



## Review

# A Meta-Analysis of the Prevalence of Toxoplasmosis in Livestock and Poultry Worldwide

Bahador Hajimohammadi,<sup>1,2</sup> Salman Ahmadian,<sup>3</sup> Zohre Firoozi,<sup>2</sup> Maryam Askari,<sup>4</sup> Masoud Mohammadi,<sup>5</sup> Gilda Eslami<sup>1,3</sup>, Vahideh Askari,<sup>1</sup> Elahe Loni,<sup>1</sup> Raziye Barzegar-Bafrouei,<sup>2</sup> and Mohammad Javad Boozhmehrani<sup>3</sup>

<sup>1</sup>Research Center for Food Hygiene and Safety, Shahid Sadoughi University of Medical Sciences, Shohadaye Gomnam Blvd., Yazd 8916188638, Islamic Republic of Iran

<sup>2</sup>Department of Food Hygiene and Safety, School of Public Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran

<sup>3</sup>Department of Parasitology and Mycology, School of Medicine, Shahid Sadoughi University of Medical Sciences, Yazd, Iran

<sup>4</sup>Diabetes Research Center, Shahid Sadoughi University of Medical Sciences, Yazd, Iran

<sup>5</sup>Cellular and Molecular Research Center, Gerash University of Medical Sciences, Gerash, Iran

**Abstract:** *Toxoplasma gondii* causes toxoplasmosis with a global prevalence in the world. A large proportion of human illness is most frequently associated with consuming raw and undercooked meat or other animal products containing infective parasitic stages of *T. gondii*. This systematic review and meta-analysis study evaluated the prevalence of toxoplasmosis in cattle, sheep, camels, goats, and poultry worldwide. The search was performed in databases including PubMed, WoS, Scopus, Science Direct, Google Scholar, and ISC from 2000 to 2019 in Persian and English. The main inclusion criteria were the prevalence of toxoplasmosis among livestock and poultry and the prevalence indices by sample size. During these 20 years, the overall prevalence of toxoplasmosis in livestock and poultry was 28.3% (95% confidence interval (CI) 25–31.9%) using the random-effects meta-analysis model. The highest prevalence of *T. gondii* in livestock and poultry animals was found in Asia in 2014 with 89.8% (95% CI 78.5–95.5%). The lowest prevalence was found in Asia in 2013 with 1.26% (95% CI 0.4–3.8%). A quarter of livestock and poultry were infected with *T. gondii*. Since livestock products are globally important sources of people's diet, our findings are useful for policymakers to control *T. gondii* infection in livestock.

**Keywords:** *Toxoplasma gondii*, Systematic review, Worldwide, Prevalence, Livestock animals

## INTRODUCTION

*Toxoplasma gondii* is an obligate intracellular opportunistic parasite that is the causative agent of toxoplasmosis with a

global prevalence in most parts of the world (Mammari et al. 2019). This zoonotic infection represents a major public health problem in human and veterinary medicine (Aguirre et al. 2019).

*T. gondii* infects a broad spectrum of warm-blooded vertebrates, including humans as intermediate hosts. On the other hand, cat family members (Felidae) are the only known definitive hosts of this infection (Dubey and Jones 2008). Besides, *T. gondii* has different forms of trophozoite,

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Correspondence to: Gilda Eslami, e-mail: [eslami\\_g2000@yahoo.com](mailto:eslami_g2000@yahoo.com)

oocyst, and tissue cyst (Dubey et al. 1998). Most transmission routes that humans acquire toxoplasmosis are ingestion of oocysts (shed by infected cats) or tissue cysts of contaminated food or water and raw or semi-raw meat, respectively (Mosallanejad et al. 2011). Also, the consumption of infected raw milk is a possible route of tachyzoite transmission to humans (Koethe et al. 2017). Additionally, *T. gondii* can cross the placenta in some species, particularly humans, sheep, goats, camels, and cattle (Stelzer et al. 2019). These animals become easily infected through ingestion or inhalation of oocysts with food or water sources (Sharif et al. 2015). This parasite is involved in reproductive failure and production losses in livestock. As a result, toxoplasmosis in livestock animals is responsible for economic losses through death, abortion, and neonatal mortality.

It is estimated that 1.5 billion individuals are infected with this parasite worldwide. However, at least one-third of the world's human population has antibodies against *Toxoplasma* (Hill and Dubey 2013). Infection with *T. gondii* causes clinical manifestations of toxoplasmosis, including lymphadenopathy and blindness (Weiss and Dubey 2009). *T. gondii* infection in healthy adults is asymptomatic, but it has a greater impact on immunocompromised individuals (Wang et al. 2017).

Studies showed that the prevalence of infection caused by *T. gondii* in livestock varies greatly depending on the localities of the world (Dong et al. 2018; Holec-Gasior et al. 2013; Boughattas and Bouratbine 2014). Therefore, consuming contaminated meat and milk of infected animals can damage human health (Boughattas 2017; Dalir Ghaffari and Dalimi 2019; Boughattas and Bouratbine 2015). Because of the high importance of this issue, this systematic review with meta-analysis was performed to evaluate the prevalence of toxoplasmosis in cattle, sheep, camels, goats, and poultry worldwide.

## METHODS

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### Search Strategy

This study was conducted according to the preferred reporting items for systematic reviews and meta-analysis (PRISMA guideline 2009) (Moher et al. 2010). For this purpose, we conducted a systematic search of articles from English and Persian databases to address the prevalence of *T. gondii* infection in livestock animals (cattle, sheep, ca-

