Continental Veterinary Journal
ISSN: 3079-0212 (ONLINE)
www.cvetj.com; editor@cvetj.com

REVIEW ARTICLE
DOI: 10.71081/cvj/2026.084

Anthelmintic Resistance in Equine Gastrointestinal Nematodes: Challenges and Emerging Alternatives

Umm Ul Khair[1], Muhammad Abdullah Qureshi[2], Muqadas[3], Muhammad Usama Javed[1] and Aftab Shaukat[4,5*]

[1]Faculty of veterinary Science, University of Agriculture, Faisalabad, Pakistan; [2]Department of Parasitology, Faculty of veterinary Science, University of Agriculture, Faisalabad, Pakistan; [3]Department of Life Sciences, Kunming university of science and technology, China; [4]Animal Science Division, Department of Modern Agriculture, College of Life and Environmental Sciences, Hunan University of Arts and Science, Changde, Hunan, 415000, China; [5]College of Veterinary Medicine, South China Agricultural University, Guangzhou, China
*Correspondence: dr.aftabshaukat@huas.edu.cn

ARTICLE INFO

ARTICLE HISTORY: CVJ-26-623

Received:	18 May 2026
Revised:	03 July 2026
Accepted:	05 July 2026
Published online:	07 July 2026

Key words:
Anthelmintic resistance
Cyathostomins
Gastrointestinal nematodes
Parascaris.

ABSTRACT

Gastrointestinal nematodes are still one of the major limiting factors for the health, welfare and productivity of horses globally. Cyathostomins, *Parascaris* spp., and *Strongylus* species are the most significant parasites because they cause significant clinical and economic losses from damage to gastrointestinal integrity, poor nutrient utilization, poor growth performance, and reduced health status. Past control strategies were mainly based on the use of anthelmintics of broad-spectrum effectiveness at high frequency, leading to significant decreases in morbidity associated with parasites. But with heavy use, and often indiscriminate use, of dewormers the development and prevalence of anthelmintic resistance is rapidly gaining levels of importance as one of the most serious issues facing horse parasite control today. Multidrug resistance (MDR) through resistance to major classes of anthelmintics (benzimidazoles, tetrahydropyrimidines and macrocyclic lactones) is now reported globally and is affecting the nematode population in New Zealand. Resistance is on the rise and traditional methods of parasite control are becoming increasingly unsustainable, so integrated methods of managing parasites are needed. This paper critically reviews the epidemiology and biology of important GIT nematodes of equids, the mechanisms of development of resistance, world-wide trends of anthelmintic resistance and limitations of present diagnostic methods. Moreover, other novel paradigms such as targeted selective treatment, pasture management, nutraceuticals, bio-control agents, phytotherapeutics, vaccines, microbiome technologies and precision parasite management technologies are covered. The review highlights the importance of not only using pharmaceuticals as part of a parasite control programme, but also non-pharmacologic measures to ensure effective use of the drugs and enhance the long-term health of horses.

To Cite This Article: Khair UU, Qureshi MA, Muqadas, Javed MU and Shaukat A, 2026. Anthelmintic resistance in equine gastrointestinal nematodes: challenges and emerging alternatives. Continental Vet J, x(x): xxx http://dx.doi.org/10.71081/cvj/2026.084

INTRODUCTION

Although the field of veterinary medicine closely related to livestock health and production has made many new advances, parasitic diseases are still a major problem in horse health (Agrawal et al. 2024). Gastrointestinal nematodes are one of the most common types of parasites found in horses worldwide and can have a big effect on horse health, athleticism, reproductive ability and economic productivity (Ogbein et al. 2022). Pasture-based systems mean that horses are constantly infected with infective larval stages of parasites and are quickly infected by the parasites they meet (Sharpe and Kenny 2025). Traditionally, regular deworming practices revolutionized health care for horses, significantly lowering the incidence of clinical signs of parasitic infection and mortality (Turner 2024). In the past, the impact of routine deworming practices on management of equine health has been profound and has made a significant impact on the reduction of clinically visible signs of parasitic disease

and mortality (Rendle et al. 2024). But there has been extensive use of repeated mass treatment programs which have led to resistance developing to both classes of anthelmintic drugs (Harshita and Nonika 2024).
Anthelmintic resistance is the ability of a parasite to survive a dose of an anthelmintic which it was previously susceptible to (Marsh and Lakritz 2023). Frequent treatment and under-dosing, inappropriate drug rotation, and not considering the parasite ecology are important factors in resistance development (Ugoala 2023). Biological attributes of equine gastrointestinal nematodes that enable rapid adaptation are that they have broad genetic diversity, high reproductive potential and are environmentally persistent (Cunha et al. 2024). These properties enhance genotype selection for resistant types and impede the control over the long-term (Mapuranga et al. 2022).
With increasing worries about drugs becoming less effective, there's more attention now on focussed and evidence-based parasite control programmes (Shang et al. 2025). A thorough knowledge of parasite biology, host-parasite interactions, parasite resistance and alternative control options are essential for the sustainable management of parasites (Wells and Flynn 2022). This current review focuses on the most significant issues of gastrointestinal nematode anthelmintic resistance in horses and investigates new alternative drugs that could help maintain the effectiveness of current drugs and help achieve long-term control of these parasites.

Major equine gastrointestinal nematodes and their clinical importance

The gastrointestinal nematodes of horses are a group of species that have different life cycles, pathogenic characteristics and epidemiology (Khan et al. 2023). In these, cyathostomins are the most common and clinically significant group that occurs in horses all over the world (Lawson et al. 2023). There are over 50 species of cyathostomins collectively called "small strongyles (Halvarsson et al. 2024). They have a direct life cycle with ingested infective third stage larvae from contaminated pastures and then mucosal encystation in the large intestine (Kimeli et al. 2025). Encysted larval stages are a significant therapeutic problem, as the efficacy of many drugs is less against isolated stages (Marsh and Lakritz 2023).
The large strongyles (mainly *S. vulgaris*) are the most pathogenic of the equine parasites, because they migrate through the mesenteric arteries (Domshy et al. 2024). On migration, larvae cause vascular damage, thrombosis, ischemia and ultimately may cause death (thromboembolic colic) (Souto et al. 2025) (Figure 1). Presence of strategic deworming and this significantly lowered the prevalence in many areas, but due to decreased monitoring and treatment procedures, there are concerns re-emergence is a potential issue (Collyer et al. 2023). Foals and young horses are at the highest risk of being affected by *Parascaris* species (Boelow et al. 2023). They are very prolific and hardy in their environment, which contributes to their ability to spread (Hardy et al. 2025). In severe cases, intestinal blockage, stunted growth, respiratory symptoms due to larval migration and body condition problems occur (Shrestha et al. 2024). Increasing resistance of *Parascaris* to the macrocyclic lactones has raised significant concerns for the young horse industry (Martin et al. 2024).
Other nematodes of importance are *Oxyuris equi, Habronema spp., Trichostrongylus axei* and *Strongyloides westeri* (Amer et al. 2022). These parasites are less pathogenic but can be significant contributors to cumulative disease and are difficult to control in an integrated approach (Buchmann 2022). Given the diversity of equine nematode populations, there is a need for nematode-specific control strategies, considering the specific age of the host, their environment, and management (Playford and Besier 2025).

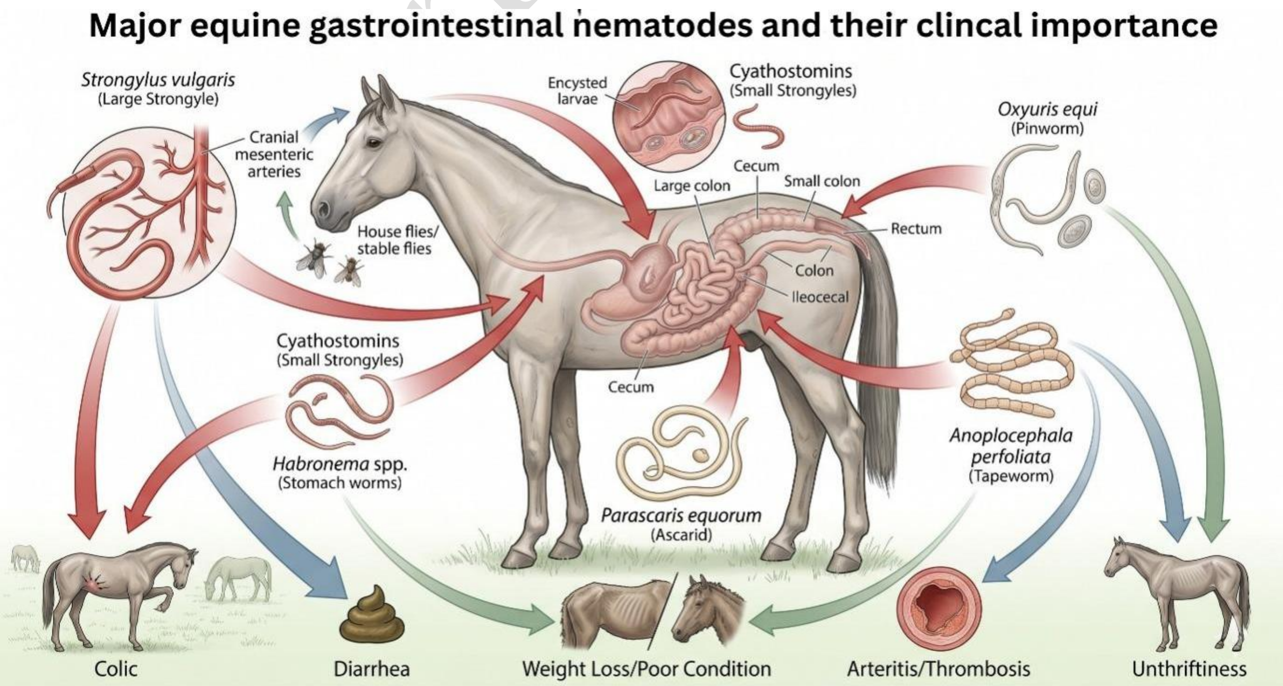

Fig. 1: Major equine gastrointestinal nematodes and their clinical importance.

