Archives of Current Research International

Volume 25, Issue 9, Page 728-741, 2025; Article no.ACRI.144912
ISSN: 2454-7077

Bovine Tropical Theileriosis: A Comprehensive Review of Epidemiology, Immunopathogenesis and Integrated Management Strategies

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/acri/2025/v25i91537

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy.Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/144912

Review Article

Received: 22/07/2025
Published: 28/09/2025

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Cite as: *P.K.Ram, S.K.Singh, Mukesh Srivastava, Sheikh T.J, Amit Kumar Jha, Rajeev Ranjan, and Baleshwari Dixit. 2025. "Bovine Tropical Theileriosis: A Comprehensive Review of Epidemiology, Immunopathogenesis and Integrated Management Strategies". Archives of Current Research International 25 (9):728–741. https://doi.org/10.9734/acri/2025/v25i91537.*

ABSTRACT

Bovine tropical theileriosis, a serious tick-borne illness caused by *Theileria annulata*, poses a significant threat to cattle health and productivity in tropical countries. The disease spreads through *Hyalomma* ticks and results in substantial economic losses due to high infection rates, fatalities, and decreased productivity in cattle. Symptoms typically include fever, anemia, jaundice, swollen lymph nodes and multi-organ failure. Young calves are at higher risk, emphasizing the importance of early preventive measures. Study shows that the disease follows seasonal patterns, with outbreaks peaking during summer and monsoon months. Diagnostic tools, like PCR and serological tests, have enhanced detection precision. The parasite manipulates host immune cells, triggering uncontrolled cell growth, oxidative damage, disrupted cytokine activity, and weakened immunity. Blood tests often reveal low hemoglobin, reduced red blood cell counts, and increased inflammatory markers. Diagnosis can be carried out by clinical signs, microscopic lesions, and advanced molecular testing. Treatment involves specific antiparasitic drugs like buparvaquone along with supportive care. Though, the eliminating the disease is difficult due to carrier animals and widespread tick populations. Effective control requires multi-pronged strategy, that includes tick control, vaccination programs, and selective breeding of resistant native cattle breeds. Sustainable solutions are essential to minimize economic damage and enhance cattle health in affected areas.

Keywords: Bovine tropical theileriosis buparvaquone; cytokine dysregulation; hemato-biochemical alterations, Hyalomma ticks; Theileria annulate.

1. INTRODUCTION

Theileriosis is a serious protozoan disease caused by*Theileria* species, intracellular parasites spread by *ixodid* ticks. These pathogens, part of the *Apicomplexa* phylum, infect domestic and wild animals, with *T. annulata* and T. *parva* being the most dangerous. *T. annulata* causes bovine tropical theileriosis, while T. *parva* leads to East Coast Fever-both resulting in high death rates, decreased milk production, weight loss, and abortions in cattle and buffalo. The disease creates major economic challenges, especially in livestock-dependent regions like India, Africa, and China (Sivakumar et al., 2014). The *Apicomplexa* phylum includes various eukaryotic parasites that use specialized structures called apical complexes to invade host cells. *Theileria*initiate its lifecycle with tick transmission, followed by white blood cell invasion, replication (schizogony), and at last infection of red blood cells, where it formpiroplasms. These allow the parasite to spread rapidly within the host (McKeever, 2009). *Theileria* species are classified as transforming (e.g., *T. parva*, *T. annulata*) or non-transforming. Transforming species induce uncontrolled lymphocyte proliferation, causing severe clinical disease, whereas non-transforming species primarily cause anemia through erythrocyte destruction (Sivakumar et al., 2014). Emerging Theileria strains in both domestic and wild reservoirs make diagnosis and management more difficult, requiring sophisticated molecular techniques to distinguish between benign and pathogenic infections (Criado-Fornelio et al., 2004). In developing nations like India, theileriosis remains a critical challenge for dairy and meat industries. *T. annulata,* causes massive losses, India alone suffers annual losses of ~USD 384 million due to cattle mortality, treatment costs, and productivity decline (Minjauw & McLeod, 2003). According to Atif et al. (2012), tick-borne diseases cause losses of USD 13.9–18.7 billion annually worldwide, highlighting the need for better interventions. Despite its significance, there is still a dearth of systematic data on the prevalence and risk factors of Theileria. Although meta-analyses have evaluated other livestock illnesses, such as anaplasmosis and mastitis (Krishnamoorthy et al., 2019), comprehensive studies on theileriosis are scarce. In China, rising beef and dairy demand has increased cattle movement, elevating transmission risks, yet epidemiological gaps persist (Jacob et al., 2020).

