Journal of Science and Sustainable Development (JSSD), 2019, 7(2), 1-14 [1]

ISSN: 2304-2702 (print); 2414-4479 (online)
DOI: https://doi.org/10.20372/au.jssd.7.2.2019.0132

REVIEW PAPER

Toxoplasma gondii infection in domestic animals in Ethiopia: Seroprevalence, risk factors, Clinical disease, isolation and genotyping: A review

Endrias Zewdu Gebremedhin

Ambo Univerisity, College of Agricultural and Veterinarey Sciences, P.O.Box 19, Ambo, Ethiopia, E-mail: endrias.zewdu@gmail.com

Abstract

Toxoplasmosis is one of the most prevalent parasitic infectious diseases of medical and veterinary importance due to its implication in abortion and congenital disease in its intermediate hosts. In order to compile data on *Toxoplasma gondii* in animals in Ethiopia, published data on the seroprevalence, risk factors for infection, clinical disease, isolation and genotyping in Ethiopia were retrieved from databases of Pub Med, Science Direct, Google Scholar and Universities libraries regardless of the year of publication. No statistical method was employed in this study. The compiled review generally indicate high prevalence which varies with species of animals, diagnostic methods and across regions and areas of the country. Age, sex, management, presence of cats, altitude and herd size were identified as important risk factors in most studies. High proportions of seropositive sheep, goats, cats, chicken, and pigs harbor viable tissue cysts. The four genotypes of *T. gondii* found in Ethiopia so far suggest limited genetic diversity. Most publications of *T. gondii* infection are from wet part of the country. Environmental contamination with oocysts from cats appears to be widespread contributing for the high prevalence of infection in domestic animal. The high rate of occurrence of viable tissue cysts might constitute important food safety concerns Prevention and control methods of toxoplasmosis mainly through education, establishment of health infrastructures, capacity building, surveillance, stakeholders' collaboration, and further large-scale studies are recommended.

Keywords: Seroprevalence; risk factor; bioassay; genotyping; domestic animals; Ethiopia.

Introduction

Toxoplasmosis is one of the most prevalent parasitic infectious diseases of medical and veterinary importance (Tenter et al., 2000; Dubey, 2010). It is caused by the obligate intracellular protozoan parasite *Toxoplasma gondii (T. gondii).* Wild and domestic cats are the final hosts, which play a central role in the epidemiology of *T. gondii* infections by shedding resistant oocysts in the environment. Intermediate hosts like felids, can acquire *T. gondii* through ingestion of tissues of infected animals, food or drink contaminated with sporulated oocysts or by transplacental transmission (Tenter et al., 2000; Radostits et al., 2006). Pigs, sheep, and goats are more commonly infected intermediate hosts than other livestock and represent a significant source of *T. gondii* for humans and other animals (Tenter et al., 2000).

It has been suggested that the genotype of *T. gondii*, dose of inoculum and infecting stage of the parasite might account for the difference in the disease outcome (Olivier et al., 2007). According to Carruthers and Suzuki (2007) the genotype of *T. gondii,* genetic factors of the host, and probably the route of infection and the stage (tachyzoite, cyst, or oocyst) of the parasite initiating infection all contribute to the establishment of a balance between the host and the parasite and affect the outcome of the infection. The outcome of infection in most

cases in immunocompetent hosts is latent infection. Congenital infection is one of the possible outcome leading to severe neurological and ophthalmological disease (Carruthers and Suzuki, 2007). In sheep, goats and pig reproductive failure is an important outcome (Dubey, 2010). Ocular disease is another outcome of *T. gondii* infection, which is higher in Africa and South America compared to that of Europe. In South America, ocular toxoplasmosis due to virulent strains is associated with high burden of visual disability (Peterson et al., 2012).

Previous studies have shown that nearly 90% of *T. gondii* isolates from animals and humans in North America and Europe belonged to three clonal lineage Types (I, II and III) with low genetic diversity (Sibley et al., 2002). However, studies have shown that the population structure of *T. gondii* isolates is more diverse (Khan et al., 2011) and genotyping methods using multilocus markers indicate greater genetic diversity than initially thought mainly due to emergence of atypical and recombinant non-clonal strains (Ajzenberg et al., 2004; Ferreira et al., 2006; Khan et al., 2011). In immunocompetent patients, severe toxoplasmosis with multi-organ failure has been linked to atypical strains acquired from the Amazonian rainforest (Carme et al., 2002). Similarly, severe cases of congenital toxoplasmosis in France (Ajzenberg et al., 2002; Delhaes et al**.,** 2010) and Suriname (Demar et al., 2007) and abortion in sheep in Uruguay (Su et al., 2003; Ajzenberg et al., 2004) were observed in relation to infection with atypical genotypes. Severe or lethal infections in immunocompetent subjects, with pneumonitis, myocarditis, meningoencephalitis, or polymyositis were also reported due to atypical genotypes (Ajzenberg et al., 2002).

A meta-analysis of the prevalence of *Toxoplasma gondii* infection in animals and humans in Ethiopia showed pooled IgG seroprevalence of 87.72 %, 34.59 % and 74.73 % in cats, small ruminants and humans respectively (Gebremedhin and Tadesse, 2015). The current work tries to add an updated review on seroprevalence. To the best of my knowledge, a review on risk factors, clinical toxoplasmosis, bioassay and genotyping in animals in Ethiopia is lacking.The objective of this paper is to report the state of the art reviews on seroprevalence, risk factors, clinical toxoplasmosis, bioassay and genotypes of *T. gondii* in animals in Ethiopia and the way forward to counteract *T. gondii* infection.

Diagnosis of *T. gondii* infection

Toxoplasmosis is conventionally diagnosed by serology. However, a positive serological result does not mean that viable parasites are present in all tissues. The bioassay is used as the gold standard test for diagnosis of *T. gondii* infection. It can also be used for isolating strains of *T. gondii* for assessing their pathogenicity in mice or for further genotyping (Dubey, 2010; Su and Dubey, 2010).

