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The Ever-changing Battle against Haemonchosis: Epidemiology, Diagnosis and Control Strategies: A Review

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ABSTRACT

Haemonchosis, caused by the hematophagous nematode *Haemonchus contortus*, remains a major challenge to ruminant health and production worldwide. This review explores the epidemiology, diagnosis and control strategies for haemonchosis, emphasizing the growing threat of anthelmintic resistance. The parasite thrives in warm, humid climates, with transmission dynamics significantly influenced by regional environmental conditions. Epidemiological investigations, including tracer animal studies, fecal sample analyses and slaughterhouse surveys, provide crucial insights into parasite burden and infection trends. However, seasonal variations and host immunity complicate accurate assessments. Climate plays a pivotal role in the persistence and transmission of *H. contortus*. In tropical and subtropical regions, continuous parasite transmission occurs, whereas hypobiosis ensures survival in harsh climates. Understanding these regional infection patterns aids in designing effective parasite control programs. The increasing prevalence of anthelmintic resistance, characterized by genetic mutations in β-tubulin, nicotinic acetylcholine receptors and glutamate-gated chloride channels, necessitates alternative control measures. The failure of benzimidazoles, imidazothiazoles and macrocyclic lactones due to resistance highlights the urgency of sustainable strategies, including targeted selective treatment, pasture management and genetic selection for parasite-resistant breeds. Advancements in diagnostic methodologies, such as molecular techniques (PCR, LAMP) and immunodiagnostics, have enhanced the precision of haemonchosis detection. Traditional approaches, including fecal egg count, hematological parameters and post-mortem findings, remain valuable but require integration with modern diagnostics for improved accuracy. This review underscores the need for a multifaceted approach combining epidemiological surveillance, innovative diagnostics and integrated parasite management strategies to mitigate the economic and health impacts of haemonchosis in grazing ruminants.

Key words: Anthelmintic resistance, Diagnostic methodologies, Epidemiology, *Haemonchus contortus*, Integrated parasite management.

Haemonchosis, caused by the blood-feeding nematode *Haemonchus contortus*, is a major parasitic disease affecting grazing ruminants worldwide (Besier *et al.,* 2016). This gastrointestinal parasite primarily inhabits the abomasum of infected animals, where it attaches to the mucosa and feeds on blood, leading to clinical and subclinical anemia (Kotze and Prichard, 2016). The life cycle of *H. contortus* includes egg shedding in feces, development through free-living larval stages (L1-L3) in the environment and oral ingestion of infective L3 larvae by the host, where they mature to adults and complete the cycle (Gasser *et al.,* 2016). *H. contortus* thrives in warm, humid climates and poses a significant challenge to livestock health and productivity. The economic impact of haemonchosis is substantial, leading to severe anemia, reduced weight gain, decreased milk production and increased mortality, particularly in small ruminants like sheep and goats (Flay *et al.,* 2022). Emerging challenges include widespread multidrug resistance, reduced efficacy of conventional treatments and subclinical infections that impair productivity without overt clinical signs, complicating timely diagnosis and control (Kaplan and Vidyashankar, 2012; Rose Vineer *et al.,* 2020). Understanding the epidemiology, transmission dynamics, diagnostic techniques and control strategies of *H. contortus* is crucial for effective parasite management. This review highlights key factors influencing the spread of haemonchosis, the role of climate in its transmission, emerging challenges due to anthelmintic

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resistance and the importance of integrating advanced diagnostic and control measures to combat the disease.