To address these challenges, this review will examine the epidemiology and seasonal patterns of bovine tropical theileriosis, focusing on key risk factors including climate variations, tick distribution, and host susceptibility. By examining hematological, biochemical, and immunological alterations in infected cattle, it will further explore the pathophysiology of *T. annulata*. In order to determine the best control measures, the study will also assess the effectiveness of current diagnostic techniques, treatment options (such as oxytetracycline and buparvaquone), and integrated tick management strategies. In order to effectively manage theileriosis in endemic areas, these initiatives seek to improve treatment guidelines, bolster surveillance systems, and aid in the creation of policies.

2. BOVINE TROPICAL THEILERIOSIS AND THE PARASITE

Animal husbandry plays a crucial role in the economy of many countries. It is providing a primary source of income for rural households. However, livestock production in developing countries, including India, faces major challenges due to haemoprotozoan diseases, which significantly impact productivity by causing high morbidity and mortality in livestock (Khan et al., 2004). These diseases lead to reduced meat and milk production, increased treatment costs, and loss of draught power. Among tick-borne diseases, bovine tropical theileriosis stands out as one of the most economically damaging. Caused by *Theileriaannulata*, this protozoan parasite triggers abnormal lymphocyte growth and a dangerous drop in white blood cells, often leading to severe illness and high death rates (Demessie & Derso, 2015). In India, tropical theileriosis poses a major challenge to livestock development efforts. The country's warm climate and diverse tick populations create ideal conditions for the disease. While native cattle breeds show natural resistance, imported and crossbred cattle are far more vulnerable (Nair et al., 2011). The financial impact is severe—farmers face costs for treatments and vaccines, while animals suffer stunted growth, lower milk production, longer intervals between calving, and delayed sexual maturity in females (Gharbi et al., 2006). Mortality is especially high in calves, with T. *annulata* killing up to 70% of infected young stock, while T. *parva* infections prove almost universally fatal in non-native breeds (Moorehouse et al., 2001). Worldwide, an estimated 250 million cattle are exposed to tropical theileriosis, with countries like Egypt experiencing major losses in livestock productivity (Erdemir et al., 2012).

2.1 Parasite Biology and Transmission

Theileria, first identified by Arnold Theiler, belongs to the Apicomplexa phylum (class Piroplasmasida, order Piroplasmorida). These parasites invade host cells using specialized structures called rhoptries (Gul et al., 2015). T. *annulata* infects both white and red blood cells, taking on various shapes-round, oval, irregular, or rod-like (Darghouth et al., 1996). Scientists classify *Theileria* species based on their physical traits, symptoms they cause, preferred hosts, tick vectors, and geographic range. Also known as Mediterranean Coast Fever, tropical theileriosis spreads through bites from *Hyalomma* ticks (Saeed et al., 2016). The parasite's life cycle alternates between ticks and ruminants as described in below Fig. 1. When infected ticks feed on cattle, they transmit sporozoites, with disease outbreaks coinciding with peak tick activity in warmer months (Beniwal et al., 1997).

In India, the three-host tick *Hyalommaanatolicum* is the main carrier of the disease (Ghosh et al., 2008). Weather plays a critical role-summer heat and humidity drive higher infection rates. Even a single tick bite can be lethal, making tick infestations a major concern (Khattak et al., 2012). Calves born during summer or monsoon face greater risks due to early exposure (Sangwan et al., 1994). Globally, T. *annulata* and T. *parva* remain the deadliest strains, causing the most widespread damage (Gebrekidan et al., 2016). Distribution of the possible vector tick species of *Theileria* in different regions of India is mentioned in Fig. 2 (Kakati et al., 2015).

2.2 Prevalence of Bovine Tropical Theileriosis

Bovine tropical theileriosis, caused by *Theileriaannulata*, continues to threaten cattle populations across India, particularly affecting exotic and crossbred animals. First described by Lingard in 1905, this disease remains endemic in tropical and subtropical zones, causing significant challenges for small-scale farmers, peri-urban dairy operations, and imported cattle herds (Sahoo et al., 2001). Study has demonstrated the extensive reach of *Theileria* infections. A notable East African study found the parasite present in 97.1% of examined African buffalo (Syncerus caffer) populations across 13 different regions (Young et al., 1978). The disease shows clear climate dependence, with transmission rates increasing in warmer conditions as infected ticks - primarily *Hyalomma* species - thrive in higher temperatures (Ochanda et al., 1988). This temperature sensitivity helps explain the seasonal patterns of outbreaks observed in endemic areas. Young calves, especially those under one month old, are highly susceptible, necessitating early immune prophylaxis (Mudgal, 1993).