Methodology of the study

In order to compile data on *Toxoplasma gondii* in animals in Ethiopia, published data on the seroprevalence, risk factors for infection, clinical disease, isolation and genotyping in Ethiopia were retrieved from databases of Pub Med, Science Direct, Google Scholar and Universities libraries regardless of the year of publication. No statistical method was employed in this study

Epidemiology of toxoplasmosis in domestic animals in Ethiopia

So far, the epidemiological study of risk factors in *T. gondii* infected and non -infected individuals was the most useful way of assessing the relative importance of different sources of *T. gondii* infection (Peterson et al., 2012).

Toxoplasma gondii infection in cats

The reported IgG and IgM seroprevalence of *T. gondii* infection in feral cats of Addis Ababa were 85.4% (41/48) and 23.9% (11/46), respectively (Tiao et al., 2013). A few studies were conducted on the prevalence of oocysts shed by cats using microscopic examination. Negash (2000) reported a prevalence of 12.5%

(5/37) in Debre-Birhan, Central Ethiopia. In Bahir-Dar (North-West of Addis Ababa), 52 (13.5%) cats were coprologically positive (Yihinew, 2012). Dubey et al. (2013a) also detected *T. gondii* oocysts in feces of 19% of 36 cats in Addis Ababa which is very high compared to the 2% reported worldwide (Dubey, 2010). The high percentage of oocyst shedding was attributed to outdoor living, hunting, feeding on scraps or garbage (Dubey et al., 2012) and tissues of backyard-slaughtered animals. However, differential diagnosis of *T. gondii* oocysts from *Hammondia hammondi* oocysts was not given in these reports.

Clinical toxoplasmosis in animals

Published studies on clinical toxoplasmosis in animals in Ethiopia are scarce except for the report of Demissie and Tilahun (2002) that implicated *T. gondii* infection as the most probable cause of clinical toxoplasmosis in the form of abortion in sheep due to the finding of high antibody titres (by MAT) in two ewes (1:1024 and 1:4096) and their aborted foetuses (1:4096 and 1:16384). However, differential diagnosis of causes of abortion was not made in the reports of Demissie and Tilahun (2002). Getachew et al. (2016), in their questionnaire survey involving 100 livestock owners, revealed reproductive abnormalities in the form of abortion, stillbirth and neonatal mortality as important economic problems in sheep. However, the authors did not report the association of these abnormalities with *T. gondii* seropositivity.

Seroprevalence of T. gondii infections in animals

The limited number of studies undertaken to investigate the magnitude of sub-clinical *T. gondii* infection in animals in Ethiopia indicate a high seroprevalence ranging from, 22.9% - 56% in sheep (Table 1), 11.6% - 82% in goats (Table 2), 8.33% - 49.62% in camels, 6.6% - 25.0% in cattle (Table 3), 30.5-38.4% in chickens and 32.1-47.5% in pigs (Table 4). No published literature was found about *T. gondii* infection in wildlife.

Risk factors of Toxoplasma gondii infection in domestic animals

Epidemiologic studies have identified the following risk factors for *T. gondii* infection in Ethiopian sheep and goats: adult age (Teshale et al., 2007; Gebremedhin and Gizaw, 2014; Gebremedhin et al., 2014a; Tegegne et al., 2016; Tilahun et al., 2018), being female (Teshale et al., 2007; Zewdu et al., 2013; Gebremedhin et al., 2013; Tegegne et al., 2016; Tilahun et al., 2018), small flock size, drinking water from tap, semi-intensive management, sedentary and agro-pastoral farming systems (Gebremedhin et al., 2013a) and season (dry season) (Gebremedhin et al., 2014a).

Seroprevalence was higher in sheep than goats (Gebremedhin and Gizaw, 2014). Getachew et al. (2016) reported significantly high seroprevalence in male than female sex; however, the type of species of livestock was not specified. In chicken extensive management, an increase in age and presence of cats were identified as significant risk factor for seropositivity (Gebremedhin et al. (2015a). However, presences of domestic cats, as well as wild felids, were not shown as significant factors for *T. gondii* seropositivity (Zewdu et al., 2013; Gebremedhin et al., 2013b).

Toxoplasma gondii seroprevalence was higher in sheep from the highlands (2300–3200 meters above sea level-masl) and midlands (1500–2300 masl) as compared to animals from the lowlands (<1500 masl) areas (Zewdu et al., 2013; Gebremedhin et al., 2013a; Gebremedhin and Gizaw, 2014; Gebremedhin et al., 2014a; Tegegne et al., 2016).

Studies on the effect of management on *T. gondii* seroprevalence gave contrasting results. For example, Demissie and Tilahun (2002) reported a significantly higher seroprevalence in extensively managed sheep flocks compared to intensively or semi-intensively managed sheep flocks. In contrast, management was reported to have no significant effect on seroprevalence (Teshale et al., 2007).

In a study of *T. gondii* infection of camels *(Camelus dromedaries*) of Borena zone and

Fentale districts of Ethiopia, age (adult), study area (district, pastoral association (PA) (Geberemedhin et al., 2014b; Geberemedhin et al., 2016) and presence of domestic cats were found to be independent predictors (Geberemedhin et al., 2014b).