Epidemiology and Transmission Dynamics

The epidemiology of equine gastrointestinal nematodes involves interactions between the biology of these parasites, host immunity, the environment and management systems (Wang et al. 2025). The effects of climatic factors on larval development and survival on pastures are strong (Cristaldo et al. 2026). The high temperatures and moderate humidity promote formation of infective stages, whereas extremes of temperature and humidity limit survival (Guarnieri et al. 2023). However, there are many that show a remarkable resilience and thus can survive in different climatic regions (Lüscher et al. 2022).

The main source of infection is from the contamination of pastures. If the grazing paddocks are over stocked, the horses are constantly re-exposed to infective larvae (Forbes and Ellis 2023). Fecal density is greater if overstocked and transmission is greater if there is more density of feces (Muñoz-Vargas et al. 2022). The mixed-age system of grazing adds to the infection dynamics with possible high parasite shedding by younger horses and reservoirs by older horses (Dowling et al. 2024).

The epidemiology is strongly related to the host immunity (Wolf et al. 2024). It is generally accepted that mature horses are partially immune to most nematode species and that their clinical disease severity and egg shedding is also decreased (Jürgenschellert et al. 2022). Foals and young horses are more resistant because their immune system is less developed (Bordin et al. 2022). The cause of the predominance of younger animals being affected by *Parascaris* infections and of the occurrence of cyathostomins in all ages is called age-related immunity (Buono et al. 2023).

Parasite transmission is heavily influenced by the management practices (Jack et al. 2022). The higher the likelihood of being exposed, the more often people move between facilities, the more communal grazing practices there are, and the less management of manure (Mwalugelo et al. 2024). Parasite epidemiology is also made more complex by the modern equine industries (racing, breeding and overseas transport); these all facilitate the spread of resistant populations of parasites throughout geographical areas (Sacarrão-Birrento et al. 2024).

Historical Evolution of Anthelmintic Use in Horses

Until modern equine anthelmintics were developed, the control of equine parasites was revolutionized (Cain and Nielsen 2022). The first generation of compounds, such as piperazine and organophosphates, were somewhat effective, but also had their narrow spectra and safety issues (Saad et al. 2025). The advent of the benzimidazoles was a significant improvement as they showed activity against multiple organisms and safety margins were greater (Hernández-López et al. 2022). The use of fenbendazole and its analogs saw a tremendous drop in parasite levels in the second part of the 20th century (Cray and Altman 2022).

Later, tetrahydro-pyrimidines and macrocyclic lactones were introduced and this led to further improvement of therapeutic possibilities (Shah and Kachhadiya 2025). Pyrantel compounds were effective against adult strongyles and ascarids; and ivermectin and moxidectin were excellent against several stages of the parasites (Malik et al. 2022). These drugs were very convenient, wide in range and assumed to be reliable, so they were routinely administered and sometimes without diagnosis (Huelsmeyer et al. 2023).

The old deworming method used intervals to determine when to deworm regardless of infection status (every 6-8 weeks) (Gasparinho et al. 2022). These practices worked in the short term but had unforeseen side effects of selecting resistant parasites (Nielsen et al. 2023). Slowly the focus on resistance development changed and started to focus on more specific methods - the use of diagnostic monitoring and the conservation of refugia (Keppel et al. 2024).

Mechanisms Underlying Anthelmintic Resistance

The process of anthelmintic resistance occurs because of evolutionary selection mechanisms, which involve the survival of resistant members of an anthelmintic-treated population resulting in greater representation of them in future generations (Tenorio 2025). Parasites can build up mutations that reduce their susceptibility to a drug when they are being highly selected (Bharadava et al. 2024). The mutations of the beta tubulin genes are the main cause of benzimidazole resistance (Venkatesan et al. 2023). These mutations change the drug binding sites which lead to less binding with microtubules and hence less interference with cellular functions (Friedman 2022). Resistance phenotypes have been found to consistently be associated with single nucleotide polymorphisms at certain codons in several nematode species (da Silva Medeiros et al. 2022).

Several more complicated mechanisms have been linked with macrocyclic lactone resistance (Amdan et al. 2024). Multiple changes to glutamate-gated chloride channels, alterations to neuronal signaling pathway, increased drug efflux mechanisms and changes to pharmacokinetic interactions may all play a role in decreasing susceptibility (Lespine et al. 2024). Over-expression of transporter proteins that can remove drugs from the tissues of a parasite is one important resistance mechanism (Dimunová et al. 2022). The pyrantel resistance is related to changes in nicotinic acetylcholine receptor (Gallo et al. 2023). Structural changes desensitise the receptors, and prevent drug induced neuromuscular paralysis (Bickler et al. 2023). Some parasite populations show polygenicity of inheritance which makes the prediction and monitoring of progression of parasite resistance more difficult (Coffeng et al. 2024).

Development of resistance to equine nematodes is facilitated by their biology (Raza et al. 2023). Small populations lead to low genetic variation and quick spread of beneficial traits are possible with short generation times (Salgotra and Chauhan 2023). Regular treatments kill susceptible individuals and leave resistant individuals with more reproductive success (Pienta et al. 2025). When the pressure for drugs is intense and continuous, the development of resistance is a natural result of evolution, making it a part of their nature (Muteeb et al. 2023).

Global Status of Anthelmintic Resistance in Equine Nematodes

The development of anthelmintic resistance has become a world-wide issue and a problem in virtually all-important equine production systems (Alara and Alara 2024). The level of cyathostomin resistance to benzimidazole drugs is now believed to be widespread and several studies have shown a dramatic decrease in the effectiveness of the drugs on several continents (Venkatesan et al. 2023). High prevalence of resistance is caused by the intensive use of these products and the lack of rotation over the past several decades (Endale et al. 2023). Evolution of Pyrantel resistance in cyathostomin has also been increasing (Alm et al. 2023). Although some efficacy is still variable in different areas, there is growing evidence of progressive selection pressure (fecal egg count reduction) (Morgan et al. 2022). Co-occurring benzimidazole and pyrantel resistance (MDR) is becoming more prevalent (Schlosser-Brandenburg et al. 2023).

Macrocyclic lactones were remarkably long-lasting but there have been indications of resistance in the past few years, especially in populations of *Parascaris* (Ewence and Whitlock 2024). Efficacy of ivermectin against *Parascaris* spp. has been significantly decreased now and has been well documented (Le et al. 2024). In general, moxidectin is more effective against some of the stages of a parasite but concerns about decreasing sensitivity have risen (Mwacalimba et al. 2024). Variations in climate, management, availability of treatment and drugs, and treatment frequency contribute to regional variations in patterns of resistance (Li et al. 2025b). However, the overall pattern suggests an overall decline in effectiveness in each of the big therapeutic groups (Albarracín et al. 2024). This is due to the increasing occurrence of resistant populations over a wider geographic area, which underlines urgent coordinated surveillance and sustainable control strategies (Struelens et al. 2024).

Risk Factors Contributing to Resistance Development

Resistance can be expedited by more than one management factor (McIntyre et al. 2023). The frequent blanket treatment programs are one of the most important drivers as they are the programs that exert the greatest selection pressure with the lowest numbers of susceptible populations (Ng'etich et al. 2024). This is further accentuated by treatment schedules which are set into motion by calendar dates rather than epidemiological evidence (Meyer et al. 2022). Historically, treatment intervals have been reliant on calendar dates rather than epidemiological evidence resulting in an accentuation of this (Kimbrough et al. 2024). Underdosing is another factor that must not be overlooked (Hunter and Blobner 2024). Errors in the estimation of weight often mean that not enough exposure is delivered and some individuals are partially resistant to death (Reeves et al. 2024). Risks of underdosing are further increased when administration techniques are not used correctly or when errors occur in the calibration of equipment (Mulac et al. 2022).