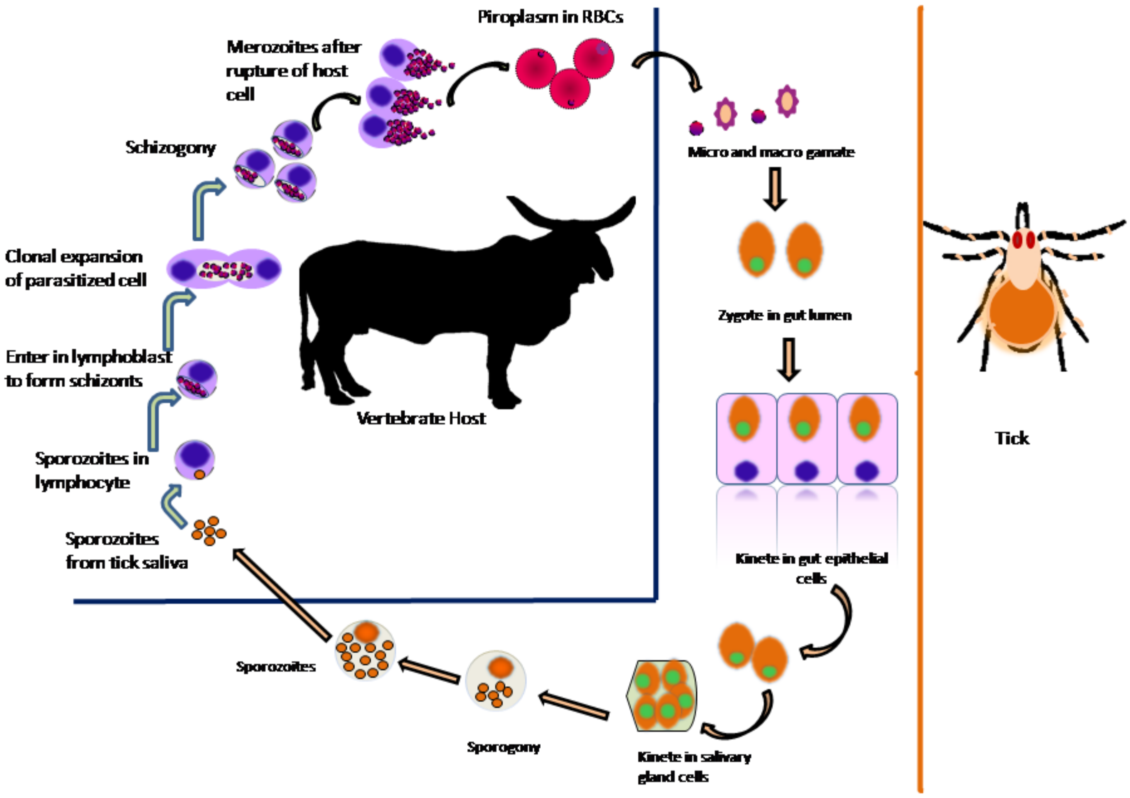

Fig. 1. Life cycle of *Theilera spp.*

In China, the disease peaks between June and September, coinciding with increased tick activity (Zhang, 1997). In Faisalabad, Pakistan, cases typically rise from February, peak in June, and decline by November, with no cases observed in December and January (Muhammad et al., 1999). The disease incidence in Lahore peaked in August (Durrani et al., 2006). A study in Madhya Pradesh province of India, reported a 16.91% prevalence in 692 exotic and crossbred cattle from 1985 to 1988 (Sisodia, 1998). Serological surveys in Andhra Pradesh (India), revealed *T. annulata* antibodies in 30–60% or more of crossbred cattle (Singh et al., 2001). In Ludhiana (India), the overall prevalence was 6.94%, with peaks in September-October and March-April, corresponding to periods of high tick activity (Aulakh et al., 1998). While Haryana (India) recorded 162 outbreaks between 2001 and 2003, primarily during the rainy season (Gupta et al., 2006). In Gujarat, blood smear analysis detected *T. annulata* in 37% of 3,152 crossbred cattle and 17% of 1,129 buffaloes, with peak incidence from June to September in cattle and June to August in buffaloes (Vahora et al., 2012). PCR-based studies further confirmed *T. annulata* in 72.52% of cattle and 32% of buffaloes (Kundave et al., 2014).

