EcoHealth 19, 55–74, 2022
https://doi.org/10.1007/s10393-022-01575-x

EcoHealth



*Review*

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

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**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,

**Supplementary Information:** The online version contains supplementary material available at https://doi.org/10.1007/s10393-022-01575-x.

Published online: February 8, 2022

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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

### 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, camels, 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

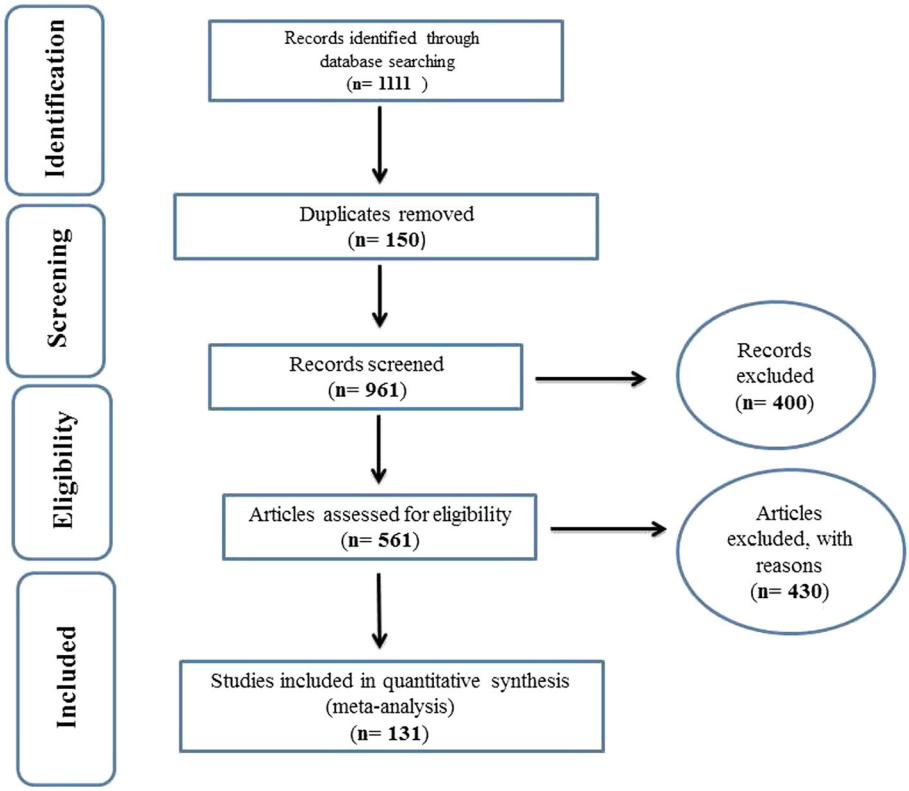


**Figure 1.** The flowchart on the stages of including the studies in the systematic review and meta-analysis (PRISMA 2009).

(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 mentioned 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 (%) |
|---|---|---|---|---|---|
| lchikawa 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 countries 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). Oocytes 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, Akhoundi 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 (%) |
|---|---|---|---|---|---|
| *North America* | | | | | |
| 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 |
| *South America* | | | | | |
| 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.

