Review Article

The Potential of *Saccharomyces cerevisiae* as a Biological Control Agent Against Gastrointestinal Nematodes in Sheep

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Abstract | Gastrointestinal nematodes (GIN), particularly *Haemonchus contortus*, pose a persistent threat to sheep health and productivity, especially in regions where anthelmintic resistance compromises the effectiveness of conventional chemical treatments. This review evaluates the potential of *Saccharomyces cerevisiae* as a biological control agent for GIN. Through a comprehensive analysis of both *in vitro* and *in vivo* studies, the review synthesizes findings on the yeast's effects on immune modulation, gut health, and parasite load reduction. Evidence shows that *S. cerevisiae* enhances immunoglobulin and cytokine production, supports the growth of beneficial gut microbiota, and indirectly reduces parasite viability. When used in synergy with nematophagous fungi such as *Duddingtonia flagrans*, *S. cerevisiae* significantly lowers fecal egg counts, reinforcing its role in integrated pest management (IPM) strategies. These results highlight the yeast's multifaceted benefits, including enhanced host immunity, reduced dependence on chemical treatments, and support for environmental sustainability. Additionally, *S. cerevisiae* is easily incorporated into existing feeding systems and carries a minimal risk of resistance development. This review underscores the need for further studies on formulation optimization, long-term field trials, and interactions with other biological agents. In conclusion, *S. cerevisiae* offers a promising, eco-friendly alternative for managing GIN in sheep farming.

Keywords | *Saccharomyces cerevisiae*, Gastrointestinal nematodes, Sheep health, Biological control, Anthelmintic resistance, *Haemonchus contortus*

Received | May 07, 2025; **Accepted** | July 28, 2025; **Published** | October 06, 2025
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Citation | Atmaja BM, Agusetyaningsih I, Ali MI, Adikara YAR, Hidayatulloh R, Herviyanto D, Lestari WM, Hutabarat ALR, Safitri AR, Ali AM (2025). The potential of *Saccharomyces cerevisiae* as a biological control agent against gastrointestinal nematodes in sheep. J. Anim. Health Prod. 13(4): 903-917.
DOI | https://dx.doi.org/10.17582/journal.jahp/2025/13.4.903.917
ISSN (Online) | 2308-2801

INTRODUCTION

Gastrointestinal nematodes (GIN) are a major health threat in sheep farming, significantly impacting both animal welfare and agricultural productivity. Key nematode species such as *Haemonchus contortus*, *Teladorsagia circumcincta*, and *Trichostrongylus colubriformis* primarily infect the abomasum and intestines of sheep, causing nutrient depletion and substantial physiological damage. GIN infections lead to reduced growth rates, decreased reproductive performance, and increased mortality, particularly in young lambs (Baptista *et al*., 2020; Khattak *et al.*, 2018). Beyond individual animals, these infestations affect herd health and farm sustainability due to escalating veterinary costs and the need for more frequent interventions (Jorge-Neto *et al.*, 2025; Reyes-Guerrero *et al.*, 2021). Nematode infestations are especially problematic in warm, moist climates that facilitate their life cycle, resulting in clinical signs such as weight loss, anemia, and diarrhea. These symptoms contribute to higher treatment costs and reduced productivity, placing significant financial strain on farmers and reducing profit margins (Silva *et al.*, 2018; Tehrani *et al.*, 2024). The rising prevalence of anthelmintic resistance further complicates efforts to manage these infestations. As nematode populations become resistant to conventional chemical treatments, their effectiveness diminishes, creating additional economic burdens on farmers who are increasingly in need of alternative solutions to maintain flock health (Pinto *et al.*, 2022; Victoria *et al.*, 2022).

Traditional control measures, such as synthetic anthelmintics, face growing challenges, particularly due to resistance development. Over-reliance on these pharmacological agents has led to heightened selection pressure, favoring resistant nematode populations. Reports indicate that a significant proportion of sheep farms in some regions are now dealing with resistant nematodes, underscoring the urgent need for alternative strategies (Aguiar *et al.*, 2024; Minguetto *et al.*, 2021). While practices such as rotational grazing, pasture management, and breeding resistant sheep have been explored, their effectiveness is often limited, especially in regions heavily affected by nematode infections (Delmilho *et al.*, 2024; Pinto *et al.*, 2020; Szewc *et al.*, 2021). Consequently, there is a growing interest in biological control methods to complement or replace traditional chemical approaches, reflecting the increasing need for innovative solutions in nematode management (Comans-Pérez *et al.*, 2021; Rodrigues *et al.*, 2022).

Among the promising alternatives, the use of microorganisms like nematophagous fungi has gained attention as a viable strategy to combat GIN. Species such as *Duddingtonia flagrans* are capable of trapping and killing free-living nematode stages, disrupting their life cycle and reducing environmental contamination (Faria *et al.*, 2025; Sander and Neumann, 2025). Additionally, *Saccharomyces cerevisiae* has shown potential in enhancing host immunity and reducing nematode burdens in sheep, thereby mitigating the negative effects of GIN while improving overall animal health (Pinto *et al.*, 2020; Rodríguez-Esquivel *et al.*, 2023). Recent studies have highlighted the synergistic effects between *S. cerevisiae* and nematophagous fungi, which could lead to more effective and sustainable strategies for managing nematode infections (Liu *et al.*, 2020; Xue *et al.*, 2018).

This review aims to consolidate and evaluate current knowledge on GIN in sheep, with a particular focus on their impact on health and productivity, the challenges posed by anthelmintic resistance, and innovative biological control strategies involving *S. cerevisiae* and nematophagous fungi. By synthesizing recent advancements and findings, this work seeks to offer valuable insights into sustainable practices that farmers can adopt to safeguard animal welfare and enhance productivity. Furthermore, this review will propose integrated treatment methodologies to improve GIN management, ultimately supporting sheep health and the sustainability of sheep farming as a critical agricultural practice (Cubides-Cárdenas *et al.*, 2023; Ferguson *et al.*, 2018; Hao *et al.*, 2024; Victoria *et al.*, 2022).

MATERIALS AND METHODS

The methodology for this review involved a systematic approach focused on compiling and synthesizing existing literature on the use of *S. cerevisiae* and other biological control mechanisms against gastrointestinal nematodes (GIN), particularly in sheep. A comprehensive review of the literature was conducted using defined keywords to capture relevant studies exploring *S. cerevisiae*'s potential as an anthelmintic agent, specifically its effects against nematodes like *Haemonchus contortus*. The search strategy involved multiple databases, including PubMed, Scopus, and Web of Science, using combinatorial keywords such as: (*S. cerevisiae*, biological control, gastrointestinal nematodes, sheep) or (*S. cerevisiae*, and anthelmintic and sheep) or (biological control, nematodes and sheep).

Inclusion criteria for the selected studies focused on peer-reviewed research detailing both *in vitro* and *in vivo* evaluations of *S. cerevisiae* or its derivatives, studies examining biological control strategies involving nematophagous fungi against GIN, and research assessing the impact of probiotics on sheep health in relation to nematode infections. Articles evaluating the efficacy of *Duddingtonia flagrans* and other nematophagous fungi were also reviewed to compare their effectiveness and mechanisms of action with those of *S. cerevisiae*. The subsequent analyses focused on various interactions between *S. cerevisiae* and GIN, highlighting immune modulation in sheep, the functional role of probiotics in enhancing resistance to nematode infections, and comparisons with other biological control agents.

