Toxoplasma gondii infection in meat animals from Africa: Systematic review and meta-analysis of sero-epidemiological studies

Aretas Babatoundé Nounnagnon Tonouhewa1, Yao Akpo2, Philippe Sessou1, Camus Adoligbe1, Eric Yessianou1, Yvoi Gildas Hounmanou1,3, Marc Napoléon Assogba1, Issaka Yousso1 and Souaïbou Farougou1

1. Laboratory of Research in Applied Biology, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, 01 P.O. Box 2009, Cotonou, Benin; 2. Laboratory of Ecology, Health and animal Production, Faculty of Agronomy, University of Parakou, P.O. Box 123 Parakou, Benin; 3. Department of Veterinary Medicine and Public Health, Sokoue University of Agriculture, P.O. Box 3121, Chuo Kikoo, Morogoro, Tanzania.

Corresponding author: Aretas Babatoundé Nounnagnon Tonouhewa, e-mail: tonouhewaaretas@gmail.com, Co-authors: YA: yao.akpo@gmail.com, PS: sessouphilippe@yahoo.fr, CA: adolcam83@yahoo.fr, EY: eric.yessianou@uac.bj, YGH: gilmahu@yahoo.fr, MNA: assonapo1@yahoo.fr, IF: iyousso@ yahoo.fr, SF: farougou@gmail.com

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Abstract

Aim: Toxoplasma gondii is an ubiquitous apicomplexan parasite which causes toxoplasmosis in humans and animals. Felids especially cats are definitive hosts and almost all warm-blooded mammals, including livestock and human can serve as intermediate hosts. Food animals can be reservoirs for T. gondii and act as one of the sources for parasite transmission to humans. The objective of this study is to collect serological data on the prevalence of anti-T. gondii antibody, and risk factors for certain food animals from Africa to provide a quantitative estimate of T. gondii infection among these species from different African countries.

Materials and Methods: Four databases were used to search seroepidemiological data on the prevalence of anti-T. gondii antibody in food animals between 1969 and 2016 from African countries. The search focused on data obtained by serologic test in food animals and meta-analyses were performed per species.

Results: A total of 30,742 individual samples from 24 countries, described in 68 articles were studied. The overall estimated prevalence for toxoplasmosis in chicken, camel, cattle, sheep, goat, pig were 37.4% (29.2-46.0%), 36% (18-56%), 12% (8-17%), 26.1% (17.0-37.0%), 22.9% (12.3-36.0%), and 26.0% (20-32.0%), respectively. Moreover, major risk factor of infection was age, farming system, and farm location.

Conclusions: A significant variation in the seroepidemiological data was observed within each species and country. The results can aid in an updated epidemiological analysis but also can be used as an important input in quantitative microbial risk assessment models. Further studies are required for a better and continual evaluation of the occurrence of this zoonotic infection.

Keywords: animal health, meta-analysis, Toxoplasmosis, zoonosis.

Introduction

Toxoplasma gondii is a coccidian parasite that is globally widespread and causes a common infection in animal and human. The parasite was described for the first time in a North African rodent (Ctenodactylus gon- dii) independently by Nicolle, Manceaux, and Splendore in 1908 [1]. Felids especially cats are definitive hosts and represent the key element in the epidemiology of disease caused by this parasite. Almost all warm-blooded mammals, including livestock, and human can serve as intermediate hosts [2]. T. gondii can infect all homeotherms and is responsible for many abortions and fetal malformations in human and animal [3].

According to estimates, approximately 1/3 of the world’s population would be infected [4] and T. gondii infection represent the most prevalent parasitic zoonotic disease worldwide [5]. This parasite is present on all continents, and the rate of infection vary highly according to areas [2]. However, climate change has led to an increase of T. gondii infections in different regions of the world as a result of changing environmental conditions [6].

Humans get infected after ingesting undercooked or raw meat, by ingesting cat-shed oocysts via contaminated soil, food, water or congenitally by transplacental transmission of tachyzoites [5]. However, the clinical disease is seen only in few cases with serious consequences in immunocompromised people and pregnant women [7]. Toxoplasmosis is a major cause of reproductive failure in sheep, goats, and pigs [8,9] and also recognized as a serious problem in immunocompromised patients particularly AIDS patient [10,11]. Furthermore, recent studies have shown that toxoplasmosis is a risk factor for...
schizophrenia [12], epilepsy [13], and traffic accidents [14] and highly virulent atypical strains of *T. gondii* have been incriminated with pneumonia, even in immunocompetent people [15].

Toxoplasmosis, especially cerebral toxoplasmosis has become the most common opportunistic infection of the central nervous system during HIV infection in the world [10,11]. Africa is the most continent affected by HIV/AIDS infection that affects about 30 million people on the continent [16]. Unluckily countries most affected are those least able to meet the cost of prevention and treatment of disease. Thus, toxoplasmosis has become an important public health problem on the continent account to the severity of the infection in AIDS patients more frequent in Africa. The absence of public health schemes to manage the spread of this disease places African populations at risk of ongoing and possibly increasing incidence and prevalence, as well as a corresponding increase in mortality and morbidity due to toxoplasmosis [17].

Food animals are important livestock species, especially in developing countries and their products (meat and milk) are used in various parts of the world. Pork and chicken are the most consumed meat in the world with global production estimated at 115.5 and 108.7 million tons in 2014 [18]. In Africa; cattle, chicken, sheep, goat, pig, and camel represent the most consumed animal species. According to estimate, the meat production on the continent was estimated at 17352 thousands of tons in 2013 and increasing every year [18]. Food animals can be reservoirs for *T. gondii* and act as one of the sources for parasite transmission to humans. Many epidemiologic studies have found an association between consumption of undercooked or raw meat and *T. gondii* infection in human [19,20].