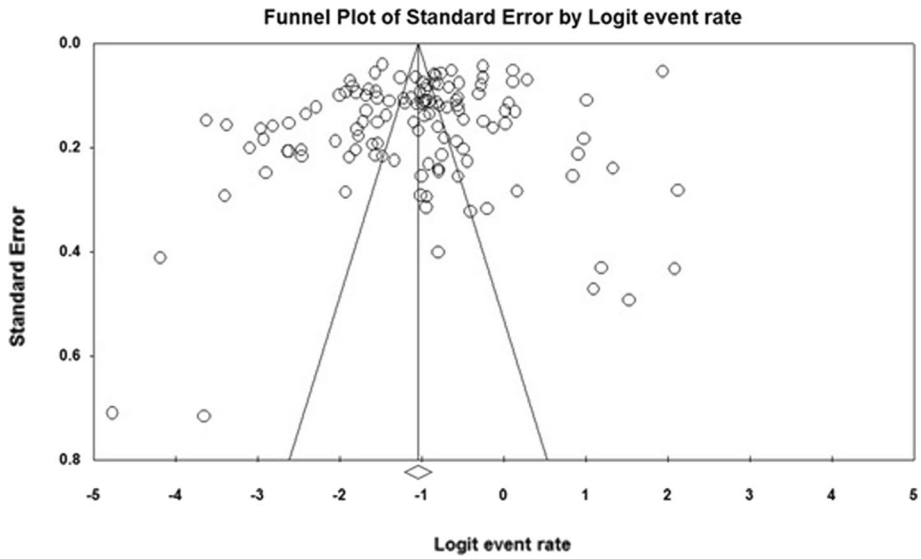


**Figure 2.** Funnel plot. Results of toxoplasmosis prevalence in livestock and poultry animals worldwide.

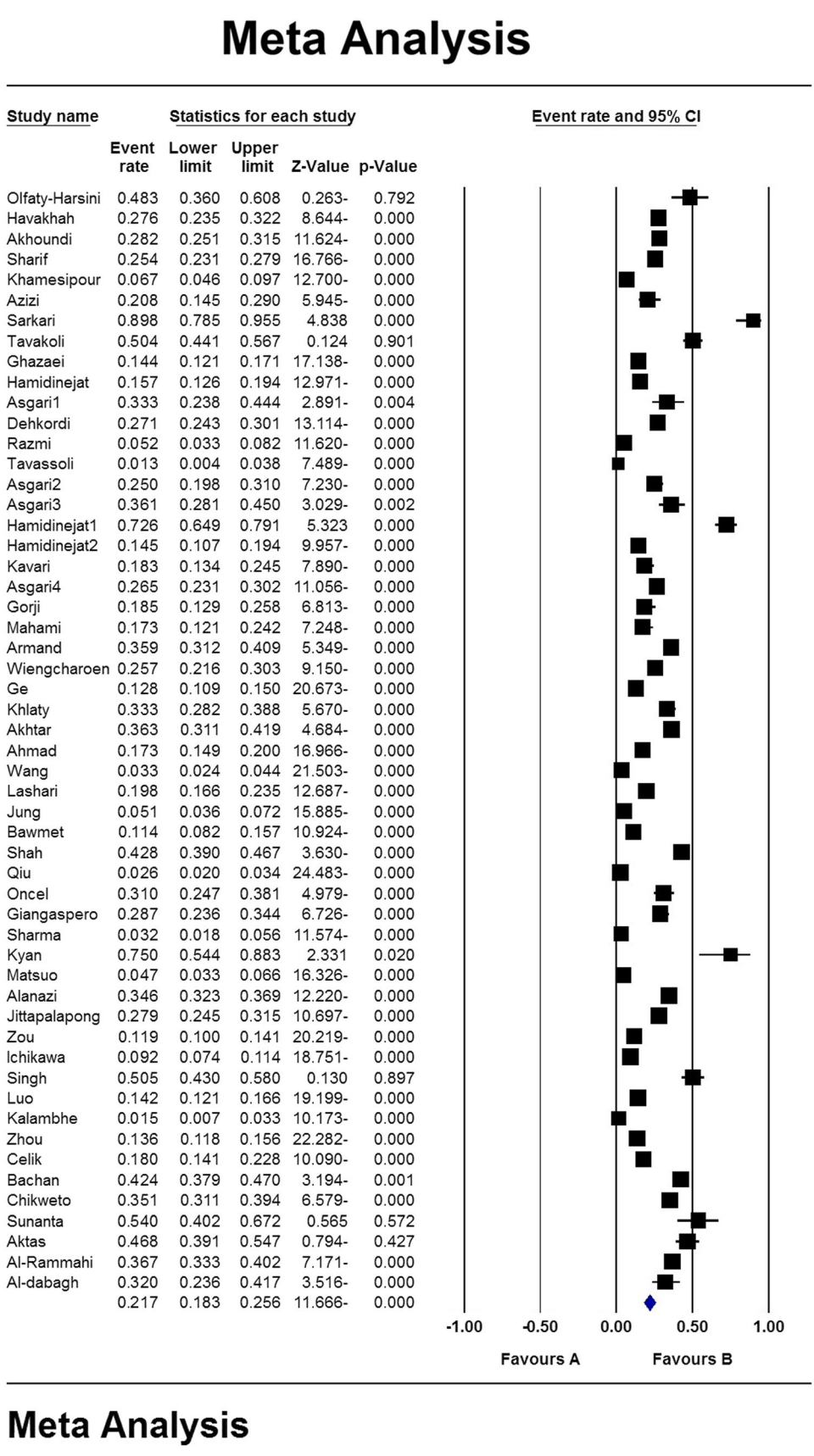


**Figure 3.** The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in Asia.

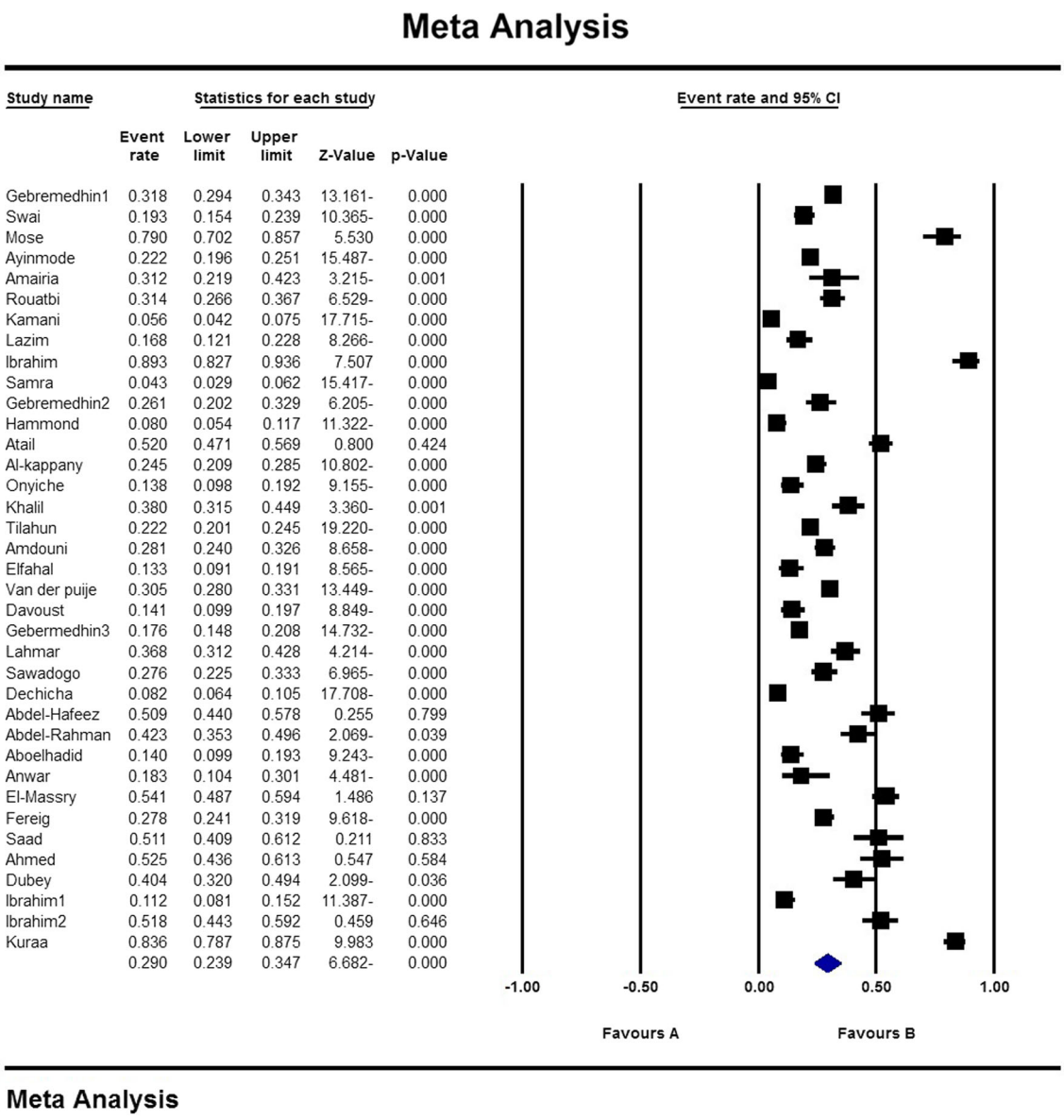


