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Review

Toxoplasma gondii Infection in Small Ruminants: Risk Factors, Diagnosis, and Prevention Strategies

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ABSTRACT

Toxoplasma gondii is a protozoan parasite that infects humans and animals worldwide with the ability to result in abortion, congenital malformations, neurological disorders, and immunosuppression in the hosts. The objective of this review is to state the potential risk factors among small ruminants and humans and recommend practicable control and prevention strategies. The global and regional distribution and prevalence of the infection vary depending on environmental, climatic, cultural, and behavioral factors. There are many risk factors for *Toxoplasma gondii*, whose genotypes also vary geographically and may influence the pathogenicity and clinical manifestations of the infection. Eating raw or undercooked meat or shellfish, contact with infected cat feces, and vertical transmission during pregnancy are some of the main transmission routes for *Toxoplasma gondii* infection. The clinical signs in small ruminants vary depending on the stage of infection, the strain of the parasite, and the immune status of the host. These signs and symptoms can be diagnosed by different methods, such as serological and molecular tests, histopathology, and isolation of the parasite. The treatment options for small ruminants are not very effective, as most drugs can only kill the active forms of the parasite, not the dormant cysts. The prevention is based on reducing the exposure, keeping cats away from farms or vaccinating them, and, if available, vaccinating the small ruminants. The epidemiological situation and trends in small ruminants were not well studied, leading to more significant socio-economic impact and public health implications in developing countries like Ethiopia, where the prevalence of infection is high and the resources for prevention and treatment are limited. Even though it is very vital to have standardized rules and regulations established, there is no specific policy or program for toxoplasmosis control and eradication in Ethiopia. It is indirectly prevented and managed by some of the existing policies and programs for neglected tropical diseases. Therefore, it is essential to focus on the epidemiology of *Toxoplasma gondii* infection in small ruminants.

Keywords
Epidemiology; Prevention; Small ruminants; Socioeconomic importance; *Toxoplasma gondii*.

INTRODUCTION

Toxoplasma gondii is a protozoan parasite that infects humans and animals worldwide. It can cause toxoplasmosis, a disease that can result in abortion, congenital malformations, neurological disorders, and immunosuppression in the host.[1] Small ruminants, such as sheep and goats, are important intermediate hosts of *Toxoplasma gondii* and can transmit the infection to humans through the consumption of raw or undercooked meat, milk, or dairy products.[2] Therefore, understanding the sero-epidemiology of *Toxoplasma gondii* in small ruminants is crucial for the prevention and control of toxoplasmosis in both animals and humans. Ethiopia is a country in East Africa with a population of about 114 million people and a livestock sector that contributes to 12% of the gross domestic product. Small ruminants are widely kept by rural households for meat, milk, income, and social functions.[3] However, the productivity and health of these animals are affected by various infectious diseases, including toxoplasmosis. Several studies have reported the seroprevalence of *Toxoplasma gondii* in small ruminants in different regions of Ethiopia, ranging from 5.6-71.4%.[4] However, there is limited information on the risk factors, genetic diversity, and zoonotic potential of *Toxoplasma gondii* in small ruminants in Ethiopia.

Moreover, the consumption of infected meat, cured meat products, or unpasteurized milk and dairy products can facilitate zoonotic transmission to humans, especially pregnant women and immunocompromised individuals.[5] *Toxoplasma gondii* infection can range from asymptomatic to severe, depending on the host's immune status and the stage of infection. It can cause flu-like symptoms, eye disease, brain inflammation, lung infection, miscarriage, birth defects, and other complications. Sero-epidemiology is the study of the occurrence and distribution of antibodies to infectious agents in a population. It can provide information on the exposure, immunity, transmission, and risk factors of infectious diseases.[6]

Seroprevalence is the frequency of individuals in a population who have antibodies to an infectious agent in their blood serum. It reflects the cumulative incidence of past or current infections in a population.[7] Seroincidence is the rate of new seroconversions (the development of detectable antibodies) to an infectious agent in a population over a period of time. It reflects the current or recent incidence of infections in a population.[8] Small ruminants are hoofed herbivorous mammals that have a specialized stomach for fermenting plant-based food before digestion. They include sheep, goats, and other related species. They are often raised for meat, milk, fiber, and skins.[9]

Toxoplasma gondii is a protozoan parasite that can infect a wide range of warm-blooded animals and humans, causing toxoplasmosis, a zoonotic disease of global importance. Sheep and goats are among the most susceptible hosts, serving as sources of infection for humans. Therefore, the objective of this paper is:

• To state the potential risk factors of Gondii that influence its transmission and spread among small ruminants and humans to address control and prevention strategies.