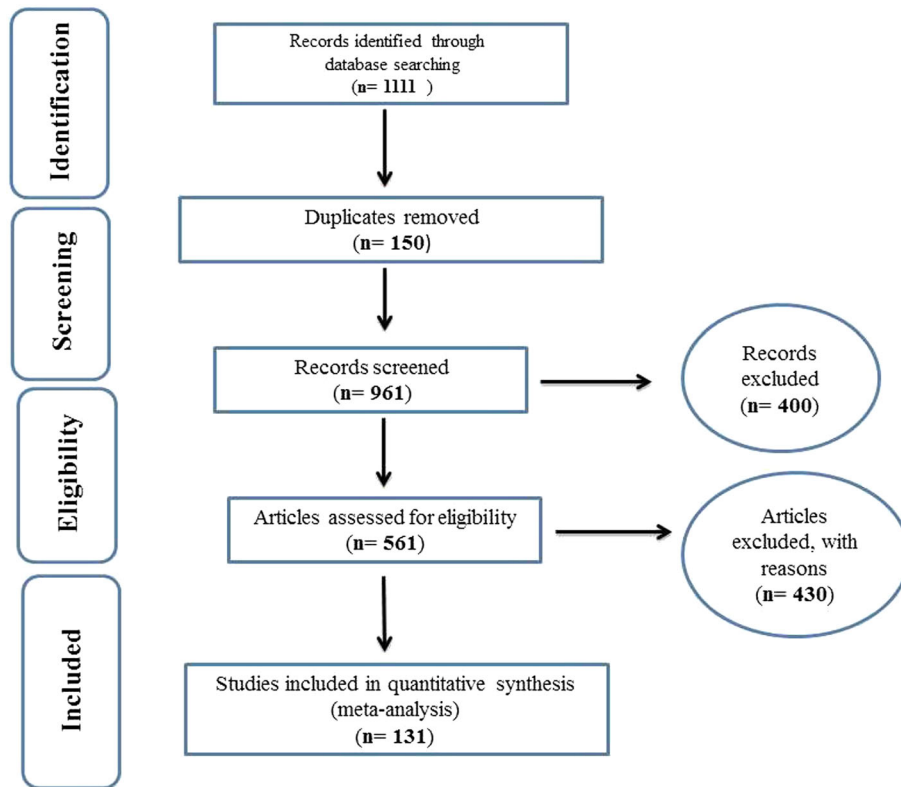
mels, goats) and poultry all around the world. Data were collected from electronic databases, including PubMed, WoS, Scopus, Science Direct, Google Scholar, and Islamic World Science Citation (ISC) from 2000 to 2019. The inclusion criteria were the main epidemiological parameters of interest: the prevalence of toxoplasmosis among livestock and poultry and the prevalence indices by sample size. This research was conducted using the Medical Subject Headings (MeSH) terms as "*Toxoplasma*", "*Toxoplasma gondii*", "Toxoplasmosis", "*T. gondii*", "Prevalence", "Goat", "Sheep", "Camel", "Cattle", "Toxoplasmosis in Animal", and "Livestock" combined using OR and/or AND.

### Selecting Studies and Data Extraction

We searched all mentioned databases comprehensively; then, the relevant articles were selected based on the title and abstract content. Two independent reviewers evaluated the papers in parallel. If the article was rejected, the reason for the rejection was mentioned, and in the case of disagreement between the two reviewers, the third reviewer evaluated the article. The remaining articles were read in full text and screened for eligibility using a checklist of inclusion–exclusion criteria. The data, including title, year of publication, prevalence rate, location of study, the corresponding author, aims, main findings, sample size, and diagnostic methods, were extracted carefully from databases. Additionally, reference lists of published data were examined to extend the research and prevent missing additional studies.

### Statistical Analysis

In each study, the prevalence of toxoplasmosis was obtained in livestock animals. The meta-analysis was performed using comprehensive meta-analysis software (Biostat, Englewood, NJ, USA) version 3. The heterogeneity of the studies was assessed by  $I^2$  statistics. Heterogeneity was classified into three categories: heterogeneity less than 25% (low level of heterogeneity), between 25 and 75% (average level of heterogeneity), and more than 75% (high level of heterogeneity). The probability of publication bias in the result was investigated using the funnel plot and Egger's test. Furthermore, publication bias in the results was measured using Begg and Mazumdar rank correlation test at a significance level of 0.1 due to the large sample size



**Figure 1.** The flowchart on the stages of including the studies in the systematic review and meta-analysis (PRISMA 2009).

(Begg and Mazumdar 1994; Egger et al. 1997). Meta-regression was used for the sample size to investigate the effects of potentially effective factors on heterogeneity in the prevalence of *T. gondii* worldwide.

## RESULTS

### Search Output and Eligible Studies

We identified 1111 documents following the initial literature search of national and international databases using relevant keywords; after removing 150 duplicated papers, the number of remaining articles decreased to 961. A total of 400 irrelevant documents were excluded by reviewing the title and/or abstracts. Also, after a full-text review and using a checklist of inclusion–exclusion criteria, 430 irrelevant records were removed. Eventually, 131 articles were qualified to be included in this systematic review and meta-analysis, including 54 studies in Asia, 21 studies in Europe, 37 studies in Africa, 12 studies in South America, and seven studies in North America. A flow diagram depicting the study selection process is presented in Figure 1.

### Characteristics of the Eligible Studies

Tables 1, 2, 3 and 4 show the characteristics of the final 131 articles eligible for inclusion which contain information from selected papers, including the name of the researcher, the year and place of the study, the number of samples, the kind of animal, diagnostic assay, and the prevalence of *T. gondii* in the studies. Our analysis contains 61,716 infected animals from 45 countries and five continents. The maximum sample size was related to the study conducted by Verhelst et al. (2014) in Belgium (3170 sheep), and the minimum sample size ( $n = 24$ , goat) was reported from Japan by Kyan et al. (2012). The diagnostic methods used in eligible studies were enzyme-linked immunosorbent assay (ELISA), indirect fluorescent antibody test (IFA), total lysate antigens (TLA), direct agglutination test (DAT), modified agglutination test (MAT), latex agglutination test (LAT), polymerase chain reaction (PCR), nested PCR, and real-time PCR.

### Heterogeneity and Publication Bias

The heterogeneity of the studies was evaluated using the  $I^2$  test, and the results showed  $I^2 = 98\%$ . The high I-squares

**Table 1.** Baseline Characteristics of Selected Studies Reporting Seroprevalence of *T. gondii* in Animals in Europe.

Authors (References)	Country	Kind of animals	Diagnostic method	Sample size	Prevalence (%)
Deng et al. (2016)	Netherlands	Dairy goat	ELISA	1664	13.3
Lorencová et al. (2016)	Czech	Goat, lamb	ELISA, real-time PCR	57	28.07
Lopes et al. (2015)	Portugal	Cattle, sheep, goat	Nested PCR	75	68
Sechi et al. (2013)	Italy	Sheep	IFA	630	33.97
Misurova et al. (2009)	Czech	Goat	IFA	28	82.1
Cenci-Goga et al. (2013)	Italy	Sheep	IFA	630	34
Balea et al. (2012)	Romania	Sheep, goat	ELISA	513	44.2
Moskwa et al. (2018)	Poland	Sheep, goat	ELISA	103	36.8
Roqueplo et al. (2011)	France	Cattle	ELISA	30	3.3
Tzanidakis et al. (2012)	Greece	Sheep, goat	ELISA	2042	43.8
Garcia et al. (2013)	Spain	Cattle, sheep, goat	ELISA	1501	52.56
Luptakova et al. (2015)	Slovakia	Ewes	real-time PCR, ELISA	80	31.25
Verhelst et al. (2014)	Belgium	Sheep	ELISA (TLA), IFA	3170	87.4
Sroka et al. (2017)	Poland	Goat	DAT, Nested – PCR, real- time PCR	73	70
Vismarra et al. (2016)	Italy	Chicken	ELISA	66	36.4
Villena et al. (2012)	France	Ovine	ELISA, MAT, Bioassay	419	27
Diakoua et al. (2013)	Greece	Sheep, goat	ELISA	833	57.1
Iovu et al. (2012)	Romania	Dairy goat	ELISA	735	52.8
Morley et al. (2008)	UK	Sheep	PCR	29	31
Djokic et al. (2014)	Serbia	Goat	MAT	431	73.3
Stormoen et al. (2012)	Norwegian	Dairy goat	DAT	2188	17