A comprehensive literature search and critical analysis were carried out in 2024 at the College of Veterinary Science and Animal Husbandry, NDVSU, Madhya Pradesh, India, to collate and synthesize current knowledge on the epidemiology, diagnosis and control of Haemonchus contortus. Scientific databases, including PubMed, Scopus, Google Scholar and ScienceDirect, were systematically searched for peer-reviewed articles published between 2010 and 2024. Keyword combinations using Boolean operators such as *Haemonchus contortus*, epidemiology, anthelmintic resistance, diagnosis, control strategies," climate influence and "targeted selective treatment" were applied. Preference was given to recent meta-analyses, systematic reviews and original research articles with relevance to small ruminant haemonchosis, emphasizing both global trends and region-specific data from India. Additional literature was identified by manually screening the reference lists of key publications. The collected materials were thoroughly evaluated to extract emerging trends, identify research gaps and propose sustainable control strategies.

Epidemiology and transmission dynamics of haemonchosis

Epidemiological investigations have provided valuable insights into the transmission dynamics of *H. contortus* in grazing ruminants. Several methodological approaches have been employed to elucidate the factors influencing its development and spread. These approaches include:

Tracer animal studies

Healthy animals are introduced to contaminated pastures at varying intervals to monitor parasite exposure.

Fecal sample analysis

The examination of fecal samples from naturally infected hosts helps quantify parasite egg output, providing an indirect measure of infection intensity.

Slaughterhouse surveys

Post-mortem worm burden assessments enable direct evaluation of infection levels and facilitate the identification of hypobiotic larvae.

Despite their utility, these methodologies possess inherent limitations. Ruminants frequently harbor mixed parasitic infections, leading to interspecific competition that influences observed parasite burdens. Moreover, seasonal fluctuations significantly impact infection dynamics across different geographical regions. Notably, fecal egg counts do not always accurately reflect the true worm burden due to variations in host immunity and prepatent infections. Conversely, assessing worm loads in grazing ruminants facilitates the detection of hypobiotic larvae-a critical survival strategy employed by *H. contortus* to endure adverse climatic conditions (Carvalho *et al.,* 2023).

Influence of climatic conditions on *H. contortus* infections

The epidemiology of *H. contortus* is profoundly influenced by environmental variables, particularly temperature and humidity (Santos *et al.,* 2012). Climatic conditions dictate the parasite's survival, transmission and seasonality across different ecological zones:

Tropical and subtropical regions (*e.g.*, Africa, Southeast Asia, northern Australia, southern U.S.)

High humidity facilitates continuous parasite transmission, whereas dry seasons induce hypobiosis, ensuring larval survival until favorable conditions return (Bautista-Garfias *et al.,* 2022).

Warm temperate regions (*e.g.*, South America, southern Africa, eastern Australia)

Seasonal rainfall during summer promotes larval development, while cold winters suppress parasite activity.

Mediterranean regions (*e.g.*, southwestern South Africa, Mediterranean basin, parts of Australia)

High temperatures and arid summers inhibit larval development, leading to infection peaks in autumn and spring.

Cool and cold temperate regions (*e.g.*, Northern Europe, Canada, New Zealand)

Severe winter conditions prevent larval development, but hypobiosis enables parasite persistence until more favorable climatic conditions arise.

Arid regions (*e.g.*, Sub-Saharan Africa, continental Australia, Middle East)

Extreme dryness restricts larval survival; However, intermittent rainfall can temporarily enhance transmission dynamics (Sutherland and Scott, 2010).

A comprehensive understanding of these regional patterns is instrumental in devising effective parasite management strategies. By integrating climatic parameters into targeted control programs, veterinarians and livestock producers can optimize anthelmintic treatment schedules, implement pasture rotation systems and enhance overall herd health management practices.

Anthelmintic resistance: A growing concern

Anthelmintic resistance is a phenomenon where parasites develop the ability to withstand drug doses that were previously effective. In the case of gastrointestinal nematodes such as *H. contortus*, this resistance leads to a decline in the efficacy of widely used anthelmintics. The World Association for the Advancement of Veterinary Parasitology (WAAVP) defines resistance based on the fecal egg count reduction test (FECRT), with resistance confirmed when post-treatment egg count reduction is below 95% and the lower 95% confidence limit falls below 90% (Coles *et al.,* 2006).