Based on limited population-based data, the Food and Agriculture Organization and World Health Organization estimated that approximately 22% of human *T. gondii* infections are meatborne [21].

To detect *T. gondii* in meat animal, three methods have been used. These methods include serological assays, bioassay, and polymerase chain reaction (PCR) [22]. Among these three methods, serological assays are rapid and have good accuracy for detecting anti-*T. gondii* antibodies in food animals [23-25] and the modified agglutination test (MAT) and enzyme-linked immunosorbent assay (ELISA), are the most commonly used serological test.

Compared to other continents, few studies have been conducted on toxoplasmosis in Africa. Studies available on the seroprevalence of toxoplasmosis in African countries are still fragmented, except some countries including Ethiopia where the infection is well documented. Therefore, there have been a few studies on seroprevalence rates of *T. gondii* in animal species on the continent, and the results of the available studies are sometimes contradictory.

Meta-analysis is a method to synthesize the results of various studies for a given question and was applied to a wide range of food safety questions [26]. The quantitative results obtained from meta-analysis were used as inputs in risk assessment models [27]. According to Gliner et al. [28], the advantages of performing a meta-analysis include providing summary statistics based on multiple individual studies, increasing precision in estimating effects, and taking the size of studies into account.

The aim of this systematic review and meta-analysis study is to collect serological data on the prevalence of anti-*T. gondii* antibody, and risk factors for most consumed food animals from Africa to provide a quantitative estimate of *T. gondii* infection among these species.

**Materials and Methods**

**Ethical approval**

This study did not require an ethical approval as it was based on information/data retrieved from published studies already available in the public domain.

**Data sources and searches**

We conducted a systematic literature review on the seroprevalence of *T. gondii* among food animals in African countries as per preferred reporting items for systematic reviews and meta-analyses criteria [29]. Relevant studies were identified by searching four literature databases including PubMed, Web of Science, Scopus, and Google Scholar. No time limitation was imposed. The search criteria were specified in advance and the search was executed on 11/12/2015 and last updated on 01/04/2016. The search string used was the following: “toxoplasma” OR “toxoplasmosis” AND “seroprevalence” OR “seroepidemiology” AND “sheep” OR “goat” OR “pig” OR “cattle” OR “chicken” OR “camel” AND “Africa”.

**Data collection and eligibility criteria**

For this review, only articles written in English and French were considered. Two investigators studied titles and abstract of all the articles and retrieved data. Several criteria were used to select eligible studies (1) study were performed in animals raised in different African countries; (2) the prevalence of *T. gondii* had to be detected by serologic methods (ELISA, MAT, direct agglutination test [DAT], modified direct agglutination test [MDAT], indirect fluorescent antibody test [IFAT], latex agglutination test [LAT], and Sabin and Feldman test [SFT]); (3) samples had to originate from food animals (cattle, chicken, camel, pigs, sheep and goat); (4) samples had to be collected from animals which were naturally infected; (5) sampling strategy had to be directed toward a random population; (6) the sample size was <35. The extracted data included: Year of publication, host, country of the study, sample size, number of cases, diagnostic test, and risk factors. Reference lists of full-text publications and textbooks were also examined to identify studies not retrieved by the original search. All studies were coded according to the previously chosen parameters, and data were recorded in Microsoft Excel table.
Quality and bias assessment of eligible studies

Each eligible study was assessed for quality and bias using the risk of bias tool, which is a methodological quality assessment checklist for prevalence studies [30]. Ten questions were contained in this checklist, and each of the ten questions was scored 1 or 0 based on the quality of each eligible study [30]. This question was as follows:

Q1: Was the study’s target population a close representation of the national population in relation to relevant variables?

Q2: Was the sampling frame a true or close representation of the target population?

Q3: Was some form of random selection used to select the samples, or was a census undertaken?

Q4: Was the likelihood of non-response bias minimal?

Q5: Were data collected directly from the subjects (as opposed to a proxy)?

Q6: Was an acceptable case definition used in the study?

Q7: Was the study instrument that measured the parameter of interest shown to have reliability and validity (if necessary)?

Yes (if using MAT, ELISA, DAT, and MDAT).
No (using other serologic detection methods).

Q8: Was the same mode of data collection used for all subjects?

Q9: Was the length of the shortest prevalence period for the parameter of interest appropriate? Q10: Were the numerator(s) and denominator(s) for the parameter of interest appropriate?

Eight different detection methods were used in these eligible studies. For question 7, which was to determine the reliability and validity of the measurement, MAT, ELISA, DAT and MDAT were considered as reliable diagnostic methods (score 1) [24,25], and other diagnostic tests such as LAT, indirect immunofluorescent assay (IFA), indirect hemagglutination assay (IHA), SFT, were determined as unreliable methods (score 0). A quality score was determined by rescaling the sum of scores of each eligible study between 0 and 1 [30]. Quality assessment was completed independently by two assessors, and a table of quality score computation for each eligible study is provided in the Supplementary Table-S1.

Data analysis

Data were recorded in Microsoft Excel spreadsheet and analysed by MetaXL version 4.0 software (EpiGear Int Pty Ltd., Wilston) [31] for the meta-analyses and graphed as forest plot. For pooled prevalence analysis, random effects model was adopted over fixed effect model because there is more robust when analyzing heterogeneous studies [32]. Data were transformed by a double arcsine transformation as described by Barendregt et al. [33] to stabilize the variance. Publication bias was assessed by funnel plots representing the double arcsine transformation of the prevalence against the standard error [34]. Heterogeneity among studies was evaluated by Cochrane Q and I² statistical methods. A significant value (p<0.05) in the Cochrane Q method suggests a real effect difference in the meta-analysis. A value of I² was used to measure the inconsistency across studies. Values of 25%, 50%, and 75% were considered as having a low, moderate, and high degree of heterogeneity, respectively [35].