ELISA enzyme-linked immunosorbent assay, IFA indirect fluorescent antibody, TLA total lysate antigen, DAT direct agglutination test, MAT modified agglutination test, PCR polymerase chain reaction.

indicate considerable heterogeneity between the results. Therefore, a random-effects model was used to combine the results of the studies. The funnel plot indicated no publication bias, and Begg's and Egger's tests were not statistically significant ( $P = 0.890$ ) (Fig. 2).

### Meta-Analysis

In this 20-year survey, the prevalence of toxoplasmosis in livestock and poultry in the continents of Asia, Africa, America (North and South), and Europe was 21.7% (95% CI 18.3–25.6%), 29% (95% CI 23.9–34.7%), 16.4% (95% CI 8.6%–29%), 38.5% (95% CI 31–46.5%), and 43.5% (95% CI 32.1–55.6%), respectively (Figs. 3, 4, 5, 6, 7); and the overall prevalence using the random-effects meta-analysis model was 28.3% (95% CI 25–31.9%) (Fig. 8). The highest prevalence of *T. gondii* in livestock and poultry was in Iran and Asia in 2014 with 89.8% (95% CI 78.5–95.5%), while the lowest prevalence was also in Iran and Asia in 2013 with 1.26% (95% CI 0.4–3.8%). It should be men-

tioned that the prevalence rate of this parasite in India (2017) was 1.5%.

In Figures 3, 4, 5, 6, 7 and 8, test displays the prevalence of toxoplasmosis based on the random-effects model, with black squares representing the prevalence, square section length showing 95% CI in each study, and the diamond sign indicating the total prevalence in the country for all studies. The studies' range in the chart is considered between 1 and -1. As can be seen in the figures, the prevalence values are positive and greater than zero.

### Meta-Regression

Meta-regression was used for the sample size to investigate the effects of potentially effective factors on heterogeneity in the prevalence of toxoplasmosis in livestock and poultry in the world (Fig. 9). The prevalence of *T. gondii* infection increases with the growing sample size in the studies, and statistically significant differences were found ( $P < 0.05$ ).

**Table 2.** Baseline Characteristics of Selected Studies Reporting Seroprevalence of *T. gondii* in Animals in Asia.

Authors (references)	Country	Kind of animals	Diagnostic method	Sample size	Prevalence (%)
Olfaty-Harsini et al. (2017)	Iran	Ewe	Nested PCR	60	48.3
Havakhah et al. (2014)	Iran	Sheep, goat	Sabin-Feldman Dye	402	27.6
Akhoundi and Youssefi (2017)	Iran	Sheep	IFA	764	28.2
Sharif et al. (2005)	Iran	Cattle, sheep, goat	IFA	1278	25.4
Khamesipour et al. (2014)	Iran	Cattle, camel, sheep	PCR	372	6.7
Azizi et al. (2014)	Iran	Sheep, cattle	PCR	120	20.8
Sarkari et al. (2014)	Iran	reared turkey	PCR, MAT, Bioassay	54	89.8
Tavakoli et al. (2017)	Iran	Sheep, goat	Nested – PCR	240	50.4
Ghazaei (2006)	Iran	Cattle, sheep, goat, chicken	ELISA	750	14.4
Hamidinejat et al. (2009)	Iran	Cattle	MAT	450	15.7
Asgari et al. (2011)	Iran	Sheep, goat	Nested – PCR	78	33.3
Dehkordi et al. (2013)	Iran	Caprin, ovine, buffalo, camel, bovine	Bioassay, ELISA, PCR	889	27.1
Razmi et al. (2010)	Iran	Ovine	IFA	325	5.2
Tavassoli et al. (2013)	Iran	Sheep, goat	PCR	237	1.26
Asgari et al. (2009a, b)	Iran	Chicken	IFA, Nested-PCR	231	25
Asgari et al. (2006)	Iran	Chicken	IFA	122	36.1
Hamidinejat et al. (2008)	Iran	Ewe	ELISA, MAT	150	72.6
Hamidinejat et al. (2013)	Iran	Camel	MAT	254	14.5
Kavari et al. (2013)	Iran	Sheep, goat	ELISA, Nested PCR	186	18.3
Asgari et al. (2009a, b)	Iran	Sheep	IFA	603	26.5
Gorji et al (2018)	Iran	Sheep	Nested – PCR	140	18.5
Mahami et al. (2017)	Iran	Beef, chicken, lamb	PCR	150	17.3
Armand et al. (2016)	Iran	Sheep	ELISA, Nestad – PCR	370	35.9
Wiengcharoen et al. (2012)	Thailand	Cattle	IFA	389	25.7
Ge et al. (2014)	China	Cattle	ELISA, Nested, RFLP	1040	12.8
Khlaty et al. (2015)	Iraq	Sheep	LAT, PCR	300	33.3
Akhtar et al. (2014)	Pakistan	Chicken	LAT, Bioassay	300	36.3
Ahmad et al. (2014)	Pakistan	Cattle, buffalo	ELISA	822	17.3
Wang et al. (2011)	China	Sheep, goat	IHA	1270	3.3
Lashari et al. (2010)	Pakistan	Sheep	LAT, ELISA	518	19.8
Jung et al. (2014)	Korean	Goat	ELISA	610	5.1
Bawmet al. (2016)	Myanmar	Goat	LAT	281	11.4
Shah et al. (2013)	Pakistan	Goat, sheep	IHA	640	42.8
Qiu et al. (2012)	China	Cattle	IHA	1803	2.6
Oncel et al. (2006)	Turkey	Sheep	ELISA	181	31
Giangaspero et al. (2013)	Japan	Sheep	ELISA	267	28.7
Sharma et al. (2008)	India	Sheep, cattle, buffalo	ELISA	372	3.2
Kyan et al. (2012)	Japan	Goat	RFLP, LAT	24	75
Matsuo et al. (2014)	Japan	Cattle, chicken	LAT	657	4.7
Alanazi et al. (2013)	Saudi Arabia	Sheep, goat, camel	IFA	1628	34.6
Jittapalapong et al. (2005)	Thailand	Goat	LAT	631	27.9
Zou et al. (2015)	China	Buffalo, sheep, goat	IHA	973	11.9