Table 1. Prevalence of *Toxoplasma gondii* infection in sheep in Ethiopia

Origin/site	Design	Study year	Sample size	Prevalence (%)	Test	Ig detected & Cut-off titer	References
Addis Ababa abattoir and Debre-Birhan	NG	1985-87	899	22.9	IHAT-1	NG, 1:64	Bekele and Kassali (1989)
NG, abattoir/ farms	NG	NG	94	25.6	IHAT-2	NG	Deconinck et al. (1996)
Debre-Birhan	CS	2000-01	375	34	MDAT*	IgG, 1:32	Demissie and Tilahun (2002)
Nazareth	NG	1999-00	116	52.6	MDAT**	IgG, 1:32	Negash et al. (2004)
Nazareth	NG	1999-00	116	56	ELISA*	IgG, NG	Negash et al. (2004)
South Wollo	CS	2007-08	426	45.4	MAT	IgG, 1 :40	Yibeltal (2008)
East and West Shewa	CS	2010-2011	1130	31.6	ELISA***	IgG, (S/P≥50%)	Gebremedhin et al. (2013a)
Central Ethiopia	CS	2011-2012	305	20	DAT	IgG, 1:40	Gebremedhin et al. (2014a)
South west Ethiopia	CS	2014-2015	252	58.18	LAT	IgG, 4 IU/ml	Tegegne et al. (2016)
Veterinary Clinics, Addis Ababa	CS	2011-2012	194	36.6	SAT	NG, 4 IU/ml	Getachew et al. (2016)
Wondo Genet, Ethiopia	CS	2008-2009	80	48.75	DAT	IgG, 1:40	Eticha et al. (2017)
East Hararghe Zone, Oromia, Ethiopia	CS	2011-2013	332	33.7	ELISA***	IgG, (S/P≥50%)	Tilahun et al. (2018)

Table 2. Prevalence of *Toxoplasma gondii* infection in goats in Ethiopia

Origin/site	Design	Study Year	Sample size	Prev. (%)	Test	Ig detected & Cut-off titre	References
Addis Ababa abattoir and Abomessa	NG	1985-87	753	11.6	IHAT-1	NG, 1:64	Bekele and Kassali (1989)
NG, slaughterhouse or in farms	NG	NG	133	19.5	IHAT-2	NG	Deconinck et al. (1996)
Debre-Birhan	CS	2000-01	93	35	MDAT*	IgG, 1:32	Demissie and Tilahun (2002)
Nazareth	NG	1999-00	58	25.9	ELISA*	IgG, NG	Negash et al. (2004)
South Omo	CS	2005-06	256	82	MAT***	IgG, 1 :20	Teshale et al. (2007)
North Omo	CS	2005-06	176	79.5	MAT***	IgG, 1 :20	Teshale et al. (2007)
East Shewa	CS	2005-06	209	62,2	MAT***	IgG, 1 :20	Teshale et al. (2007)
South Wollo	CS	2007-08	86	37.2	MAT	IgG, 1 :40	Yibeltal (2008)
East and West Shewa	CS	2010-2011	927	19.7	ELISA***	IgG, (S/P≥50%)	Zewdu et al.(2013)
SNNPR	CS	2013 -2014	184	29.09	ELISA***	IgG, (S/P≥50%)	Gebremedhin and Gizaw (2014)
Central Ethiopia	CS	2011-2012	323	15.48	DAT	IgG, 1:40	Gebremedhin et al. (2014a)
South west Ethiopia	CS	2014-2015	116	55.18	LAT	IgG, 4 IU/ml	Tegegne et al. (2016)
Veterinary Clinics, Addis Ababa	CS	2011-2012	40	37.5	SAT	NG, 4 IU/ml	Getachew et al. (2016)
East Hararghe Zone, Oromia	CS	2011-2013	410	27.6	ELISA***	IgG, (S/P≥50%	Tilahun et al. (2018)

Table 3. Prevalence of *Toxoplasma gondii* infection in cattle and camels in Ethiopia

Origin/site	Design	Study Year	Species	Sample size	Prev. (%)	Test	Ig detected & Cut-off titre	References
Ghibe and Gobe	NG	1985-87	Cattle	785	6.6	IHAT-1	NG, 1:64	Bekele and Kassali (1989)
Fentale,, Ethiopia	CS	2012-2013	Camel	455	40.49	ELISA***	IgG, (S/P≥50%)	Gebremedhin et al. (2014b)
Fentale, Ethiopia	CS	2012-2013	Camel	451	49.62	DAT	IgG, 1:40	Gebremedhin et al. (2014b)
Borena zone, Oromia region, Ethiopia	CS	2013-2014	Camel	396	8.33	DAT	IgG, 1:40	Gebremedhin et al. (2016)
Borena zone, Oromia region	CS	2013-2014	Camel	396	8.33	DAT	IgG, 1:40	Gebremedhin et al. (2016)
Vet.Clinics, AA	CS	2011-2012	Cattle	44	25.0	SAT	NG, 4 IU/ml	Getachew et al. (2016)
East Hararghe, Oromia	CS	2011-2013	Cattle	326	10.7	ELISA***	IgG, (S/P≥50%)	Tilahun et al. (2018)
East Hararghe Zone, Oromia	CS	2011-2013	Camel	292	14.4	ELISA***	IgG, (S/P≥50%)	Tilahun et al. (2018)

Table 4. Prevalence of *Toxoplasma gondii* infection in pigs and chickens in Ethiopia

Origin/site	Design	Study Year	Species	Sample size	Prevalence (%)	Test	Ig detected & Cut-off titre	References
Addis Ababa	NG	2012	Chicken	125	38.4	MAT	IgG, 1:5	Tilahun et al. (2013)
Central Ethiopia	CS	2012-2013	Chicken	601	30.5	MAT	IgG, 1:40	Gebremedhin et al. (2015a)
Central Ethiopia	CS	2013-2014	pig	402	32.1	DAT	IgG, 1:40	Gebremedhin et al. (2015b)
Veterinary Clinics, Addis Ababa	CS	2011-2012	pig	40	47.5	SAT	NG, 4 IU/ml	Getachew et al. (2016)