Over time, *H. contortus* has developed resistance to all major classes of anthelmintics, including benzimidazoles, imidazothiazoles and macrocyclic lactones (Fissiha and Kinde, 2021). Resistance typically emerges within a decade of a drug's introduction, though certain anthelmintics retain partial efficacy due to variations in resistance mechanisms among drug classes. Combination therapy, utilizing drugs from different classes, can temporarily mitigate resistance; however, reports indicate that resistance to such combinations is also emerging.

Benzimidazole resistance

Benzimidazoles act by binding to *β-tubulin*, a structural protein critical for parasite survival. Resistance arises due to mutations in the *β-tubulin* gene, with a key mutation substituting tyrosine (Tyr) with phenylalanine (Phe) at codon 200, reducing drug binding efficiency. Additional mutations at codons 167 and 198 further contribute to resistance (Kwa *et al.,* 1994). While resistant parasite populations frequently exhibit these mutations, no single individual carries all three simultaneously, suggesting diverse evolutionary pathways for resistance development. The persistence of resistant alleles in field populations highlights the role of repeated drug exposure in selecting for resistant strains. In India, benzimidazole resistance exceeds 70%, with F200Y mutations highly prevalent. In Brazil, over 90% of goat farms report resistance to all major drug classes. Australia shows 80-100% resistance to benzimidazoles, levamisole and macrocyclic lactones in sheep. In South Africa, resistance to benzimidazole and levamisole is reported in >75% of farms. In the USA, 61% of small ruminant farms show multidrug resistance. New Zealand and the UK report resistance on 60-80% of farms (Kaplan, 2020). Parmar *et al.* (2020) reported that closantel, given at 10 mg/kg, showed over 91% efficacy against benzimidazole-resistant *Haemonchus contortus* in naturally infected sheep. This highlights closantel as a promising alternative for targeted selective treatment to help reduce pasture contamination and complement benzimidazole use.

Imidazothiazole and macrocyclic lactone resistance

Imidazothiazoles, such as levamisole, act on nicotinic acetylcholine receptors, inducing neuromuscular paralysis in parasites. Resistance in *H. contortus* is linked to genetic mutations in *Hco-unc-63* and *Hco-acr-8*, which alter receptor conformation and reduce drug binding efficiency (Harder, 2016). Resistance in this class is polygenic, complicating management efforts due to multiple contributing genes.

Macrocyclic lactones, including ivermectin, target glutamate-gated chloride channels, disrupting neuromuscular function and leading to paralysis (Greenberg, 2014). Resistance mechanisms include altered expression of P-glycoproteins, which function as drug efflux pumps, reducing intracellular drug concentrations. Additionally, mutations in chloride channel genes diminish drug binding, further decreasing efficacy. Given the complexity of these resistance mechanisms, continuous monitoring through molecular diagnostics is essential for early detection and resistance management in livestock populations.

Strategies to mitigate anthelmintic resistance

To counteract anthelmintic resistance, sustainable parasite control approaches must be implemented. Targeted selective treatment (TST), which involves treating only animals with high infection burdens rather than mass administration, helps slow resistance development. Other strategies include rotational use of different drug classes, improved pasture management and genetic selection for parasite-resistant livestock. Routine surveillance using molecular diagnostic tools enables early detection of resistance, allowing for timely intervention. By integrating these approaches, the longevity of anthelmintic efficacy can be preserved, ensuring effective parasite control in livestock systems.

Advanced diagnostic approaches for haemonchosis

Clinical assessment

Haemonchosis primarily manifests as anemia due to the blood-feeding activity of *H. contortus*. The larval stage (L4) initiates blood consumption and adult worms continue feeding in the abomasum, leading to clinical anemia within 10-12 days post-infection. Each adult parasite can extract approximately 30-50 µL of blood daily, causing significant blood loss in heavily infected animals (Besier *et al.,* 2016). The severity of the disease depends on parasite burden, host immunity and hematopoietic response.