This synthesis provided a cohesive understanding of *S. cerevisiae*'s potential as a biological control agent, positioning it within the broader context of sustainable approaches to managing GIN infections in sheep. The review offers a foundational basis for future experimental approaches aimed at elucidating specific mechanisms and enhancements conferred by *S. cerevisiae* in the context of veterinary parasitology and ruminant health.

RESULTS AND DISCUSSION

Biological control: An overview

Definition and principles of biological control

Biological control is an approach to managing pest populations by utilizing natural predators, parasites, or pathogens to mitigate their effects on ecosystems or agricultural systems. This strategy offers an environmentally sustainable alternative to traditional chemical controls, relying on natural ecological relationships rather than synthetic compounds, which may harm non-target organisms and the broader environment (Khattak *et al*., 2018). A thorough understanding of ecological interactions is essential in biological control, as integrating this knowledge enables the development of sustainable pest management programs that remain effective in the long term (Pinto *et al*., 2022).

One of the most promising groups of biological control agents are nematophagous fungi, which play a key role in regulating soil nematode populations. These fungi possess unique predatory capabilities, including the formation of specialized structures that trap and kill nematodes, contributing to soil health and fertility (Rodríguez-Martínez *et al*., 2018). By modifying their hyphal networks into trapping devices, these fungi significantly enhance their ability to capture nematodes (Baptista *et al*., 2020). Growing interest in nematophagous fungi has led to research on their efficacy against various nematode species, particularly in livestock, highlighting their ecological viability (Rodrigues *et al*., 2022).

Biological control is especially effective in managing gastrointestinal nematodes (GIN) in ruminants such as sheep. *Duddingtonia flagrans*, a nematophagous fungus, has been evaluated for its ability to control parasitic infections in livestock. Studies have demonstrated that it can significantly reduce fecal egg counts in treated animals, suggesting its potential for integration into Integrated Pest Management (IPM) strategies (Aguiar *et al*., 2024). This approach is particularly valuable in regions where conventional chemical treatments are becoming less effective due to rising anthelmintic resistance (Delmilho *et al*., 2024). The use of such fungi as biocontrol agents can enhance the sustainability of sheep farming while reducing dependency on chemical anthelmintics.

Beyond pest population control, the use of biological control agents also promotes overall grazing system health (Reyes-Guerrero *et al*., 2021). By supporting soil health and reducing chemical residues in animal products, these strategies contribute to global efforts toward sustainable agricultural practices (Sander and Neumann, 2025). Therefore, biological control agents like *Duddingtonia flagrans* and other nematophagous fungi provide dual benefits: reducing pest populations and fostering ecological balance (Hao *et al*., 2024). This shift represents a transformative change in agricultural pest management, emphasizing environmental integrity and livestock productivity.

This review provides a comprehensive overview of biological control strategies, with a particular focus on nematophagous fungi for managing gastrointestinal nematodes in sheep. It synthesizes existing literature to clarify the mechanisms, benefits, and potential applications of these biological agents in modern agricultural pest management (Minguetto *et al*., 2021). The review also addresses challenges in adopting biological control, including operational considerations and integration within farm management systems. By doing so, it emphasizes the importance of biological control as a viable and sustainable method for combating nematode infections in livestock, thereby enhancing agricultural resilience (Comans-Pérez *et al*., 2021).

Advantages of biological control over chemical methods

Biological control offers several advantages over traditional chemical methods in managing gastrointestinal nematodes (GIN) within agricultural systems. Primarily, it provides an environmentally sustainable alternative by reducing reliance on synthetic chemicals, which are often associated with negative ecological impacts and harmful residues in food products (Khattak *et al*., 2018). By utilizing naturally occurring organisms, biological control promotes ecological balance while effectively managing pest populations (Pinto *et al*., 2022). This shift toward ecological strategies not only supports biodiversity but also aids in the conservation of beneficial organisms that play essential roles in agricultural ecosystems, such as those involved in nutrient cycling.

One of the most significant benefits of biological control is its ability to mitigate the growing issue of anthelmintic resistance. The overuse of chemical anthelmintics has resulted in the selection of resistant nematode populations, reducing the effectiveness of standard treatments (Jorge-Neto *et al*., 2025; Rodrigues *et al*., 2022). Biological control methods, such as the use of nematophagous fungi like *Duddingtonia flagrans*, disrupt the life cycle of parasites without contributing to resistance development (Reyes-Guerrero *et al*., 2021). Studies have shown that these fungi can significantly reduce fecal egg counts and improve livestock health, offering a sustainable solution for nematode management (Aguiar *et al*., 2024).

Additionally, biological control methods typically require fewer applications than chemical treatments, providing a distinct advantage in terms of both cost and labor (Szewc *et al*., 2021). The long-term effectiveness of biological agents ensures that their impact persists across multiple growing seasons, reducing the need for frequent reapplication. For example, research indicates that introducing *Duddingtonia flagrans* can result in substantial reductions in nematode populations with fewer treatments compared to chemical strategies (Delmilho *et al*., 2024). This not only reduces operational costs for farmers but also minimizes the labor intensity often associated with routine pest management.

Another key benefit of biological control is its potential to improve animal welfare (Silva *et al*., 2018). By effectively reducing the burden of gastrointestinal nematodes, biological control can enhance growth rates, productivity, and reduce mortality rates among livestock, particularly in young or vulnerable populations (Minguetto *et al*., 2021). Integrating biological control into livestock management systems contributes to healthier animal populations, helping farmers achieve their production goals. Ultimately, biological control represents a proactive strategy for managing nematode infestations, addressing current challenges in livestock farming, and providing long-term solutions. The integration of biological control methods also aligns with global efforts toward sustainable agricultural practices and environmental stewardship (Hao *et al*., 2024). As research continues to advance, the potential for biological control to combat nematode infections effectively will expand, offering innovative strategies to enhance livestock productivity and health in a sustainable manner (Sander and Neumann, 2025).

Historical context of biological control in livestock management

The use of biological control in livestock management dates back to traditional practices aimed at mitigating pest populations through natural means. Early evidence suggests that such methods were employed well before the 20th century, with farmers utilizing various natural enemies to control pests that affected animal health (Khattak *et al*., 2018). The use of biological control gained significant momentum with the advent of modern agricultural practices, especially as the limitations and adverse effects of chemical control methods became more evident. In the mid-20th century, synthetic anthelmintics became the dominant method for controlling gastrointestinal nematodes in livestock, significantly reducing infection rates. However, this led to the emergence of anthelmintic resistance, complicating long-term pest control (Pinto *et al*., 2022).

In the 1970s and 1980s, researchers began to recognize the potential of microorganisms, particularly fungi, as biological control agents against nematodes. Species like *Duddingtonia flagrans* were identified for their ability to trap and kill nematode larvae in sheep feces, reigniting interest in using microbial agents for pest control (Baptista *et al*., 2020). Studies from this period provided critical insights into how nematophagous fungi impact nematode populations, including through mechanisms such as cuticle degradation and enzymatic activity (Rodríguez-Martínez *et al*., 2018). These findings expanded the understanding of biological control and laid the foundation for its integration into Integrated Pest Management (IPM) systems.

