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Histopathological and molecular perspectives of major parasitic diseases in ruminants: Current challenges and integrated control strategies

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Abstract

Background: Parasitic diseases remain one of the major causes of economic losses in ruminant livestock production worldwide, particularly in tropical and subtropical regions. Gastrointestinal helminths, blood protozoa, and ectoparasites significantly reduce animal productivity through anemia, impaired growth, decreased milk production, reproductive disorders, and mortality. In recent years, advances in veterinary pathology and molecular biology have improved understanding of host–parasite interactions, disease pathogenesis, and diagnostic approaches.

Objective: This review aimed to summarize the major parasitic diseases affecting ruminants from histopathological and molecular perspectives, focusing on pathogenesis, clinical manifestations, diagnostic methods, and integrated control strategies.

Methods: This article was conducted as a narrative literature review using scientific articles, textbooks, and international publications obtained from databases including PubMed, ScienceDirect, Google Scholar, and Scopus. Literature published between 2010 and 2025 was prioritized. Keywords used included "ruminant parasites", "histopathology", "molecular diagnosis", "helminths", "protozoa", and "ectoparasites". Relevant studies discussing pathology, molecular detection, epidemiology, and parasite control strategies were critically analyzed and synthesized.

Results: The review identified major parasitic diseases in ruminants, including haemonchosis, babesiosis, theileriosis, trypanosomiasis, coccidiosis, mange, and myiasis. Histopathological findings commonly included inflammatory infiltration, necrosis, hemorrhage, hyperkeratosis, and tissue degeneration. Molecular diagnostic approaches such as PCR and qPCR demonstrated higher sensitivity and specificity compared with conventional methods. Increasing antiparasitic resistance and climate-associated changes in parasite distribution were identified as emerging challenges.

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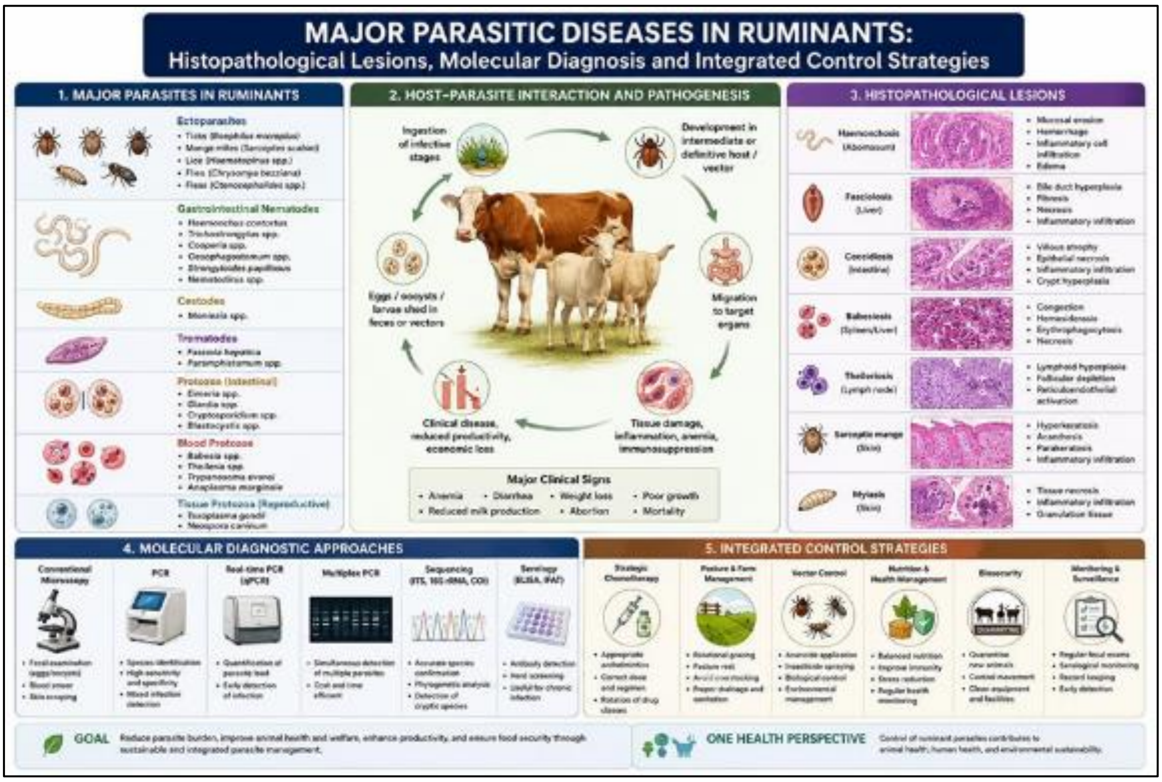
Conclusion: Histopathological and molecular approaches provide valuable insights into parasite-induced lesions and disease mechanisms in ruminants. Integrated parasite management combining conventional therapy, molecular diagnostics, environmental control, and improved farm management is essential for sustainable livestock production and effective parasite prevention.