The higher the densities, the more intense the transmissions, and the more of the cycles are repeated (Xu et al. 2022). Pasture systems that are continuously grazed do not allow for a rotation and therefore have high contamination levels (Wróbel et al. 2023). Short quarantine is conducive to the spread of resistant parasites via movement of animals (Wei et al. 2023). Resistance development is greatly hastened if refugia are not used (Rendle et al. 2024). Resistant gene can persist in the total population by means of refugia, in which the organism is not treated (Metzger et al. 2022). If refugia are eliminated via universal treatment programs, there is no more genetic dilution effect, and the problem of resisting genotype dominance is eliminated (Brown et al. 2022).

Poor monitoring practices are also important etale factors (George et al. 2022). Lacking a treatment that can be tested to assess its effectiveness, the use of a routine treatment would make it difficult to diagnose the onset of treatment resistance (Howes et al. 2022). There are also some limitations in diagnosing and the use of veterinary services is inconsistent, which impede implementation of evidence-based programs (Block 2024).

Diagnostic Approaches for Detection of Resistance

Good diagnosis is essential to successful parasite control. Fecal egg count test is a useful technique in determining the level of the parasite and the identification of high shedders (Nielsen 2022). The use of quantitative techniques like the McMaster methods enable routine monitoring and treatment decision making to be carried out (Elghryani et al. 2023a). Fecal egg count reduction testing is still the most used test for assessing the efficacy of drugs (Morgan et al. 2022). This is done by comparing egg counts before and after treatment to determine egg reduction percentages (Denwood et al. 2023). There is relatively easy access to interpretation, but it requires the establishment of standardized protocols and adequate sample size (Ahmed 2024).

Techniques for the larval culture are useful for species identification for morphologically similar egg species (Lira et al. 2023). Dominant populations of parasites can be identified and intervention strategies aimed at these parasites can be implemented (Gagne et al. 2022). But there are some factors, such as the requirement for labor and technicalities, that restrict the regular use (Guanglei et al. 2026). Diagnosis of resistance using molecular methods may be useful (Gerace et al. 2022). Polymerase chain reaction assays of mutations associated with resistance are more sensitive and earlier detect mutations than phenotypic methods (Huygens et al. 2023). The growing knowledge about the population genetics and evolution of pathogens with advances in NGS technology improve knowledge of parasite resistance evolution (Al-Malki 2025).

New technologies like environmental DNA surveillance, machine learning algorithms and automated image analysis could enhance monitoring capabilities in the future (Adebayo 2025). However, these need to be reduced, standardized and improved to be more easily available to help achieve widespread adoption (Rajaeifar et al. 2022).

Clinical and Economic Consequences of Resistance

Health and economic losses are caused using anthelmintics (Strydom et al. 2023). High blood parasite densities cause digestive inefficiency, hinder body condition, affect the performance of athletes and make them more vulnerable to secondary infections (Ullah et al. 2025). Clinical illness, such as diarrhea, weight loss, recurrent colic and poor growth reduce welfare and productivity (Al-Beltagi et al. 2025). Costs are not limited to that of treatment (Gitlin et al. 2022). The effects of higher veterinary treatment costs, diagnostic costs, decreased production and reproductive capacity result in significant economic losses (Kappes et al. 2023). Moreover, resistance requires more complicated management systems and more labor and monitoring to manage (Habib et al. 2023).

Owners and vets can easily be affected psychologically as this should not be ignored (Steffey et al. 2023). This decreased confidence in therapeutic interventions poses a challenge to clinical decision making and can lead to the use of inappropriate therapeutic practices (Kothinti 2024). Educational programs are hence needed along with technical innovations to facilitate the Sustainable Solutions (Lv et al. 2022). This method of selective treatment is called targeted selective treatment and is being used sustainably (Periyasamy 2024). Treatment for parasite problems selectively has become a mainstay of parasite control in a sustainable program (Obeidat and Al-Najjar 2025). This approach takes the case-by-case basis when it comes to treatment as all horses are not treated alike; treatment is targeted to the individual(s) who are making the most significant contribution to environmental contamination (Hardefeldt et al. 2025). Egg shedding is consistently found to be small numbers of horses shedding a large percentage of the eggs (Elghryani et al. 2023b).

The regular testing of the feces usually accompanied by some predetermination of treatment thresholds (Overmars et al. 2022). Low egg counts horses are not treated, helping to maintain refugia populations and minimize selection pressure (Bechert et al. 2022). Selective treatment also reduces drug consumption and reduces the contamination to the environment (Murray et al. 2024). Two key components to being successful are owner education and maintenance and monitoring procedures (Chaurey et al. 2023). Because parasite burdens vary with time, it is necessary to repeat parasite evaluations because of individual differences in shedding (Ferreira-Sá et al. 2024). If integrated into broader management practices, this will further boost their long-term effectiveness (Alkhodary 2023).

Pasture and Grazing Management Strategies

Management of the pasture is one of the best and easiest non-drug management strategies (Rendle et al. 2024). Routine manure collection will significantly diminish environmental pollution and will help to break cycles of transmission (Jimenez et al. 2023). High frequency collections lead to more reduction in availability of larvae (Sardi et al. 2023). In rotational grazing reducing cumulative exposure is achieved because there is a natural reduction in infective larvae (Sands et al. 2024). Further, because some of the parasites common to an equine host are host specific, it is possible that contamination may be further reduced using mixed species grazing systems (Fleurance et al. 2022). Health and outcomes are better and the intensity of the contamination of the pasture lower when appropriate stocking densities are used (Villaverde et al. 2025).

The use of pastures for harrowing (WCH) is still a controversial practice as it is greatly affected by environmental conditions (Verdon 2023). Harrowing can spread infective larvae under optimum climatic conditions and may not have a negative effect on their numbers (Osterman-Lind et al. 2022). Therefore, recommendations that are specific for the climate are needed (Ranius et al. 2023). Another important management aspect is the quarantine measures that need to be taken with newly introduced horses (Health et al. 2022). Diagnostic testing and targeted treatment, together with isolation, minimize the chances of introduction of resistant population of parasites into established herds (Antonopoulos et al. 2024).

Nutraceuticals and Plant-Derived Alternatives

An increasing problem with drug resistance has led to an enhanced interest in phyto-therapeutics and nutraceutical methods (Ashraf et al. 2023). Many of the compounds isolated from plants have antiparasitic effects, for example by interfering with the metabolism of parasites, disrupting the hatching of eggs, interfering with neuromuscular signaling and modulating host immune system (Shang et al. 2025). The condensed tannins have been a topic of great discussion as they could have a negative effect on larval development and reduce fecals (Besharati et al. 2022). Plants with high levels of tannins seem to have the ability to influence parasite establishment and fecundity and promote gastrointestinal health (Rodríguez-Hernández et al. 2023).

Saponins have membrane disruptive effects which could lead to a decrease in the survival of the parasites (Kholif 2023). On the other hand, flavonoids also have antioxidant and anti-inflammatory properties that could have beneficial effects on the host resistance and may also have direct antiparasitic properties (Hamad 2023). Plants with aromatic properties are important sources of essential oils with the potential of demonstrating good in vitro activity against various stages of nematodes (Sarri et al. 2024). But compositional differences, bioavailability and safety concerns cause issues when moving to the clinic (Stielow et al. 2023).

Although promising compounds are available, there are many products available that are not clinically substantiated and have varying formulations (Thapa and Kim 2023). Optimization of the dose, safety evaluation and controlled field trials should be the focus of future studies (Fourie Zirkelbach et al. 2022).

Biological Control Approaches

Biological control provides environmentally friendly opportunities in the quest for parasite control (Lahlali et al. 2022). One of the most thoroughly studied ones is nematophagous fungi. Species that can collect and kill free living larvae will decrease the level of contamination and transmission (Berhanu et al. 2024). Fungal spores added to the feed survive and penetrate the intestinal tract to initiate activity in the feces which prevents activity on the larvae in development before spreading on the hay (Robi et al. 2023). Field applications of repeated use of the programs have shown reductions in infective larvae (Macedo et al. 2026). Other biological strategies involve manipulating dung beetle communities, and microbial antagonists which can interfere with parasite development (Boughton et al. 2024). Biological control is one of the aspects of integrated management that has potential but will require effort to implement, if there are no problems (Bueno et al. 2023).

Vaccines and Immunological Strategies

Vaccination is an extremely attractive long-term strategy as it may lead to a decrease in the need for multiple drug doses (Hausdorff et al. 2024). Despite this, the development of effective vaccines for nematodes is quite difficult because of the complexity of the antigen and the complex immune avoidance mechanisms in nematodes (Stear et al. 2023). The development of molecular biology and immunology has enhanced the identification of the current or potential larval antigens that are involved in larval invasion, feeding and/or reproduction (Jeria et al. 2023). It is also possible to increase efficacy with the use of multi-antigen vaccine targeting different life stages (Rajneesh et al. 2023). The other promising one is host-directed immunomodulation (Wallis et al. 2023). There is potential for complementing traditional control measures with nutritional interventions and/or microbial manipulation that can be shown to boost protective immunity (Collins and Belkaid 2022). Immunological research is still a key area of research that needs to be continued for future breakthroughs (Alsayb 2025).