Seasonal patterns of *Rhipicephalus appendiculatus*, a vector for *T. parva*, are influenced by rainfall, with outbreaks often occurring after wet periods (Demessie & Derso, 2015). Theileriosis prevalence is shaped by factors such as geography, tick populations, climate, age, sex, management practices, and immunity levels (Gul et al., 2015). Exotic and crossbred cattle (*Bos taurus*) are more susceptible than indigenous breeds (*Bos indicus*), with mortality rates reaching 80% in untreated exotic cattle (Jabbar et al., 2015).A study of 150 cattle reported a 23.33% prevalence of *T. annulata*, with infection rates higher in females (25.45%) than males (17.5%). Among breeds, Holstein-Friesian crossbreeds had the highest infection rate (29.85%), followed byJersey crosses (23.33%), Sahiwal (15.38%), and Gir (14.81%) (Naik et al., 2016). Younger animals showed a higher prevalence (23.4%) compared to adults (15%) (Saeed et al., 2016). In Northern Tunisia, molecular studies estimated *T. annulata* prevalence at 61%, with

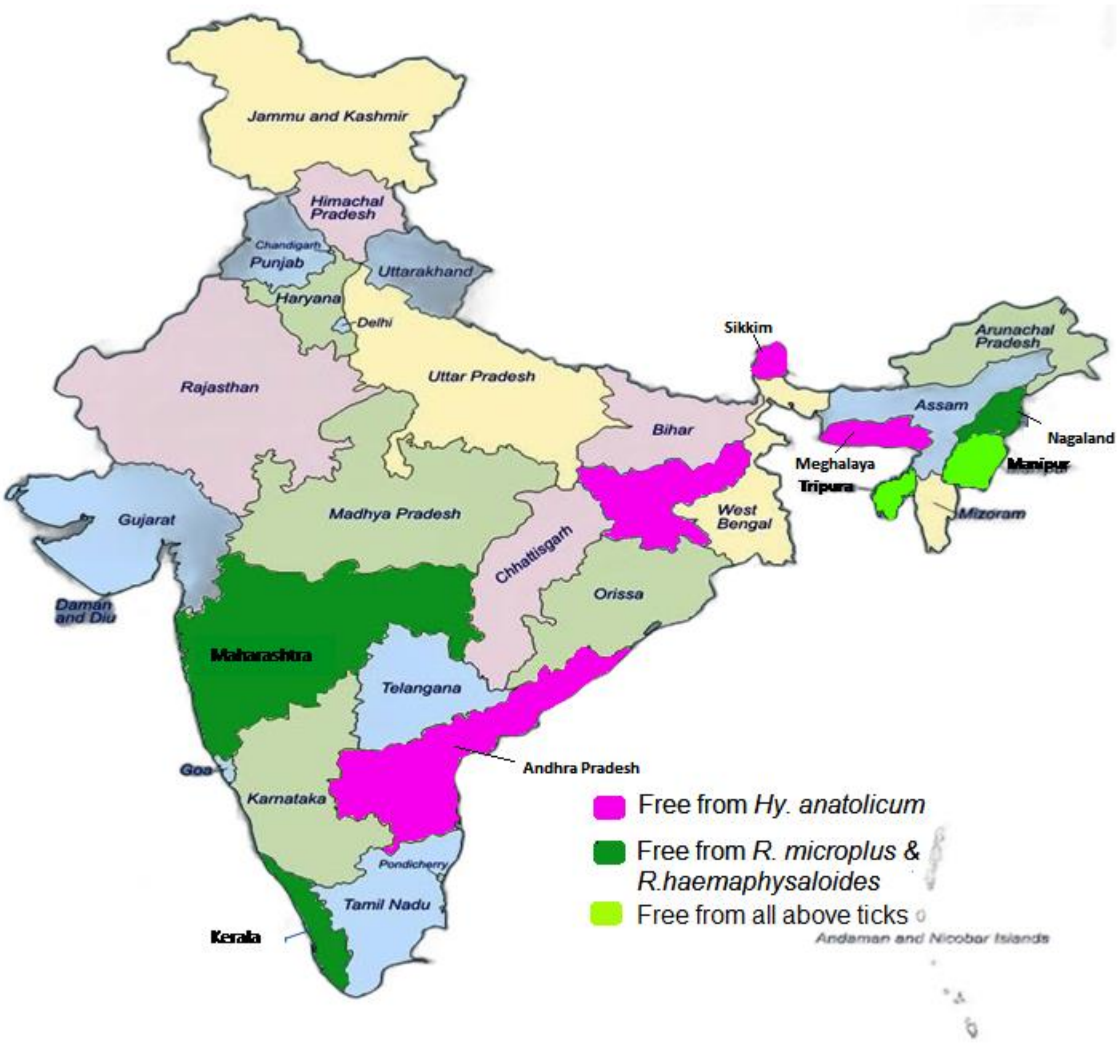

Fig. 2. Distribution of *Theileria* ticks in Indian states

Trypanosoma evansi co-infection in 6% of cases. While age significantly correlated with *T. annulata* infection, no such association was found for *T. evansi* (Sallemi et al., 2017). Higher infection rates of 85% in female cattle and 34% in animals aged 3–4 years were reported in India, where *Theileriaorientalis* infections were found in 24.21% of cases that were brought to veterinary hospitals (Devadevi et al., 2018). According to seasonal trends, 31% of calves younger than six months were most affected, and the highest prevalence (27.27%) occurred during the monsoon season (Brahmbhatt et al., 2019). These results demonstrate how urgently region-specific control measures against bovine tropical theileriosis are needed. On the Indian subcontinent, *Theileria annulata, Theileriaorientalis, Theileria mutans,* and *Theileriavelifera* mainly affect cattle and buffalo, whereas *T. lestoquardi, T. luwenshuni*, and *T. ovis* are frequently found in small ruminants like goats and sheep. Similar patterns are observed in Pakistan, where recent studies by Zeb et al. (2022) have identified additional *Theileria* species variants in small ruminants, suggesting complex regional epidemiological patterns.

2.3 Clinical Manifestations of Tropical Theileriosis