• To provide future directions for public health and animal production interventions so that the disease burden will be reduced.

EPIDEMIOLOGY OF *Toxoplasma gondii* INFECTION IN SMALL RUMINANTS

Toxoplasma gondii is a protozoan parasite that can infect humans and various animals, especially cats, which are the definitive hosts. The infection can cause toxoplasmosis, a disease that can have serious consequences for immunocompromised individuals and pregnant women.[10] The global and regional distribution and prevalence of *Toxoplasma gondii* in small ruminants and humans vary depending on environmental, climatic, cultural, and behavioral factors.[11]

The Global and Regional Distribution and Its Prevalence

According to Wanget al,[12] the global seroprevalence of *Toxoplasma gondii* in humans was estimated to be 30.8% (95% CI: 27.7-34.0%), with the highest rates in Africa (50.8%), Latin America (45.5%), and Oceania (37.4%), and the lowest rates in North America (12.3%) and Asia (18.5%). The global seroprevalence of *Toxoplasma gondii* in sheep was estimated to be 47.1% (95% CI: 43.9-50.4%), with the highest rates in Africa (62.9%), Europe (58.6%), and Asia (51.8%), and the lowest rates in North America (17.6%) and Oceania (23.8%). The global seroprevalence of *Toxoplasma gondii* in goats was estimated to be 36.7% (95% CI: 33.2-40.3%), with the highest rates in Africa (54.2%), Asia (42.9%), and Europe (40.4%), and the lowest rates in North America (13.8%) and Oceania (19.4%). In China, a large-scale study conducted by Zhou et al[13] reported that the overall seroprevalence of *Toxoplasma gondii* in food animals was 23.7% (95% CI: 23.49-23.90%), which was significantly higher than that in humans (8.2%, 95% CI: 8.06-8.39%). The seroprevalence of *Toxoplasma gondii* in animals and humans increased significantly from 2000-2017, suggesting a rising trend of infection in China.

In Iran, another study by Yousefvand et al[14] found that the seroprevalence of *Toxoplasma gondii* in sheep and goats was 13.3% and 10.6%, respectively, based on enzyme-linked immunosorbent assays (ELISA). The polymerase chain reaction (PCR) analysis of liver, meat, and heart samples from sheep and goats showed positive results for *Toxoplasma gondii* deoxyribonucleic acid (DNA) in 17.3%, 22%, and 32% of sheep samples, and 16%, 17.3%, and 24% of goat samples, respectively. The risk factors for *Toxoplasma gondii* infection include water contamination by oocysts from cat feces, consumption of raw or undercooked meat containing tissue cysts, contact with soil or animals, blood transfusion or organ transplantation, congenital transmission from mother to fetus, and genetic susceptibility of the host.[15] The genotypes of *Toxoplasma gondii* also vary geographically, which may influence the pathogenicity and clinical manifestations of the infection.[16] The most common genotype in food animals from China is Chinese 1 (ToxoDB#9), which belongs to the type I lineage.[17]

The Main Transmission Routes and Risk Factors

Eating raw or undercooked meat or shellfish that contain the parasite's cysts is one way of transmission. This is a common way of infecting both humans and animals, especially sheep and goats that graze on contaminated pastures. To prevent this, meat and shellfish should be cooked thoroughly and handled with care to avoid cross-contamination.[18] Contact with infected cat feces that contain the parasite's oocysts. Cats are the only animals that can shed the parasite in their feces, and they can infect other animals or humans who accidentally ingest the oocysts from the soil, water, litter box, or unwashed fruits and vegetables.[10] To prevent this, cat owners should dispose of cat litter properly, wash their hands after handling cats or their litter, and keep cats indoors or away from wildlife. Pregnant women and immunocompromised people should avoid contact with cats or their feces altogether.[19]