Haemonchosis is classified into three distinct forms:

Hyperacute haemonchosis

Characterized by severe anemia due to a massive parasite load (~30,000 worms), leading to rapid death. Survivors exhibit profound mucosal pallor, weakness and edema.

Acute haemonchosis

Symptoms include progressive anemia, weight loss, submandibular edema and hypoproteinemia. If untreated, iron depletion and suppressed hematopoiesis exacerbate anemia, impacting productivity.

Chronic (long-standing) haemonchosis

Marked by gradual weight loss, reduced efficiency and immunosuppression. It often results from prolonged exposure to smaller worm burdens or anthelmintic resistance (Flay *et al.,* 2022).

Despite its utility, clinical assessment alone is insufficient for definitive diagnosis, as symptoms resemble other parasitic or nutritional disorders.

Post-mortem examination

Necropsy findings provide definitive evidence of haemonchosis, particularly in fatal cases:

Hyperacute cases

Large numbers of adult *Haemonchus* worms in the abomasum, with petechial hemorrhages on the gastric mucosa.

Acute cases

Findings include pallor of carcass tissues, fluid accumulation in body cavities (ascites), submandibular edema and unclotted blood. The abomasal mucosa exhibits edema and hemorrhagic lesions with attached parasites.

Chronic cases

Often inconclusive due to lower worm burdens. Diagnosis relies on clinical history, reduced productivity and occasional microscopic worm identification.

The presence of *Haemonchus* is confirmed by its characteristic appearance: a spiral-striped barber's pole pattern in females and red-colored males (Crilly *et al.,* 2020). However, post-mortem diagnosis is retrospective and not useful for timely intervention.

Parasitological methods

Parasitological techniques confirm infection through fecal sample analysis:

Qualitative tests

Techniques like flotation (*e.g.*, Teleman method) detect *Haemonchus* eggs in feces.

Quantitative tests

The McMaster method estimates fecal egg counts (FEC) to assess parasite burden.

Egg morphology

Haemonchus eggs are elliptical with a thin shell, requiring additional methods for differentiation from other strongylid nematodes (Rinaldi *et al.,* 2022).

While fecal examination is practical, it has limitations. FEC does not always correlate with worm burden due to variable egg shedding and host immune responses. Mixed infections can further complicate interpretation.

Hematological and biochemical markers: Indirect indicators of infection

Blood tests provide supportive diagnostic evidence:

Packed cell volume (PCV)

Decline in PCV indicates anemia due to *H. contortus* (Flay *et al.,* 2022).

Serum protein levels

Hypoproteinemia, particularly hypoalbuminemia, is common due to blood loss.

Erythrocyte indices

Changes in red blood cell count and hemoglobin levels further support diagnosis.

Although these parameters suggest infection, they are non-specific and can be influenced by other diseases, nutritional deficiencies, or physiological conditions.

Molecular and immunological diagnostics

Advanced diagnostic techniques have significantly enhanced the precision of haemonchosis detection, facilitating early and accurate identification of *H. contortus* infections.

Polymerase chain reaction (PCR)

PCR enables the amplification and detection of Haemonchus-specific DNA from fecal or tissue samples, providing high sensitivity and specificity. This technique allows differentiation from other strongylid nematodes, making it a reliable tool for molecular diagnosis (Amarante *et al.,* 2017).

Loop-mediated isothermal amplification (LAMP)

LAMP is an alternative molecular diagnostic approach that operates under isothermal conditions, requiring minimal laboratory equipment. It provides rapid, field-applicable results, making it particularly useful in resource-limited settings (Melville *et al.,* 2014).