IHAT-1: Indirect Hemagglutination Test (Wellcome Diagnostics, UK), IHAT-2: Indirect Hemagglutination Test (ToxoplasmoseFumouze, France); ELISA*: Enzyme-Linked Immunosorbent Assay (Enzygnost, BioMerieux, France), MDAT*: Modified Direct Agglutination Test (AntigeneToxo-Screen AD, Biomerieux SA, Lyon, France), MDAT**: Modified Direct Agglutination Test (Toxo-Screen DA, Dace Behring Marburg, GmBH, Germany), MAT*** : Modified Agglutination Test (in-house), DAT: Direct agglutination test (Toxo screen DA,vbiomerieux®, France), ELISA*** : enzyme-linked immunosorbent assay (ID VET Innovative Diagnostic, ID Screen ®, Montpellier, France), LAT (SPINREACTGirona/Spain),NG : not given, Ig: Immunoglobulin, CS= Cross-Sectional, S/P: Optical Density (OD) of sample – OD of negative control / OD positive control - OD negative control*100. SNNPR: Southern Nations Nationalities Peoples Region, Slide Agglutination Test (HUMATEX TOXO, Human Gesellsfür Biochemica und Diagnostoica mbH Max-Plank-ring21.65205 Wiesbaden. Germany, SAT-Slide agglutination test. Prev.=prevalence

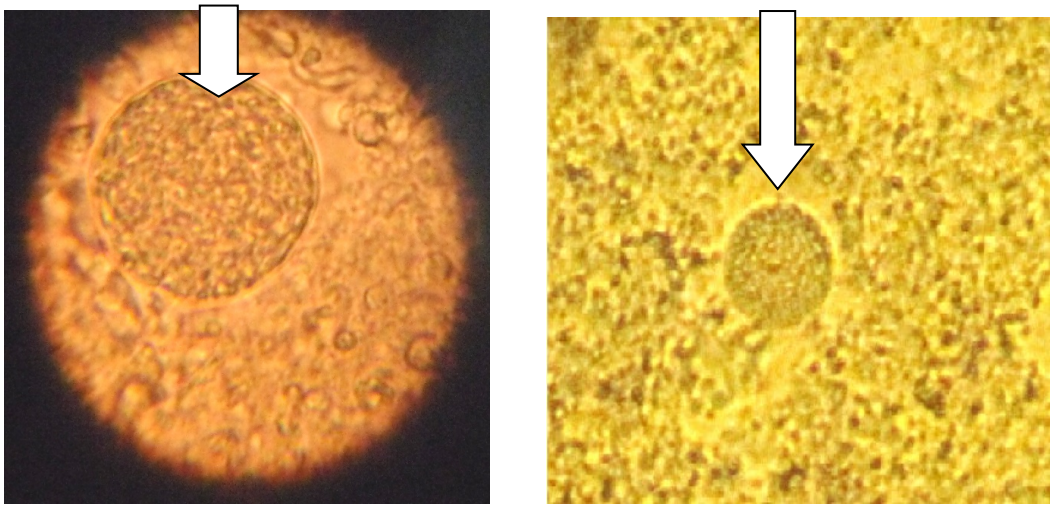
Tilahun et al. (2018) also identified age (> 4 years) in camels, and district, large herd size, and water source (pipe and pond) in cattle as risk factors for *T. gondii* infection in East Hararghe, Oromia, Ethiopia. In chicken, altitude (midland), breed (exotic and cross breed), extensive management, presence of cats and increased age were identified as risk factors (Gebremedhin et al., 2015a). In pigs, extensive management system and feed type containing animal byproducts were identified as important risk factors to acquire *T. gondii* infection (Gebremedhin et al., 2015b).

Reports also indicated that *T. gondii* infection increases the risk of abortion, neonatal mortality and weak births in sheep and goats (Demissie and Tilahun, 2002; Negash et al., 2004; Yibeltal, 2008; Gebremedhin et al., 2013b).

So far, there is no conclusive evidence as to the factors that play greatest role in acquiring *T. gondii* infection in animals in Ethiopia. Few studies attempted to isolate and genotype the parasite from animals.

Bioassay and genotyping

Viable *T. gondii* were isolated from 26 (72.2%) heart samples and 6 (16.7%) fecal samples of Ethiopian cats bioassayed on mice (Dubey et al., 2013a). Gebremedhin et al. (2014b) isolated viable *T. gondii* from 16.13% (5/31) of DAT seropositive camels of Fentale district, central Ethiopia. The same authors reported absence of viable cysts in brain of 17 seropositive mice while some cyst and/or seropositive mice showed weight loss, tachypnea and neurological signs suggesting the virulence of the isolates. It was reported that the burden of brain cyst in mice inoculated with seropositive camels' heart tissue homogeneity was lower compared to sheep, goat (Gebremedhin et al., 2014b) and pig (Gebremedhin et al., 2015b). Similarly, viable *T. gondii* were isolated from hearts of 48% (24/50) DAT seropositive pigs and from the two pooled seronegative pig hearts. All isolates were asymptomatic except one isolate from Bishoftu, Central Ethiopia, which was lethal for mice on day 28 post-inoculation (Gebremedhin et al., 2015c). On the other hand, Gebremedhin et al. (2014c) reported isolation rate of 70.7% in mice from pooled heart and brain of 41 DAT seropositive (≥1:40) free-range chickens (*Gallus domesticus*) of central Ethiopia. None of these isolates were lethal for mice. Gebremedhin et al. (2014d) also isolated viable *T. gondii* strains from 57.45% (27/47) and 45.45% (20/44) DAT seropositive sheep and goats, respectively (Figure 1). The isolation rate of viable *T. gondii* cysts was significantly higher from adult (39.90%) than from young (17.91%) small ruminants. These isolates caused sub-clinical infections in mice except 2 sheep and 1 goat isolates which were virulent strain lethal for mice between19–27 days' post-inoculation. The same authors also reported isolation of viable *T. gondii* from 2 of 10 sheep and 2 of 4 goat samples. Presence of viable *T. gondii* cysts in edible organs of sheep and goats provides a definitive diagnosis of *T. gondii* infection. Considering the increasing trend and habit of eating raw or undercooked meat and offal from small ruminants in Ethiopia, the high rate of isolation of viable tissue cysts is of great public health significance. It is a reflection of the high degree of contamination of the environment by oocysts of cats and the outdoor management system of animals (Dubey, 2010). Although bioassay is the only method that can detect live *T. gondii* parasites from infected animal tissue (Yai et al., 2003), the findings of the research on isolation of *T. gondii* from seropositive sheep and goats heart samples on Swiss Albino mice showed that microscopic brain tissue cyst detection was less sensitive as compared to nPCR and direct agglutination test (Zewdu et al., 2015).