Keywords: Ruminants; Parasitic diseases; Histopathology; Molecular diagnosis; Veterinary; parasitology

Graphical Abstract



Schematic illustration of major parasitic diseases affecting ruminants, associated histopathological lesions, molecular diagnostic approaches, and integrated control strategies in veterinary medicine

1. Introduction

Parasitic diseases remain one of the major constraints affecting ruminant health and productivity worldwide, particularly in tropical and subtropical regions where environmental conditions favor parasite survival and transmission (Salem *et al*., 2025). High humidity, temperature, and rainfall facilitate the development of infective stages of parasites, increasing the risk of continuous exposure in cattle, sheep, and goats. Consequently, parasitic infections contribute significantly to economic losses through reduced body weight gain, decreased milk and meat production, impaired reproduction, treatment costs, and mortality (Rashid *et al*., 2019). Ruminants are susceptible to a wide range of parasites, including gastrointestinal helminths such as *Haemonchus contortus* and *Trichostrongylus* spp., blood protozoa including *Babesia, Theileria*, and *Trypanosoma*, as well as ectoparasites such as ticks, mites, and flies (Sharma *et al*., 2023). These parasites induce various pathological effects, including anemia, inflammation, tissue degeneration, immunosuppression, and organ dysfunction. Histopathological lesions commonly observed include epithelial erosion, hemorrhage, necrosis, hyperkeratosis, inflammatory cell infiltration, and vascular congestion (Saini *et al*., 2025). Histopathological evaluation therefore plays an important role in understanding parasite-induced tissue damage and disease progression. Conventional diagnostic methods such as fecal examination, blood smear analysis, and skin scraping remain widely used in veterinary practice (Modrý *et al*., 2017). However, these techniques often have limited sensitivity, particularly in subclinical infections. Recent advances in molecular diagnostics, including polymerase chain reaction (PCR), quantitative PCR (qPCR), and sequencing, have improved the accuracy and sensitivity of parasite detection and epidemiological surveillance (Pomari *et al*., 2019). Despite the availability of antiparasitic drugs, effective parasite control remains challenging due to increasing antiparasitic resistance, climate change, and inadequate farm management.

Therefore, integrated parasite management combining conventional therapy, molecular diagnostics, vector control, environmental sanitation, and improved livestock management is essential for sustainable ruminant production (Charlier *et al*., 2020). This review discusses major parasitic diseases in ruminants from histopathological and molecular perspectives, emphasizing disease pathogenesis, diagnosis, and integrated control strategies.

2. Major Ectoparasitic Diseases in Ruminants

Ectoparasitic infestations remain a major concern in ruminant production systems due to their significant impact on animal health, welfare, and economic productivity (Charlier *et al.,* 2020). Among the most important ectoparasitic diseases are mange and myiasis, both of which are widely distributed in tropical and subtropical regions where environmental conditions favor parasite development and transmission. These infestations not only cause direct tissue damage but also predispose animals to secondary bacterial infections, chronic inflammation, stress, and immunosuppression, ultimately leading to decreased livestock performance.