Microbiome-Based Interventions

The microbial communities of the gut are vital to the host's immune system, nutrient usage and resistance to disease (Rastogi et al. 2022). Interactions within the parasite populations and with the microbial community can affect infection outcome, with emerging evidence for the effect of such interactions (Venter et al. 2022). Modulation of the microbial composition and/or suppression of the establishment of parasites and modification of immune responses, may be indirect, due to the presence of probiotics and prebiotics (Sardinha-Silva et al. 2022). Another possible strategy is to manipulate microbial metabolites, which also have potential to impact parasite fitness (Haider et al. 2025). Microbiome-based interventions are still a relatively new field, with new discoveries from the ever-evolving sequencing technology and systems biology studies on host-microbe-parasite interactions (Pallaval 2023).

Precision Parasite Management and Future Technologies

There are an emerging convergence of technological innovation and parasite surveillance and management (Parija and Poddar 2024). Digital monitoring systems with the integration of the different diagnoses from feces, environmental data and treatment histories aid in making individual decisions (Coman et al. 2024). AI algorithms could enhance the ability to predict risk of infection and/or optimal timing of interventions (Li et al. 2025a). However, there are other opportunities for precision management using remote sensing technologies that are able to assess the contamination of pastures and grazing behavior (Ogungbuyi et al. 2023). More advanced detection of disease could be achieved if behavioral changes, characteristic of parasitism, were detected using a sensor that was worn (Džermeikaitė et al. 2023). Technologies such as population sequencing and resistance marker surveillance offer opportunities for novel insights into parasite evolution via genomic approaches that are unparalleled (Vashisht et al. 2023). Incorporating such technologies into everyday practice can have a significant impact on the sustainability of practices (Yavuz et al. 2023).

Integrated Parasite Management Framework

There will be no one single remedy for anthelmintic resistance (Marsh and Lakritz 2023). Effective control will need parasite management which involves parasite diagnosis, selective treatment, pasture management, alternative treatments and surveillance (Höglund and Gustafsson 2023). Programs should focus on evidence-based treatment decisions, on the conservation of refugia and on monitoring of the efficacy continuously (Phillips et al. 2026). It is necessary, as ever, for veterinarians and researchers, as well as horse owners and industry stakeholders to work together (Douglas et al. 2022). Educational activities are therefore key as they are essential for implementation success, assuming that the latter is dependent on behaviour change (Jakučionytė-Skodienė and Liobikienė 2022). With better understanding of resistance principles responsible drug use and sustainability can be encouraged (Muteeb et al. 2023).

Future Perspectives

Precision medicine, ecological sustainability, and multidisciplinary integration are key areas into which future control strategies will focus. Molecular diagnostics developed in recent years could allow for fast point-of-care resistance detection. Knowledge of the genome of parasites and host immunity could speed up vaccine development. With climate change comes now an added layer of complexity, changing the dynamics of transmission and distribution. Depending on the changing epidemiological circumstances, adaptive management systems that can adapt to shifting conditions will become more important. To maintain surveillance and data sharing and for the standardization of resistance monitoring procedures, international collaboration is still key. Ultimately the balance of effective disease control and maintenance of therapeutic resources are essential to sustainable parasite management.

Conclusions

Equine gastrointestinal nematode resistance is a significant problem that impacts equine health, welfare and productivity worldwide. The above may indicate that resistance is a broad community affair and point to the shortcomings of conventional concepts of parasite control, which have been used for decades. The need for sustainable management is to shift from blanket deworming to integrated management that includes diagnostics, targeted and judicious deworming, pasture management and refugia. Several emerging alternatives, such as phyto-therapeutics, biological control agents, manipulation of the microbiome, vaccines, and precision technologies offer new prospects for minimizing reliance on conventional drugs. But for the success of such implementation, there must be strong scientific validity and effective involvement of stakeholders. Future parasite control programs should focus on developing evidence-based approaches that combine both chemical and non-pharmacological measures but that can be modified to respond to changes and new threats in the parasite resistance field. Preserving the effectiveness of anthelmintics and their long-term contribution to improving health in horses is still an attainable goal with the help of cross-disciplinary collaboration and sustainable management practices.

Funding
This work was supported by the National Natural Science Foundation of China (Grant No. W2433064).

Acknowledgement
None

Ethical Compliance
Not applicable

Data Access Statement
Research data supporting this publication are available from the NN repository located at www.NNN.org/download/.

Conflict of Interest declaration
The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

Author's contribution
MAQ, AS: Conceptualization, supervision, funding acquisition; UUK, M: Data collection and Writing-original draft preparation; MUJ: reviewing and editing of the manuscript. All authors have read and agreed to the published version of this manuscript.

Generative AI statement
All authors declare that no AI tool has been used to complete this article.

Publisher's Note
All claims stated in this article are exclusively those of the authors and do not necessarily represent those of their affiliated organizations or those of the publisher, the editors, and the reviewers. Any product that may be evaluated/assessed in this article or claimed by its manufacturer is not guaranteed or endorsed by the publisher/editors.

REFERENCES

Adebayo AS, 2025. Ai driven species recognition and digital systematics: Applying artificial intelligence for automated organism classification in ecological and environmental monitoring. International Journal of Research Publication and Reviews 6(2):31-49.

Agrawal V, Tiwari SP, Choudhary NS and Shrivastava N, 2024. Technological advances for sustainable helminth control in animal health amidst changing climate. Indian Journal of Animal Health 63(2):31-42.

Ahmed SK, 2024. How to choose a sampling technique and determine sample size for research: A simplified guide for researchers. Oral Oncology Reports 12:100662.

Al-Beltagi M, Saeed NK, Bediwy AS and Elbeltagi R, 2025. Breaking the cycle: Psychological and social dimensions of pediatric functional gastrointestinal disorders. World Journal of Clinical Pediatrics 14(2):103323.

Al-Malki ES, 2025. Synthetic biology and parasite genomics: Engineering parasite-resistant human microbiomes for sustainable disease prevention. Beni-Suef University Journal of Basic and Applied Sciences 14(1):16.

Alara JA and Alara OR, 2024. An overview of the global alarming increase of multiple drug resistant: A major challenge in clinical diagnosis. Infectious Disorders-Drug TargetsDisorders) 24(3):26-42.

Albarracín D, Fayaz-Farkhad B and Granados Samayoa JA, 2024. Determinants of behaviour and their efficacy as targets of behavioural change interventions. Nature Reviews Psychology 3(6):377-392.

Alkhodary D, 2023. Integrating sustainability into strategic management: A path towards long-term business success. International Journal of Professional Business Review: International Journal of Professional Business Review. 8(4):39.

Alm YH, Halvarsson P, Martin F, Osterman-Lind E, Törngren V and Tydén E, 2023. Demonstration of reduced efficacy against cyathostomins without change in species composition after pyrantel embonate treatment in swedish equine establishments. International Journal for Parasitology: Drugs and Drug Resistance 23:78-86.

Alsayb MA, 2025. Innovations in immunotherapy for autoimmune diseases: Recent breakthroughs and future directions. Frontiers in Immunology 16:1647066.

Amdan NAN, Shahrulzamri NA, Hashim R and Jamil NM, 2024. Understanding the evolution of macrolides resistance: A mini review. Journal of Global Antimicrobial Resistance 38:368-375.

Amer MM, Desouky AY, Helmy NM, Abdou AM and Sorour SS, 2022. Identifying 3rd larval stages of common strongylid and non-strongylid nematodes (class: Nematoda) infecting egyptian equines based on morphometric analysis. BMC Veterinary Research 18(1):432.

Antonopoulos A, Gilleard JS and Charlier J, 2024. Next-generation sequencing technologies for helminth diagnostics and surveillance in ruminants: Shifting diagnostic barriers. Trends in parasitology 40(6):511-526.

Ashraf MV, Pant S, Khan MAH, Shah AA, Siddiqui S, Jeridi M, Alhamdi HWS and Ahmad S, 2023. Phytochemicals as antimicrobials: Prospecting himalayan medicinal plants as source of alternate medicine to combat antimicrobial resistance. Pharmaceuticals 16(6):881.

Bechert US, Turner JW, Baker DL, Eckery DC, Bruemmer JE, Lyman CC, Prado TM, King SRB and Fraker MA, 2022. Fertility control options for management of free-roaming horse populations. Human-Wildlife Interactions 16(2):179-216.

Berhanu M, Gebeyaw DT, Kefale D and Kang Y, 2024. Overview of nematophagous fungi, isolation techniques, and their role in biological control of helminthic parasites: A literature review. Acta Entomology and Zoology 5(1):133-143.