Enzyme-linked immunosorbent assay (ELISA)

ELISA detects parasite-derived antigens or host antibodies against Haemonchus, allowing for early-stage diagnosis before clinical signs manifest. This serological approach is advantageous for epidemiological surveillance and herd health monitoring (Li *et al.,* 2007). Das *et al.* (2018) evaluated the efficacy of plate and paper ELISA using homologous antigens for detecting *Haemonchus contortus* infections in small ruminants, demonstrating the potential of these immunodiagnostic tools in identifying natural infections.

Despite their high accuracy, molecular and immunological methods are often associated with elevated costs and the necessity for specialized equipment, limiting their widespread application in field conditions.

The FAMACHA system

The FAMACHA (Faffa malan chart) system is a practical, field-based method for estimating anemia severity by assessing conjunctival mucous membrane coloration. This technique is particularly effective for targeted selective treatment (TST) strategies in endemic regions (Van Wyk and Bath, 2002)..

The system utilizes a five-point scale (1–5), where 1 corresponds to a normal red conjunctiva and 5 indicates severe anemia, suggesting a high probability of Haemonchus infection.

It is most effective in regions where *H. contortus* predominates, as the parasite's blood-feeding activity directly correlates with anemia.

However, limitations arise in areas with mixed infections, particularly where other gastrointestinal nematodes, such as *Teladorsagia circumcincta*, do not induce anemia, potentially leading to diagnostic misclassification.

While FAMACHA is valuable for guiding selective deworming practices and reducing anthelmintic resistance, it does not confirm haemonchosis definitively. Hence, it should be employed in conjunction with complementary diagnostic techniques.

Integrated diagnostic approach for haemonchosis

A comprehensive diagnostic strategy for haemonchosis necessitates a multifaceted approach, integrating clinical evaluation, parasitological screening, hematological analysis and molecular assays. While post-mortem findings provide definitive evidence, fecal egg count (FEC) remains a valuable screening tool, albeit with limitations in estimating true parasite burden. Molecular diagnostics offer the highest specificity, enabling precise parasite identification (Prashanth *et al.,* 2020). Additionally, the FAMACHA system aids in selective treatment strategies, mitigating anthelmintic resistance and promoting sustainable parasite control.

By tailoring diagnostic protocols to regional epidemiological patterns and resource availability, livestock health and productivity can be effectively safeguarded, ensuring long-term sustainability in parasite management.

Future strategies for controlling haemonchosis

Pharmaceutical control: Targeted and selective approaches

Several classes of anthelmintics have demonstrated efficacy against *H. contortus*, including benzimidazoles (*e.g.*, albendazole), imidazothiazoles (*e.g.*, levamisole), macrocyclic lactones (*e.g.*, ivermectin), salicylanilides (*e.g.*, closantel), amino-acetonitrile derivatives (*e.g.*, monepantel) and spiroindoles (*e.g.*, derquantel). These drugs can be administered individually or in combination to enhance therapeutic efficacy.

However, the widespread emergence of anthelmintic resistance has necessitated the adoption of alternative control strategies, such as targeted treatment (TT) and targeted selective treatment (TST), which aim to optimize drug use while maintaining a population of untreated worms (*in refugia*), thereby preserving anthelmintic efficacy (Singh and Swarnkar, 2008).

Targeted treatment (TT)

Strategic administration of anthelmintics to all animals at predetermined intervals, ensuring that a portion of the parasite population remains susceptible to treatment.

Targeted selective treatment (TST)

Selective treatment of only those animals exhibiting clinical signs of infection, thereby reducing overall drug exposure and mitigating resistance development.

Epidemiological studies indicate that *Haemonchus* infections exhibit an aggregated distribution, with approximately 20-30% of the flock harboring the majority of the parasite burden (Agrawal *et al.,* 2024). By identifying and treating only high-burden individuals, TST strategies effectively minimize anthelmintic resistance, reduce treatment costs and decrease drug residues in livestock products. However, careful monitoring is essential, as untreated individuals may develop severe infections under high parasitic loads.