Mother-to-child transmission during pregnancy: If a woman gets infected with Toxoplasma for the first time during pregnancy, she can pass the infection on to her unborn child, which can cause serious complications such as miscarriage, stillbirth, or congenital defects.[15] To prevent this, pregnant women should avoid the risk factors mentioned above, get tested for *Toxoplasma* antibodies before or during pregnancy, and take preventive medication if needed.[20]

Clinical Signs and Diagnosis

The clinical signs of toxoplasmosis in small ruminants vary de-

pending on the stage of infection, the strain of the parasite, and the immune status of the host.[21] The most common clinical signs are abortion, stillbirth, mummification, and congenital malformations in the fetuses. Other signs may include fever, anorexia, weight loss, lymphadenopathy, pneumonia, and neurological disorders.[22]

The diagnosis of toxoplasmosis in small ruminants can be done by different methods, such as serological tests, molecular tests, histopathology, and isolation of the parasite. Serological tests are useful for detecting the presence of specific antibodies against *Toxoplasma gondii* in the serum or milk of animals.[23] However, serological tests cannot distinguish between acute and chronic infections, nor between maternal and fetal antibodies. Molecular tests are based on the amplification of DNA or ribonucleic acid (RNA) of *Toxoplasma gondii* from various samples, such as blood, tissues, placenta, or fetal fluids. These tests are more sensitive and specific than serological tests and can also provide information on the genetic diversity of the parasite.[5] Histopathology is the examination of tissue sections stained with special dyes to identify the characteristic lesions and cysts of *Toxoplasma gondii*. Isolation of the parasite is the definitive method for confirming the infection, but it is laborious and requires biohazard facilities and animal models.[21]

Prevention and Treatment

The treatment of toxoplasmosis in small ruminants is not very effective, as most drugs can only kill the active forms of the parasite but not the dormant cysts. Moreover, some drugs may have adverse effects on animals or cause residues in their products. Therefore, treatment is usually reserved for valuable animals or those with severe clinical signs. Some of the drugs that have been used for treating toxoplasmosis in small ruminants are sulfonamides, pyrimethamine, clindamycin, spiramycin, and toltrazuril.[24] The prevention of toxoplasmosis in small ruminants is based on reducing exposure to the sources of infection, such as cat feces, contaminated feed and water, raw meat and milk, and infected rodents.[25]

Keeping cats away from farms or vaccinating them against *Toxoplasma gondii*, providing clean and dry bedding for pregnant animals, disposing of aborted fetuses and placentas properly, cooking or freezing meat before feeding it to animals, pasteurizing milk before consumption, controlling rodent populations, and testing animals for *Toxoplasma gondii* before introducing them to a flock or herd are some of the preventive measures.[26] Additionally, vaccination of small ruminants with attenuated or recombinant *Toxoplasma gondii* strains has been shown to induce protective immunity against abortion and congenital infection. However, there is no commercially available vaccine for small ruminants yet.[27]

TRENDS OF TOXOPLASMOSIS IN SMALL RUMINANTS IN ETHIOPIA

The epidemiological situation and trends of toxoplasmosis in small ruminants in Ethiopia are not well studied, but some recent research has provided some insights.[10] According to a cross-sectional study conducted from November 2016 to April 2017 in six peasant associations in the Yabello district of Borana zone, Southern Ethiopia, the overall seroprevalence of *Toxoplasma gondii* infection in small ruminants was 52.8%. The study identified age, sex, water source, and altitude as significant risk factors for *Toxoplasma gondii* infection in small ruminants. The study also revealed that 97% of the respondents had no knowledge about toxoplasmosis, and 75% of them consumed raw milk and meat from sheep and goats, indicating a potential public health threat.[25]

Another cross-sectional study conducted from November 2019 to April 2020 in three towns in West Shewa Zone, Oromia regional state, Ethiopia, reported a high seroprevalence of *Toxoplasma gondii* infection in dogs, which are considered potential reservoirs and indicators of environmental contamination by the parasite. The study found that 82.86% of the dogs were seropositive for *Toxoplasma gondii* IgG antibodies and that the seroprevalence was significantly different among the study towns and higher in adult dogs than juvenile dogs.[26] The study also detected a high seroprevalence of *Leishmania spp.* infection in dogs (92.47%), suggesting a possible co-infection or cross-reactivity with *Toxoplasma gondii*.