A (sheep, Ambo, 40X) B (goat, Fentale, 10 X)

Figure 1. Tissue cysts of *Toxoplasma gondii* (unstained) isolated from mouse brain after inoculation of heart tissue homogenates from *T. gondii* seropositive sheep from Ambo (A) and goats from Fentale districts (B), Light Microscope. Note the thin cyst wall (arrow) enclosing bradyzoites (A) (Source: adapted from Gebremedhin (2014).

So far, two published reports are available on genotyping of *T. gondii*; one from sheep and goats (Gebremedhin et al., 2014d) and the other from cats (Dubey et al., 2013b). Of the 33 sheep and goat isolates genotyped using multiplex-PCR microsatellite method 87.88%, 9.09%, and 3.03% were identified as Type II, Type III and atypical *T. gondii* genotypes. The atypical strain as well as one Type II and one Type III strains, all from East Shewa zone of Oromia region, Ethiopia, were mouse virulent. This atypical genotype was highly divergent from the type I, II, and III strains and did not group with the reference African strains (Gebremedhin et al., 2014d). Dubey et al. (2013b) genotyped 33 *T. gondii* isolates from 27 feral cats of Addis Ababa and revealed four ToxoDB PCR-RFLP genotypes. Interestingly, in the same study, two cats harbored different genotypes that were isolated from the feces and the heart, suggesting re-infection. The identified genotypes from Ethiopian cats were similar to those *T. gondii* isolates from Egypt (Velmurugan et al., 2008; Al-Kappany et al., 2010). Overall, the genotyping studies suggest limited genetic diversity perhaps due to the limited sampling, geographical coverage and species of animals sampled.

Overview of public health and economic significance of *T. gondii* infection

Toxoplasmosis is among the global major zoonotic diseases (Petersen et al., 2010; Torgerson and Macpherson, 2011). Worldwide, 30% of the world's population is estimated to have antibodies to *Toxoplasma gondii* with large variation between countries (Montoya and Liesenfeld, 2004) and with high prevalence in low-income countries than in middle-income and high-income countries (Wang et al., 2017). Globally about 36·7 million people are infected with HIV. About 87·1% of the worldwide co-infection of *T. gondii* and HIV is found in sub-Saharan Africa (Wang et al.., 2017). Recently, Wang et al. (2017) showed that in sub-Saharan Africa people living with HIV infection have very high burden of *T. gondii* infection. The same others also stressed regular surveillance of *T.*

gondii infection in all HIV-infected people play important role.

Toxoplasmosis is an economically important disease in animal husbandry globally as it is a major cause of reproductive failure by leading to early embryonic death and resorption, fetal death and mummification (Dubey, 2009), abortion, stillbirths, and neonatal death in small ruminants (Dubey, 2009; Dubey, 2010). The severity of infection is associated with the stage of gestation at which the ewe becomes infected; the earlier in gestation, the more severe the consequences (Dubey, 2009).

Overall, toxoplasmosis results in increased production costs, diminished marketability of meat, fewer replacement animals, retardation of genetic progress and a major source of human infection (Freyre et al., 1997).

Conclusions

Most of the published reports are from wet part of the country (Addis Ababa, southern, southwestern, central, northwestern Ethiopia). Though the studies might not represent the whole nation, it appears that there is regional variations in prevalence and the environment might be highly contaminated with *T. gondii* oocysts perhaps from the abundant cat population. As a result, the prevalence of *T. gondii* infection in domestic animals was generally high and heterogeneous across regions, from area to area as well between animal species and diagnostic methods. Risk factors for *T. gondii* infection of animals are diverse and common. Moreover, the proportion of seropositive animals harboring the viable tissue cyst was high and hence constitute important food safety concerns. The limited studies suggest limited genetic diversity of *T. gondii* in Ethiopia.

Recommendations

Some of the shortcomings of the literatures on *T. gondii* infection in Ethiopia include fragmented studies often with inadequate sample size and geographical coverage to represent snapshot of the entire population. The heterogeneity of the prevalence across the studies might be due to differences in the species, sample size, environment, and climate, relative density of felids, food habit and diagnostic tests used.

Considering the raw as well as undercooked meat consumption behavior, the absence of Toxoplasma control programs, the remarkable rise in incidence of new HIV infection and AIDS-related death in recent days in Ethiopia (Girum et al., 2018) the high prevalence of *T. gondii* infection in animals might constitute great health burden in the country. Thus, the overall high prevalence of *T. gondii* infection in domestic animals in Ethiopia suggests the need for preventive measures, mainly education of humans on the identified risk factors, in order to reduce associated morbidities and mortalities. Primary infection prevention at farm level should focus on education of producers about the role of cats in the epidemiology of *T. gondii* infection so that new infection of food animals and humans is curtailed. This should be supplemented with the development of robust health infrastructures, human capacity building, strong surveillance system supported with modern information communication technology and stakeholders' collaboration.