**Figure 4.** The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in Africa.

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-

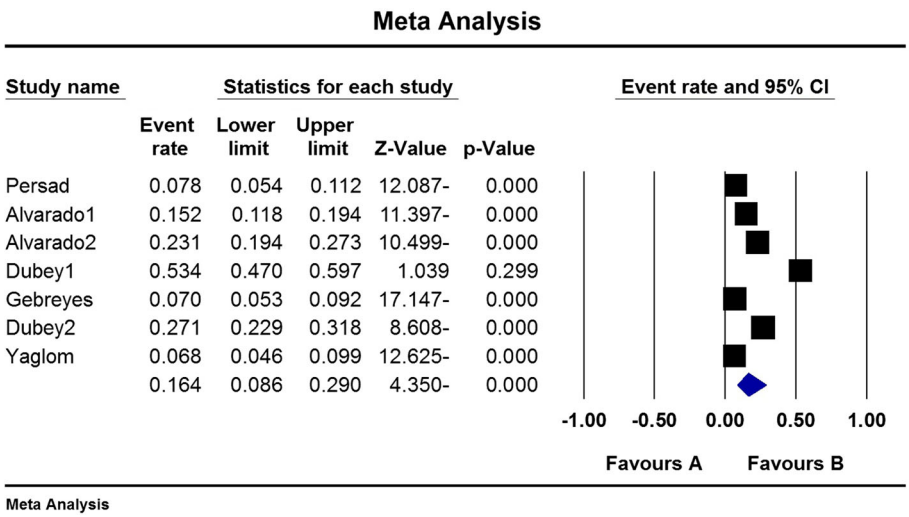


**Figure 5.** The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in North America.

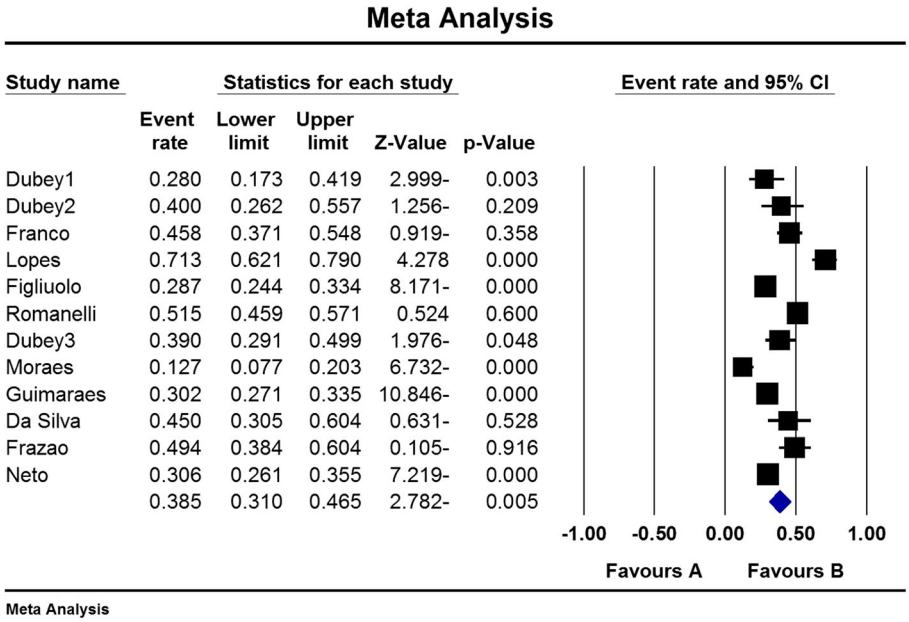


**Figure 6.** The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in South America.