Another study indicates that toxoplasmosis is a prevalent and important disease in small ruminants and other animals in Ethiopia and that it poses a significant economic and public health impact.[28] However, there is still a lack of comprehensive data on the epidemiology, transmission dynamics, genetic diversity, and clinical manifestations of *Toxoplasma gondii* infection in small ruminants and humans in Ethiopia.[1] Therefore, further research is needed to fill these knowledge gaps and to design effective prevention and control strategies for toxoplasmosis in Ethiopia.

THE SOCIO-ECONOMIC IMPACT AND PUBLIC HEALTH IMPLICATIONS

The socio-economic impact and public health implications of toxoplasmosis are significant, especially in developing countries like Ethiopia, where the prevalence of infection is high and the resources for prevention and treatment are limited.[29] Loss of productivity and income due to morbidity and mortality of humans and animals infected with *Toxoplasma gondii*. For example, toxoplasmosis can cause abortion, stillbirth, neonatal death, and reduced growth and milk yield in small ruminants, which are important sources of food and income for many rural households in Ethiopia.[22]

Increased health care costs and burden on the health system due to the diagnosis, treatment, and management of toxoplasmosis cases. For example, toxoplasmosis can cause severe complications such as encephalitis, chorioretinitis, myocarditis, pneumonitis, and disseminated infection in immunocompromised persons, such as those with human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS), cancer, or organ transplantation.[30] Reduced quality of life and social stigma for persons affected by toxoplasmosis, especially those with ocular or neurological manifestations. For example, toxoplasmosis can cause visual impairment, blindness, cognitive impairment, seizures, and psychiatric disorders.[31]

Risk of congenital transmission and adverse outcomes

for pregnant women and their fetuses or newborns. For example, congenital toxoplasmosis can result in miscarriage, intrauterine growth restriction, hydrocephalus, microcephaly, cerebral calcifications, hearing loss, mental retardation, and epilepsy.[32] Risk of foodborne transmission and outbreaks due to consumption of raw or undercooked meat or milk products contaminated with *Toxoplasma gondii* tissue cysts or oocysts. For example, several outbreaks of clinical toxoplasmosis have been reported worldwide after the ingestion of infected meat or dairy products.[33] Risk of environmental transmission and zoonotic potential due to exposure to soil, water, or vegetation contaminated with *Toxoplasma gondii* oocysts shed by cats or other felids. For example, *Toxoplasma gondii* oocysts can survive for long periods in the environment and infect a wide range of intermediate hosts, including rodents, birds, livestock, wildlife, and humans.[34]

THE EXISTING POLICIES AND PROGRAMS FOR CONTROL AND ERADICATION

Toxoplasmosis is usually transmitted through contact with contaminated cat feces, undercooked meat, or congenitally from mother to fetus. It can cause serious complications in pregnant women and immunocompromised individuals, such as miscarriage, stillbirth, neurological disorders, and ocular lesions.[18] In Ethiopia, toxoplasmosis is not considered a neglected tropical disease (NTD), unlike other parasitic infections such as malaria, dracunculiasis, schistosomiasis, and soil-transmitted helminths. Therefore, there is no specific national policy or program for toxoplasmosis control and eradication in the country. However, some of the existing policies and programs for NTDs may have indirect impacts on toxoplasmosis prevention and management.[10]

For example, the Ethiopia Malaria Elimination Strategic Plan 2021-2025 aims to reduce malaria morbidity and mortality by strengthening vector control interventions, improving case management and surveillance, and enhancing community engagement and health system capacity.[35] These measures may also reduce the exposure of humans and animals to *Toxoplasma gondii* by decreasing the density of mosquitoes that can transmit the parasite from infected animals to humans. Another example is the World Health Organization (WHO) Support for Ethiopian Dracunculiasis Eradication Program,[36] which focuses on interrupting the transmission of Guinea worm disease by providing safe drinking water sources, promoting health education and behavior change, and implementing surveillance and case containment activities. These interventions may also prevent the ingestion of *Toxoplasma gondii* oocysts from contaminated water sources by humans and animals.