**Table 2.** continued

Authors (references)	Country	Kind of animals	Diagnostic method	Sample size	Prevalence (%)
Ichikawa et al. (2015)	Indonesia	Cattle, pig	ELISA	803	9.2
Singh et al. (2015)	India	Sheep, goat, cattle	PCR, ELISA, IFA	168	50.5
Luo et al. (2017)	China	Cattle, goat, buffalo	IHA	935	14.2
Kalambhe et al. (2017)	India	Sheep, goats	Nested- PCR	400	1.5
Zhou et al. (2016)	Turkey	Sheep, goat, cattle	ELISA	1236	13.6
Celik et al. (2018)	Turkey	Cattle	ELISA	300	18
Bachan et al. (2018)	India	Goat	ELISA, IFA	445	42.4
Chikweto et al. (2011)	India	Sheep, goat, cattle	MAT	503	35.1
Sunanta et al. (2009)	Thailand	Dairy cow	ELISA, IFAT, LAT, PCR	50	54
Aktas et al. (2000)	Turkey	Sheep	Sabin-Feldman (SF)	154	46.8
Al-Rammahi et al. (2010)	Iraq	Cattle, sheep, goat	LAT	745	36.7
Al-dabagh et al. (2014)	Iraq	Sheep	ELISA	100	32

IFA indirect fluorescent antibody, PCR polymerase chain reaction, MAT modified agglutination test, ELISA enzymed-linked immunosorbent assay, RFLP restriction fragment length polymorphism, LAT latex agglutination test, IHA indirect haemagglutination test.

## DISCUSSION

Toxoplasmosis is considered one of the most widespread zoonotic diseases around the globe that were mainly transmitted to humans via consuming contaminated food (water and vegetables) with oocysts and eating the meat of livestock and poultry harboring tissue cysts (Mosallanejad et al. 2011). Recently, the consumption of raw and semi-raw meat and dairy products has been increasing worldwide. Hence, the safety assessment of livestock and poultry products is worthwhile for public health policymakers. To the best of our knowledge, this is the first meta-analysis to review and evaluate the prevalence of *T. gondii* in livestock (sheep, goats, camels, and cattle) and poultry considering different countries and continents from 2000 to 2019.

According to this meta-analysis, the overall global prevalence of toxoplasmosis in livestock and poultry was 28.3%. This prevalence rate is higher than *Toxoplasma* seroprevalence in pigs (19%) reported by Foroutan (Foroutan et al. 2019). This difference could be explained by the fact that pork consumption is forbidden in Muslim countries, and they mostly consume cattle, sheep, camel, goat, and poultry products.

Also, the highest prevalence rate of toxoplasmosis was 89.8%, while the lowest prevalence was 1.26%. The worldwide prevalence of toxoplasmosis differs from 16.4% in North America to 43.5% in Europe. In previous studies, the toxoplasmosis prevalence has been reported in coun-

tries worldwide from 10 to 90% (Torgerson and Mastroiacovo 2013). These variations can be explained by climate, different characteristics of the studies (sample size and various diagnostic serological methods), animal production systems, and specific control measures.

Climatic variations (temperature and humidity) in different parts of the world can cause different prevalences of the parasite (Rostami et al. 2017). The prevalence of *Toxoplasma* in livestock has been studied in most parts of the world for the last 20 years that could be a reason for the heterogeneity in the astonishing findings found. One research has reported that the prevalence of toxoplasmosis is higher in temperate climate and low-altitude regions. Besides, they reported that the prevalence is lower in cold and hot and dry areas (Rahimi et al. 2015). Oocysts do not grow in hot and dry climates, leading to a low prevalence of toxoplasmosis in such areas. Thus, it can be concluded that infections in cats are different among various regions concerning the climate. Our results also demonstrated a significant influence of geographical and climate factors on *T. gondii* seroprevalence so that decreasing and increasing seroprevalence was reported from North and South America, respectively, even though the number of studies was different in North and South America. Moreover, its prevalence in the Middle East (26.4%) differs from other Asian countries (17.8%). (Supplementary file).

With respect to diagnostic methods, our findings suggest that the diagnostic methods may be a source of



**Table 3.** Baseline Characteristics of Selected Studies Reporting Seroprevalence of *T. gondii* in Animals in Africa.

Authors (references)	Country	Kind of animals	Diagnostic method	Sample size	Prevalence (%)
Gebremedhin et al. (2013)	Ethiopia	Sheep, goat	ELISA	1372	31.8
Swai et al. (2012)	Tanzania	Dairy goat	LAT	337	19.3
Mose et al. (2016)	Kenya	Chicken	Nested – PCR	105	79
Ayinmode et al. (2016)	Nigeria	Cattle, sheep, goat	ELISA	883	22.2
Amairia et al. (2016)	Tunisia	Goat	ELISA,Nested-PCR	77	31.2
Rouatbi et al. (2017)	Tunisia	Sheep	Nested – PCR	324	31.4
Kamani et al. (2009)	Nigeria	Sheep, goat	ELISA	744	5.6
Lazim et al. (2018)	Sudan	Cattle, sheep, goat	LAT	191	16.8
Ibrahim et al. (2014)	Sudan	Dairy cow	ELISA	131	89.3
Samra et al. (2007)	South Africa	Sheep	IFA – ELISA	600	4.3
Gebremedhin and Gizaw (2014)	Ethiopia	Sheep, goat	ELISA	184	26.08
Hammond et al. (2015)	South Africa	Sheep	ELISA	292	8
Atail et al. (2017)	Sudan	Sheep, goat	LAT, iELISA	400	52
Al-kappany et al. (2018)	Egyptian	Sheep, goat	IFA, ELISA	498	24.5
Onyiche et al. (2015)	Nigeria	Cattle	ELISA	210	13.81
Khalil et al. (2011)	Sudan	Camel, cattle, sheep	LAT	200	38
Tilahun et al. (2018)	Ethiopia	Sheep, goat, cattle, camel	ELISA	1360	22.2
Amdouni et al. (2017)	Tunisia	Sheep, goat, cattle	PCR	420	28.09
Elfahal et al. (2013)	Sudan	Dairy cattle	ELISA	181	13.3
Van der puije et al. (2000)	Ghana	Sheep, goat	ELISA, IFA	1258	30.5
Davoust et al. (2015)	Senegal	Bovine, ovine, caprin	MAT	198	14.1
Gebremedhin et al. (2014)	Ethiopia	Sheep, goat	DAT	628	17.6
Lahmar et al. (2015)	Tunisia	Sheep, cattle, goat	MAT, PCR	261	36.8
Sawadogo et al. (2005)	Morocco	Sheep	ELISA	261	27.6
Dechicha et al. (2015)	Algeria	Cattle, sheep, goat	IFA	714	8.2
Abdel-Hafeez et al. (2015)	Egypt	Cattle, goat	IHA	200	50.9
Abdel-Rahman et al. (2012)	Egypt	Caprine	IHA	182	42.3
Aboelhadid et al. (2013)	Egypt	Chicken	MAT	215	13.95
Anwar et al. (2013)	Egypt	Sheep	Necropsy	60	18.3
El-Massry et al. (2000)	Egypt	Turkey, chicken, duck	MAT	329	54.1
Fereig et al. (2016)	Egypt	Sheep, goat, cattle	LAT, ELISA	506	27.8
Saad et al. (2018)	Egypt	Goat, sheep, camel	ELISA and qPCR	90	51.11
Ahmed et al. (2017)	Egypt	Camel	ELISA	120	52.5
Dubey et al. (2003a, b)	Egypt	Chicken	MAT	121	40.4
Ibrahim et al. (2016)	Egypt	Chicken	ELISA	304	11.18
Ibrahim et al. (2017)	Egypt	Sheep	ELISA	170	51.76
Kuraa et al. (2016)	Egypt	Camel, cattle buffaloes, sheep, goat	ELISA	274	83.6