2.1. Mange (Scabies)

Mange, commonly caused by *Sarcoptes scabiei,* is characterized by severe pruritic dermatitis resulting from mite burrowing activity within the epidermis (Benti *et al.,* 2020). The disease induces hypersensitivity reactions and progressive skin damage manifested by hyperkeratosis, alopecia, crust formation, epidermal thickening, and inflammatory cell infiltration. In severe infestations, affected animals exhibit intense itching, reduced feed intake, weight loss, and impaired growth performance. Histopathological examination commonly reveals acanthosis, parakeratosis, dermal edema, and infiltration of eosinophils, lymphocytes, and macrophages (Sharaf *et al.,* 2024). Secondary bacterial infections caused by opportunistic pathogens may further aggravate tissue destruction and delay recovery (Fernando *et al.,* 2024).

2.1.1. Histopathological Findings

Histological examination commonly reveals:

- hyperkeratosis,
- acanthosis,
- epidermal tunnel formation,
- inflammatory cell infiltration,
- dermal edema,
- crust formation.

Inflammatory infiltrates are dominated by eosinophils, macrophages, and lymphocytes.

2.1.2. Molecular Perspectives

Polymerase chain reaction (PCR)-based assays have improved the sensitivity and specificity of mange diagnosis compared to conventional skin scraping (Fraser *et al.,* 2018). Molecular identification also assists epidemiological surveillance and differentiation among mite strains.

2.1.3. Control Strategies

Management according to Fernando *et al.* (2024) includes:

- ivermectin or doramectin administration,
- environmental sanitation,
- quarantine,
- and biosecurity improvement.

2.2. Myiasis

Myiasis is another economically important ectoparasitic condition caused by infestation of living tissues by dipteran fly larvae, particularly *Chrysomya bezziana* and *Cochliomyia hominivorax* (Chowdary *et al.,* 2025). Larval invasion results in extensive tissue necrosis, hemorrhage, ulceration, and foul-smelling wounds (Gour *et al.,* 2018). The proteolytic activity of larvae accelerates tissue destruction and increases susceptibility to bacterial contamination. Severe cases may progress to toxemia, systemic infection, and death if untreated. Histopathologically, myiasis lesions are characterized by necrotic tissue debris, inflammatory infiltration, vascular congestion, and granulation tissue formation (Francesconi and Lupi, 2012).

2.2.1. Histopathological Changes

Histological lesions include:

- Tissue necrosis,
- Hemorrhage,
- Inflammatory infiltration,
- Bacterial colonization,
- And progressive destruction of dermal structures.

Severe infestations may lead to systemic toxemia and secondary infections.

2.2.2. Emerging Control Approaches

Integrated control according to Gour et al. (2018) using these strategies involve:

- Wound management,
- Insecticide application,
- Sterile insect technique (sit),
- And pheromone-based trapping systems

3. Gastrointestinal helminthiasis

Gastrointestinal helminthiasis represents one of the most economically important parasitic problems affecting ruminant livestock worldwide, particularly in tropical and subtropical production systems (Hamid *et al.,* 2023). Infections caused by gastrointestinal nematodes are associated with substantial reductions in growth performance, feed conversion efficiency, reproductive capacity, and overall animal productivity (Strydom *et al.,* 2023). Young animals and immunocompromised hosts are particularly susceptible to severe infections, resulting in increased morbidity and mortality. The epidemiology and transmission of these parasites are strongly influenced by environmental conditions, grazing management, stocking density, and nutritional status of the host (Saha *et al.,* 2026). Among the most pathogenic gastrointestinal helminths in ruminants are *Haemonchus contortus, Strongyloides* spp., *Bunostomum* spp., *Cooperia* spp., *Trichostrongylus* spp., and *Nematodirus* spp. (Fentahun, 2020). These parasites inhabit different regions of the gastrointestinal tract, including the abomasum, small intestine, colon, and cecum, where they induce varying degrees of tissue damage and physiological dysfunction (Khan *et al.,* 2023). Infection generally occurs through ingestion of infective third-stage larvae (L3) present on contaminated pasture, feed, or water, while some species such as Bunostomum spp. and Strongyloides spp. may also infect hosts through skin penetration.