Furthermore, the NTDs Program of the Ministry of Health[37] and the Third National Neglected Tropical Diseases Strategic Plan 2021-2025 address several NTDs that affect millions of people in Ethiopia, such as lymphatic filariasis, onchocerciasis, trachoma, leishmaniasis, podoconiosis, and rabies. These programs aim to eliminate or control these diseases by implementing mass drug administration, vector control, environmental sanitation, health education, case management, and surveillance. These actions may also reduce the co-infection of *Toxoplasma gondii* with other parasites, which can worsen the clinical outcomes of toxoplasmosis.[38]

CONCLUSION AND RECOMMENDATIONS

This review has shown that *Toxoplasma gondii* is a widespread and serious parasite that affects both small ruminants and humans, especially in developing countries like Ethiopia. The infection can cause various health problems, such as abortion, congenital malformations, neurological disorders, and immunosuppression. The risk factors for the infection include eating raw or undercooked meat or shellfish, contact with infected cat feces, and vertical transmission during pregnancy. The diagnosis of the infection can be done by different methods, such as serological, molecular, histopathological, and parasitological tests. However, the treatment options are limited and not very effective, as most drugs can only kill the active forms of the parasite, not the dormant cysts. Therefore, the prevention of the infection is crucial and based on reducing the exposure, keeping cats away from farms or vaccinating them, and, if available, vaccinating the small ruminants. The epidemiological situation and trends of the infection in small ruminants are not well studied and require more attention and research, as they have significant socio-economic and public health implications.

Depending on the above conclusion, the following recommendations are suggested:

- Toxoplasmosis epidemiology in ruminants and humans should be researched more in developing countries, using uniform and sound methods.
- Toxoplasmosis control in ruminants and humans should be improved and applied using low-cost and efficient methods like hygiene, education, testing, treatment, and vaccination.
- Stakeholders should work together and align to increase awareness and resources for toxoplasmosis prevention and control in ruminants and humans.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. Dubey JP, Murata FHA, Cerqueira-Cézar CK, Kwok OCH. Public health and economic importance of *Toxoplasma gondii* infections in goats: The last decade. *Res Vet Sci.* 2020; 132: 292-307. doi: 10.1016/j.rvsc.2020.06.014

2. Basso W, Holenweger F, Schares G, et al. *Toxoplasma gondii* and Neospora caninum infections in sheep and goats in Switzerland: Seroprevalence and occurrence in aborted foetuses. *Food Waterborne Parasitol.* 2022; 28: e00176. doi: 10.1016/j.fawpar.2022.e00176

3. Taylor L, Harris C, Abebe T, Addissie A, Assefa M, Kantelhardt EJ. A decade of strengthening breast oncology in Ethiopia. *The Lancet Oncology.* 2021; 22(9): 1219-1220. doi: 10.1016/S1470-

2045(21)00254-0

4. Consalter A. Epidemiological investigation, histopathological analysis, immunohistochemical analysis and genotyping of *Toxoplasma gondii* in sheep. 2019.

5. de Barros RAM, Torrecilhas AC, Marciano MAM, Mazuz ML, Pereira-Chioccola VL, Fux B. Toxoplasmosis in human and animals around the world. Diagnosis and perspectives in the one health approach. *Acta Tropica*. 2022; 231: 106432. doi: 10.1016/j.actatropica.2022.106432

6. Fereig RM, Wareth G, Abdelbaky HH, et al. Seroprevalence of specific antibodies to *Toxoplasma gondii*, Neospora caninum, and Brucella spp. in sheep and goats in Egypt. *Animals (Basel)*. 2022; 12(23): 3327. doi: 10.3390/ani12233327

7. Marzok M, Al-Jabr OA, Salem M, et al. Seroprevalence and Risk Factors for *Toxoplasma gondii* Infection in Horses. *Vet Sci*. 2023; 10(3): 237. doi: 10.3390/vetsci10030237

8. Tsai MJ, Sun HY, Hsieh SM, et al. Sero-epidemiology of the human herpesvirus 8 infection among people living with HIV in Taiwan, 2014–2018. *J Microbiol Immunol Infect*. 2021; 54(5): 934-943. doi: 10.1016/j.jmii.2020.11.005

9. Saarinen J. The paleontology of browsing and grazing. In: *The Ecology of Browsing and Grazing II*. 2019: 5-59. doi: 10.1007/978-3-030-25865-8_2