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

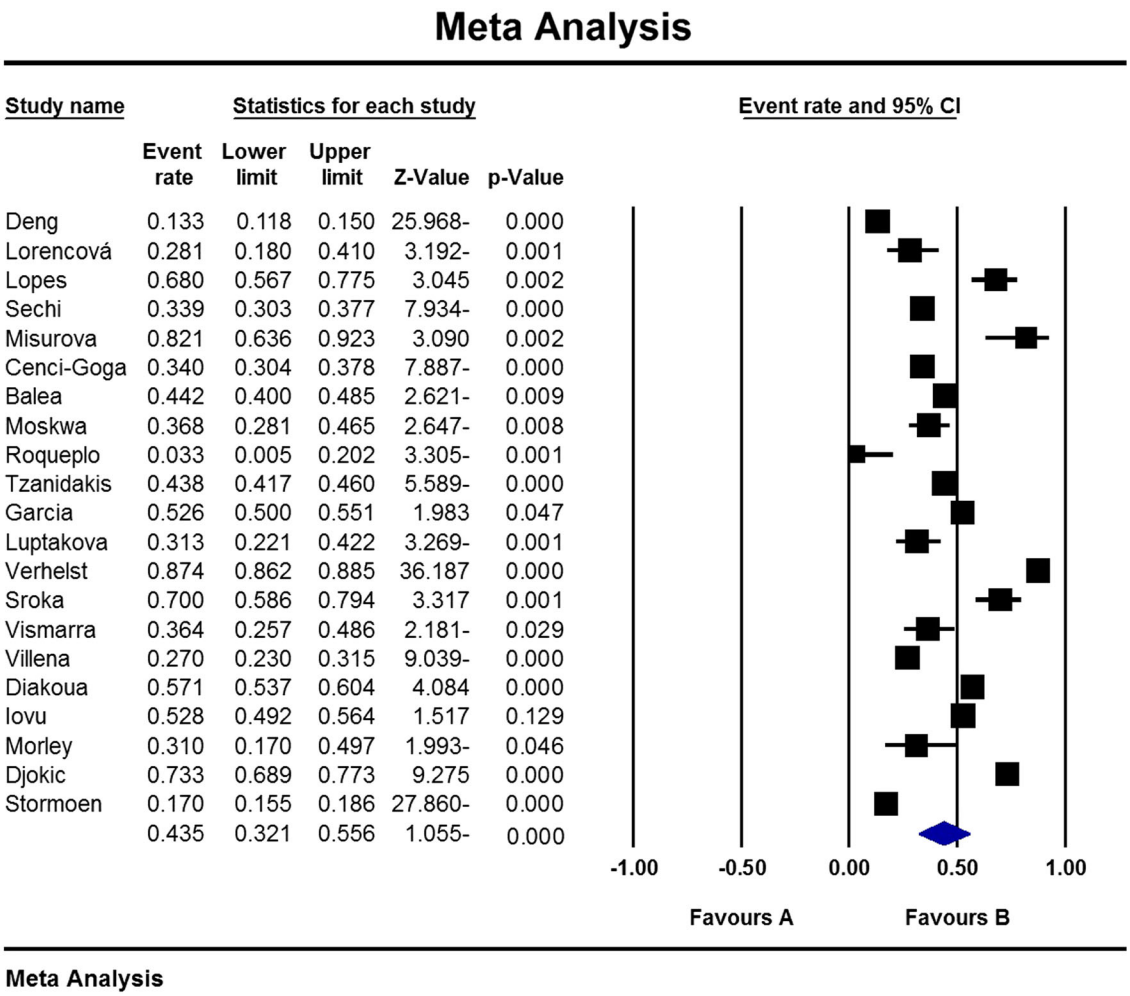


**Figure 7.** The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis in Europe.

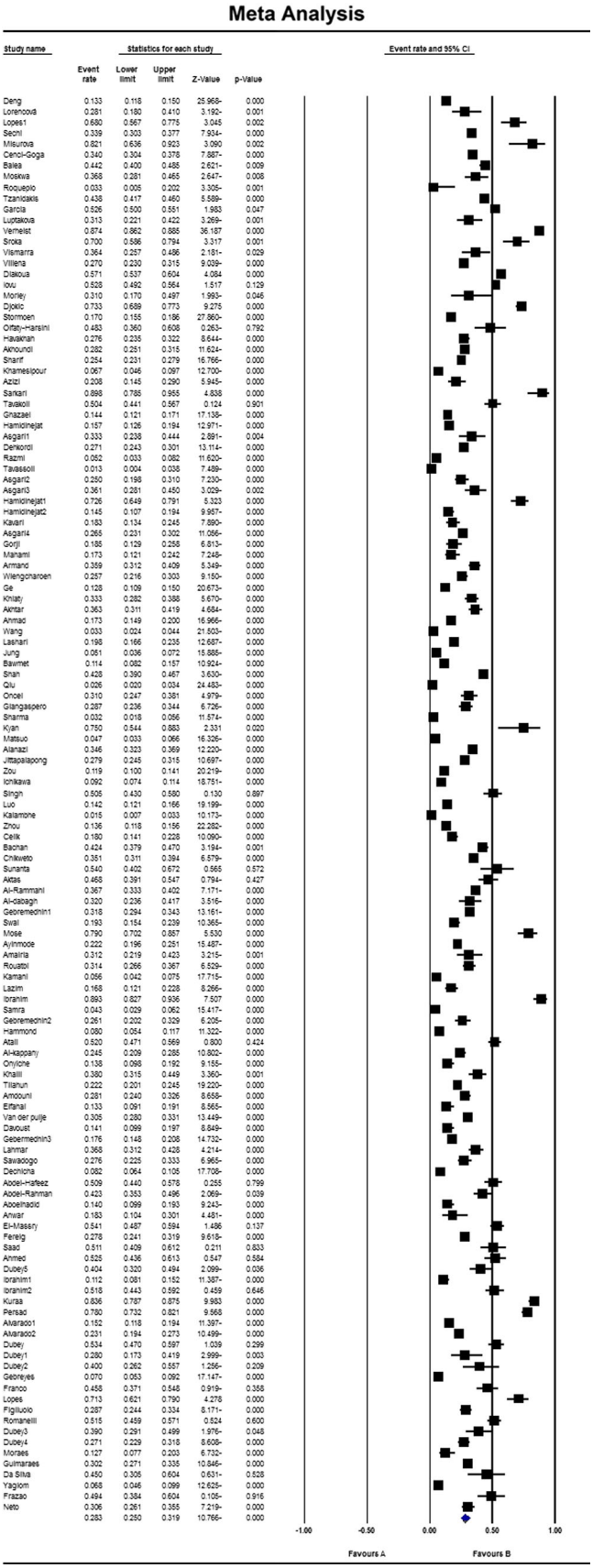


**Figure 8.** The forest plot of prevalence of toxoplasmosis in livestock and poultry: meta-analysis plot of toxoplasmosis worldwide.