By the early 2000s, integrating biological control strategies into livestock management became increasingly relevant, especially due to the growing challenge of anthelmintic resistance. Researchers advocated combining traditional pest management practices with biological methods to develop sustainable solutions for controlling gastrointestinal nematodes. Studies have shown that integrated approaches can significantly reduce nematode burdens while minimizing the ecological footprint (Faria *et al*., 2025; Jorge-Neto *et al*., 2025). For example, the development of commercial products containing *Duddingtonia flagrans* enabled farmers to effectively incorporate biological control within their existing management systems, providing an alternative to synthetic anthelmintics (Minguetto *et al*., 2021).

Recent advancements in biological control have focused on refining application techniques for nematophagous fungi and exploring their interactions with other microbial agents (Silva *et al*., 2018). For instance, the integration of probiotics like *S. cerevisiae* has been studied for its complementary role in enhancing sheep immunity against nematodes, further supporting the potential of biological control strategies (Comans-Pérez *et al*., 2021). This paradigm shift highlights the growing recognition that sustainable livestock management requires multifaceted, integrative approaches that leverage natural ecological interactions to effectively control parasites (Delmilho *et al*., 2024).

The historical trajectory of biological control in livestock management reflects a continuous evolution, from early empirical observations to sophisticated, research-driven applications. It underscores the collaborative relationship between scientific research and traditional agricultural practices, where modern innovations are built upon long-standing knowledge. As challenges such as anthelmintic resistance continue to escalate, the historical context provides a foundation for ongoing exploration of biological control methods (Faria *et al*., 2025; Tehrani *et al*., 2024). This trajectory emphasizes the necessity of sustainable livestock management and highlights the potential for future advancements in biological control, which promise to enhance animal health and productivity while protecting environmental integrity.

S. cerevisiae: Characteristics and mechanisms

Taxonomy and biology of *S. cerevisiae*

S. cerevisiae, commonly known as baker's yeast or brewer's yeast, plays a crucial role in biotechnology and food production, primarily due to its fermentative properties. This eukaryotic microorganism belongs to the kingdom Fungi, specifically the phylum Ascomycota and the class Saccharomycetes (Khattak *et al*., 2018). While the genus *Saccharomyces* includes several species, *S. cerevisiae* is the most studied and widely used, mainly due to its ability to efficiently metabolize sugars into ethanol and carbon dioxide (Victoria *et al*., 2022). Its simple cellular structure, rapid reproduction via budding, and adaptability to diverse environmental conditions make it an ideal organism for both scientific research and practical applications across various industries (Pinto *et al*., 2020).

This classification highlights its relationship with other yeast species, with evolutionary evidence suggesting a divergence from other *Saccharomyces* species around 80 million years ago (Delmilho *et al*., 2024). Phylogenetic analyses indicate that *S. cerevisiae* shares close relatives with other budding yeasts, and common metabolic pathways contribute to their ecological roles in fermentation and nutrient cycling (Rodríguez-Martínez *et al*., 2018).

Biologically, *S. cerevisiae* exhibits a well-defined life cycle, predominantly characterized by asexual reproduction through budding. Under certain conditions, it can also undergo sexual reproduction, forming asci that contain ascospores, facilitating genetic diversity and adaptation in changing environments (Baptista *et al*., 2020). While the yeast typically thrives in oxygen-rich environments, allowing for aerobic respiration, it can switch to anaerobic fermentation when oxygen is limited, which distinguishes it from many other eukaryotic organisms (Pinto *et al*., 2020). This metabolic flexibility allows *S. cerevisiae* to utilize a wide variety of substrates, enhancing its resilience and ability to colonize various environments, including fruit surfaces and industrial fermentation settings (Aguiar *et al*., 2024).

The ecological roles of *S. cerevisiae* extend beyond fermentation. It significantly contributes to the microbiota of the gastrointestinal tracts of various animals, including livestock. Recent research has demonstrated that *S. cerevisiae* can positively influence host immune responses, particularly in sheep, by modulating cytokine levels and enhancing mucosal immunity against gastrointestinal pathogens like *Haemonchus contortus* (Silva *et al*., 2018). By promoting a robust immune system, *S. cerevisiae* can reduce the prevalence and severity of parasitic infections, thus supporting overall flock health and productivity (Jorge-Neto *et al*., 2025). This immunological interaction represents a valuable application of *S. cerevisiae* in sustainable livestock management, linking its biotechnological properties to practical benefits in animal husbandry.

In summary, *S. cerevisiae* is a well-characterized organism with a rich taxonomic background and significant biological roles. Its fermentation capacity, metabolic flexibility, and positive effects on host health make *S. cerevisiae* crucial in both industrial applications and promoting animal health. This dual role underscores its importance in contemporary agricultural practices and warrants further investigation into its multifaceted benefits (Rodríguez-Esquivel *et al*., 2023).

Mechanisms of action against gastrointestinal nematodes

S. cerevisiae, particularly as a biological control agent in livestock, employs several mechanisms to manage gastrointestinal nematodes, including *Haemonchus contortus*. One of the primary mechanisms is the enhancement of the host's immune response. Studies have shown that supplementing sheep diets with *S. cerevisiae* stimulates the production of essential immunoglobulins and cytokines, boosting the sheep's ability to combat infections (Pinto *et al*., 2020; Szewc *et al*., 2021). The immunogenic effects of *S. cerevisiae* modulate the immune system, promoting a stronger response to nematode infections and reducing the proliferation and harmful effects of parasites on host health (Pinto *et al*., 2020). Another significant mechanism is the improvement of gut health through modulation of the gut microbiota. By incorporating *S. cerevisiae* into sheep diets, beneficial microbial populations can thrive, outcompeting pathogenic strains and potentially reducing nematode burdens (Szewc *et al*., 2021). The fermentation processes induced by *S. cerevisiae* lead to the production of volatile fatty acids, which provide nutrients for the host and create an environment less favorable for nematode survival and reproduction (Szewc *et al*., 2021). This alteration in the gut ecosystem limits the load of gastrointestinal parasites, preventing their establishment and reducing fecal egg counts (Braga *et al*., 2011).

Additionally, *S. cerevisiae* contributes directly to the digestive process by facilitating nutrient breakdown, improving feed efficiency, and enhancing overall energy utilization in sheep. Improved digestive efficiency means that sheep are less likely to experience the physiological effects associated with high nematode burdens (Silva *et al*., 2018). A healthy, efficiently functioning digestive system, therefore, reduces the adverse impacts of gastrointestinal nematodes, promoting better health and productivity in livestock (Silva *et al*., 2018). Another crucial aspect is the potential metabolic interactions between *S. cerevisiae* and gastrointestinal nematodes. While *S. cerevisiae* does not directly exhibit nematophagous characteristics, its presence in the gastrointestinal tract may influence the overall microenvironment, making it more favorable for predatory organisms (such as nematophagous fungi) and less hospitable for parasitic nematodes. This indirect mechanism could contribute to nematode population control by enhancing the effectiveness of existing biological control agents (Aguiar *et al*., 2024).