ELISA enzyme-linked immunosorbent assay, LAT latex agglutination test, IFA indirect fluorescent antibody, PCR polymerase chain reaction, DAT direct agglutination test.

heterogeneity. A fluctuation in outcomes was observed in studies; e.g., in Iran, Akhondi and Youssefi (2017) reported 28.2% of infection prevalence using the IFA method in Northern Iran, while Tavakoli et al. (2017) reported 50.4% using PCR methods in Eastern Iran. However, it

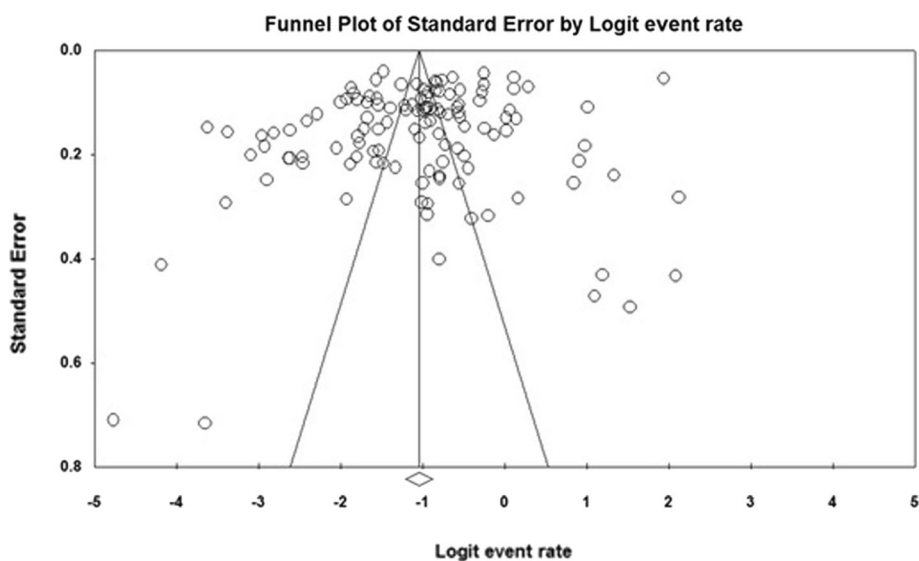
should be taken into consideration that these studies were conducted in different sample sizes and areas.

Our findings demonstrated an association between the prevalence of *T. gondii* and sample size. In the current meta-analyses, we observed that *T. gondii* prevalence in-

**Table 4.** Baseline Characteristics of Selected Studies Reporting Seroprevalence of *T. gondii* in Animals in America.

Authors (references)	Country	Kind of animals	Diagnostic method	Sample size	Prevalence (%)
<i>North America</i>					
Persad et al. (2011)	Trinidad	Water buffalo	LAT	333	7.8
Alvarado et al. (2013a; b)	Mexico	Dairy goat	MAT	341	15.2
Alvarado et al. (2013a; b)	Mexico	Sheep	MAT	429	23.1
Dubey et al. (2011)	USA	Goat	MAT – Bioassay	234	53.4
Gebreyes et al. (2008)	USA	Swine	ELISA	675	7
Dubey et al. (2008)	USA	Sheep	MAT, PCR, Bioassay	383	27.1
Yaglom et al. (2014)	USA	Boer goat	LAT	367	6.8
<i>South America</i>					
Dubey et al. (2004)	Peru	Chicken	MAT – Bioassay	50	28
Dubey et al. (2003a, b)	Brazil	Chicken	MAT, Bioassay	40	40
Franco et al. (2016)	Colombia	Beef, chicken	PCR	120	45.8
Lopes et al. (2016)	Brazil	Chicken	MAT, ELISA, PCR	108	71.3
Figliuolo et al. (2004)	Brazil	Goat	IFA	394	28.7
Romanelli et al. (2007)	Brazil	Sheep	MAT	305	51.5
Dubey et al. (2002)	Brazil	Chicken	MAT – Bioassay	82	39
Moraes et al. (2011)	Brazil	Goat, sheep	IFA	110	12.7
Guimaraes et al. (2013)	Brazil	Sheep	IFA	795	30.2
Da Silva et al. (2014)	Brazil	Ovine(sheep)	IFA	40	45
Frazao et al. (2011)	Brazil	Cattle	ELISA	77	49.4
Neto et al. (2008)	Brazil	Goat	IFA	366	30.6