Besharati M, Maggiolino A, Palangi V, Kaya A, Jabbar M, Eseceli H, De Palo P and Lorenzo JM, 2022. Tannin in ruminant nutrition. Molecules 27(23):8273.

Bharadava K, Upadhyay TK, Kaushal RS, Ahmad I, Alraey Y, Siddiqui S and Saeed M, 2024. Genomic insight of leishmania parasite: In-depth review of drug resistance mechanisms and genetic mutations. ACS omega 9(11):12500-12514.

Bickler PE, Abouyannis M, Bhalla A and Lewin MR, 2023. Neuromuscular weakness and paralysis produced by snakebite envenoming: Mechanisms and proposed standards for clinical assessment. Toxins 15(1):49.

Block G, 2024. Evidence-based veterinary medicine—potential, practice, and pitfalls. Journal of Veterinary Internal Medicine 38(6):3261-3271.

Boelow H, Krücken J and von Samson-Himmelstjerna G, 2023. Epidemiological study on factors influencing the occurrence of helminth eggs in horses in germany based on sent-in diagnostic samples. Parasitology research 122(3):749-767.

Bordin AI, Huber L, Sanz MG and Cohen ND, 2022. Rhodococcus equi foal pneumonia: Update on epidemiology, immunity, treatment and prevention. Equine Veterinary Journal 54(3):481-494.

Boughton CJ, Lancaster LT and Morgan ER, 2024. Biotic interactions in soil and dung shape parasite transmission in temperate ruminant systems: An integrative framework. Ecological Applications 34(3):e2956.

Brown TL, Airs PM, Porter S, Caplat P and Morgan ER, 2022. Understanding the role of wild ruminants in anthelmintic resistance in livestock. Biology Letters 18(5)

Buchmann K, 2022. Control of parasitic diseases in aquaculture. Parasitology 149(14):1985-1997.

Bueno AdF, Sutil WP, Jahnke SM, Carvalho GA, Cingolani MF, Colmenarez YC and Corniani N, 2023. Biological control as part of the soybean integrated pest management (ipm): Potential and challenges. Agronomy 13(10):2532.

Buono F, Veneziano V, Veronesi F and Molento MB, 2023. Horse and donkey parasitology: Differences and analogies for a correct diagnostic and management of major helminth infections. Parasitology 150(12):1119-1138.

Cain JL and Nielsen MK, 2022. The equine ascarids: Resuscitating historic model organisms for modern purposes. Parasitology research 121(10):2775-2791.

Chaurey S, Kalpande SD, Gupta RC and Toke LK, 2023. A review on the identification of total productive maintenance critical success factors for effective implementation in the manufacturing sector. Journal of quality in maintenance engineering 29(1):114-135.

Coffeng LE, Stolk WA and de Vlas SJ, 2024. Predicting the risk and speed of drug resistance emerging in soil-transmitted helminths during preventive chemotherapy. Nature communications 15(1):1099.

Collins N and Belkaid Y, 2022. Control of immunity via nutritional interventions. Immunity 55(2):210-223.

Collyer BS, Truscott JE, Mwandawiro CS, Njenga SM and Anderson RM, 2023. How important is the spatial movement of people in attempts to eliminate the transmission of human helminth infections by mass drug administration? Philosophical Transactions of the Royal Society B: Biological Sciences 378(1887)

Coman L-I, Ianculescu M, Paraschiv E-A, Alexandru A and Bădărău I-A, 2024. Smart solutions for diet-related disease management: Connected care, remote health monitoring systems, and integrated insights for advanced evaluation. Applied Sciences 14(6):2351.

Cray C and Altman NH, 2022. An update on the biologic effects of fenbendazole. Comparative medicine 72(4):215-219.

Cristaldo CM, Salomão RP, De Oliveira PLM, Abot AR and Correa CMDA, 2026. Rainfall shapes the physiological condition, but not the body size, of an introduced dung beetle in brazilian pastures. Ecological Entomology 51(2):346-355.

Cunha SMF, Willoughby O, Schenkel F and Cánovas Á, 2024. Genetic parameter estimation and selection for resistance to gastrointestinal nematode parasites in sheep—a review. Animals 14(4):613.

da Silva Medeiros C, Furtado LFV, Miranda GS, da Silva VJ, Dos Santos TR and Rabelo ÉML, 2022. Moving beyond the state of the art of understanding resistance mechanisms in hookworms: Confirming old and suggesting new associated snps. Acta Tropica 233:106533.

Denwood MJ, Kaplan RM, McKendrick IJ, Thamsborg SM, Nielsen MK and Levecke B, 2023. A statistical framework for calculating prospective sample sizes and classifying efficacy results for faecal egg count reduction tests in ruminants, horses and swine. Veterinary Parasitology 314:109867.

Dimunová D, Matoušková P, Podlipná R, Boušová I and Skálová L, 2022. The role of udp-glycosyltransferases in xenobioticresistance. Drug metabolism reviews 54(3):282-298.

Domshy KA, Whitehead AE, Poissant J, Goldsmith DA, Legge C, Knight CG, Zachar EK, Loch SS and Davies JL, 2024. A retrospective study of the prevalence in equine postmortems of cranial mesenteric arteritis caused by strongylus vulgaris in alberta (2010 to 2022). The Canadian Veterinary Journal 65(6):587-593.

Douglas J, Owers R and Campbell MLH, 2022. Social licence to operate: What can equestrian sports learn from other industries? Animals 12(15):1987.

Dowling A, Lawrence KE, Howe L, Scott I and Pomroy WE, 2024. Assessment of accuracy of liver fluke diagnostic tests using the gold standard of total worm counts. Veterinary Parasitology: Regional Studies and Reports 54:101102.

Džermeikaitė K, Bačėninaitė D and Antanaitis R, 2023. Innovations in cattle farming: Application of innovative technologies and sensors in the diagnosis of diseases. Animals 13(5):780.

Elghryani N, McAloon C, Mincher C, McOwan T and Waal Td, 2023a. Comparison of the automated ovacyte telenostic faecal analyser versus the mcmaster and mini-flotac techniques in the estimation of helminth faecal egg counts in equine. Animals 13(24):3874.

Elghryani N, McOwan T, Mincher C, Duggan V and de Waal T, 2023b. Estimating the prevalence and factors affecting the shedding of helminth eggs in irish equine populations. Animals 13(4):581.

Endale H, Mathewos M and Abdeta D, 2023. Potential causes of spread of antimicrobial resistance and preventive measures in one health perspective-a review. Infection and drug resistance:7515-7545.

Ewence H and Whitlock F, 2024. The horse. The UFAW Handbook on the Care and Management of Laboratory and Other Research Animals:628-661.

Ferreira-Sá LCE, Machado ER, Gurgel-Gonçalves R and Abad-Franch F, 2024. Disentangling the effects of intermittent faecal shedding and imperfect test sensitivity on the microscopy-based detection of gut parasites in stool samples. PLoS neglected tropical diseases 18(12):e0012719.

Fleurance G, Sallé G, Lansade L, Wimel L and Dumont B, 2022. Comparing the effects of horse grazing alone or with cattle on horse parasitism and vegetation use in a mesophile pasture. Grass and Forage Science 77(3):175-188.

Forbes A and Ellis K, 2023. Parasite control in regenerative livestock farming. Livestock 28(3):112-120.

Fourie Zirkelbach J, Shah M, Vallejo J, Cheng J, Ayyoub A, Liu J, Hudson R, Sridhara R, Ison G and Amiri-Kordestani L, 2022. Improving dose-optimization processes used in oncology drug development to minimize toxicity and maximize benefit to patients. Journal of Clinical Oncology 40(30):3489-3500.

Friedman R, 2022. Computational studies of protein–drug binding affinity changes upon mutations in the drug target. Wiley Interdisciplinary Reviews: Computational Molecular Science 12(1):e1563.

Gagne RB, Crooks KR, Craft ME, Chiu ES, Fountain-Jones NM, Malmberg JL, Carver S, Funk WC and VandeWoude S, 2022. Parasites as conservation tools. Conservation Biology 36(1):e13719.

Gallo KJ, Wheeler NJ, Elmi AM, Airs PM and Zamanian M, 2023. Pharmacological profiling of a brugia malayi muscarinic acetylcholine receptor as a putative antiparasitic target. Antimicrobial Agents and Chemotherapy 67(1):e01188-01122.

Gasparinho C, Gonçalves MH, Chissaque A, Silva GL, Fortes F and Gonçalves L, 2022. Wasting, stunting, and anemia in angolan children after deworming with albendazole or a test-and-treat approach for intestinal parasites: Binary longitudinal models with temporal structure in a four-arm randomized trial. Nutrients 14(11):2185.

George J, Häsler B, Komba EVG, Rweyemamu M, Kimera SI and Mlangwa JED, 2022. Mechanisms and contextual factors affecting the implementation of animal health surveillance in tanzania: A process evaluation. Frontiers in Veterinary Science 8:790035.