3.1. Haemonchosis

Haemonchus contortus and *Mecistocirrus digitatus* are hematophagous nematodes inhabiting the abomasum of ruminants of tropical and subtropical regions around the world (Ahmad *et al.,* 2024).

3.1.1. Pathogenesis

Adult worms consume blood and damage abomasal mucosa, leading to:

- Anemia,
- Diarrhea
- Hypoproteinemia,
- Edema,
- Bottle jaw,
- And growth retardation.

3.1.2. Histopathological Findings

Histopathological lesions include

- Mucosal erosion,
- Hemorrhage,
- Edema,
- Goblet cell hyperplasia,
- Inflammatory infiltration,
- And degeneration of gastric glands.

3.1.3. Anthelmintic Resistance

Increasing resistance against ivermectin, benzimidazoles, and levamisole on haemonchosis has become a major global concern (Rodrigues *et al.,* 2025). Excessive and uncontrolled deworming practices contribute significantly to resistance development. Therefore, sustainable parasite control should emphasize targeted selective treatment, fecal egg count monitoring, accurate dosing, maintenance of refugia, pasture management, and regular evaluation of drug efficacy (Greer *et al.,* 2020).

3.1.4. Integrated Control

Current recommendations include:

- Rotational grazing,
- Selective deworming,
- Nutritional supplementation,
- Breeding for parasite resistance,
- And integrated pasture management.

3.2. Intestinal Nematodiasis

Important intestinal nematodes according to Fentahun (2020) include:

- *Strongyloides* spp.,
- *Bunostomum* spp.,
- *Cooperia* spp.,
- *Trichostrongylus* spp.,
- and *Nematodirus* spp.

3.2.1. Histopathology

Microscopic lesions include:

- Enteritis,
- Villous atrophy,
- Mucosal ulceration,
- Hemorrhage,
- And inflammatory infiltration.

Severe infections impair nutrient absorption and reduce feed efficiency.

4. Blood protozoal diseases

Babesiosis, theileriosis, and trypanosomiasis are vector-borne diseases causing systemic infection, anemia, fever, and mortality. These diseases are mainly transmitted by arthropod vectors such as ticks and biting flies, allowing the parasites to enter the bloodstream and invade erythrocytes, lymphocytes, or extracellular blood compartments depending on the haemoparasitic species (Kaur *et al.,* 2023).

4.1. Babesiosis

Babesiosis is caused by intraerythrocytic protozoa such as *Babesia bovis* and *Babesia bigemina* are important babesia species in ruminant. Furthermore, *Babesia divergens* is one of the main babesia species that causes bovine babesiosis, and raised concerns among international health authorities (OIE) (Ali and Marif, 2020).

4.1.1. Clinical Manifestations

Common signs include:

- Fever,
- Hemoglobinuria,
- Anemia,
- Jaundice,
- Weakness,
- And death in severe cases.

4.1.2. Histopathological Findings

Histological lesions include:

- Hepatic necrosis,
- Splenomegaly,
- Pulmonary congestion,
- Renal tubular degeneration,
- And erythrophagocytosis.

4.1.3. Molecular Diagnosis

PCR and quantitative PCR (qPCR) are highly sensitive methods for detecting low parasitemia and differentiating Babesia species (Ndayikengurukiye *et al.,* 2025).

4.2. Theileriosis

Theileria species infect lymphocytes and erythrocytes, causing severe lymphoproliferative disease (Kiara *et al.,* 2017).

4.2.1. Histopathology

Microscopic findings include:

- Lymphoid hyperplasia,
- Necrosis,
- Inflammatory infiltration,
- And vascular damage.

4.2.2. Molecular and Immunological Aspects

Recent studies demonstrate that Theileria manipulates host immune signaling pathways to promote intracellular survival (Kyaw *et al.,* 2025).

4.3. Trypanosomiasis

Trypanosomiasis caused by *Trypanosoma evansi* remains a significant disease in tropical livestock (Fatima *et al.,* 2024).