Multiple studies conducted across endemic regions have described the typical clinical presentation of tropical theileriosis, which starts with a high fever, nasal and ocular discharge, and generalized weakness before frequently progressing to severe anemia, jaundice, and lymphadenopathy (Oryan et al., 2013). Post-mortem examinations consistently reveal hallmark pathological changes including watery blood consistency, splenomegaly, lymph node enlargement, and mucosal hemorrhages. A five-year clinical study of 112 cases in Faisalabad, Pakistan (1993-1998) demonstrated that fever represents the most consistent clinical marker, present in 100% of cases, typically accompanied by pronounced swelling of prescapular, parotid, and prefemoral lymph nodes. The disease progression follows a predictable course from initial tick bite exposure through acute febrile phase to either recovery or fatal outcomes, with severity influenced by host factors, parasite strain virulence, and timely intervention. Additional clinical signs included exophthalmos with hemorrhagic conjunctiva, subcutaneous swelling, diarrhea (sometimes bloody), tachycardia, respiratory distress, pneumonia, and neurological manifestations such as convulsions and neck twisting. Hemoglobinuria, anemia, and anorexia were also frequently observed (Muhammad et al., 1999). As the disease advances, symptoms worsen, leading to dysentery and recumbency (Stockham et al., 2000).

Cerebral theileriosis presents with neurological symptoms, including uncoordinated movement, depression, circling, head pressing, hyperesthesia, blindness, and aggression. In severe cases, affected animals develop seizures, coma, and eventually death (Saville, 2002). In Friesian cattle, naturally infected with *Theileriaannulata* reported fever, lymphadenopathy, tachycardia, respiratory distress, and weakness, with less common signs such as exophthalmos, excessive tearing, drooling, bilirubinuria, and bloody diarrhea (Omer et al., 2003).

Buffaloes infected with *Theileria* exhibit clinical signs similar to those in cattle, including high fever, tearing, lymphadenopathy, weakness, tachypnea, tachycardia, cloudy corneas, weight loss, pale conjunctiva, anemia, unsteady movement, and a rough coat (Durrani et al., 2008). In advanced cases, hypothermia, jaundice, dehydration, and occasional hematochezia are reported (Hasanpour et al., 2008). Similarly, *Theileriaannulata*-infected cows display fever, respiratory distress, lymphadenopathy, and soft yellowish diarrhea (Al-Emarah et al., 2012). In young calves (1-9 days old), the disease manifests as fever, lymphadenopathy, exophthalmos, pale or jaundiced mucous membranes with petechiae, tearing, respiratory distress, and depression. Clinical examinations frequently reveal dry corneas, generalized lymph node enlargement, anemia, hyperthermia, and sternal recumbency (Alsaad et al., 2013).