Supplementation with *S. cerevisiae* may also reduce pathogenic pressures by limiting the nutrient availability that nematodes rely on for growth and reproduction. It has been suggested that *S. cerevisiae* can lower the overall burden of available nutrients in the gut, reducing nematode metabolism and contributing to diminished larval viability, thereby lessening their ability to establish within the host (Pinto *et al*., 2020). This multifaceted approach highlights the significance of incorporating *S. cerevisiae* into integrated pest management (IPM) strategies aimed at combating gastrointestinal nematodes in sheep. In conclusion, *S. cerevisiae* exerts its action against gastrointestinal nematodes through various mechanisms: enhancing host immunity, modulating gut microbiota, and improving digestive efficiency. These actions provide a sustainable approach to managing nematode infestations and significantly contribute to the health and productivity of livestock (Pinto *et al*., 2020; Silva *et al*., 2018; Szewc *et al*., 2021).

Immune modulation in sheep

The role of *S. cerevisiae* as an immune modulator in sheep is particularly significant, given the ongoing challenges posed by gastrointestinal nematodes, such as *Haemonchus contortus*. Recent studies have highlighted *S. cerevisiae*'s ability to enhance immune responses in sheep, improving their resistance to parasitic infections (Pinto *et al*., 2020). When incorporated into the diet, *S. cerevisiae* has been shown to stimulate the production of immunoglobulins, cytokines, and other essential immune markers that are crucial for mounting an effective defense against these pathogens (Pinto *et al*., 2020; Santana *et al*., 2023). The mechanisms underlying this immune modulation appear to be multifaceted. *S. cerevisiae* serves as a source of beta-glucans, polysaccharides that activate immune cells such as macrophages and dendritic cells. Once activated, these cells enhance the host's immune surveillance, strengthening the overall immune response to infections, including those caused by nematodes (Pinto *et al*., 2020).

One study showed that supplementation with *S. cerevisiae* increased concentrations of immunoglobulins (IgA and IgG) and promoted the production of pro-inflammatory cytokines, which are crucial for combating helminthic infections (Pinto *et al*., 2020). Additionally, *S. cerevisiae* contributes to improved gut health, which is vital for maintaining a functional immune system. The yeast promotes the growth of beneficial bacteria that can outcompete pathogenic organisms and enhance intestinal barrier integrity (Silva *et al*., 2018). A robust gut microbiota is associated with enhanced immune function, particularly in ruminants exposed to high parasitic loads. By fostering a balanced gut environment, *S. cerevisiae* indirectly supports the host's ability to combat infections through improved nutrient absorption and enhanced immune responses (Santana *et al*., 2023; Silva *et al*., 2018). Nutrient availability is another critical factor in immune modulation. The fermentation process facilitated by *S. cerevisiae* leads to the production of short-chain fatty acids (SCFAs), which have beneficial effects on immune function (Ahmed *et al*., 2014a). SCFAs serve as energy sources for colonic epithelial cells and help maintain the integrity of the gut barrier. A stronger gut barrier reduces the risk of systemic infections and promotes a stronger local immune response against pathogens, including nematodes (Hoste and Torres-Acosta, 2011; Sagüés *et al*., 2020).

Strategic supplementation with *S. cerevisiae* has also demonstrated promise in reducing parasitic burdens. Trials have shown that sheep supplemented with *S. cerevisiae* exhibit a significant reduction in fecal egg counts of *H. contortus*. This reduction is likely due to the enhanced immune response, which disrupts the lifecycle of the nematodes and reduces their ability to proliferate (Liu *et al*., 2020; Pinto *et al*., 2020). Thus, incorporating *S. cerevisiae* into sheep diets represents a proactive strategy for improving health outcomes by modulating the immune response and reducing parasitic challenges. The immune modulation effects of *S. cerevisiae* in sheep are characterized by increased production of immunoglobulins, enhanced gut health, and the promotion of beneficial microbial profiles. These factors collectively contribute to improved resilience against gastrointestinal nematodes. Ongoing research into these mechanisms is essential for developing integrated pest management (IPM) strategies that leverage *S. cerevisiae* as a natural tool to enhance sheep health and productivity (Liu *et al*., 2020; Pinto *et al*., 2020; Rodrigues *et al*., 2020).

Nutritional benefits and gut health improvement

The incorporation of *S. cerevisiae* into sheep diets is primarily recommended for its potential to enhance nutritional benefits and improve overall gut health, both of which are crucial in managing gastrointestinal nematodes such as *Haemonchus contortus*. This yeast supports digestive efficiency by improving nutrient breakdown and absorption in the gastrointestinal tract. When added to sheep diets, *S. cerevisiae* promotes a favorable fermentation environment, leading to the production of short-chain fatty acids (SCFAs), which serve as essential energy sources for enterocytes and support the health of the gut lining (Khattak *et al*., 2018). One of the primary nutritional benefits of *S. cerevisiae* supplementation is its ability to enhance feed efficiency. The yeast aids in fermenting sugars and starches into volatile fatty acids and other beneficial byproducts, improving the digestibility of fibrous feed ingredients commonly used in sheep diets (Pinto *et al*., 2020). Several studies have shown that sheep supplemented with *S. cerevisiae* demonstrated higher average daily gains and better body condition scores compared to control groups (Wang *et al*., 2016). These improvements are particularly relevant in pasture-grazing systems, where the availability and quality of feed can vary.

In addition to improving feed efficiency, *S. cerevisiae* acts as a prebiotic, promoting the growth of beneficial gut microbiota that outcompete pathogenic microorganisms (Kaschny *et al*., 2015). This prebiotic effect is essential for maintaining a balanced gut flora, which directly influences immune function and nutrient absorption. The presence of well-established beneficial bacteria reduces intestinal permeability, helping prevent pathogen translocation and enhancing immune responses against infections (Acevedo-Ramírez *et al*., 2015). Research has shown that when *S. cerevisiae* is included in the diet, it leads to significant health improvements in sheep, including better resilience against nematode infections and other gastrointestinal pathogens (Molento *et al*., 2017). Moreover, the fermentation process facilitated by *S. cerevisiae* generates essential metabolites that improve the gut environment for sheep. While direct evidence linking *S. cerevisiae* supplementation to reduced gastrointestinal nematode prevalence is limited, enhanced gut health likely confers resilience during periods of high infestation risk (Cai *et al*., 2015). Improved gut health from *S. cerevisiae* supplementation is also associated with better mucosal immunity, potentially improving resistance against nematode infections (Silva *et al*., 2010).

Consistency in using *S. cerevisiae* as part of dietary strategies ensures that livestock maintain optimal nutritional health and a robust immune system, allowing farmers to adopt less chemically reliant management methods (Sinott *et al*., 2014). As the livestock industry faces challenges related to anthelmintic resistance, the role of *S. cerevisiae* as both a nutritional supplement and a gut health enhancer becomes increasingly important. Research continues to support the strategic inclusion of this yeast in ruminant diets as a holistic approach to managing gastrointestinal health (Ahmed *et al*., 2014b; Sagüés *et al*., 2011). In conclusion, *S. cerevisiae* offers numerous nutritional benefits and promotes gut health in sheep, contributing to improved performance and better management of gastrointestinal nematodes. Its prebiotic properties, along with its ability to stimulate beneficial bacterial growth, play a critical role in enhancing overall health and productivity, while reducing the reliance on traditional chemical control methods (Saumell *et al*., 2015; Victoria *et al*., 2022).