10. Tarekegn ZS, Dejene H, Addisu A, Dagnachew S. Potential risk factors associated with seropositivity for *Toxoplasma gondii* among pregnant women and HIV infected individuals in Ethiopia: A systematic review and meta-analysis. *PLOS Negl Trop Dis*. 2020; 14(12): e0008944. doi: 10.1371/journal.pntd.0008944

11. Bigna JJ, Tochie JN, Tounouga DN, et al. Global, regional, and country seroprevalence of *Toxoplasma gondii* in pregnant women: A systematic review, modelling and meta-analysis. *Sci Rep*. 2020; 10(1): 12102. doi: 10.1038/s41598-020-69078-9

12. Wang Z, Wang C, Liu H, et al. Global seroprevalence of *Toxoplasma gondii* in humans, sheep, and goats: A systematic review and meta-analysis. *Parasites and Vectors*. 2020; 13(1): 1-18.

13. Zhou, X, Zhang, H, Peng, H, et al. Seroprevalence of *Toxoplasma gondii* infection in food animals and humans in mainland China: A systematic review and meta-analysis (2000-2017). *Parasites & Vectors*. 2021a; 14(1): 1-16.

14. Yousefvand A, Mirhosseini SA, Ghorbani M, Mohammadzadeh T, Moghaddam MM, Mohammadyari S. Molecular and serological detection and of *Toxoplasma gondii* in small ruminants of southwest Iran and the potential risks for consumers. *J Verbrauch Lebensm*. 2021; 16: 117-127. doi: 10.1007/s00003-020-01306-w

15. Kassie E, Kebede N, Kassa T, et al. Seroprevalence and risk factors for *Toxoplasma gondii* infection among pregnant women at Debre Markos Referral Hospital, northwest Ethiopia. *Trans R Soc Trop Med Hyg*. 2024; 118(1): 61-68. doi: 10.1093/trstmh/trad053

16. Adugna B, Tarekegn ZS, Damtie D, Woldegebreal SN, Raju RP, Maru M, Ayele A. Seroepidemiology of *Toxoplasma gondii* among pregnant women attending antenatal care in northwest Ethiopia. *Infect Drug Resist*. 2021; 14: 1295-1303. doi: 10.2147/IDR.S299106

17. Wang Y, Han C, Zhou R, et al. Differential expression of Tg-MIC1 in isolates of Chinese 1 Toxoplasma with different virulence. *Parasit Vectors*. 2021; 14(1): 253. doi: 10.1186/s13071-021-04752-z

18. Balcha TM, Aga BI, Disasa DD, Berhanu G. Public health and economic significance of toxoplasmosis. *Am-Euras J Sci Res*. 2020; 15: 112-121. doi: 10.5829/idosi.aejsr.2020.112.121

19. Tamiru Y, Abdeta D, Amante M. Knowledge, attitude, and practice toward pet contact associated zoonosis in Western Ethiopia. *Vet Med (Auckl)*. 2022; 13: 47-58. doi: 10.2147/VMRR.S346806

20. Van der Colf BE, Ntirampeba D, Van Zyl GU, Noden BH. Seroprevalence of *Toxoplasma gondii* infection among pregnant women in Windhoek, Namibia, in 2016. *S Afr J Infect Dis*. 2020; 35(1), 25. doi: 10.4102/sajid.v35i1.25

21. Holec-Gąsior L, Sołowińska K. Detection of *Toxoplasma gondii* infection in small ruminants: Old problems, and current solutions. *Animals (Basel)*. 2023; 13(17): 2696. doi: 10.3390/ani13172696

22. Stelzer S, Basso W, Silván JB, et al. *Toxoplasma gondii* infection and toxoplasmosis in farm animals: Risk factors and economic impact. *Food Waterborne Parasitol*. 2019; 15: e00037. doi: 10.1016/j.fawpar.2019.e00037

23. Abdallah MC, Kamel M, Karima B, Samir A, Djamel K, Rachid K, Khatima AO. Cross-sectional survey on *Toxoplasma gondii* infection in cattle, sheep, and goats in Algeria: Seroprevalence and risk factors. *Vet Sci*. 2019; 6(3): 63. doi: 10.3390/vetsci6030063

24. Mehlhorn H. Toxoplasmosis in South America. In: *Infectious Tropical Diseases and One Health in Latin America*. Cham, USA: Springer International Publishing; 2022: 129-150.