Results

Schematic flow diagram describing the selection of relevant studies Figure-1.

Characteristics of eligible studies

Figure-1 shows the flow diagram of the selection of eligible studies. A total of 5700 papers published between 1969 and 2016 were identified by literature search among the four database searched. After duplicate removed and irrelevant studies based on titles and abstracts, 81 articles were retrieved for detailed full-text analysis. 13 were excluded due to the following reasons: Two were not available; the sample size was lower than 35 in four study; the diagnosis was established on the basis of other methods than serologic test in seven studies. Table-1 shows the characteristics of included studies [36-103]. Finally, a total of 68 articles from 24 countries were included in this systematic review and meta-analysis study. Approximately, 60% (41/68) of the studies were published within the last 10 decade (2007-2016) of the review period. The regional distribution of studies was west Africa (18), East Africa (17), North Africa (21), Southern Africa (8), and Central Africa (4). Our analysis included a totally 30,742 individual samples distributed as follows: 14,272 sheep, 6355 goats, 3366 cattle, 2798 chickens, 2080 pigs, and 1621 camels. Eight different types of diagnostic tests were employed to evaluate T. gondii infection. These diagnostic methods were MAT, ELISA, IHA, DAT, MDAT, IFA, LAT, and SFT. The most used diagnostic tests in 47 year surveys were ELISA and MAT in 24 and 20 studies, which was followed by LAT (14), IHA (13), DAT (6), IFA (6), MDAT (3) and SFT (1). Sensitivity and specificity of diagnostic test are described in Table-2 as reported in literature.

Quality and bias assessments

Supplementary Table-S1 (Appendix) represents the quality score of different eligible study. The quality score in 54/84 eligible studies ranged from 6 and 8 (Table-S1) [36-103]. It shows that the risk of bias in these studies was moderate. Besides, many of the eligible studies were conducted in regional and local farms or slaughterhouses, which were not representative of the national population of animals sampled in these countries. Only 5 of the 84 studies were conducted at the national level (Table-S1). Moreover, studies on animal toxoplasmosis were available only in 24 countries out of 54 of African continent. The risk of bias due to quality deficiency in eligible studies was mainly due to external validity criteria, while the flaws internal validity recorded
in eligible studies concerned the use of diagnostic tests other than reference methods such as ELISA and MAT (Table-2) [104]. Finally, the symmetry in the funnel plots ruled out substantial publication bias (Figure-2).

**Population prevalence in food animals**

**Prevalence of anti-T. gondii antibody in sheep**

Data from 27 studies from 17 countries were obtained among sheep. 10 studies used ELISA, 6 studies used MAT, 5 used LAT, 2 used IHA and IFA, DAT and MDAT were used in 1 study, respectively. A total number of individual samples was 14,272. The prevalence of toxoplasmosis in sheep varied from 4.30% to 68.00%. The random effect model used in the meta-analysis (Figure-3) gave an overall estimated prevalence of 26.1% (95% confidence interval [CI] 17.0-37.0%). The result of heterogeneity was also 96.83% (95% CI 96.18-97.38%) for the degree of inconsistency.

**Prevalence of anti-T. gondii antibody in goats**

The data obtained from T. gondii infection in goat result from 17 studies from 9 countries. For diagnostic methods, 5 studies performing ELISA, 2 studies performing LAT, 2 studies, performing MDAT, IFAT, IHA, respectively, and 1 study performing MAT and DAT, respectively. The total number of individual samples was 6355. The random effect model (Figure-4) gave an overall estimated prevalence of 22.9% (95% CI 12.3-36.0%). The result of heterogeneity was also 99.1% (95% CI 99.0-99.3%) for the degree of inconsistency.

**Prevalence of anti-T. gondii antibody in cattle**

Information on T. gondii infection in cattle was obtained from 11 studies from 8 countries. 5 studies performing LAT; 4 studies performing ELISA; 4 studies performing IFAT and IHA, respectively. The total number of individual samples was 3366. T. gondii infection prevalence among cattle ranged from 3.6% to 32%. The random effect model (Figure-5) gave an overall estimated prevalence of 12% (95% CI 8-17%, p<0.001). The result of heterogeneity was also 92.56% (95% CI 88.65-95.12) for the degree of inconsistency. A detailed description of each study is given in Figure-5.

**Prevalence of anti-T. gondii antibody in camels**

For camels, 6 studies from 4 African countries were obtained. Most countries concerned were East African countries: Sudan, Ethiopia, and Somalia.
### Table-1: Characteristics of included studies.