4.3.1. Pathogenesis

The parasite induces chronic anemia, immunosuppression, oxidative stress, and neurological disorders (Banwo *et al.,* 2024).

4.3.2. Histopathological Findings

Lesions may include:

- Hepatic degeneration,
- Meningoencephalitis,
- Myocarditis,
- And splenic hyperplasia.

4.3.3. Current Challenges

Drug resistance and vector abundance continue to hinder effective disease control. The reduced efficacy of commonly used drugs may lead to persistent parasitemia, recurrent infection, and continued disease transmission within herds. At the same time, the widespread presence of biting flies and other mechanical vectors increases the risk of parasite spread, particularly in tropical and subtropical production systems. Therefore, sustainable disease control should not rely solely on chemotherapy but must integrate rational drug use, vector control, regular surveillance, early diagnosis, and improved herd management to reduce infection pressure and prevent long-term productivity losses. (Fatima *et al.,* 2024).

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5. Protozoal Diseases Associated with Reproductive Disorders

Toxoplasmosis and neosporosis are important causes of reproductive failure and abortion in ruminants (Sánchez-Sánchez *et al.,* 2018).

5.1. Toxoplasmosis

Toxoplasma gondii infection causes abortion and congenital infection in sheep and goats (Moreno *et al.,* 2012).

5.1.1. Histopathological Findings

Placental lesions include:

- Necrosis,
- Inflammatory infiltration,
- Mineralization,
- And placentitis.

5.1.2. Molecular Diagnosis

PCR-based detection from placental tissues and fetal organs improves diagnostic accuracy.

5.2. Neosporosis

Neospora caninum is a major abortifacient protozoan in cattle (Nayeri *et al.,* 2022).

5.2.1. Histopathological Lesions

Characteristic findings include:

- Nonsuppurative encephalitis,
- Myocarditis,
- Gliosis,
- And tissue cyst formation.

5.2.2. Economic Impact

Neosporosis contributes significantly to reproductive failure and abortion storms in dairy herds.

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6. Molecular Diagnostics in Veterinary Parasitology

Traditional diagnostic methods such as fecal examination and blood smear analysis remain important in veterinary practice. However, molecular diagnostics provide superior sensitivity and specificity.

Common molecular techniques include:

- Pcr,
- Quantitative pcr,
- Loop-mediated isothermal amplification (lamp),
- Sequencing,
- And elisa-based antigen detection.

Molecular approaches are useful for:

- Early infection detection,
- Species differentiation,
- Epidemiological surveillance,
- And monitoring antiparasitic resistance.

7. Histopathological Contributions in Parasitic Disease Research

Histopathological evaluation remains a fundamental approach in veterinary parasitology for understanding the pathogenesis, tissue tropism, and host parasite interactions associated with parasitic infections in ruminants. Microscopic examination of affected tissues provides critical information regarding the progression of lesions, severity of organ damage, inflammatory responses, and cellular alterations induced by parasitic invasion (Saini *et al.,* 2025). In many parasitic diseases, histopathology serves not only as a diagnostic tool but also as an important method for investigating disease mechanisms, immune responses, and therapeutic efficacy (Modrý *et al.,* 2017).