Clinical signs usually encompass behavioral changes such as decreased feed intake and lethargy, and physical signs such as pale or white mucous membranes and prolonged capillary refill time. When an infestation is in a moderate to severe state, the affected animal may develop a high fever and swollen lymph nodes (which may be axially symmetric). The cardiovascular and respiratory system is compromised, evidenced by increases in heart rate and respiratory rate, and the gastrointestinal function is compromised, evidenced by decreased motility of the rumen. In severe cases, neurologic signs are present (e.g., muscle fasciculations) and bruxism (e.g., teeth grinding), as well as respiratory signs (e.g., nasal discharge and cough). The disease progression leads to profound metabolic disturbances resulting in dramatic weight loss and the development of characteristic yellow discoloration of mucous membranes (jaundice) and protruding eyeballs (exophthalmos). Hematological changes become apparent through worsening anemia, while respiratory function continues to deteriorate, often culminating in labored breathing (Nagar et al., 2019). These comprehensive clinical and epidemiological observations underscore the significant economic and animal health impacts of theileriosis across South Asia, necessitating continued research and targeted control measures.

2.4 Hematological and Biochemical Alterations

Theileriosis induces significant hematological and biochemical alterations in affected animals, including a progressive decline in hemoglobin levels, packed cell volume (PCV), and erythrocyte counts (Salama et al., 2007). Infected animals also exhibit reduced levels of calcium, cholesterol, triglycerides, total serum protein, albumin, and immunoglobulins, along with a decreased albumin-to-immunoglobulin ratio. Elevated blood urea nitrogen (BUN) levels are commonly observed.

In *Theileria annulata*-infected cattle, acute-phase proteins such as haptoglobin (Hp), serum amyloid A (SAA), ceruloplasmin, and fibrinogen increase significantly, particularly at varying parasitemia rates (Nazifi et al., 2010). Buffaloes and crossbred calves affected by *Theileria* exhibit significantly lower erythrocyte counts, hemoglobin levels, and PCV, along with leukopenia in later stages of infection (Mahammod et al., 2011).

Biochemical analysis of infected animals revealed significantly elevated levels of alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), creatinine kinase, gamma-glutamyltransferase(GGT), uric acid, BUN, and bilirubin. While total protein, albumin, glucose, cholesterol, and calcium concentrations showed non-significant decreases, phosphorus levels declined significantly in the terminal stages of the disease. Additionally, infected animals exhibited lower mean levels of sodium, calcium, phosphorus, and potassium, with a significant reduction in potassium. Hematological examinations of diseased buffaloes also revealed neutropenia, eosinopenia, lymphopenia, and monocytopenia, while thrombocyte numbers increased significantly (El-Deeb & Younis, 2009).

2.5 Immunopathology of Theileriosis

The host immune response to pathogens involves a complex network of immune effector cells and signaling molecules. *Theileriaannulata* infects bovine macrophages, transforming them into aggressively invasive cells by hijacking leukocyte regulation and inhibiting apoptosis, leading to excessive proliferation and clonal expansion (Metheni et al., 2014). Over-proliferating leukocytes generate high levels of reactive oxygen species (ROS), compromising the host's antioxidant defense system and resulting in oxidative stress, which causes lipid peroxidation and protein oxidation (Saleh et al., 2012). Protein oxidation produces stable carbonyl groups, serving as markers of oxidative injury, while lipid peroxidation reflects oxidative stress (Sordillo & Aitken, 2009). Antioxidants play a critical role in mitigating ROS-induced damage to lipids and proteins (Halliwell, 2006).

A significant reduction in total antioxidant capacity (TAC) has been observed in calves with theileriosis compared to healthy ones, with a similar decline reported in adult cattle and buffaloes as anemia progresses (Singh et al., 2018). *T. annulata* infections also compromise corpuscular antioxidant enzyme levels, further reducing TAC in infected cattle and buffaloes (Turunç&Aşkar, 2012). This decline is attributed to the depletion of enzymatic and non-enzymatic antioxidants due to excessive free radical generation in diseased animals (Singh et al., 2018).