25. Jilo K, Tegegne D, Kasim S, Dabasa G, Zewdei W. Seroprevalence and public health significance of toxoplasmosis in small ruminants of pastoral community in Yabello district, Borana zone, southern Ethiopia. *Vet Med Int*. 2021; 2021: 6683797. doi: 10.1155/2021/6683797

26. Gebremedhin EZ, Sarba EJ, Tola GK, et al. Prevalence and risk factors of *Toxoplasma gondii* and Leishmania spp. infections in apparently healthy dogs in west Shewa zone, Oromia, Ethiopia. *BMC Vet Res*. 2021; 17: 284. doi: 10.1186/s12917-021-02992-w

27. Rahman MM. *Toxoplasma gondii Infection Kinetics and Immune Responses Following Infection and Vaccination*. [dissertation]. Ghent, Bel-

gium; Ghent University: 2020.

28. Alemayehu G, Mamo G, Desta H, Alemu B, Wieland B. Knowledge, attitude, and practices to zoonotic disease risks from livestock birth products among smallholder communities in Ethiopia. *One Health*. 2021; 12: 100223. doi: 10.1016/j.onehlt.2021.100223

29. Alemnew GM, Mitiku BA, Yihun TY. Seroprevalence and associated risk factors of *Toxoplasma gondii* infection in immuno-compromised women and sheep of Bahir Dar City, Ethiopia. *Ethiopian Veterinary Journal*. 2023; 27(1): 93-111. do: 10.4314/evj.v27i1.5

30. Zhou Z, Lopez HIAO, Pérez GE, et al. Toxoplasmosis and the Heart. *Current Problems in Cardiology*. 2021b; 46(3): 100741. doi: 10.1016/j.cpcardiol.2020.100741

31. Hermawaty L, Amirah A, Jitasari J. Factor analysis affecting quality of life of PLWHA at the community health center service. *Journal of Asian Multicultural Research for Medical and Health Science Study*. 2021; 2(3): 15-21. doi: 10.47616/jamrmhss.v2i3.157

32. Demirtaş MS. The pathogenesis of congenital anomalies: roles of teratogens and infections. In: *Congenital Anomalies in Newborn Infants-Clinical and Etiopathological Perspectives*. 2020. doi: 10.5772/intechopen.92580

33. Pal M, Berhanu G, Steinmetz CH, Durglishvili N. Toxoplasmosis: an emerging and re-emerging zoonosis of global public health concern. *American Journal of Infectious Disease and Microbiology*. 2021; 9: 32-38. doi: 10.12691/ajidm-9-2-1

34. Shapiro K, Bahia-Oliveira L, Dixon B, Dumètre A, de Wit LA, Van Wormer E, Villena I. Environmental transmission of *Toxoplasma gondii*: Oocysts in water, soil and food. *Food Waterborne Parasitol*. 2019; 15: e00049. doi: 10.1016/j.fawpar.2019.e00049

35. Githure JI, Yewhalaw D, Atieli H, et al. Enhancing malaria research, surveillance, and control in endemic areas of Kenya and Ethiopia. *Am J Trop Med Hyg*. 2022; 107(4 Suppl): 14. doi: 10.4269/ajtmh.21-1303

36. Hopkins DR, Weiss AJ, Yerian S, Sapp SG, Cama VA. Progress toward global eradication of Dracunculiasis—worldwide, January 2021–June 2022. *MMWR Morb Mortal Wkly Rep*. 2022; 71(47): 1496-1502. doi: 10.15585/mmwr.mm7147a2

37. Barry A, Olsson S, Khaemba C, et al. Comparative assessment of the pharmacovigilance systems within the neglected tropical diseases programs in East Africa—Ethiopia, Kenya, Rwanda, and Tanzania. *Int J Environ Res Public Health*. 2021; 18(4): 1941. doi: 10.3390/ijerph18041941

38. Venter F, Matthews KR, Silvester E. Parasite co-infection: An ecological, molecular and experimental perspective. *Proc Biol Sci*. 2022; 289(1967): 20212155. doi: 10.1098/rspb.2021.2155