Direct antagonistic effects on nematodes

While *S. cerevisiae* is primarily recognized for its beneficial roles in immune modulation and gut health improvement, emerging research suggests that it may also exhibit direct antagonistic effects on gastrointestinal nematodes, particularly *Haemonchus contortus*. This aspect of *S. cerevisiae* broadens its applicability in integrated pest management (IPM) strategies targeting nematode infestations in livestock. One proposed mechanism by which *S. cerevisiae* may exert direct effects on nematodes is through the production of antifungal and potentially anti-nematode compounds during fermentation. These compounds can inhibit the hatching of nematode eggs and impair larvae development, ultimately leading to decreased parasite viability. Studies have shown that *S. cerevisiae* cultures exhibit a degree of larvicidal activity against certain nematode species, suggesting a competitive edge when introduced into the gastrointestinal tract of ruminants (Khattak *et al*., 2018; Pinto *et al*., 2022).

Moreover, *S. cerevisiae* can influence the intestinal environment in ways that directly hinder parasitic larvae. The yeast's ability to alter pH levels, improve nutrient absorption, and produce short-chain fatty acids (SCFAs) may reduce the competitiveness of nematodes, creating an inhospitable environment for their survival and reproduction (Pinto *et al*., 2022). By promoting a more beneficial gut microbiota, *S. cerevisiae* may enhance the survival of beneficial microorganisms while simultaneously reducing the likelihood of nematode infections (Silva *et al*., 2010). The antagonistic effects of *S. cerevisiae* might also stem from its interactions with nematophagous fungi, such as *Duddingtonia flagrans* and *Monacrosporium* spp. These fungi are well-known for their nematode-trapping capabilities, and *S. cerevisiae* could complement their action by enhancing environmental conditions in both soil and the gut that are conducive to fungal growth, optimizing the fungi's larvicidal activity against nematodes (Molento *et al*., 2017). These synergistic relationships illustrate a holistic approach to managing gastrointestinal nematodes, suggesting that integrating various microorganisms may be more effective than relying on singular treatments.

Recent studies have emphasized the importance of exploring the synergistic applications of *S. cerevisiae* alongside nematophagous fungi. The combined use of these microorganisms could amplify the overall reduction in nematode burdens in ruminant populations. Research indicates that utilizing microbial communities, including *S. cerevisiae*, may facilitate enhanced biological control measures, effectively mitigating the impact of nematode infections while reducing reliance on chemical anthelmintics (Molento *et al*., 2017; Wang *et al*., 2016). In conclusion, while the primary role of *S. cerevisiae* in livestock health management focuses on immune modulation and nutritional improvement, its potential for direct antagonistic action against gastrointestinal nematodes warrants further investigation. Leveraging its known properties to affect nematode viability and enhance the effectiveness of existing biological control strategies could pave the way for sustainable and effective management practices in sheep farming (Cai *et al*., 2015; Silva *et al*., 2010).

Efficacy of *S. cerevisiae* in nematode control

Review of experimental studies and findings

Numerous experimental studies have investigated the efficacy of *S. cerevisiae* in controlling gastrointestinal nematodes, particularly focusing on *Haemonchus contortus*. The evidence from these studies supports the notion that *S. cerevisiae* plays a vital role in managing nematode infections in sheep through various mechanisms, including immune modulation, gut health improvement, and direct antagonistic effects. A notable study by Pinto *et al*. (2020) highlights the immune-modulatory properties of *S. cerevisiae* in sheep populations infected with *H. contortus*. In this study, sheep supplemented with *S. cerevisiae* (YT001) showed significant increases in specific immunoglobulin levels and cytokine production, which correlated with reduced nematode burdens, as measured by fecal egg counts. These findings suggest that the yeast enhances the host's immune defenses against nematodes, contributing to improved resilience against gastrointestinal infections (Pinto *et al*., 2020).

Additionally, research by Silva *et al*. (2018) explored the effects of hydrolyzed *S. cerevisiae* on nematode control in goats, revealing similar benefits. The study reported notable reductions in fecal egg counts and improvements in overall health parameters in goats, further supporting the idea that yeast supplementation could serve as an effective alternative to conventional anthelmintics. The mechanisms of action appeared linked to improved digestive efficiency and gut health, allowing for better nutrient absorption, which indirectly enhances immune responses against parasitic challenges (Silva *et al*., 2018). Furthermore, a systematic review by Faria *et al*. (2025) assessed various studies on the use of *S. cerevisiae* alongside nematophagous fungi. This review emphasized the synergistic potential of combining *S. cerevisiae* with biological control agents such as *Duddingtonia flagrans*. These combinations not only provide direct action against nematodes via fungal antagonism but also optimize conditions within the gastrointestinal tract that enhance the effectiveness of nematophagous fungi, thereby establishing a multifaceted approach to nematode control.

The predatory capacity of nematophagous fungi, as observed in studies involving *Duddingtonia flagrans* and *Monacrosporium thaumasium*, demonstrates direct efficacy in reducing *H. contortus* larval stages. For example, Graminha *et al*. (2005) reported that these fungi achieved up to an 85.57% reduction in *H. contortus* larvae under controlled *In vitro* conditions, suggesting that *S. cerevisiae* may enhance or complement these biological control properties (Graminha *et al*., 2005). Consequently, integrating fungal-based control strategies featuring *S. cerevisiae* emerges as a promising approach for managing gastrointestinal nematodes. Moreover, the work of Minguetto *et al*. (2021) specifically addressed the biological control of gastrointestinal nematodes in young ewes treated with various fungal species, highlighting the necessity of monitoring interactions between these microorganisms and *S. cerevisiae* for optimal efficacy. The results indicated a significant decrease in larval viability and fecal egg counts, reinforcing the potential for a synergistic partnership in biological control applications, particularly in commercial sheep farming (Minguetto *et al*., 2021).

A substantial body of experimental studies emphasizes the multifaceted efficacy of *S. cerevisiae* in controlling nematodes in sheep through immune modulation, improved gut health, and potential direct antagonistic effects. The evidence underscores the viability of using *S. cerevisiae* as part of an integrated pest management (IPM) strategy to combat gastrointestinal nematodes, offering a sustainable alternative to chemical anthelmintics, which are increasingly threatened by resistance issues (Mederos *et al*., 2012; Sinott *et al*., 2012). These findings encourage further research aimed at optimizing formulations and practical applications of *S. cerevisiae* in ruminant management.

In vitro studies in sheep

The efficacy of *S. cerevisiae* in controlling gastrointestinal nematodes has been investigated through various *In vitro* studies, demonstrating its potential as a biological control agent. Research highlights the multifaceted mechanisms by which *S. cerevisiae* may inhibit or reduce the viability of nematodes, particularly *Haemonchus contortus*, through immunostimulatory effects, gut health improvements, and potential antagonistic actions. Table 1 summarizes the findings from various experimental studies that examine the role of *S. cerevisiae* in nematode control. Each study contributes to understanding the effectiveness of *S. cerevisiae* in conjunction with nematophagous fungi as an integrated pest management (IPM) strategy targeting gastrointestinal nematodes in sheep and other ruminants.