Parasitic infections induce a wide spectrum of histopathological alterations depending on parasite species, predilection sites, parasite burden, and host immune status (Taye *et al.,* 2014). Gastrointestinal helminths commonly cause epithelial erosion, villous atrophy, mucosal ulceration, goblet cell hyperplasia, hemorrhage, edema, and inflammatory infiltration dominated by eosinophils, lymphocytes, macrophages, and plasma cells. In severe haemonchosis, extensive hemorrhage and degeneration of abomasal glands are frequently observed due to the hematophagous activity of adult worms (Ahmad *et al.,* 2024). Chronic infections may additionally result in fibrosis and tissue remodeling that impair nutrient absorption and gastrointestinal function. Protozoal infections such as babesiosis, theileriosis, and trypanosomiasis are frequently associated with systemic pathological changes involving multiple organs (Fatima *et al.,* 2024). Histopathological findings in these diseases may include hepatic degeneration, splenic hyperplasia, pulmonary congestion, renal tubular necrosis, myocarditis, vascular damage, and erythrophagocytosis (Kaur *et al.,* 2023). In cerebral or neurological involvement, parasitic infections may induce meningoencephalitis, gliosis, perivascular cuffing, and neuronal degeneration. Reproductive protozoal diseases such as toxoplasmosis and neosporosis commonly produce placentitis, focal necrosis, inflammatory infiltration, and nonsuppurative encephalitis in fetal tissues, contributing to abortion and reproductive failure (Moreno *et al.,* 2012). Ectoparasitic infestations including mange and myiasis also produce characteristic histopathological lesions. Sarcoptic mange typically induces hyperkeratosis, acanthosis, parakeratosis, epidermal tunnel formation, dermal edema, and severe inflammatory cell infiltration (Sharaf *et al.,* 2024). Meanwhile, myiasis is characterized by extensive tissue necrosis, hemorrhage, granulation tissue formation, and secondary bacterial colonization caused by larval invasion and proteolytic tissue destruction (Gour *et al.,* 2018). Recent developments in veterinary pathology have integrated histopathology with immunohistochemistry, molecular pathology, and biomarker analysis to improve understanding of parasite-induced tissue responses. Immunohistochemical techniques allow visualization of parasite antigens, inflammatory mediators, and immune cell populations within infected tissues. Molecular approaches such as in situ hybridization and PCR-based tissue analysis further enhance the identification and localization of parasitic agents at the cellular level. Moreover, histopathological assessment plays an important role in evaluating the efficacy of antiparasitic drugs, vaccines, herbal therapies, and biomaterials through analysis of tissue repair, inflammatory modulation, and reduction of parasite-associated lesions. Consequently, the integration of histopathology with molecular and immunological techniques has become increasingly important for advancing research in veterinary parasitology, improving disease diagnosis, and developing effective control strategies for parasitic diseases in ruminants (Pomari *et al.,* 2025).

8. Current Challenges and Future Perspectives

Despite considerable advances in veterinary medicine and parasite control strategies, parasitic diseases in ruminants continue to present major global challenges affecting livestock health, productivity, and economic sustainability (Charlier *et al.,* 2020). The increasing complexity of parasite epidemiology, together with environmental and management-related factors, has complicated efforts to achieve effective and sustainable control programs (Saha *et al.,* 2026). Among the most critical concerns in modern veterinary parasitology are the emergence of antiparasitic resistance, climate-associated changes in parasite ecology, expansion of vector-borne diseases, and limitations in diagnostic and preventive technologies. Antiparasitic resistance, particularly anthelmintic resistance among gastrointestinal nematodes, has become one of the most serious threats to livestock production worldwide. Resistance against commonly used drugs such as benzimidazoles, macrocyclic lactones, and levamisole has been extensively reported in cattle, sheep, and goats (Rodrigues *et al.,* 2025). The indiscriminate and repetitive use of antiparasitic agents, underdosing, frequent mass deworming, and poor pasture management have accelerated the selection of resistant parasite populations. As resistance continues to spread, treatment efficacy declines, resulting in persistent infections, increased production losses, and reduced effectiveness of conventional parasite control programs (Greer *et al.,* 2020). Consequently, there is an urgent need to develop sustainable parasite management approaches that reduce reliance on chemical anthelmintics. Climate change also plays a substantial role in altering the epidemiology and geographical distribution of parasitic diseases (Saha *et al.,* 2026). Increasing global temperatures, changes in rainfall patterns, humidity, and extreme weather events directly influence parasite development, survival, and transmission dynamics. Warmer environmental conditions may accelerate the maturation of infective larval stages and expand the habitat range of arthropod vectors such as ticks, flies, and mosquitoes. These ecological changes increase the risk of emergence and re-emergence of vector-borne diseases including babesiosis, theileriosis, trypanosomiasis, and anaplasmosis in previously non-endemic regions (Kaur *et al.,* 2023). In addition, environmental stress associated with climate change may compromise host immunity, increasing susceptibility to parasitic infections (Taye *et al.,* 2014). Another significant challenge involves the limited availability of effective vaccines against many parasitic diseases. Unlike bacterial and viral infections, parasites possess highly complex life cycles, antigenic variation, and sophisticated immune evasion mechanisms that complicate vaccine development (Alshammari, 2025). Current research increasingly focuses on identifying parasite-specific antigens, immunomodulatory molecules, and molecular targets that may contribute to protective immunity. Advances in genomics, proteomics, transcriptomics, and bioinformatics provide promising opportunities for discovering novel vaccine candidates and therapeutic targets.