| Study No | Country          | Author                        | Year | Hosts                  | Method | Sample size | Positive (%) | Quality score |
|----------|------------------|-------------------------------|------|------------------------|--------|-------------|--------------|---------------|
| 1        | Burkina-Faso     | Bamba et al. [36]             | 2016 | Pig                    | MAT    | 300         | 87 (29)      | 8             |
| 2        | Ethiopia         | Gebremedhin et al. [37]       | 2015 | Chicken                | MAT    | 601         | 183 (30.50)  | 9             |
| 3        | Egypt            | Abdel-Hafeez et al. [38]      | 2015 | Goat                   | IHAT   | 100         | 64 (64)      | 7             |
| 4        | Algeria          | Dechica et al. [39]           | 2015 | Sheep, Goat, Cattle    | IFAT   | 714         | 59 (8.26)    | 6             |
| 5        | Nigeria          | Onyiche et al. [40]           | 2015 | Cattle, Pig            | ELISA  | 512         | 117 (22.85)  | 9             |
| 6        | Sudan            | Elfahal et al. [41]           | 2015 | Cattle                 | ELISA  | 181         | 24 (13.30)   | 6             |
| 7        | Ethiopia         | Gebremedhin et al. [42]       | 2015 | Pig                    | DAT    | 402         | 129 (32.10)  | 9             |
| 8        | Ethiopia         | Hadush et al. [43]            | 2015 | Camel                  | DAT    | 384         | 262 (68.20)  | 9             |
| 9        | Tunisia          | Lahmar et al. [44]            | 2015 | Sheep, Goat, Cattle    | MAT    | 261         | 82 (36.78)   | 7             |
| 10       | South-Africa     | Hammond-Aryee et al. [45]     | 2015 | Sheep                  | ELISA  | 292         | 23 (8.00)    | 9             |
| 11       | Tunisia          | Boughattas et al. [46]        | 2014 | Chicken                | MAT    | 40          | 40 (100)     | 8             |
| 12       | Nigeria          | Ayinmode et al. [47]          | 2014 | Chicken                | MAT    | 225         | 81 (40.40)   | 9             |
| 13       | Senegal          | Davoust et al. [48]           | 2014 | Cattle, Goat, Horse, Sheep | MAT | 419 | 148 (35.33) | 8             |
| 14       | Ethiopia         | Gebremedhin and Gizaw [49]    | 2014 | Sheep, Goat            | ELISA  | 184         | 48 (26.08)   | 9             |
| 15       | Ethiopia         | Gebremedhin et al. [50]       | 2014 | Sheep, Goat            | DAT    | 628         | 50 (17.62)   | 9             |
| 16       | Sudan            | Medani and Kamal [51]         | 2014 | Cattle, Sheep          | ELISA  | 540         | 153 (28.33)  | 7             |
| 17       | Somalia          | Kadle [52]                    | 2014 | Camel                  | LAT    | 64          | 4 (6.3)      | 7             |
| 18       | Ethiopia         | Gebremedhin et al. [53]       | 2014 | Camel                  | DAT    | 455         | 220 (49.62)  | 9             |
| 19       | Ethiopia         | Tilahun et al. [54]           | 2013 | Chicken                | MAT    | 64          | 41 (64.00)   | 9             |
| 20       | Egypt            | Abolhaddad et al. [55]        | 2013 | Chicken                | MAT    | 215         | 30 (13.95)   | 8             |
| 21       | Ethiopia         | Zewdu et al. [56]             | 2013 | Goat                   | ELISA  | 927         | 183 (19.70)  | 9             |
| 22       | Tanzania         | Sawai and Kaaya [57]          | 2013 | Goat                   | LAT    | 337         | 65 (19.30)   | 8             |
| 23       | South-Africa     | Ndou et al. [58]              | 2013 | Cattle                 | ELISA  | 178         | 37 (20.80)   | 8             |
| 24       | Nigeria          | Ayinmode and Olaosebikan [59] | 2013 | Pig                    | ELISA  | 100         | 25 (25)      | 8             |
| 25       | Ethiopia         | Gebremedhin et al. [60]       | 2013 | Sheep                  | ELISA  | 1130        | 357 (31.59)  | 9             |
| 26       | Burkina-Faso     | Bamba et al. [61]             | 2013 | Sheep                  | MAT    | 339         | 96 (28.3)    | 8             |
| 27       | Libya            | Al-Mabruk et al. [62]         | 2013 | Sheep                  | LAT    | 5806        | 4120 (71.00) | 9             |
| 28       | Tunisia          | Gharbi et al. [63]            | 2013 | Sheep                  | ELISA  | 350         | 38 (10.85)   | 8             |
| 29       | Egypt            | Barakat et al. [64]           | 2012 | Chicken                | ELISA  | 125         | 48 (38.40)   | 8             |
| 30       | Madagascar       | Rakotoharinome et al. [65]    | 2012 | Pig                    | ELISA  | 250         | 57 (22.80)   | 8             |
| 31       | Tanzania         | Swai and Schoonman [66]       | 2012 | Cattle                 | LAT    | 51          | 06 (12.80)   | 6             |
| 32       | Sudan            | Khalil and Abdel Gadir [67]   | 2011 | Cattle, Camel, Sheep   | LAT    | 200         | 76 (38.00)   | 7             |
| 33       | Tunisia          | Boughattas and Bouratbine [68]| 2011 | Sheep                  | MAT    | 158         | 28 (17.70)   | 9             |
| 34       | Nigeria          | Kamani et al. [69]            | 2010 | Sheep, Goat            | ELISA  | 744         | 42 (5.45)    | 8             |
| 35       | Egypt            | Ibrahim et al. [70]           | 2009 | Cattle                 | ELISA  | 93          | 10 (10.75)   | 8             |
| 36       | Ghana            | Dubey et al. [71]             | 2008 | Chicken                | MAT    | 85          | 40 (47.00)   | 7             |
| 37       | Uganda           | Lindstrom et al. [72]         | 2008 | Chicken                | MAT    | 50          | 25 (50.00)   | 8             |
| 38       | Egypt            | Shapaan et al. [73]           | 2008 | Sheep                  | MAT    | 300         | 131 (43.70)  | 7             |
| 39       | Ethiopia         | Teshale and Dumairte [74]     | 2007 | Goat                   | MDAT   | 641         | 480 (74.80)  | 9             |
| 40       | South-Africa     | Samra et al. [75]             | 2007 | Sheep                  | ELISA  | 600         | 26 (4.30)    | 9             |
| 41       | Egypt            | Dubey et al. [76]             | 2003 | Chicken                | MAT    | 108         | 51 (47.20)   | 8             |
| 42       | Egypt            | Deysab and Hassanein [77]      | 2005 | Chicken                | MAT    | 150         | 28 (18.1)    | 9             |
| 43       | Zimbabwe         | Hove et al. [78]              | 2005 | Goat                   | IFAT   | 312         | 214 (68.58)  | 8             |
| 44       | Tanzania         | Schoonman et al. [79]         | 2010 | Cattle                 | LAT    | 665         | 24 (3.60)    | 8             |
| 45       | Zimbabwe         | Hove et al. [80]              | 2005 | Pig                    | IFAT   | 238         | 47 (26.79)   | 8             |
| 46       | Morocco          | Sawadogo et al. [81]          | 2005 | Sheep                  | ELISA  | 261         | 72 (27.60)   | 9             |
| 47       | Ethiopia         | Negash and Tilahun [82]       | 2004 | Sheep, Goat            | MDAT   | 174         | 79 (45.40)   | 9             |
| 48       | RDC, Mali,       | Dubey et al. [83]             | 2005 | Chicken                | MAT    | 80          | 29 (36.25)   | 7             |