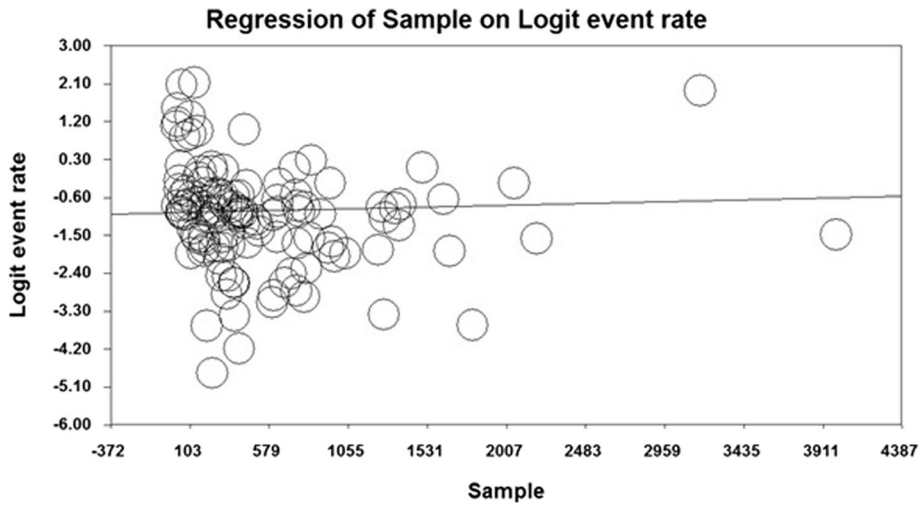


**Figure 9.** Meta-regression of prevalence of toxoplasmosis in cattle, sheep, camels, goats, and poultry worldwide based on sample size.

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

## Acknowledgements

This research was done by Research Center of Food Hygiene and Safety, Shahid Sadoughi University of Medical Sciences, Yazd, Iran (ID. No. 6808). We sincerely thank the technical supports of the staff of Research Center of Food Hygiene and Safety, Shahid Sadoughi University of Medical Sciences, Yazd, Iran.

## 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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