Gerace E, Mancuso G, Midiri A, Poidomani S, Zummo S and Biondo C, 2022. Recent advances in the use of molecular methods for the diagnosis of bacterial infections. Pathogens 11(6):663.

Gitlin M, Fadli E and Chung KC, 2022. Increased healthcare costs by later stage cancer diagnosis. BMC health services research 22(1):1155.

Guanglei Z, Huaying W, Mingze L and Dong L, 2026. Does technological tools make dirty-work engagement easier? When occupational stigma leads to increased emotional exhaustion and avoidant behaviors at work. Annals of Operations Research 359(1):189-206.

Guarnieri G, Olivieri B, Senna G and Vianello A, 2023. Relative humidity and its impact on the immune system and infections. International journal of molecular sciences 24(11):9456.

Habib AKM, Hasan MK, Issa GF, Singh D, Islam S and Ghazal TM, 2023. Lithium-ion battery management system for electric vehicles: Constraints, challenges, and recommendations. Batteries 9(3):152.

Haider K, Abbas D, Galian J, Ghafar MA, Kabir K, Ijaz M, Hussain M, Khan KA, Ghramh HA and Raza A, 2025. The multifaceted roles of gut microbiota in insect physiology, metabolism, and environmental adaptation: Implications for pest management strategies. World Journal of Microbiology and Biotechnology 41(3):75.

Halvarsson P, Grandi G, Hägglund S and Höglund J, 2024. Gastrointestinal parasite community structure in horses after the introduction of selective anthelmintic treatment strategies. Veterinary Parasitology 326:110111.

Hamad RS, 2023. Rutin, a flavonoid compound derived from garlic, as a potential immunomodulatory and anti-inflammatory agent against murine schistosomiasis mansoni. Nutrients 15(5):1206.

Hardefeldt L, Thomas K, Page S, Norris J, Browning G, El Hage C, Stewart A, Gilkerson J, Muscatello G and Verwilghen D, 2025. Antimicrobial prescribing guidelines for horses in australia. Australian veterinary journal 103(12):781-889.

Hardy NG, Kuebbing SE, Duguid MC, Ashton MS, Sheban KC, Inman SE and Martin MP, 2025. Non-native invasive plants in tropical dry forests: A global review of presence, impacts, and management. Restoration Ecology 33(1):e14288.

Harshita A and Nonika R, 2024. Emerging antihelminthic drug resistance: Implications for mass drug administration program. One Health Bulletin 4(4):157-163.

Hausdorff WP, Madhi SA, Kang G, Kaboré L, Bayona MT and Giersing BK, 2024. Facilitating the development of urgently required combination vaccines. The Lancet Global Health 12(6):e1059-e1067.

Health EPoA, Welfare, Nielsen SS, Alvarez J, Bicout DJ, Calistri P, Canali E, Drewe JA, Garin-Bastuji B, Gonzales Rojas JL and Gortázar C, 2022. Assessment of listing and categorisation of animal diseases within the framework of the animal health law (regulation (eu) no 2016/429): Infection with equine herpesvirus-1. EFSA Journal 20(1):e07036.

Hernández-López H, Tejada-Rodríguez CJ and Leyva-Ramos S, 2022. A panoramic review of benzimidazole derivatives and their potential biological activity. Mini Reviews in Medicinal Chemistry 22(9):1268-1280.

Höglund J and Gustafsson K, 2023. Anthelmintic treatment of sheep and the role of parasites refugia in a local context. Animals 13(12):1960.

Howes OD, Thase ME and Pillinger T, 2022. Treatment resistance in psychiatry: State of the art and new directions. Molecular Psychiatry 27(1):58-72.

Huelsmeyer M, Kuzman D, Bončina M, Martinez J, Steinbrugger C, Weusten J, Calero-Rubio C, Roche W, Niederhaus B and VanHaelst Y, 2023. A universal tool for stability predictions of biotherapeutics, vaccines and in vitro diagnostic products. Scientific reports 13(1):10077.

Hunter JM and Blobner M, 2024. Under-dosing and over-dosing of neuromuscular blocking drugs and reversal agents: Beware of the risks No. 132. 461-465. Elsevier.

Huygens S, Dunbar A, Buil JB, Klaassen CHW, Verweij PE, van Dijk K, de Jonge N, Janssen JJWM, van der Velden WJFM and Biemond BJ, 2023. Clinical impact of polymerase chain reaction–based aspergillus and azole resistance detection in invasive aspergillosis: A prospective multicenter study. Clinical Infectious Diseases 77(1):38-45.

Jack C, Hotchkiss E, Sargison ND, Toma L, Milne C and Bartley DJ, 2022. Determining the influence of socio-psychological factors on the adoption of individual 'best practice'parasite control behaviours from scottish sheep farmers. Preventive Veterinary Medicine 200:105594.

Jakučionytė-Skodienė M and Liobikienė G, 2022. The changes in climate change concern, responsibility assumption and impact on climate-friendly behaviour in eu from the paris agreement until 2019. Environmental management 69(1):1-16.

Jeria E, Oyanedel D, Rojas R, Farlora R, Lira G, Mercado A, Muñoz K, Destoumieux-Garzón D, Brokordt K and Schmitt P, 2023. Resistance of argopecten purpuratus scallop larvae to vibriosis is associated with the front-loading of immune genes and enhanced antimicrobial response. Frontiers in immunology 14:1150280.

Jimenez CEP, Keestra S, Tandon P, Cumming O, Pickering AJ, Moodley A and Chandler CIR, 2023. Biosecurity and water, sanitation, and hygiene (wash) interventions in animal agricultural settings for reducing infection burden, antibiotic use, and antibiotic resistance: A one health systematic review. The Lancet Planetary Health 7(5):e418-e434.

Jürgenschellert L, Krücken J, Bousquet E, Bartz J, Heyer N, Nielsen MK and von Samson-Himmelstjerna G, 2022. Occurrence of strongylid nematode parasites on horse farms in berlin and brandenburg, germany, with high seroprevalence of strongylus vulgaris infection. Frontiers in Veterinary Science 9:892920.

Kappes A, Tozooneyi T, Shakil G, Railey AF, McIntyre KM, Mayberry DE, Rushton J, Pendell DL and Marsh TL, 2023. Livestock health and disease economics: A scoping review of selected literature. Frontiers in Veterinary Science 10:1168649.

Keppel G, Stralberg D, Morelli TL and Bátori Z, 2024. Managing climate-change refugia to prevent extinctions. Trends in Ecology & Evolution 39(9):800-808.

Khan A, Jamil M, Ullah S, Ramzan F, Khan H, Ullah N, Ali M, Rehman AU, Jabeen N and Amber R, 2023. The prevalence of gastrointestinal nematodes in livestock and their health hazards: A review. World's Veterinary Journal 13(1):57-64.

Kholif AE, 2023. A review of effect of saponins on ruminal fermentation, health and performance of ruminants. Veterinary Sciences 10(7):450.

Kimbrough BA, Crowson CS, Davis Iii JM, Matteson EL and Myasoedova E, 2024. Decline in incidence of extra-articular manifestations of rheumatoid arthritis: A population-based cohort study. Arthritis care & research 76(4):454-462.

Kimeli P, Mwacalimba K, Tiernan R, Mijten E, Miroshnychenko T and Poulsen Nautrup B, 2025. Important diseases of small ruminants in sub-saharan africa: A review with a focus on current strategies for treatment and control in smallholder systems. Animals 15(5):706.

Kothinti RR, 2024. Deep learning in healthcare: Transforming disease diagnosis, personalized treatment, and clinical decision-making through ai-driven innovations. World J Adv Res Rev 24(2):2841-2856.

Lahlali R, Ezrari S, Radouane N, Kenfaoui J, Esmaeel Q, El Hamss H, Belabess Z and Barka EA, 2022. Biological control of plant pathogens: A global perspective. Microorganisms 10(3):596.

Lawson AL, Malalana F and Mair TS, 2023. Larval cyathostominosis: Clinicopathological data and treatment outcomes of 38 hospitalised horses (2009–2020). Equine Veterinary Education 35(8):424-435.

Le B, Clarke NE, Legrand N and Nery SV, 2024. Effectiveness of ivermectin mass drug administration in the control of soil-transmitted helminth infections in endemic populations: A systematic review and meta-analysis. Infectious Diseases of Poverty 13(01):1-15.

Lespine A, Blancfuney C, Prichard R and Alberich M, 2024. P-glycoproteins in anthelmintic safety, efficacy, and resistance. Trends in parasitology 40(10):896-913.

Li F, Wang S, Gao Z, Qing M, Pan S, Liu Y and Hu C, 2025a. Harnessing artificial intelligence in sepsis care: Advances in early detection, personalized treatment, and real-time monitoring. Frontiers in Medicine 11:1510792.

Li W, Huang T, Liu C, Wushouer H, Yang X, Wang R, Xia H, Li X, Qiu S and Chen S, 2025b. Changing climate and socioeconomic factors contribute to global antimicrobial resistance. Nature medicine 31(6):1798-1808.