(Contd...)
Table-1: (Continued)

| Study No | Country | Author | Year | Hosts | Method | Sample size | Positive (%) | Quality score |
|----------|---------|--------|------|-------|--------|-------------|--------------|--------------|
| 57       | Burkina-Faso, Ivory-Coast, Djiboutia, Ethiopia, Niger, Senegal | Deconinck et al. [92] | 1996 | Sheep | IHAT | 1042 | 15 (23.00) | 6 |
| 58       | Cameroon | Achu-Kwi and Ekue [93] | 1994 | Sheep | LAT | 211 | 67 (31.80) | 7 |
| 59       | Egypt | El-Ghazy and Mansour [94] | 1994 | Sheep | MAT | 102 | 50 (49.00) | 8 |
| 60       | Nigeria | Amin and Silsmore [95] | 1994 | Sheep, Goat | LAT | 465 | 37 (7.95) | 7 |
| 61       | Senegal | Pangui et al. [96] | 1993 | Sheep | IFAT | 190 | 88 (46.30) | 7 |
| 62       | Sudan | Elamin et al. [97] | 1992 | Camel | LAT | 482 | 323 (67.00) | 7 |
| 63       | Zimbabwe | Pandley and Van Knappen [98] | 1992 | Sheep | ELISA | 216 | 13 (06.00) | 10 |
| 64       | Niger | Weitzman and Stem [99] | 1991 | Sheep | LAT | 70 | 10 (14.00) | 8 |
| 65       | Ethiopia | Bekele and Kasali [100] | 1999 | Sheep, Goat, Cattle | LAT | 2437 | 349 (14.32) | 8 |
| 66       | Nigeria | Aganga and Belino [101] | 1984 | Chicken | IHAT | 250 | 112 (44.80) | 7 |
| 67       | Nigeria | Falade [102] | 1978 | Goat | LAT | 751 | 23 (3.06) | 7 |
| 68       | Egypt | Rifaat et al. [103] | 1969 | Chicken | DAT | 85 | 17 (20.00) | 7 |

MAT: Modified agglutination test, DAT: Direct agglutination test, MDAT: Modified direct agglutination test, ELISA: Enzyme-linked immunosorbent assay, LAT: Latex agglutination test, IFAT: Indirect fluorescent antibody test, IHAT: Indirect hemagglutination test

Table-2: Comparing diagnostic methods.

| Diagnostic test | Study (%) | Sensitivity (%) | Specificity (%) | References |
|-----------------|-----------|-----------------|-----------------|------------|
| N=68 | | | | |
| MAT, DAT, MDAT | 38.23 | 82.9 | 92.29 | Dubey et al. [23] |
| ELISA | 29.41 | 72.9 | 85.90 | Dubey et al. [23] |
| LAT | 17.64 | 45.9 | 96.90 | Dubey et al. [23] |
| IHA | 07.35 | 29.4 | 98.30 | Dubey et al. [23] |
| IFA | 05.88 | 80.40 | 91.40 | Arthur and Blewett [103] |
| SFT | 01.47 | 54.4 | 90.80 | Dubey et al. [23] |

For diagnostic tests, 3 studies used LAT and 3 used DAT. The total number of individual samples was 1621. Prevalence varied from 6.3 to 68.2. The overall estimated prevalence (Figure-6) for toxoplasmosis in camel by random-effect model was 36% (95% CI 18.56%). The result of heterogeneity was also 98.28% (95% CI 97.47-98.81%) for the degree of inconsistency.

Prevalence of anti-T. gondii antibody in pig

For diagnostic studies, 3 tests used LAT and 3 used DAT. The total number of individual samples was 1621. Prevalence varied from 6.3 to 68.2. The overall estimated prevalence (Figure-6) for toxoplasmosis in camel by random-effect model was 36% (95% CI 18.56%). The result of heterogeneity was also 98.28% (95% CI 97.47-98.81%) for the degree of inconsistency.

Prevalence of anti-T. gondii antibody in pig

Data on T. gondii infection in pig were obtained from 8 studies from 6 countries in Africa. 4 studies, performing ELISA, 2 studies, performing MAT and 1 study performing DAT and IFAT respectively. A total number of individual samples was 2330. Prevalence varied from 9.3 to 40.6. Overall estimated prevalence for anti-T. gondii antibody in pig (Figure-7) was 26.0% (95% CI 20.0-32.2). The result of heterogeneity was also 91.3% (95% CI 85.26-94.8) for the degree of inconsistency. Detailed description of each study is given in Figure-7.