The available literature on *T gondii* infection in Ethiopia focuses mainly on seroepidemiological studies. The identification of atypical *T. gondii* strains in small ruminants of Ethiopia virulent for mice (Gebremedhin et al., 2014c) coupled with the association between acute toxoplasmosis in immunocompetent individuals and repeated seizure (Beltrame et al., 2015) is of great concern. Infection dynamics of *T. gondii,* the prevalence, risk factors, isolation and genotypes of the parasite in wildlife hosts as well as in remote drier peripheral parts of Ethiopia such as Gambella, Benshangul, Afar and Somali regions, where medical and public health services are limited, is still unknown. Studies on clinical disease and overall burden of the infection are generally absent. These have limited our knowledge of reservoirs of *T. gondii* infection, circulating genotypes and true burden of the disease. Thus, the disease

remained neglected and underestimated. These available evidences indicate that there is a need to strongly undertake well-designed large scale researches in the future in different agro-ecologies by sampling domestic animals, wild animals and humans in order to adequately determine the genetic diversity and population structure in order to answer questions relating to *T. gondii* infection in Ethiopia.

Data availability

The data used to support the findings of this study are available from the corresponding author upon request

Conflict of Interest

The authors declare that this article's content has no conflict of interest.

References

Ajzenber, D, Banuls AL, Su C, Dumetre A, Demar M, Carme B, Darde ML (2004). Genetic diversity, clonality, and sexuality in Toxoplasma gondii. Int. J. Parasitol. 34: 1185–1196.

Ajzenberg D, Banuls AL, Tibayrenc M, Dardé ML (2002). Microsatellite analysis of Toxoplasma gondii shows considerable polymorphism structured into two main clonal groups. Int. J. Parasitol. 32: 27–38.

Al-Kappany YM, Rajendran C, Abu-Elwafa SA, Hilali M, Su C, Dubey JP. (2010). Genetic diversity of *Toxoplasma gondii* isolates in Egyptian feral cats reveals new genotypes. J. Parasitol. 96: 1112–1114.

Bekele T, Kasali OB. (1989). Toxoplasmosis in sheep, goats, and cattle in Central Ethiopia. *Vet. Res. Commun.* 13: 371 - 375.

Beltrame A, Venturini S, Crichiutti G, Meroni V, Buonfrate D, Bassetti M. (2015). Recurrent seizures during acute acquired toxoplasmosis in an immunocompetent traveler returning from Africa. *Infection*, 44(2): 259–262. Doi: 10.1007/s15010-015-0821-7.

Carme B, Bissuel F, Ajzenberg D, Bouyne R, Aznar C, Demar M, Bichat S, Louvel D, Bourbigot AM, Peneau C, Neron P, Darde ML. (2002). Severe acquired toxoplasmosis in immunocompetent adult patients in French Guiana. *J. Clin. Microbiol.* 40: 4037-4044.

Carruthers VB, Suzuki Y. (2007). Effects of *Toxoplasma gondii* Infection on the Brain. *Schizophr. Bull*., 33 (3): 745–751.

Deconinck P, Pangui LJ, Akakpo J, Garrouste A, Ouattara L, Roger F, Tibayrenc R. Dorchies P. (1996). Sero-epidemiology of toxoplasmosis in sheep and goats from Africa [in French]. *Rev. Méd. Vét* 147: 377–378.

Delhaes L, Ajzenberg D, Sicots B, Bourgeots P, Dardé ML, Dei-Cas E, Houfflin-Debarges V. (2010). Severe congenital toxoplasmosis due to a *Toxoplasma gondii* strain with an atypical genotype: case report and review. Prenat. Diagn. 30: 902–905.

Demar M, Ajzenberg D, Maubon D, Djossou F, Panchoe D, Punwasi W, Valery N, Peneau C, Daigre JL, Aznar C, Cottrelle B, Terzan L, Dardé ML, Carme B. (2007). Fatal outbreak of human toxoplasmosis along the Maroni River: epidemiological, clinical, and parasitological aspects. *Clin. Infect. Dis.* 45: e88-95.

Demissie T, Tilahun G. (2002). Study on toxoplasmosis in sheep and goats in Debre Birhan and surrounding areas in Ethiopia. Bull. Anim. Health Prod. Afr, 50: 138-147.

Dubey JP. (2009). Toxoplasmosis in sheep-The last 20 years. Vet. Parasit. 163: 1-14.

Dubey JP. (2010). Toxoplasmosis of animals and humans. 2nd edition. CRC Press; Boca Raton, Florida, U.S.A, pp 1-313.

Dubey JP, Choudhary S, Tilahun G, Tiao N, Gebreyes, WA, Zou X, Su C. (2013b). Genetic diversity of *Toxoplasma gondii* isolates from Ethiopian feral cats. Vet. Parasitol. 196: 206-208.

Dubey JP, Darrington C, Tiao N, Ferreira LR, Choudhary S, Molla B, Saville WJA, Tilahun G, Kwok OCH, Gebreyes WA. (2013a). Isolation of viable *Toxoplasma gondii* from tissues and feces of cats from Addis Ababa, Ethiopia. J. Parasitol. 99: 56-58.

Dubey JP, Tiao N, Gebreyes WA, Jones JL. (2012). A review of toxoplasmosis in humans and animals in Ethiopia. Epidemiol. Infect. 140 (11): 1935-1938.

Eticha E, Almaw G, Lemma D, Abera B. (2017). Preliminary Investigation of toxoplasmosis in selected domestic animals in Wondo Genet, Ethiopia. J. Vet. Sci. Technol. 8: 416. DOI: 10.4172/2157-7579.1000416

Ferreira, ADM., Vitor RW, Gazzinelli RT, Melo MN. (2006). Genetic analysis of natural recombinant Brazilian *Toxoplasma gondii* strains by multilocus PCR-RFLP. Infect. Genet. Evol, 6: 22–31.

Freyre A, Bonino J, Falcon J, Castells D, Correa O, Casaretto A (1997). The incidence and economic significance of ovine toxoplasmosis in Uruguay. Vet. Parasitol. 73, 13-15.