Lira NL, Tonello S, Lui RL, Traldi JB, Brandão H, Oliveira C and Blanco DR, 2023. Identifying fish eggs and larvae: From classic methodologies to DNA metabarcoding. Molecular Biology Reports 50(2):1713-1726.

Lüscher A, Barkaoui K, Finn JA, Suter D, Suter M and Volaire F, 2022. Using plant diversity to reduce vulnerability and increase drought resilience of permanent and sown productive grasslands. Grass and Forage Science 77(4):235-246.

Lv M, Zhang H, Georgescu P, Li T and Zhang B, 2022. Improving education for innovation and entrepreneurship in chinese technical universities: A quest for building a sustainable framework. Sustainability 14(2):595.

Macedo AT, Carvalho DO, Gomez M, Pires B, Brito M, Sousa N, da Cruz ARP, Khoury HJ and Virginio JF, 2026. Field implementation of the sterile insect technique against aedes aegypti in recife, brazil: Operational challenges and impact of release frequency on vector dynamics. Infectious Diseases of Poverty 15(1):16.

Malik MA, Sajid MS, Anjum FR, Khan A, Farhab M, Maqbool M, Zeeshan M, Hussain K, Rizwan HM and Tahir UB, 2022. Anthelmintic drug resistance in livestock: Current understanding. Parasitic Helminths and Zoonoses: From Basic to Applied Research:25.

Mapuranga J, Zhang N, Zhang L, Liu W, Chang J and Yang W, 2022. Harnessing genetic resistance to rusts in wheat and integrated rust management methods to develop more durable resistant cultivars. Frontiers in Plant Science 13:951095.

Marsh AE and Lakritz J, 2023. Reflecting on the past and fast forwarding to present day anthelmintic resistant ancylostoma caninum–a critical issue we neglected to forecast. International Journal for Parasitology: Drugs and Drug Resistance 22:36-43.

Martin F, Halvarsson P, Alm YH and Tyden E, 2024. Occurrence of fenbendazole resistance in parascaris spp. On breeding farms in sweden. Veterinary Parasitology 331:110272.

McIntyre RS, Alsuwaidan M, Baune BT, Berk M, Demyttenaere K, Goldberg JF, Gorwood P, Ho R, Kasper S and Kennedy SH, 2023. Treatment-resistant depression: Definition, prevalence, detection, management, and investigational interventions. World psychiatry 22(3):394-412.

Metzger GA, Ridenhour BJ, France M, Gliniewicz K, Millstein J, Settles ML, Forney LJ, Stalder T and Top EM, 2022. Biofilms preserve the transmissibility of a multi-drug resistance plasmid. npj Biofilms and Microbiomes 8(1):95.

Meyer N, Harvey AG, Lockley SW and Dijk D-J, 2022. Circadian rhythms and disorders of the timing of sleep. The Lancet 400(10357):1061-1078.

Morgan ER, Lanusse C, Rinaldi L, Charlier J and Vercruysse J, 2022. Confounding factors affecting faecal egg count reduction as a measure of anthelmintic efficacy. Parasite 29:20.

Mulac A, Hagesaether E and Granas AG, 2022. Medication dose calculation errors and other numeracy mishaps in hospitals: Analysis of the nature and enablers of incident reports. Journal of Advanced Nursing 78(1):224-238.

Muñoz-Vargas L, Pempek JA, Proudfoot K, Eastridge ML, Rajala-Schultz PJ, Wittum T and Habing G, 2022. The impact of overstocking and negative energy balance on quantitative measurement of non-typhoidal salmonella in periparturient dairy cattle. Frontiers in Veterinary Science 9:779900.

Murray LM, Hayes A, Snape J, Kasprzyk-Hordern B, Gaze WH and Murray AK, 2024. Co-selection for antibiotic resistance by environmental contaminants. npj Antimicrobials and Resistance 2(1):9.

Muteeb G, Rehman MT, Shahwan M and Aatif M, 2023. Origin of antibiotics and antibiotic resistance, and their impacts on drug development: A narrative review. Pharmaceuticals 16(11):1615.

Mwacalimba K, Sheehy J, Adolph C, Savadelis M, Kryda K and Poulsen Nautrup B, 2024. A review of moxidectin vs. Other macrocyclic lactones for prevention of heartworm disease in dogs with an appraisal of two commercial formulations. Frontiers in Veterinary Science 11:1377718.

Mwalugelo YA, Mponzi WP, Muyaga LL, Mahenge HH, Katusi GC, Muhonja F, Omondi D, Ochieng AO, Kaindoa EW and Amimo FA, 2024. Livestock keeping, mosquitoes and community viewpoints: A mixed methods assessment of relationships between livestock management, malaria vector biting risk and community perspectives in rural tanzania. Malaria Journal 23(1):213.

Ng'etich AI, Amoah ID, Bux F and Kumari S, 2024. Anthelmintic resistance in soil-transmitted helminths: One-health considerations. Parasitology research 123(1):62.

Nielsen MK, 2022. Parasite faecal egg counts in equine veterinary practice. Equine Veterinary Education 34(11):584-591.

Nielsen MK, Kaplan RM, Abbas G and Jabbar A, 2023. Biological implications of long-term anthelmintic treatment: What else besides resistance are we selecting for? Trends in parasitology 39(11):945-953.

Obeidat JM and Al-Najjar K, 2025. Integrating biomedical and sustainable strategies for effective parasite control in livestock: A review. Hunan Daxue Xuebao/Journal of Hunan University Natural Sciences 61(04):98-105.

Ogbein KE, Dogo AG, Oshadu DO and Edeh ER, 2022. Gastrointestinal parasites of horses and their socioeconomic impact in jos plateau–nigeria. Appl Vet Res 1(3):1-11.

Ogungbuyi MG, Mohammed C, Ara I, Fischer AM and Harrison MT, 2023. Advancing skyborne technologies and high-resolution satellites for pasture monitoring and improved management: A review. Remote Sensing 15(19):4866.

Osterman-Lind E, Hedberg Alm Y, Hassler H, Wilderoth H, Thorolfson H and Tyden E, 2022. Evaluation of strategies to reduce equine strongyle infective larvae on pasture and study of larval migration and overwintering in a nordic climate. Animals 12(22):3093.

Overmars LM, Niemantsverdriet MSA, Groenhof TKJ, De Groot MCH, Hulsbergen-Veelken CAR, Van Solinge WW, Musson REA, Ten Berg MJ, Hoefer IE and Haitjema S, 2022. A wolf in sheep's clothing: Reuse of routinely obtained laboratory data in research. Journal of Medical Internet Research 24(11):e40516.

Pallaval VB, 2023. A scoping review of research on the unfolding human microbiome landscape in the metagenomics era. Human Microbiome in Health, Disease, and Therapy:1-8.

Parija SC and Poddar A, 2024. Artificial intelligence in parasitic disease control: A paradigm shift in health care. Tropical parasitology 14(1):2-7.

Periyasamy AP, 2024. Recent advances in the remediation of textile-dye-containing wastewater: Prioritizing human health and sustainable wastewater treatment. Sustainability 16(2):495.

Phillips KBB, Lineman B, Murray GLD, Nelson SJ, Sperduto DD and Tourville JC, 2026. Refugia or at risk? Alpine snowbank communities in the face of climate change. Conservation Science and Practice 8(1):e70079.

Pienta KJ, Goodin PL and Amend SR, 2025. Defeating lethal cancer: Interrupting the ecologic and evolutionary basis of death from malignancy. CA: a cancer journal for clinicians 75(3):183-202.

Playford MC and Besier RB, 2025. Gastrointestinal nematode parasites of grazing ruminants: A comprehensive literature review of diagnostic methods for quantifying parasitism, larval differentiation and measuring anthelmintic resistance. New Zealand Veterinary Journal 73(3):149-164.

Rajaeifar MA, Ghadimi P, Raugei M, Wu Y and Heidrich O, 2022. Challenges and recent developments in supply and value chains of electric vehicle batteries: A sustainability perspective No. 180. 106144. Elsevier.

Rajneesh, Tiwari R, Singh VK, Kumar A, Gupta RP, Singh AK, Gautam V and Kumar R, 2023. Advancements and challenges in developing malaria vaccines: Targeting multiple stages of the parasite life cycle. ACS Infectious Diseases 9(10):1795-1814.

Ranius T, Widenfalk LA, Seedre M, Lindman L, Felton A, Hämäläinen A, Filyushkina A and Öckinger E, 2023. Protected area designation and management in a world of climate change: A review of recommendations. Ambio 52(1):68-80.

Rastogi S, Mohanty S, Sharma S and Tripathi P, 2022. Possible role of gut microbes and host's immune response in gut–lung homeostasis. Frontiers in immunology 13:954339.

Raza A, Williams AR and Abeer MM, 2023. Importance of abc transporters in the survival of parasitic nematodes and the prospect for the development of novel control strategies. Pathogens 12(6):755.