Prevalence of anti-T. gondii antibody in chicken

Out of the 16 sero-epidemiological studies from 8 countries in the African continent, 12 studies used MAT, 2 used IHA and 1 study used ELISA and SFT, respectively, for diagnostic of anti-T. gondii antibody in chicken. The total number of individual chicken samples for serological testing was 2948. The prevalence of anti-T. gondii antibody ranged from 6.3% to 100%. The random effect model gave an overall estimated prevalence (Figure-8) of 37.4% (95% CI 29.2-46.0). The result of heterogeneity was also 95.2% (95% CI 93.6-96.6) for the degree of inconsistency.

Risk factor

About 18 papers out of 68 selected articles for this systematic review reported statistically significant risk factors for the presence of anti-T. gondii antibody in different food animals.

Among sheep and goat, six main risk factors for the presence of anti-T. gondii antibody were identified from different studies. It was: Age (Table-1) [49, 56, 69, 86], management farming system (Table-1) [56, 75, 78], farm location (Table-1) [57, 60, 69, 86], climatic condition (Table-1) [49, 74], sex [48, 49], and breed (Table-1) [50, 78]. Moreover, three of these main risk factors were also identified in cattle namely: Age (Table-1) [40], management system (Table-1) [79], and sex (Table-1) [40].
Among pigs, in addition to age (Table-1) [88]; management system (Table-1) [40,80] and breed [88]; the main risk factor identified was feeding type containing bio products (Table-1) [42].

Otherwise, among chicken, the major risk factor for presence of anti-\textit{T. gondii} were cats density (Table-1) [37] and management system (Table-1) [64].

Discussion

Toxoplasmosis is one of the most widespread zoonoses in warm-blooded animals. The results of this review allowed us to compare estimates of infection with \textit{T. gondii} and exposure to the parasite in different food animals from Africa. \textit{T. gondii} infection is widespread in some food animals, especially chicken, camel, pig, sheep, and goats which represent the most consumed animal species in Africa for their meat, and there is a wide disparity between the levels of infection in different animal species considered.

The estimated prevalence of anti-\textit{T. gondii} antibody in ruminants was significantly different: Camels, 36\% (95\% CI 18-56\%); sheep, 26.1\% (95\% CI 17.0-37.0) and goat, 22.9\% (95\% CI 12.3-36.0\%); were the most infected hosts, while the lowest sero-prevalence were recorded in cattle 12\% (95\% CI 8-17\%). The highest infection levels are recorded in

![Figure-2: Funnel plot of double arcsine seroprevalence estimates in food animals.](image)

![Figure-3: Forest plot of \textit{Toxoplasma gondii} infection prevalence in sheep (random effect model).](image)

![Figure-4: Forest plot of \textit{Toxoplasma gondii} infection prevalence in goat (random-effects model).](image)

![Figure-5: Forest plot of \textit{Toxoplasma gondii} infection prevalence in cattle (random-effects model).](image)
The overall pooled estimate in small ruminants was significant and the infection is more common in sheep which represents the most sensitive species to infection [8]. The highest prevalence were obtained in Ethiopia, 74.80% (Table-1) [74] and Zimbabwe, 68.58% (Table-1) [78]. This result shows the variability of infection rates from one region to another within the same species. In most serological studies from sheep and goats included in the meta-analysis, age is considered an important risk factor, as higher seropositivity is found in older animals (Table-1) [49,56,69,86]. This result is in agreement with the results of studies conducted in France and Iran but in all the world [105-107]. According to many authors, the highest prevalence were reported in farms with epizootic abortions (Table-1) [58,108], while lower seroprevalence was recorded in intensively managed sheep systems (Table-1) [56,78,109].

Toxoplasmosis causes heavy economic losses to sheep industry worldwide and losses are mainly due to abortion and other reproductive failure [110-111]. The ingestion of undercooked meat from infected sheep, especially lamb is considered an important source of infection for humans [112]. Therefore, the estimate demonstrates the risk associated with the consumption of raw products derived from small ruminants in countries where the infection rate is high (Table-1) [50,68]. Usually, raw or undercooked lamb meat is considered a delicacy in some countries and is therefore considered an important source of infection. On the other hand, adult sheep meat is often well cooked, and therefore, probably poses a lower risk of infection to the consumer than lamb meat [112].

In pigs, T. gondii infection prevalence ranged from 26.80 to 40.60 excluding one study from Zimbabwe in 1999 reporting a prevalence of 09.60 (Table-1) [89], and lower prevalence rates were recorded in other regions around the world. Thus, prevalence of 28.9% was found in fattening pigs in Serbia [113], 20% in Argentina [114], and 15.6% in Portugal [115]. Poljak et al. [116] reported prevalence in pig farms from Canada of 11.6 in 2001, 0% in 2003 and 1.2% in 2004. High infection rate recorded in some African countries may be due to an extensive management system of pigs which is very widespread in Africa. Studies conducted in Ghana, Ethiopia and Zimbabwe have shown that a high prevalence of T. gondii was observed in extensively managed pig or backyard scavenging pigs than an intensively managed pig, hence the importance of modern intensive farming systems in reducing the prevalence of T. gondii infection in domestic pigs (Table-1) [36,80]. According to Gamble et al., the prevalence of T. gondii in pigs is also influenced by management systems [117]. In poorly managed non-confinement systems, seroprevalence in pigs was as high as 68% [8]. Moreover, most studies conducted in Ghana, Zimbabwe and Ethiopia revealed that, the age of the animal, the Breed, and the management practices appeared to be the major determinants of prevalence of...
antibodies against *T. gondii* (Table-1) [40,80,88]. Most pigs acquire *T. gondii* infection postnatally by ingestion of oocysts from contaminated environment or ingestion of infected tissues of animals. Few pigs become infected prenatally by transplacental transmission of the parasite. Raising pigs indoors in confinement has greatly reduced *T. gondii* infection in pigs, but the recent trend of organic farming is likely to increase *T. gondii* infection in pigs [8]. The consumption of pork infected by *T. gondii* is one of the main risk factors for human infection [5,112]. Pork is known as one of the most important sources of *T. gondii* infection in many countries such as China and USA, most human infections were associated with Pork consumption [3].