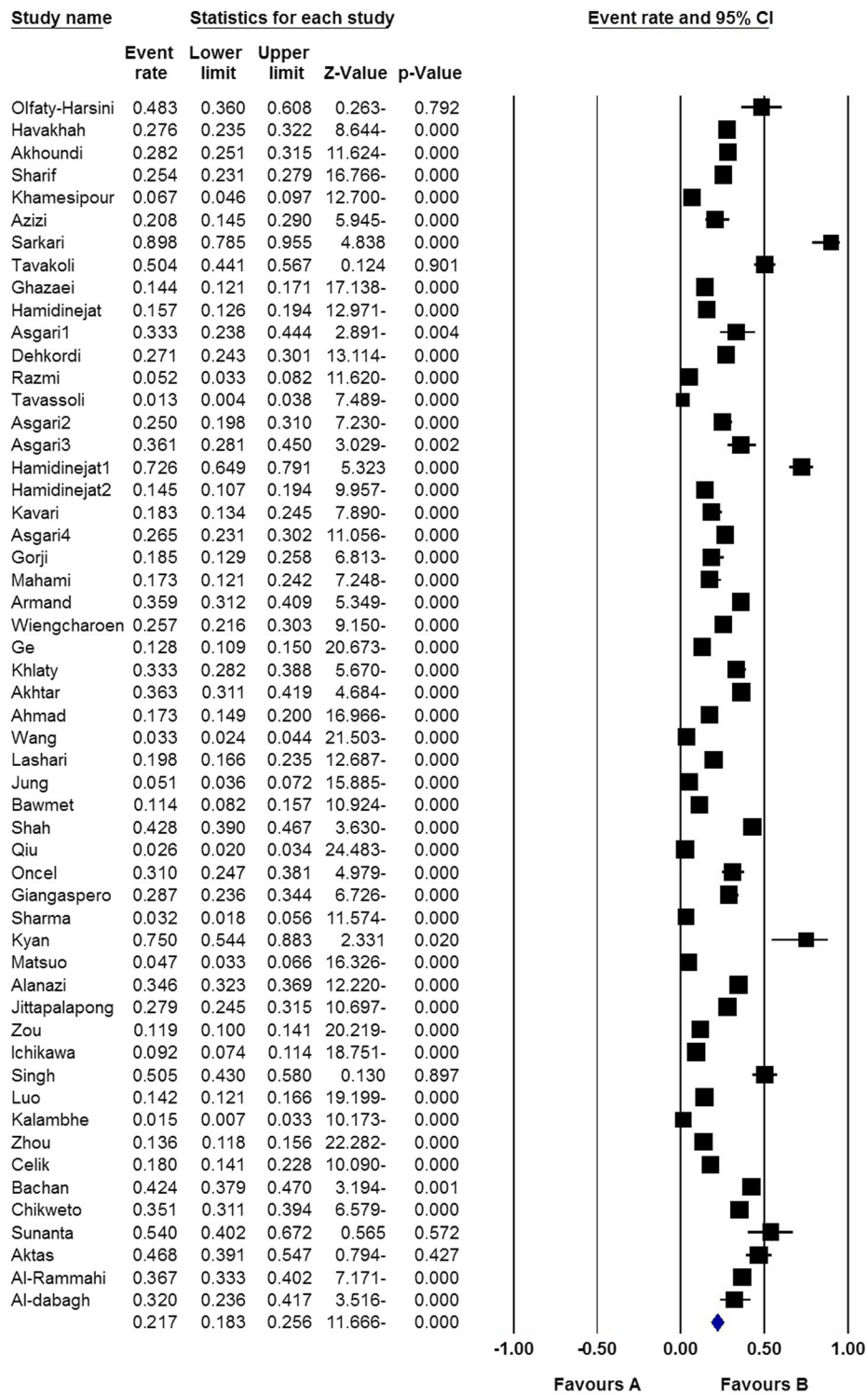
LAT latex agglutination test, MAT modified agglutination test, ELISA enzymed-linked immunosorbent assay, PCR polymerase chain reaction, IFA indirect fluorescent antibody.



**Figure 2.** Funnel plot. Results of toxoplasmosis prevalence in livestock and poultry animals worldwide.



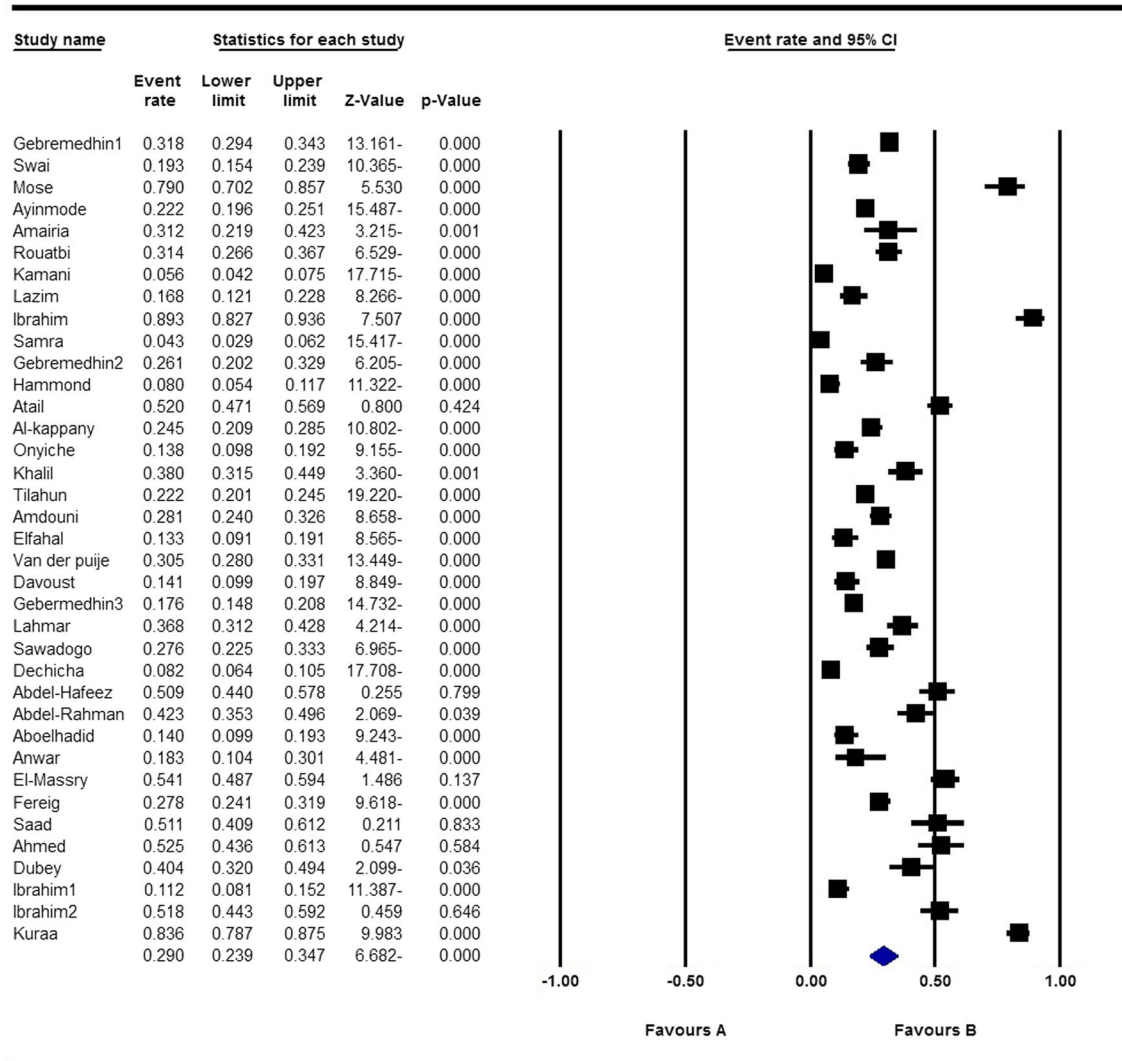
# Meta Analysis



## Meta Analysis

Figure 3. The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in Asia.