2.6 Role of Cytokines in Immune Response

Cytokines are critical signaling molecules in immunity that affect the outcomes of infectious disease through autocrine, paracrine, or endocrine mechanisms. Cytokine production is regulated by genetic, epigenetic, and post-transcriptional processes and their downstream effects depend on receptor expression and the specific signalling pathways utilized (Richter et al., 2018). In addition to being beneficial for defence against infectious disease, cytokines also contribute to the development of inflammatory and autoimmune disease. The analysis of systemic cytokine concentrations has occurred in many different infectious disease contexts, notably canine distemper, parvovirus, demodicosis, trypanosomiasis, leishmaniasis, and babesiosis (Gasparetto et al., 2018; Souza et al., 2018). In *Theileria annulata* infections, the parasite manipulates the host immune response to enhance its survival and proliferation. Infected macrophages secrete cytokines such as IL-2, IL-4, IL-10, and IL-12A, contributing to disease immunopathology (Rashid et al., 2019). Excessive pro-inflammatory cytokine production, particularly TNF-α, exacerbates symptoms like fever, anemia, and tissue damage (Forsyth et al., 1999). Disease severity is influenced by factors such as parasite strain, infection level, and host susceptibility (Mehlhorn et al., 1994). Exophthalmia is frequently observed in neonatal cases in endemic regions, though its association with theileriosis is not extensively documented (Singh et al., 2013, 2014). Unlike other apicomplexan parasites, *T. annulata* primarily induces pathology through macroschizonts rather than piroplasms, with infected cells expressing mRNA for pro-inflammatory cytokines, leading to non-specific T-cell activation (Collins et al., 1996).

A key pathogenic mechanism of *T. annulata* is the uncontrolled proliferation of schizont-infected cells. The parasite bypasses the parasitophorous vacuole, directly manipulating host cell signaling to inhibit apoptosis and induce excessive proliferation (Woods et al., 2013). It interacts with host microtubules to ensure persistence and maintains a transformed phenotype by associating with the mitotic apparatus during cell division (Hulliger et al., 1964). Primarily infecting macrophages, monocytes, and B-cells, the parasite drives lymphoproliferative disease in cattle (Woods et al., 2013).

Increased TNF-α production by Theileria-infected cells is a major contributor to clinical symptoms like pyrexia, anemia, anorexia, muscle atrophy, and necrosis (Brown et al., 1995). Additionally, TNF-α is linked to the growth of infected cells and the development of ulcerative lesions (Forsyth et al., 1999). Macrophage proliferation and cytokine dysregulation, specifically TNF-α, are the causes of the pathology seen in infected organs (Branco et al., 2010; El-Deeb & Iacob, 2012). Bovine theileriosis has been linked to changed cytokine profiles, including lower levels of TNF-α and IFN-γ and higher levels of IL-2, IL-4, and IL-10 (Gupta et al., 2017). Additionally, experimental cases show increased levels of serum IL-6, TNF-α, and IFN-γ, with strong relationships between these cytokines and a moderate relationship between IL-6 and lymphocyte counts. (Razmi et al., 2019).

2.7 Diagnosis and Therapy

Hemoprotozoan infections, including theileriosis, are difficult to diagnose due to their non-specific clinical symptoms (Maharana et al., 2016). Acute cases are primarily diagnosed through clinical findings and microscopic examination of Giemsa-stained blood and lymph node smears (Aktas et al., 2006). However, in subclinical or chronic infections, where parasitemia levels are extremely low, expertise in piroplasm microscopy is essential to avoid misdiagnosis. Accurate diagnosis is critical for effective treatment and disease management. Among serological tests, the Indirect Immunofluorescent Antibody Test (IFAT) and Enzyme-Linked Immunosorbent Assay (ELISA) are widely used for bovine theileriosis due to their ability to process large sample volumes efficiently (Tarimo, 2013). Acute cases are also diagnosed based on clinical signs such as fever, enlarged lymph nodes, and knowledge of disease and vector distribution (OIE, 2014).

Buparvaquone remains the treatment of choice for tropical theileriosis due to its high efficacy, particularly against both schizonts and piroplasms, with a reported success rate of 92% (Gharbi et al., 2015). *parva*quone and Halofuginone lactate are also used, although they do not fully eliminate the infection, often resulting in carrier states (OIE, 2014). Buparvaquone, administered at 2.5 mg/kg intramuscularly, is more effective than *parva*quone, which is given at 20 mg/kg and primarily targets schizonts. Successful treatment outcomes have been reported in calves treated with Buparvaquone every 48 hours (Muhammad, 1999). However, late-stage treatment often fails due to pulmonary complications (Mbwambo et al., 2006).