The highest estimated prevalence of anti *T. gondii* antibody was recorded in chickens 37.41% (95% CI 29.20-46.00%) with seroprevalence that ranged from 6.32% to 100% (Table-1) [46,76]. Chickens are considered one of the most important hosts in the epidemiology of *T. gondii* infection because they are an efficient source of infection for cats that excrete the environmentally resistant oocysts and because humans may become infected with this parasite after eating undercooked infected chicken meat [118]. Studies from Tunisia, Ethiopia, and Uganda revealed very high prevalence of anti-*T. gondii* antibody among chicken, not encountered in any African country (Table-1) [46,54,72], suggesting high environmental contamination by oocysts of *T. gondii* excreted by cats in these countries. The prevalence of 24.4% was reported in free-range (FR) chickens from Indonesia, 12.5% in chickens from Italy, 30% in chickens from Poland, and 24.2% in chickens from Vietnam by Dubey et al. (Table-1) [71]. In rural areas from Brazil, a prevalence higher than 50% in free ranging chickens was identified, indicating also a widespread contamination of rural environment of that country with *T. gondii* oocysts [119]. Furthermore, the prevalence rates were higher among FR than commercial farm chickens according to many authors (Table-1) [37,64]. Higher seroprevalence particularly in free range chickens (house-reared) refers to the public health importance of chickens as source of zoonotic toxoplasmosis to human (Table-1) [47,64]. In developing sub-Saharan countries, chickens are killed at home or in unsupervised slaughter facilities and the viscera are left for scavengers or are improperly disposed and *T. gondii* infection can be transmitted to human if care is not taken to wash hands thoroughly after cutting meat and during cooking of meat [120].

Results indicate that the estimated prevalence of toxoplasmosis in cattle from Africa is the lowest obtained 12% (95% CI 8-17%, p<0.001) among different food animals. The highest and the lowest prevalence were recorded in Sudan, 32%, and Tanzania, 4%, respectively (Table-1) [67,78]. This overall estimate is higher than the infection rate reported in North of Portugal that was estimated at 7.5% in cattle [121]. In West Indies, a prevalence of 8.4% was reported [122]. In Brazil, the reported sero-prevalence was 49.4% in cattle from a highly endemic area of human toxoplasmosis [123]. Whereas in Malaysia and Vietnam, lower seroprevalence of 7.9% and 10.5% were, respectively, reported in cattle [124,125]. High prevalence of toxoplasmosis of cattle in some areas may be due to the following factors: Humid and temperate climate; the absence of routine treatment against feline toxoplasmosis, considerable cat abundance and last but not least exposure to cats and their oocysts. Several epidemiological studies have mentioned that the consumption of raw or undercooked beef could be considered as a risk for *T. gondii* infection in humans [126]. But according to Kijlstra and Jongert [112] and Dubey and Jones [3] transmission from cattle is not important for human infection. Given the low level of infection in cattle from Africa, we can assume that the risk for *T. gondii* infection in humans from beefs is low as compared to other hosts of *T. gondii*. Among ruminants, camels are the most infected species by *T. gondii*, 36% (95% CI 18-56%). *T. gondii* infection rate in Africa ranged from 17% to 68% and the highest rates were obtained in Sudan (Table-1) [97]. A higher prevalence has been reported from Turkey (90.9%) [127], while lower seroprevalence was recorded earlier from Iran 3.12% [128] and Saudi Arabia 6.5% [129].

Overall, the variation of seroprevalence of *T. gondii* infection among different species might be due to the difference in density of cats and wild felids around farm, climatic conditions [130], farming and management practices [3], sample size, cut-off titer, duration of studies, and sensitivity difference in the serological tests employed. According to Guo et al. [131], the heterogeneity in prevalence could also be related to the presence of risk factors including farm type, feeding practices, presence of cats, rodent control and bird control methods, farm management, carcasses handling and disposal, and water source and quality. Moreover, studies carried out in distinct countries and various climatic conditions affect the results that could be another reason for this heterogeneity.

Results from some studies showed significant relation between animal age and *T. gondii* infection among all hosts. It shows a higher prevalence in adults animals than young which may be resulted from more exposure during animal growth. Animals acquire *Toxoplasma* infection merely via ingestion of oocyst and when prevalence is considerably high. There is a widespread oocyst contamination of the environment because of fecal contamination of soil and groundwater either by domestic or feral cats. Understanding prevalence rate of animal toxoplasmosis will help us to estimate the rate of human toxoplasmosis and it can be a good indicator of environment and final host contamination [107]. This point is extremely important to mention that it is not easy to consider prevention and control program without enough information about prevalence
of toxoplasmosis in animal since they are a major source of transmission to human.

Given the vital role of animals in the transmission of *T. gondii* to humans via their products (meat and milk) and the prominent role of cats in disseminating and contamination of the environment by oocysts [1], more emphasis should be placed on the prevention of animal toxoplasmosis in Africa.

Caution is warranted in the interpretation of results of *T. gondii* prevalence in camel. Regarding such species, the prevalence data used in this study were analyzed based on a limited number of national studies, and nationwide surveys are not available in these meat animals, which resulted in a wide 95% CI of the estimated prevalence.