Non-chemical control methods: Sustainable and natural strategies

Grazing management

Rotational grazing, wherein livestock are systematically moved between pastures, disrupts the *H. contortus* life cycle by minimizing exposure to infective larvae. This strategy has demonstrated efficacy across various agro-climatic regions but necessitates careful planning based on local climate conditions and pasture availability.

Nutritional management

Optimal nutrition plays a critical role in enhancing host immunity against parasitic infections. Diets rich in high-quality protein have been shown to improve resistance to *Haemonchus* infections, whereas protein-deficient diets increase host susceptibility. Studies indicate that sheep maintained on low-protein diets exhibit higher worm burdens, underscoring the importance of dietary management in parasite control (Khan *et al.,* 2017).

Plant-based anthelmintics

Certain plants contain bioactive compounds such as condensed tannins and polyphenols, which possess anthelmintic properties. These compounds exert their effects either by directly impairing parasite development or by modulating host immune responses. While plant-based anthelmintics offer a natural alternative to synthetic dewormers, excessive tannin intake can negatively impact nutrient absorption, necessitating careful dietary formulation (Olanrewaju *et al.,* 2023). Mares *et al.* (2023) evaluated the anthelmintic activity of methanolic extracts from *Croton tiglium* seeds against *Haemonchus contortus* and observed significant reduction in adult worm motility, indicating the plant's potential as a natural alternative for parasite control.

Biological control: Nematophagous fungi

Nematophagous fungi, such as *Duddingtonia flagrans*, produce specialized spores that actively trap and degrade nematode larvae within the gastrointestinal tract. These spores remain *via*ble as they pass through the host digestive system and subsequently reduce pasture contamination by targeting free-living parasite stages in feces, thereby lowering reinfection rates (Delmilho and da Costa, 2023).

Genetic resistance and selective breeding

Certain sheep breeds, including Morada Nova, Red Maasai and Barbados Black Belly, exhibit natural resistance to *Haemonchus* infections due to their superior immune response mechanisms. Selective breeding programs that incorporate resistant individuals can significantly reduce parasite burdens and decrease reliance on anthelmintic treatments. Advances in genomic selection and molecular markers further facilitate the identification of genetically resilient animals, offering a sustainable approach to helminth control (Shrivastava *et al.,* 2022).

Vaccination: A promising new tool

Recent advancements in immunoprophylaxis have led to the development of vaccines targeting *H. contortus*. The Barbervax® vaccine, formulated at the Moredun Research Institute, contains purified protein antigens derived from the parasite's digestive system. Experimental trials have demonstrated that repeated vaccinations at three-week intervals confer significant protection, particularly in lambs. However, efficacy in ewes subjected to high infection pressures has shown variability. Despite these limitations, Barbervax® is now commercially available in Australia, representing a novel and complementary strategy for parasite control (Adduci *et al.,* 2022).

The sustainable management of *Haemonchus* infections necessitates an integrated approach that combines strategic anthelmintic use with non-chemical interventions, including rotational grazing, nutritional optimization, biological control, selective breeding and vaccination. While non-chemical methods alone may not entirely replace conventional deworming strategies, their integration enhances sustainability, mitigates drug resistance and ensures effective long-term parasite control in livestock production systems.

CONCLUSION

Haemonchosis remains a formidable challenge in livestock production due to its complex epidemiology, climate-driven transmission and increasing anthelmintic resistance. Effective management requires a multifaceted approach, integrating climate-based control strategies, targeted selective treatment, molecular diagnostics and sustainable parasite management practices. Future research should focus on novel control strategies, including vaccines and alternative therapeutics, to mitigate the economic and health burdens of haemonchosis on global livestock production. By adopting region-specific, evidence-based interventions, stakeholders can enhance parasite control, promote sustainable livestock farming and safeguard animal health in the face of evolving parasitic threats.

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Informed consent

Not applicable. This is a review article and does not involve any original research on animals or humans.

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