Gebremedhin EZ, Agonafir A, Tessema TS, Tilahun G, Medhin G, Vitale M, Di Marco V, Cox E, Vercruysse J, Dorny P. (2013a). Seroepidemiological study of ovine toxoplasmosis in East and West Shewa Zones of Oromia Regional State, Central Ethiopia. BMC Vet. Res. 9:117, DOI: 10.1186/1746-6148-9-117.

Gebremedhin EZ, Agonafir A, Tessema TS, Tilahun G, Medhin G, Vitale M, Di Marco V. (2013b). Some risk factors for reproductive failures and contribution of *Toxoplasma gondii* infection in sheep and goats of Central Ethiopia: A cross-sectional study. Res. Vet. Sci. 95: 894–900.

Gebremedhin EZ. (2014). Seroepidemiology of *Toxoplasma gondii* infection in women of childbearing age, sheep, and goats, and molecular characterization of animal isolates in central Ethiopia. Ph.D. dissertation, Addis Ababa University (Ethiopia) and Ghent University (Belgium).

Gebremedhin EZ, Abdurahaman M, Hadush T, Tessema TS. (2014a). Seroprevalence and risk factors of *Toxoplasma gondii* infection in sheep and goats slaughtered for human consumption in Debre-Zeit, Central Ethiopia. *BMC Res. Notes*, 7:696.

Gebremedhin EZ, Abdurahaman M, Tessema TS, Tilahun G, Cox E, De Craeye S, Goddeeris B, Dorny P, Dardé M-L, Ajzenberg D. (2014d). Isolation and genotyping of viable *Toxoplasma gondii* from sheep and goats in Ethiopia destined for human consumption. Parasit Vectors 7:425.

Gebremedhin EZ, Dima N, Feyissa A, Jorga E, Feyissa N, Di Marco V, Vitale M. (2016). Toxoplasmosis in camels of Borana zone, Oromia region, Ethiopia: seroprevalence and risk factors. Trop. Anim. Prod. Health, 48 (8): 1599-1606.DOI: 10.1007/s11250-016-1133-3.

Gebremedhin EZ, Gizaw D. (2014). Seroprevalence of *Toxoplasma gondii i*nfection in sheep and goats in three districts of Southern Nations, Nationalities and Peoples' Region of Ethiopia. World Appl. Sci. J. 31 (11): 1891-1896.

Gebremedhin EZ, Tadesse G. (2015). A meta-analysis of *Toxoplasma gondii* infections in animals and humans in Ethiopia. Parasite Vectors, 8:291.

Gebremedhin EZ, Kebeta, MM, Asaye M, Ashenafi H, Di Marco, V, Vitale M. (2015b). First report on seroepidemiology of *Toxoplasma gondii* infection in pigs in Central Ethiopia. BMC Vet. Res. 11: 59. DOI 10.1186/s12917-015-0384-y.

Gebremedhin EZ, Kebeta MM, Asaye M, Ashenafi H, Di Marco V, Vitale M. (2015c). Bioassay of *Toxoplasma gondii* from apparently healthy pigs slaughtered in Addis Ababa abattoir, Ethiopia. J. Vet. Sci. Tech., 6, 258. DOI:10.4172/2157-7579.1000258.

Gebremedhin EZ, Tesfamaryam G, Duguma R, Tilahun G, Di Marco V, Vitale M. (2014c). Majority of seropositive chickens (*Gallus domesticus*) in Central Ethiopia carry infective *T. gondii*. Acta Vet Scand, 56: 60.

Gebremedhin EZ, Tesfamaryam G, Yunus, HA, Duguma R, Tilahun G, Di Marco V,

Vitale M. (2015a). Seroepidemiology of *Toxoplasma gondii* infection in free-range chickens (G*allus domesticus*) of central Ethiopia. Epidemiol. Infect. 143: 608–617. DOI: 10.1017/S0950268814000971.

Gebremedhin EZ, Yunus HA, Tesfamaryam G, Tessema TS, Dawo F, Terefe G, Di Marco V, Vitale M. (2014b). First report of *Toxoplasma gondii* in camels (*Camelus dromedarius*) from Ethiopia: seroepidemiology and bioassay. BMC Vet. Res. 10, 222. http://www.biomedcentral.com/1746-6148/10/222.

Getachew A, Tilahun A, Aylate A, Tesfaye W. (2016). Sero-prevalence of *Toxoplasma gondii* infection and associated risk factors in animals presented to Sholla and Akaki-Kality Veterinary Clinics, Addis Ababa. Global Journal of Medical Research (G), Vet. Sci. Vet. Med. 16 (3): 10-17. http://creativecommons.org/licenses/bync/3.0/).

Girum T, Wasie A, Worku A. (2018). Trend of HIV/AIDS for the last 26 years and predicting achievement of the 90–90-90 HIV prevention targets by 2020 in Ethiopia:
a time series analysis. BMC Infect. Dis. 18, 320. https://doi.org/10.1186/s12879-018-3214-6

Khan A, Dubey JP, Su C, Ajioka JW, Rosenthal BM, Sibley LD. (2011). Genetic analyses of atypical *Toxoplasma gondii* strains reveal a fourth clonal lineage in North America. Int. J. Parasitol., 41|: 645–655.

Montoya JG, Liesenfeld O. (2004). Toxoplasmosis. *Lancet*, 363: 1965–1976.

Negash T. (2000). Study on Toxoplasmosis. D.V.M. thesis. Faculty of Veterinary Medicine. Addis Ababa University, pp. 1-48.

Negash T, Tilahun G, Patton S, Prevot F, Dorchies Ph. (2004). Serological survey of toxoplasmosis in sheep and goats in Nazareth, Ethiopia. *Rev. Méd. Vét.* 155: 486–487.