**Conclusion**

This systematic review was performed to evaluate the prevalence of *T. gondii* infection among sheep, goat, cattle, pig, camel, and chicken which represent the most consumed food animal species in different African countries. The Random-effects meta-analysis approach in this current study provided an estimate of *T. gondii* prevalence in various meat animals with an increased level of precision. The widespread prevalence of *T. gondii* in sheep, chicken, camel, pig, and goats indicates a food safety concern in different African countries, especially countries where the infection is more important. Other studies are required for a better and continual evaluation of the occurrence of this zoonotic infection.

**Authors’ Contributions**

The study was conceptualized and protocols were carried out by YA. ABNT and PS were involved in the database search, data extraction, statistical analysis, and manuscript written. CA and EY Studied titles and abstract of all the articles and retrieved data. Quality assessment of each study was completed independently by YGH and IY. MNA and SF oversaw data collection and analysis of statistical results. All authors have read and approved the content.

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**Competing Interests**

The authors declare that they have no competing interests.

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Appendix

Supplementary Table-S1: Quality score assessment based on the “risk of bias tool” (Hoy et al., 2012).

| Species | Study | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Summary |
|----------|-------|----|----|----|----|----|----|----|----|----|-----|---------|
| Pig      | Bamba et al. [36] | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| Chicken  | Gebremedhin et al. [37] | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| Goat     | Gebremedhin et al. [38] | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 7 |
| Sheep    | Dechicha et al. [39] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Goat     | Dechicha et al. [39] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Cattle   | Dechicha et al. [39] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Cattle   | Onyiche and Ademola [40] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Pig      | Gebremedhin et al. [42] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Camel    | Hadush et al. [43] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Lahmar et al. [44] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Hammond-Aryee et al. [45] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Chicken  | Boughattas et al. [46] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Chicken  | Ayinmode and Olaosebikan [47] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Goat     | Davoust et al. [48] | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Davoust et al. [48] | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Gebremedhin and Gizaw [49] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Goat     | Gebremedhin and Gizaw [49] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Gebremedhin et al. [50] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Goat     | Gebremedhin et al. [50] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Cattle   | Medani and Kamil [51] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Medani and Kamil [51] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Camel    | Kadle [52] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Camel    | Gebremedhin et al. [53] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Chicken  | Tilahun et al. [54] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Chicken  | Aboelhadid et al. [55] | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Goat     | Zwedu et al. [56] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Goat     | Swai and Kaaya [57] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Cattle   | Ndou et al. [58] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Pig      | Ayinmode and Olaosebikan [59] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Gebremedhin et al. [60] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Bamba et al. [61] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Al-mabruk et al. [62] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Gharbi et al. [63] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Chicken  | Barakat et al. [64] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Pig      | Rakotoharinome et al. [65] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Cattle   | Swai and Schoonman [66] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Camel    | Kailil and Abdel Gadir [67] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Kailil and Abdel Gadir [67] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Boughattas and Bourabine [68] | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Sheep    | Kamanli et al. [69] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Goat     | Kamanli et al. [69] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| Cattle   | Ibrahim et al. [70] | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |

(Contd…)

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Supplementary Table-S1: (Continued)

| Species | Study                  | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Summary |
|---------|------------------------|----|----|----|----|----|----|----|----|----|-----|---------|
| Chicken | Dubey et al. [71]      | 0  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 7       |
| Chicken | Lindstrom et al. [72]  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 8       |
| Sheep   | Shapaa et al. [73]     | 0  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 7       |
| Goat    | Teshale and Dumaitre [74]| 0 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 9       |
| Sheep   | Samra et al. [75]      | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 9       |
| Chicken | Dubey et al. [76]      | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 8       |
| Chicken | Deyab and Hassanein [77]| 0 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 9       |
| Goat    | Hove et al. [78]       | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 1   | 9       |
| Cattle  | Schoonman et al. [79]  | 0  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 8       |
| Pig     | Hove et al. [80]       | 0  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 8       |
| Sheep   | Sawadogo et al. [81]   | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 9       |
| Sheep   | Negash and Tilahun [82] | 0 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 9       |
| Goat    | Negash and Tilahun [82] | 0 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 9       |
| Chicken | Dubey et al. [83]      | 0  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 7       |
| Cattle  | Joshua and Akinwumi [84]| 0 | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 8       |
| Chicken | El-Massry et al. [85]  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 8       |
| Sheep   | Van der Puije et al. [86]| 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 10      |
| Goat    | Van der Puije et al. [86]| 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 10      |
| Goat    | Bisson et al. [87]     | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 10      |
| Pig     | Arko Mensah et al. [88] | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 10      |
| Pig     | Hove and Dubey [89]    | 0  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 7       |
| Camel   | Hilali et al. [90]     | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 9       |
| Chicken | Hassanain and Elfadaly [91]| 0 | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 7       |
| Sheep   | Deconick et al. [92]   | 0  | 0  | 0  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 6       |
| Sheep   | Achu-Kwi and Ekue [93] | 0  | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 7       |
| Sheep   | El-Ghaysh and Mansour [94]| 0 | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 8       |
| Goat    | Amin and Silsmore [95] | 0  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 8       |
| Sheep   | Pangu et al. [96]      | 0  | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 7       |
| Camel   | Elamin et al. [97]     | 0  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 8       |
| Sheep   | Pandley and Mansour [98]| 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1   | 10      |
| Sheep   | Weitzman et al. [99]   | 0  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 8       |
| Sheep   | Bekele and Kasali [100] | 0 | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 8       |
| Goat    | Bekele and Kasali [100] | 0 | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 8       |
| Cattle  | Bekele and Kasali [100] | 0 | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 8       |
| Chicken | Aganga and Belino [101]| 0  | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 7       |
| Goat    | Falade [102]           | 0  | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 7       |
| Chicken | Rifaat et al. [103]    | 0  | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1   | 7       |