The emergence of molecular diagnostic technologies has significantly improved the detection and characterization of parasitic infections. Techniques such as polymerase chain reaction (PCR), quantitative PCR (qPCR), next-generation sequencing (NGS), and loop-mediated isothermal amplification (LAMP) offer greater sensitivity and specificity compared with conventional parasitological methods (Pomari *et al.,* 2019). These technologies enable early diagnosis, species differentiation, detection of subclinical infections, and surveillance of antiparasitic resistance. However, limited laboratory infrastructure, high operational costs, and inadequate technical expertise remain major obstacles in many developing countries. Future perspectives in veterinary parasitology increasingly emphasize integrated parasite management strategies combining chemotherapy, vector control, environmental sanitation, nutritional management, selective breeding for parasite resistance, and precision livestock farming (Fatima *et al.,* 2024). The application of digital technologies, artificial intelligence, biosensors, and remote monitoring systems may improve early detection and disease surveillance in modern livestock production systems (Fuentes *et al.,* 2022). Furthermore, multidisciplinary collaboration integrating veterinary pathology, molecular biology, epidemiology, immunology, and One Health approaches will be essential for addressing the growing challenges posed by parasitic diseases in ruminants.

Therefore, sustainable parasite control in the future will require not only improved therapeutic and diagnostic approaches but also comprehensive understanding of host parasite interactions, environmental influences, and molecular mechanisms underlying parasite survival and pathogenicity.

9. Conclusion

Parasitic diseases remain a major global challenge in ruminant livestock production due to their significant impact on animal health, welfare, and economic productivity. Gastrointestinal helminths, blood protozoa, and ectoparasites contribute to substantial production losses through anemia, tissue damage, impaired growth, reproductive disorders, decreased feed efficiency, and increased mortality. The complexity of parasite life cycles, host–parasite interactions, and environmental influences further complicates disease prevention and control, particularly in tropical and subtropical regions where favorable climatic conditions support parasite survival and transmission.

Histopathological evaluation continues to play a critical role in understanding the pathogenesis and tissue alterations associated with parasitic infections. Microscopic examination provides valuable insights into inflammatory responses, organ damage, tissue tropism, and disease progression, thereby contributing to both diagnostic and research applications in veterinary parasitology. Furthermore, the integration of histopathology with molecular and immunological approaches has improved understanding of parasite biology and host immune mechanisms.

Recent advances in molecular diagnostics, including polymerase chain reaction (PCR), quantitative PCR (qPCR), sequencing technologies, and immunodiagnostic assays, have significantly enhanced the sensitivity and specificity of parasite detection. These approaches facilitate early diagnosis, epidemiological surveillance, species differentiation, and monitoring of antiparasitic resistance. However, challenges such as increasing antiparasitic resistance, climate change, vector expansion, limited vaccine availability, and inadequate farm management continue to threaten the effectiveness of existing control programs.

Therefore, sustainable parasite control requires a comprehensive and multidisciplinary approach involving integrated parasite management strategies. The combination of conventional antiparasitic therapy, molecular diagnostics, vector and environmental control, improved nutrition, farm biosecurity, selective breeding, and precision livestock management is essential for reducing parasite burden and improving livestock productivity. Future research integrating veterinary pathology, molecular biology, epidemiology, and One Health perspectives will be crucial for developing innovative diagnostic tools, effective vaccines, and sustainable control strategies against parasitic diseases in ruminants.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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