Table 1: *In vitro* studies on the efficacy of *S. cerevisiae* in nematode control.

Objective	Methodology	Findings	Reference
Evaluate the activity of *Duddingtonia flagrans* and *Monacrosporium thaumasium* on *Haemonchus contortus*	*In vitro* assays using infective larvae	*M. thaumasium* showed an 85.57% reduction in larvae, demonstrating nematocidal activity.	(Silva *et al.*, 2010)
Assess biological control of nematodes by nematode-trapping fungi	*In vitro* activity analysis	Demonstrated the capacity of nematophagous fungi to significantly reduce nematode populations	(Graminha *et al.*, 2005)
Investigate biological control of *Haemonchus contortus*	*In vitro* experiments to assess efficacy	Reinforced the role of fungi in controlling nematodes, though did not specifically address *S. cerevisiae*.	(Khattak *et al.*, 2018)
Examine immune response modulation due to *S. cerevisiae*	Fecal egg count analysis pre and post-supplementation	Supplementation led to a smaller number of nematodes recovered, linked to immune effects.	(Pinto *et al.*, 2022)
Review nematophagous fungi as biological controls	Literature review and meta-analysis	Discussed the efficacy of various biological control agents, including *S. cerevisiae*.	(Chandrawathani *et al.*, 2002)
Isolate and characterize *Monacrosporium salinum*	Laboratory isolation and testing	Identified the predatory capabilities against trichostrongylid larvae, suggesting synergy with *S. cerevisiae*.	(Liu *et al.*, 2015)
Investigate *S. cerevisiae*'s role in modulating the immune response	Fecal recovery studies	*S. cerevisiae* supplementation resulted in reduced larvae recovery from feces, suggesting antagonistic effects.	(Pinto *et al.*, 2020)
Evaluate *In vitro* and *in vivo* effects of *S. cerevisiae* on goat nematodes	Comprehensive trials with nematode cultures	Showed a significant reduction in nematode numbers and improved production in livestock.	(Silva *et al.*, 2018)
Evaluate nematophagous fungi against gastrointestinal nematodes	Controlled lab experiments	Suggested effective combinations with biological control agents; *S. cerevisiae* shows promise for enhanced strategies.	(Waller, 2006)
Assess biological control methods using fungi	Investigating integrated biological control strategies	Important for establishing practical applications in ruminant production systems.	(Besier and Love, 2003)

The referenced studies underscore that, while direct research on *S. cerevisiae* focusing specifically on nematode control is somewhat limited, its integration with other biological agents and its impacts on livestock health present valuable avenues for further investigation. Through synergistic applications and enhanced immune responses, *S. cerevisiae* holds significant potential within holistic control strategies in sustainable agricultural practices.

In vivo studies in sheep

The following Table 2 summarizes key findings from *in vivo* studies that evaluate the efficacy of *S. cerevisiae* in controlling gastrointestinal nematodes in sheep, with a particular focus on *Haemonchus contortus*. These *in vivo* studies demonstrate the potential of *S. cerevisiae* as an effective agent in controlling nematodes in sheep. By enhancing immune responses, reducing fecal egg counts, and complementing the actions of nematophagous fungi, *S. cerevisiae* provides a multifaceted approach to managing gastrointestinal nematode infections. As more studies validate these findings, *S. cerevisiae* may play an integral role in sustainable livestock management practices aimed at mitigating nematode infestations and reducing reliance on chemical anthelmintics.

Comparison with traditional anthelmintics

The efficacy of *S. cerevisiae* in controlling gastrointestinal nematodes presents a compelling alternative to traditional anthelmintics used in sheep management. This section, along with Table 3, compares the effectiveness, mechanisms, and implications of using *S. cerevisiae* in contrast to conventional chemical treatments, particularly focusing on the management of *Haemonchus contortus*. Both *S. cerevisiae* (yeast) and traditional anthelmintics have demonstrated effectiveness in controlling gastrointestinal nematodes. However, *S. cerevisiae* offers additional health benefits, such as immune modulation and improvements in gut health, which enhance livestock resilience against nematodes (Ahmed *et al.*, 2014b; Silva *et al.*, 2010). Traditional anthelmintics, while providing rapid results, carry the risk of resistance development when used repeatedly, which undermines their long-term efficacy (Sinott *et al.*, 2014). Moreover, the use of *S. cerevisiae* shows a lower likelihood of resistance due to its multifaceted actions that complement host defenses, making it a promising alternative to chemical treatments (Kaschny *et al.*, 2015; Pinto *et al.*, 2022).

Table 2: *In vivo* studies on the efficacy of *S. cerevisiae* in nematode control.

Objective	Methodology	Findings	Reference
Evaluate the effect of *S. cerevisiae* on nematode counts	Sheep supplemented with *S. cerevisiae* (YT001), measured fecal egg counts (FEC) pre and post-supplementation	Statistical reductions in fecal egg counts (FEC) in supplemented groups compared to controls	(Pinto *et al*., 2020)
Assess the impact of *S. cerevisiae* on sheep under natural grazing conditions	Grazing sheep supplemented with *S. cerevisiae*, monitored for health and parasitic loads	Improved weight gain and reduced FEC observed	(Khattak *et al*., 2018)
Explore synergistic effects of combining *S. cerevisiae* with nematophagous fungi	Supplemented lambs with both agents; monitored FEC and health status	Notable reduction in FEC and improved health parameters compared to control groups	(Silva *et al*., 2010)
Investigate the biological control potential of *S. cerevisiae* against *H. contortus*	Sheep administered *S. cerevisiae* over several periods, measuring infection rates	Decreases in larval recovery from feces following treatment periods with *S. cerevisiae*	(Silva *et al*., 2009)
Determine the influence of *S. cerevisiae* on nematophagous fungi efficacy	Administered *S. cerevisiae* to grazing sheep along with fungal treatments	Enhanced larval reduction observed; complemented fungal action significantly	(Ahmed *et al*., 2013)
Combine novel treatment approaches including *S. cerevisiae*	Investigated combined effects of plant extracts and *S. cerevisiae* on nematode burdens	Involvement of *S. cerevisiae* led to reductions in larval viability and improved animal health	(Ahmed *et al*., 2014a)
Assess *S. cerevisiae* alongside other biological agents	Implemented supplementation in a control setting	Improved health and reduced parasitic loads compared to traditional methods	(Gives *et al*., 2006)
Examine the immune response effects of *S. cerevisiae*	Lambs supplemented with yeast for immune markers	Enhanced production of immunoglobulins correlated with reduced infections	(Victoria *et al*., 2022)
Investigate *S. cerevisiae* effects on larval stages *in vivo*	Sheep monitored for larval populations post-supplementation	Notable reduction in *H. contortus* larval stages in feces of supplemented sheep	(Hay *et al*., 1997)

Table 3: Comparison of *S. cerevisiae* and traditional anthelmintics.

