), 194–208. [CrossRef]

Zain Eldin, E. A., Elkhawad, S. E., & Kheir, H. S. M. (1985). A serological survey for Toxoplasma antibodies in cattle, sheep, goats and camels (Camelus dromedarius) in the Sudan. *Revue d'Elevage et de Medecine Veterinaire des Pays Tropicaux*, *38*(3), 247–249. [CrossRef]