For cerebral theileriosis, a combination of Buparvaquone (2.5 mg/kg) and Oxytetracycline (10 mg/kg) administered intramuscularly for five days has proven effective (Dabak et al., 2004). Oxytetracycline, along with supportive therapies, has also been used successfully in HF crossbred cows (Baghel et al., 2016). In young calves, treatment with Buparvaquone, iron sorbitol, folic acid, and meloxicam led to recovery within a week (Kumar et al., 2016). Early intervention improves treatment outcomes, with studies reporting a 100% cure rate in buffaloes treated in the early stages, whereas late-stage treatment failed due to irreversible lung damage (Salama et al., 2007).

Control of bovine theileriosis relies primarily on chemical tick control using acaricides, although vaccination offers a more sustainable long-term solution (Morrison, 2015). Effective treatment protocols include Buparvaquone administered on day 1 and repeated on day 7, combined with meloxicam and nandrolone decanoate (Singh et al., 2015). Furthermore, *Theileria annulata* has been successfully treated with oxytetracycline and diminazene aceturate, which controls fever and returns body temperature to normal in seven days (Sarma et al., 2016). Tropical theileriosis-related economic losses have decreased as a result of preventive measures like acaricide use, immunization, and buparvaquone therapy. However, in endemic areas, these tactics are frequently unavailable and expensive. Climate change's increased risk of vector dissemination emphasizes the necessity of an integrated control strategy that blends policy changes with scientific discoveries (Gomes et al., 2018). Long-term disease management requires the development of sustainable and cost-effective strategies due to the high costs and limitations of current approaches.

3. CRITICAL INSIGHTS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Theileria annulata live-attenuated vaccines currently on the market have variable effectiveness and the potential to revert to virulence. A promising substitute that provides safer and longer-lasting immunity is recombinant and DNA-based vaccinations. Enhancing point-of-care molecular diagnostics is essential for early disease detection in endemic areas, in addition to vaccine development. The increasing resistance to buparvaquone is a serious issue that highlights the need for investigation into combination treatments and new drug targets. Integrated vector management techniques, such as tracking acaricide resistance and investigating biocontrol alternatives, will be necessary for the sustainable control of theileriosis. Furthermore, examining *T. annulata's* immune evasion strategies may reveal novel treatment prospects. Theileriosis has serious economic repercussions because infected cattle have lower reproductive efficiency, decreased milk yield, and impaired weight gain.These effects lead to substantial financial losses due to treatment costs, high mortality rates, and declining productivity. A thorough assessment of these economic impacts is essential for designing cost-effective interventions.

Recent research indicates possible new therapeutic targets by highlighting the part epigenetic changes play in Theileria-induced leukocyte transformation. In the meantime, Hyalomma tick distribution is changing due to climate change, making predictive climate models necessary to predict outbreaks and direct control efforts. It is critically necessary to compare current protocols, including combination therapies, oxytetracycline, and buparvaquone, in order to maximize treatment outcomes. The effectiveness of government-led immunization and tick control programs will be increased by bolstering them with evidence-based tactics. In order to minimize the impact of the disease and encourage early diagnosis and prompt treatment, public awareness campaigns should also be given top priority.

4. CONCLUSION

Bovine tropical theileriosis, caused by *Theileriaannulata*, poses a significant threat to livestock health, particularly in exotic and crossbred cattle, with young calves being the most vulnerable. Eradication efforts are still hampered by widespread tick infestations and persistent carrier states, even with improvements in molecular diagnostics. An integrated strategy that combines vaccination, tick control, and initiatives to increase genetic resistance in native cattle breeds is necessary for effective disease management. Tick distribution patterns are changing due to climate change, making control measures even more difficult and necessitating adaptive measures. In order to combat emerging drug resistance, future research should concentrate on creating next-generation vaccines, alternative therapies, and sophisticated diagnostics. Improved therapies may also result from a better comprehension of the parasite's immune evasion strategies. Government-led initiatives must be strengthened through scientific innovation and public engagement in order to lessen the impact of theileriosis. To ensure sustainable cattle production and protect the livestock industry in endemic areas, a multidisciplinary approach will be essential.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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