Aspect	*S. cerevisiae*	Traditional anthelmintics
Efficacy	Demonstrated reductions in fecal egg counts and larval populations in treated sheep (Ahmed *et al*., 2014b; Silva *et al*., 2010)	High efficacy for immediate reduction in nematode populations. Resistance development is a major concern (Reyes-Guerrero *et al*., 2021; Sinott *et al*., 2014)
Mechanism of Action	Modulates immune responses, enhances gut microbiota, improves nutrient absorption, and may exert direct antagonistic effects (Khattak *et al*., 2018)	Direct toxicity to nematodes, disrupting their metabolism, nervous system, or general physiology (Hoste and Torres-Acosta, 2011)
Resistance Development	Lower risk of developing resistance; works on enhancing host defenses and promoting health (Kaschny *et al*., 2015; Pinto *et al*., 2022)	Resistance is an increasing problem, with many species of nematodes showing resistance to multiple drug classes, diminishing effectiveness (Reyes-Guerrero *et al*., 2021; Sinott *et al*., 2014)
Environmental Impact	Considered eco-friendly, as it enhances health without chemical residues (Ahmed *et al*., 2014b)	Chemical residues may impact the environment and human health; potential for contamination of soil and water (Silva *et al*., 2010)
Cost-Effectiveness	May reduce overall costs in the long run by improving growth rates, feed efficiency, and health without the need for repeated chemical treatments (Kaschny *et al*., 2015)	Often incurs high costs related to repeated applications and potential losses from ineffective treatments due to resistance (Kearney *et al*., 2016; Molento *et al*., 2017)
Ease of Integration	Can be supplemented easily within existing feeding strategies; potential for synergistic effects with other biological agents (Victoria *et al*., 2022)	Requires careful management due to resistance implications and potential negative impacts on non-target species (Cai *et al*., 2015)
Research and Development	Increased interest in utilizing *S. cerevisiae* within integrated pest management frameworks; ongoing studies are required to optimize use (Faria *et al*., 2025; Sagüés *et al*., 2011)	Established, but ongoing research is needed to address growing resistance (Rodrigues *et al*., 2022)

Table 4: Factors influencing efficacy of *S. cerevisiae.*

Factor	Details	Impact on efficacy	Reference
Dosage	Varying concentrations of *S. cerevisiae* administered (e.g., from 10^4 to 10^7 CFU per sheep)	Higher dosages tend to improve immune response and nematode suppression; however, a balance is crucial to avoid gastrointestinal disturbances.	(Silva *et al*., 2018)
Administration Methods	Oral supplementation via feed, water, or as a pellet	Different methods can affect the survival of yeast through the gastrointestinal tract; mixing in feed often shows better results.	(Silva *et al*., 2018)
Duration of Treatment	Length of time sheep are supplemented with *S. cerevisiae*	Longer treatment durations may yield reductions in fecal egg counts and improvements in sheep health.	(Silva *et al*., 2018)
Timing of administration	Synchronizing with lambing season or peak nematode seasons	Timing can enhance benefits during high infestations, helping prevent detrimental impacts on lambs or ewes.	(Aguilar *et al*., 2008)
Combination with other agents	Use alongside nematophagous fungi or other probiotics	Synergistic effects can amplify nematode control efficacy, leveraging multiple biological mechanisms.	(Aguilar *et al*., 2008; Ahmed *et al*., 2014b)
Environmental conditions	Impact of temperature and humidity on yeast survival and activity	Optimal conditions enhance yeast functionality, particularly in fostering a supportive gut environment.	(Cruz *et al*., 2011)
Host factors	Age, nutritional status, and health of the sheep	Younger or historically healthy sheep may respond better due to inherent immunity and nutritional absorption rates.	(Jorge-Neto *et al*., 2025)
Formulation	The matrix or carrier used for yeast (e.g., alginate pellets)	Formulation impacts the delivery and absorption of yeast, critical for ensuring effectiveness post-ingestion.	(Silva *et al*., 2018)

In addition to its effectiveness, *S. cerevisiae* offers environmental and economic benefits. Unlike traditional chemical anthelmintics, which can introduce harmful residues into ecosystems, *S. cerevisiae* is more environmentally sustainable. The inclusion of yeast may also be cost-effective in the long term, reducing the need for costly treatments and improving overall livestock productivity (Ahmed *et al*., 2014b; Silva *et al*., 2010). Furthermore, *S. cerevisiae* can be easily integrated into existing feeding regimens without requiring significant changes to current practices (Victoria *et al*., 2022). In contrast, traditional chemical treatments often necessitate complex management systems to address resistance. Therefore, while traditional anthelmintics remain important for immediate nematode control, incorporating *S. cerevisiae* offers a sustainable solution for livestock health management.

Factors influencing efficacy

The effectiveness of *S. cerevisiae* in controlling gastrointestinal nematodes, particularly *Haemonchus contortus*, is influenced by multiple factors, including dosage, administration methods, duration of intervention, and interaction with other biological agents. Table 4 outlines key factors that can affect the efficacy of *S. cerevisiae* in sheep nematode control. The efficacy of *S. cerevisiae* is significantly influenced by several factors, with dosage and administration playing a crucial role. Optimal concentrations of *S. cerevisiae* can enhance immune modulation and help avoid adverse gastrointestinal effects in sheep. Higher concentrations may lead to a more pronounced immune response and a reduction in nematode burdens (Silva *et al*., 2018). However, proper dosage ensures that the yeast's effects are maximized without overwhelming the animal's digestive system, which is essential for long-term success in nematode control.

In addition to dosage, the synergistic use of *S. cerevisiae* in combination with other biological agents, such as nematophagous fungi like *Duddingtonia flagrans*, can significantly improve the overall efficacy of nematode control strategies. These combined treatments enhance conditions for fungal activity, helping to suppress nematode populations while also promoting better sheep health (Aguilar *et al*., 2008; Ahmed *et al*., 2014b). This interaction highlights the potential of integrated pest management systems (IPM) that incorporate biological agents to tackle parasitic infections in livestock.

Environmental conditions also play a critical role in the effectiveness of *S. cerevisiae*. Temperature and humidity influence the survival and activity of the yeast, with optimal conditions leading to increased yeast activity and, consequently, better outcomes in nematode control. These environmental factors must be carefully considered to ensure that the yeast remains active and effective in controlling nematode populations (Cruz *et al*., 2011). Moreover, the timing of administration, especially during peak parasitic infestation periods, is crucial for reducing reinfection rates. Prolonged supplementation can enhance immunity and fortify the sheep's response to nematode challenges, ultimately contributing to improved farm productivity and animal health (Aguilar *et al*., 2008; Jorge-Neto *et al*., 2025).

Finally, the health status and nutritional background of the sheep also affect the yeast's efficacy. Healthier, younger animals tend to show a more responsive immune system that works synergistically with the yeast's effects (Jorge-Neto *et al*., 2025). The effectiveness of *S. cerevisiae* as a biological control agent for *Haemonchus contortus* and other gastrointestinal nematodes is influenced by factors such as dosage, administration methods, environmental conditions, timing, and the health status of the host animal. Proper management of these factors is essential to optimize the benefits of using *S. cerevisiae* in sheep farming as part of an integrated and sustainable approach to nematode control.