# Meta Analysis



## Meta Analysis

Figure 4. The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in Africa.

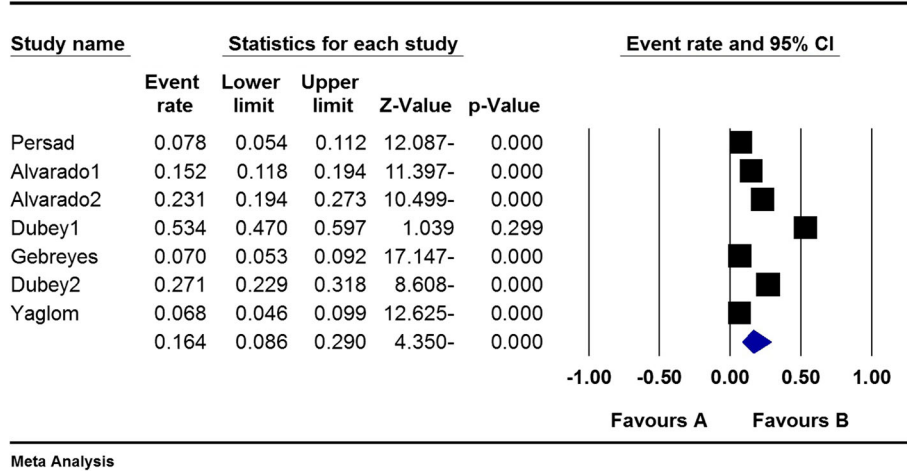
creases with growing the sample size. This increase could be due to raising the number of animals exposed to the parasite.

Considering previous meta-analyses, it can be acknowledged that a low level of health is an effective factor for increasing the prevalence of toxoplasmosis in Africa. Also, Hotez (2014) explained that toxoplasmosis is highly prevalent in poor areas because of low health literacy (Hotez 2014). Several studies have shown that good hygiene in the manufacturing of farms under intensive management practice can significantly decrease the prevalence of *T. gondii*, but a developing country cannot exploit these facilities (De Berardinis et al. 2017; Robert-Gangneux

and Darde 2012). According to our results, contrary to surveys done in Africa, advanced countries like Belgium also have high infection levels. Therefore, more critical factors contribute to the prevalence of this infection, which requires further study. This result indicates that the prevalence of toxoplasmosis is dependent not only on the poor condition of countries and socioeconomic factors but also on the different environmental factors.

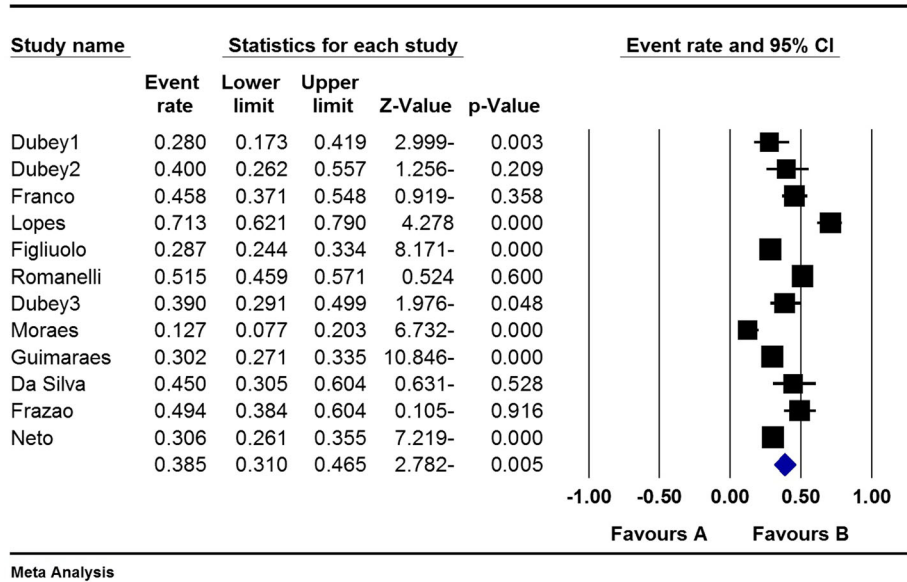
The study strengths are the large total sample size, comprehensive article search, and subgroup analyses. Moreover, this study included the accurate and strict methodology and quality assessment that two independent reviewers performed. However, this study had some limi-

### Meta Analysis



**Figure 5.** The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in North America.

### Meta Analysis



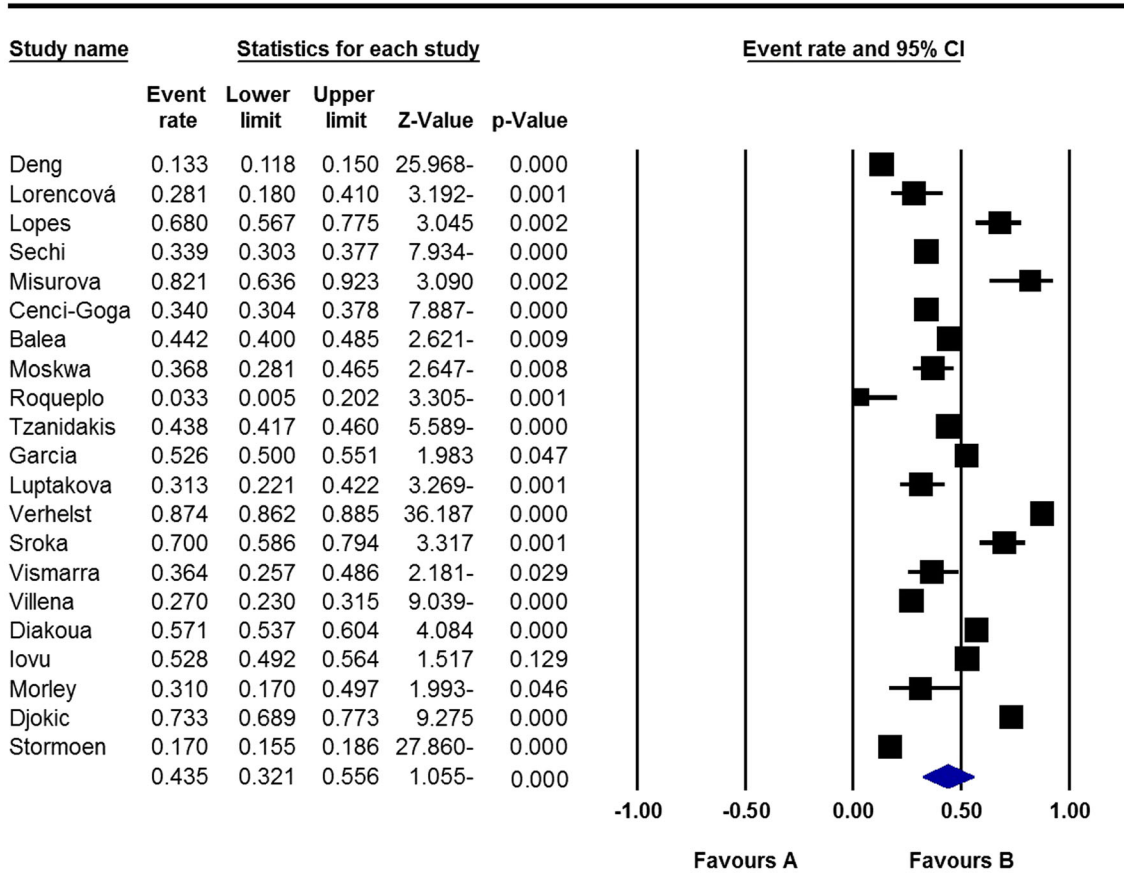
**Figure 6.** The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in South America.