Reeves S, Bertrand J, Obee SJ, Hunter S, Howard R and Flanagan RJ, 2024. A population pharmacokinetic model to guide clozapine dose selection, based on age, sex, ethnicity, body weight and smoking status. British Journal of Clinical Pharmacology 90(1):135-145.

Rendle D, Hughes K, Bowen M, Bull K, Cameron I, Furtado T, Peachey L, Sharpe L and Hodgkinson J, 2024. Beva primary care clinical guidelines: Equine parasite control. Equine Veterinary Journal 56(3):392-423.

Robi DT, Mossie T and Temteme S, 2023. Eukaryotic infections in dairy calves: Impacts, diagnosis, and strategies for prevention and control. Veterinary Medicine: Research and Reports:195-208.

Rodríguez-Hernández P, Reyes-Palomo C, Sanz-Fernández S, Rufino-Moya PJ, Zafra R, Martínez-Moreno FJ, Rodríguez-Estévez V and Díaz-Gaona C, 2023. Antiparasitic tannin-rich plants from the south of europe for grazing livestock: A review. Animals 13(2):201.

Saad H, Elfeky SA, El-Gamel NEA and Dena ASA, 2025. Organophosphate pesticides: A review on classification, synthesis, toxicity, remediation and analysis. RSC advances 15(48):40802-40822.

Sacarrão-Birrento L, Harrison LJS, Pienaar R, Toka FN, Torres-Acosta JFJ, Vilela VLR, Hernández-Castellano LE, Arriaga-Jordán CM, Soltan YA and Ungerfeld R, 2024. Challenges for animal health and production in the tropics and mediterranean for the next 55 years. Tropical animal health and production 56(8):381.

Salgotra RK and Chauhan BS, 2023. Genetic diversity, conservation, and utilization of plant genetic resources. Genes 14(1):174.

Sands B, Giroux L, Bruce J and Darby H, 2024. Integrated parasite management (ipm) and the pasture ecosystem: Optimizing outcomes for cattle, insect biodiversity, and soil health. Agriculture, Ecosystems & Environment 368:109022.

Sardi AE, Bégout M-L, Lalles A-L, Cousin X and Budzinski H, 2023. Temperature and feeding frequency impact the survival, growth, and metamorphosis success of solea solea larvae. Plos one 18(3):e0281193.

Sardinha-Silva A, Alves-Ferreira EVC and Grigg ME, 2022. Intestinal immune responses to commensal and pathogenic protozoa. Frontiers in immunology 13:963723.

Sarri K, Mourouzidou S, Ntalli N and Monokrousos N, 2024. Recent advances and developments in the nematicidal activity of essential oils and their components against root-knot nematodes. Agronomy 14(1):213.

Schlosser-Brandenburg J, Midha A, Mugo RM, Ndombi EM, Gachara G, Njomo D, Rausch S and Hartmann S, 2023. Infection with soil-transmitted helminths and their impact on coinfections. Frontiers in Parasitology 2:1197956.

Shah BM and Kachhadiya RN, 2025. Shaping the future of medicine through diverse therapeutic applications of tetralin derivatives. Medicinal Chemistry Research 34(1):86-113.

Shang X, Dai L, Cao X, Ma Y, Gulnaz I, Miao X, Li X and Yang X, 2025. Natural products in antiparasitic drug discovery: Advances, opportunities and challenges. Natural Product Reports 42(9):1419-1458.

Sharpe P and Kenny LB, 2025. Welfare of horses on pasture, Horse pasture management. Elsevier.pp:535-550

Shrestha A, Kusha KC, Baral A, Shrestha R and Shrestha R, 2024. Cutaneous larva migrans in a child: A case report and review of literature. Annals of Medicine and Surgery 86(1):530-534.

Souto EPF, Dantas VW, Oliveira AM, Garcia DS, Vilela VLR, Neto EGM, Mota RA and Dantas AFM, 2025. Arteritis, aneurysm and thromboembolic colic caused by migration of strongylus vulgaris larvae in equids. Journal of Equine Veterinary Science:105650.

Stear M, Preston S, Piedrafita D and Donskow-Łysoniewska K, 2023. The immune response to nematode infection. International journal of molecular sciences 24(3):2283.

Steffey MA, Griffon DJ, Risselada M, Buote NJ, Scharf VF, Zamprogno H and Winter AL, 2023. A narrative review of the physiology and health effects of burnout associated with veterinarian-pertinent occupational stressors. Frontiers in Veterinary Science 10:1184525.

Stielow M, Witczyńska A, Kubryń N, Fijałkowski Ł, Nowaczyk J and Nowaczyk A, 2023. The bioavailability of drugs—the current state of knowledge. Molecules 28(24):8038.

Struelens MJ, Ludden C, Werner G, Sintchenko V, Jokelainen P and Ip M, 2024. Real-time genomic surveillance for enhanced control of infectious diseases and antimicrobial resistance. Frontiers in Science 2:1298248.

Strydom T, Lavan RP, Torres S and Heaney K, 2023. The economic impact of parasitism from nematodes, trematodes and ticks on beef cattle production. Animals 13(10):1599.

Tenorio JC, 2025. Drug resistance in parasites: A review of mechanisms, drivers, and mitigation strategies. Microbes and Infectious Diseases 6(3):6152-6160.

Thapa RK and Kim JO, 2023. Nanomedicine-based commercial formulations: Current developments and future prospects. Journal of Pharmaceutical Investigation 53(1):19-33.

Turner JL, 2024. Deworming programs for horses in the united states: Past, present, and future. Animal Frontiers 14(5):32-34.

Ugoala E, 2023. Antimicrobial drug resistance: A systematic review and assessment of resistant pathogen infection prevention and control. Trends in Medical Research 18(1):36-57.

Ullah A, Geng M, Chen W, Zhu Q, Shi L, Zhang X, Akhtar MF, Wang C and Khan MZ, 2025. Effect of parasitic infections on hematological profile, reproductive and productive performance in equines. Animals: an Open Access Journal from MDPI 15(22):3294.

Vashisht V, Vashisht A, Mondal AK, Farmaha J, Alptekin A, Singh H, Ahluwalia P, Srinivas A and Kolhe R, 2023. Genomics for emerging pathogen identification and monitoring: Prospects and obstacles. BioMedInformatics 3(4):1145-1177.

Venkatesan A, Jimenez Castro PD, Morosetti A, Horvath H, Chen R, Redman E, Dunn K, Collins JB, Fraser JS and Andersen EC, 2023. Molecular evidence of widespread benzimidazole drug resistance in ancylostoma caninum from domestic dogs throughout the USA and discovery of a novel β-tubulin benzimidazole resistance mutation. PLoS Pathogens 19(3):e1011146.

Venter F, Matthews KR and Silvester E, 2022. Parasite co-infection: An ecological, molecular and experimental perspective. Proceedings of the Royal Society B: Biological Sciences 289(1967)

Verdon M, 2023. A review of factors affecting the welfare of weaned replacement heifers in pasture-based dairy production systems. Animal Production Science 63(8):723-741.

Villaverde MS, Menghini M, Martínez MF, DiLorenzo N, Bravo RD and Arelovich HM, 2025. Interconnection between pastures, grazing ecosystem, animal welfare, meat quality, and human health. Animal Frontiers 15(5):39-46.

Wallis RS, O'Garra A, Sher A and Wack A, 2023. Host-directed immunotherapy of viral and bacterial infections: Past, present and future. Nature Reviews Immunology 23(2):121-133.

Wang T, Chen X, Yan X, Su Y, Gao W, Liu C and Wang W, 2025. Progress in serology and molecular biology of equine parasite diagnosis: Sustainable control strategies. Frontiers in Veterinary Science 12:1663577.

Wei J, Guo S, Wang Q and Xu H, 2023. Present situation and countermeasure of animal quarantine in animal husbandry and veterinary. International Journal of Food Science and Agriculture 7(3):123-134.

Wells K and Flynn R, 2022. Managing host-parasite interactions in humans and wildlife in times of global change. Parasitology research 121(11):3063-3071.

Wolf J, Kist LF, Pereira SB, Quessada MA, Petek H, Pille A, Maccari JG, Mutlaq MP and Nasi LA, 2024. Human papillomavirus infection: Epidemiology, biology, host interactions, cancer development, prevention, and therapeutics. Reviews in medical virology 34(3):e2537.

Wróbel B, Zielewicz W and Staniak M, 2023. Challenges of pasture feeding systems—opportunities and constraints. Agriculture 13(5):974.

Xu Z, Guo X, Wang J, Yuan Y, Sun Q, Tian R, Yang H and Lu J, 2022. Restraining the octahedron collapse in lithium and manganese rich ncm cathode toward suppressing structure transformation. Advanced Energy Materials 12(35):2201323.

Yavuz O, Uner MM, Okumus F and Karatepe OM, 2023. Industry 4.0 technologies, sustainable operations practices and their impacts on sustainable performance. Journal of Cleaner Production 387:135951.