Olivier A, Herbert B, Sava B, Pierre C, John DC, Aline DK. (2007). Surveillance and monitoring of Toxoplasma in humans, food, and animals: A Scientific Opinion of the Panel on Biological Hazards. EFSA J. 583: 1–64.

Petersen E, Kijlstra A, Stanford M. (2012). Epidemiology of Ocular Toxoplasmosis. Ocul. Immunol. Inflamm. 20: 68–75.

Petersen E, Vesco G, Villari S, Buffolano W. (2010). What do we know about risk factors for infection in humans with *Toxoplasma gondii* and how can we prevent infections? Zoonoses Public Health, 57: 8–17.

Radostits OM, Gay CC, Hinchcliff KW, Constable PD. (2006). Veterinary Medicine: A textbook of the diseases of cattle, horses, sheep, pigs, and goats. 10th edn. Saunders, London, pp.1518-1522.

Su C, Dubey JP. (2010). *Toxoplasma gondii* In: Liu, D. (Ed.) Molecular Detection of Foodborne Pathogens, Taylor and Francis (CRC Press), Boca Raton, Florida, pp.741-751.

Sibley LD, Mordue DG, Su C, Robben PM, Howe DK. (2002). Genetic approaches to studying virulence and pathogenesis in Toxoplasma gondii. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 357: 81–88.

Su C, Evans D, Cole RH, Kissinger JC, Ajioka JW, Sibley LD. (20030. Recent expansion of Toxoplasma through enhanced oral transmission. Science, 299, 414-416.

Tegegne D, Kelifa A, Abdurahaman M, Yohannes M. (2016). Seroepidemiology and associated risk factors of *Toxoplasma gondii* in sheep and goats in Southwestern Ethiopia. BMC Vet. Res. 12: 280. DOI 10.1186/s12917-016-0906-2.

Tenter AM, Heckeroth AR, Weiss LM. (2000). *Toxoplasma gondii*: from animals to humans. Int. J. Parasitol., 30: 1217-1258.

Teshale S, Dumetre A, Dardé ML, Merga B, Dorchies P. (2007). Serological survey of caprine toxoplasmosis in Ethiopia: Prevalence and risk factors. Parasite, 14: 155–159.

Tiao N, Darrington C, Molla B, Saville WJA, Tilahun G, Kwok OCH, Gebreyes WA, Lappin MR, Jones JL, Dubey JP. (2013). An investigation into the seroprevalence

of *Toxoplasma gondii*, *Bartonella* spp., feline immunodeficiency virus (FIV), and feline leukemia virus (FeLV) in cats in Addis Ababa, Ethiopia. Epidemiol. Infect. 141: 1029–1033.

Tilahun B, Tolossa YH, Tilahun G, Ashenafi H, Shimelis S. (2018). Seroprevalence and risk factors of *Toxoplasma gondii i*nfection among domestic ruminants in East Hararghe Zone of Oromia Region, Ethiopia. Vet. Med. Int., Volume 2018, Article ID 4263470, 7 pages. https://doi.org/10.1155/2018/4263470.

Tilahun G, Tiao N, Ferreira LR, Oliveira S, Verma SK, Kwok OCH, Molla B, Saville WJA, Medhin G, Kassa T, Aleme H, Gebreyes WA, Dubey JP. (2013). Seroprevalence of *Toxoplasma gondii* from free-range Chicken (*Gallus domesticus*) from Addis Ababa, Ethiopia. J. Parasitol*.,* 99: 740-741.

Torgerson PR, Macpherson CNL (2011). The socioeconomic burden of parasitic zoonoses: global trends. Vet. Parasitol. 182: 79– 95.

Velmurugan GV, Dubey JP, Su C. (2008). Genotyping studies of *Toxoplasma gondii* isolates from Africa revealed that the archetypal clonal lineages predominate as in North America and Europe. Vet. Parasitol, 155: 314–318.

Wang Z.-D, Wang S-C, Liu H-H, Ma H-Y, Li Z-Y, Wei F, Liu Q. (2017). Prevalence and burden of *Toxoplasma gondii* infection in HIV-infected people: a systematic review and meta-analysis. The Lancet HIV, 4(4): e177–e188. Doi: 10.1016/s2352-3018(17)30005-x.

Yai LEO, Vianna MCB, Soares RM, Cortez A, Freire RL, Richtzenhain LJ, Gennari SM. (2003). Evaluation of experimental *Toxoplasma gondii* (Nicolle and Manceaux, 1909) infection in pigs by bioassay in mice and polymerase chain reaction. Braz. J. Vet. Res. Anim. Sci. 40: 227–234.

Yibeltal MM. (2008). Seroprevalence study of toxoplasmosis in small ruminants and humans (HIV/AIDS patient) in selected district of South Wollo, Ethiopia. MSc Thesis, Addis Ababa University, Faculty of Veterinary Medicine, Debre-Zeit, Ethiopia.

Yihinew C. (2012). Study on the prevalence of toxoplasmosis in cats in Bahir Dar town, DVM thesis, Jimma University College of Agriculture and Veterinary Medicine, Jimma, Ethiopia.

Zewdu E, Tessema TS, Tilahun G, Cox E, Goddeeris B, Dorny P. (2015). Comparison of diagnostic efficiency of direct agglutination test, microscopy and nPCR for detection of *Toxoplasma gondii* infection in experimentally infected mice in Central Ethiopia. Ethiop. Vet. J. 19 (1): 117-129. http://dx.doi.org/10.4314/evj.v19i1.6.

Zewdu E, Agonafir A, Tessema TS, Tilahun G, Medhin G, Vitale M, Di Marco V, Cox E, Vercruysse J, Dorny P. (2013. Seroepidemiological study of caprine toxoplasmosis in East and West Shewa Zones, Oromia Regional State, Central Ethiopia. Res. Vet. Sci. 94: 43-48.