tations, including no review of the effect of age and sex on the infection prevalence and high heterogeneity and variations in sensitivity and specificity of diagnostic methods (bioassay and serological methods).

## CONCLUSION

It was found that more than a quarter of livestock animals and poultry are infected with *T. gondii*. Since livestock products are globally important sources of people's diet

# Meta Analysis



## Meta Analysis

Figure 7. The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in Europe.

# Meta Analysis

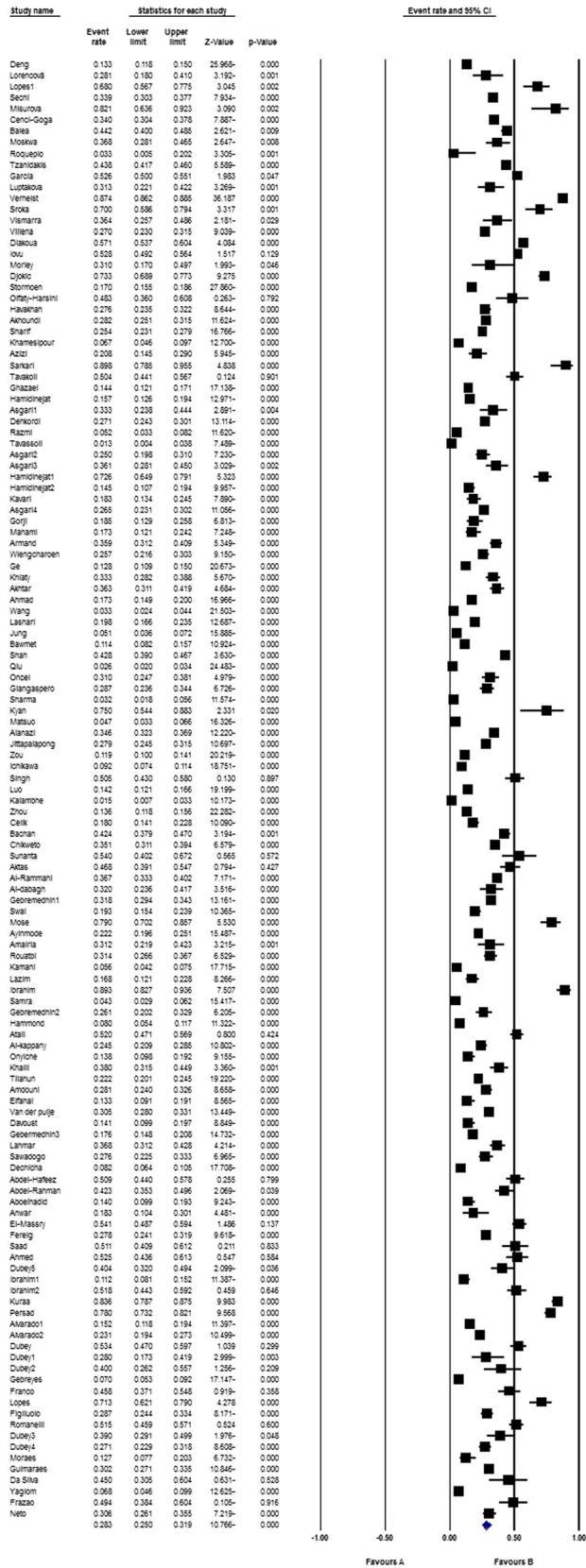
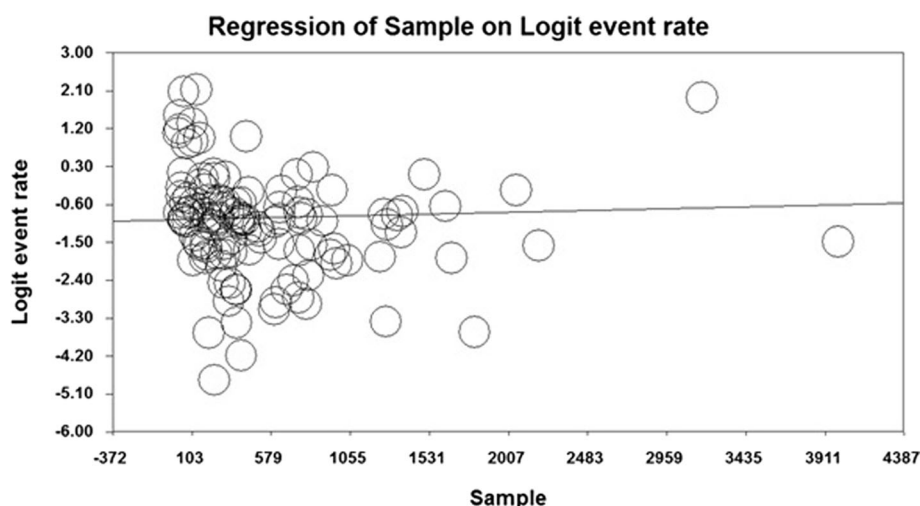


Figure 8. The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis worldwide.



**Figure 9.** Meta-regression of prevalence of toxoplasmosis in cattle, sheep, camels, goats, and poultry worldwide based on sample size.

and will increase with the growing world population, our findings can be useful for policymakers to control toxoplasmosis in livestock.

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## DECLARATIONS

**CONFLICT OF INTEREST** The authors declare that there is no conflict of interest regarding the publication of this paper.

**ETHICAL APPROVAL** In ethical approval was not required for this meta-analysis because no human or animal subjects were involved.

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