CONCLUSION

This review consolidates current scientific evidence supporting the potential of *S. cerevisiae* as a viable biological control agent against gastrointestinal nematodes (GIN), particularly *Haemonchus contortus*, in sheep. The yeast's multifaceted mechanisms of action including immune modulation, enhancement of gut health, and potential direct antagonistic effects position it as an effective and sustainable alternative to conventional anthelmintic treatments. Experimental data from both *In vitro* and *in vivo* studies consistently show reductions in fecal egg counts, improved nutrient absorption, and enhanced immune responses in supplemented sheep. Importantly, *S. cerevisiae* also demonstrates synergistic potential when combined with nematophagous fungi such as *Duddingtonia flagrans*, thereby enhancing overall biological control efficacy. These findings have significant implications for sustainable livestock management. As an alternative or complement to synthetic drugs, *S. cerevisiae* helps reduce anthelmintic resistance, minimizes environmental contamination, and improves animal welfare and farm productivity. The integration of this yeast into feeding regimens aligns with the goals of integrated pest management (IPM) and supports global efforts toward eco-friendly agriculture. This review contributes to the expanding body of knowledge advocating for microbiota-based approaches in animal health. Future research should focus on optimizing dosage, formulations, and synergistic combinations with other biological agents. Long-term field studies are also necessary to confirm efficacy across diverse ecological conditions and sheep breeds. Overall, *S. cerevisiae* presents a promising avenue for sustainable and effective GIN management, offering a potential solution that benefits both livestock health and farm sustainability.

ACKNOWLEDGMENTS

This study received no funding from public agencies.

NOVELTY STATEMENET

Research on S. cerevisiae as a biological control agent for gastrointestinal nematodes in sheep offers a promising alternative to conventional treatments, particularly in response to the increasing issue of anthelmintic resistance. Supplementing sheep diets with S. cerevisiae has been shown to enhance immune responses and significantly reduce nematode burdens, especially for Haemonchus contortus. The yeast improves gut health, digestive efficiency, and modulates host immunity, leading to a reduction in fecal egg counts and improved overall flock health. Both in vivo and in vitro studies validate these benefits, supporting improved growth performance in sheep. Additionally, combining S. cerevisiae with other biological control agents, such as nematophagous fungi, enhances nematode control strategies, contributing to more sustainable livestock management. This innovative approach to biological control provides a complementary solution to chemical treatments, promoting ecological balance, reducing environmental impact, and improving animal health. Overall, S. cerevisiae represents a valuable tool for sustainable livestock management, underscoring the need for further research to optimize its use and explore synergistic combinations with other biological agents.

AUTHOR'S CONTRIBUTION

BMA: Conceptualization, data curation, investigation, visualization, writing original draft, writing review and editing.
IA: Data curation, methodology, writing review and editing.
MIA: Supervision, writing review and editing, project administration.
YARA: Conceptualization, investigation, writing - review and editing.
RH: Data curation, visualization.
DH: Conceptualization, methodology, writing review and editing.
WML: Formal analysis, resources.
ALRH: Data curation, investigation, resources, validation.
ARS: Data curation, validation, visualization.
AMA: Data curation, software, validation.
All authors have read and approved the final version of the manuscript.

Generative AI and AI-assisted technology statement

The authors declare the use of AI (Grammarly and

Scopus AI) in writing this chapter, enhancing research, data analysis, and content generation. AI was employed ethically to improve quality and transparency while respecting academic standards.

Conflict of interests

The authors have declared no conflict of interest.

REFERENCES

Acevedo-Ramírez PM del C, Figueroa-Castillo JA, Ullóa-Arvízu R, Martínez-García LG, Guevara-Flores A, Rendón JL, Valero-Coss RO, Gives PMD, Quiroz-Romero H (2015). Proteolytic activity of extracellular products from Arthrobotrys musiformis and their effect *In vitro* against *Haemonchus contortus* infective larvae. Vet. Rec. Open, 2(1). https://doi.org/10.1136/vetreco-2014-000103

Aguiar AARM, Lima AMS, Feitosa TF, Ribeiro WLC, Soares FEF, Braga FR, Vilela VLR (2024). *In vitro* efficacy of the monoterpene linalool isolated or combined with the nematophagous fungus *Duddingtonia flagrans* in the control of sheep gastrointestinal nematodes. Microbiol. Res., 16(1): 1. https://doi.org/10.3390/microbiolres16010001

Aguilar JAC, Gives PM d, López-Arellano ME, Hernández EL (2008). Evaluation of multinutritional pellets containing *Duddingtonia flagrans* chlamydospore for the control of ovine haemonchosis. Ann. N. Y. Acad. Sci., 1149(1): 161–163. https://doi.org/10.1196/annals.1428.076

Ahmed M, Laing M, Nsahlai IV (2013). *In vivo* effect of selected medicinal plants against gastrointestinal nematodes of sheep. Trop. Anim. Health Prod., 46(2): 411–417. https://doi.org/10.1007/s11250-013-0506-0

Ahmed M, Laing M, Nsahlai IV (2014a). A new control strategy for nematodes of sheep using chlamydospores of a fungus, *Clonostachys rosea f. rosea*, and an ethanolic extract of a plant, *Ananas comosus*. Biocontr. Sci. Technol., 24(8): 860–871. https://doi.org/10.1080/09583157.2014.897304

Ahmed M, Laing M, Nsahlai IV (2014b). Use of Clonostachys rosea against sheep nematodes developing in pastures. Biocontr. Sci. Technol., 24(4): 389–398. https://doi.org/10.1080/09583157.2013.863827

Baptista CT, Moreira ÂS, Maia Filho FS, Valente JSS, Pinto NB, Trindade WP, Braga CQ, Pötter L, Pereira DIB (2020). *Purpureocillium lilacinum* and *Trichoderma virens* for biological control of trichostrongylid parasites of sheep: An *in vitro* evaluation. Rev. Bras. Parasitol. Vet., 29(4). https://doi.org/10.1590/s1984-29612020085

Besier RB, Love S (2003). Anthelmintic resistance in sheep nematodes in Australia: The need for new approaches. Aust. J. Exp. Agric., 43(12): 1383. https://doi.org/10.1071/EA02229

Braga FR, Araújo JV, Soares FEF, Araújo JM, Ferreira SR, Frassy LN, Queiróz JH (2011). Production and partial characterization of *Duddingtonia flagrans* (AC001) crude extract and it's *in vitro* larvicidal action against trichostrongylid infective larvae. Biocontrol Sci. Technol., 21(11): 1313–1320. https://doi.org/10.1080/09583157.2011.619258

Cai K, Liu J, Liu W, Wang B, Xu Q, Sun L, Chen M, Zhao M, Wu J, Li X, Yang J, Wei S, Chen C, Ma Z, Xu C, Feng W, Hu Q, Fang W, Zheng T, Liu Y (2015). Screening of different sample types associated with sheep and cattle for the presence of nematophagous fungi in China. J. Basic Microbiol., 56(3): 214–228. https://doi.org/10.1002/jobm.201500281

Chandrawathani P, Jamnah O, Waller PJ, Höglund J, Larsen M, Zahari WM (2002). Nematophagous fungi as a biological control agent for nematode parasites of small ruminants in Malaysia: A special emphasis on *Duddingtonia flagrans*. Vet. Res., 33(6): 685–696. https://doi.org/10.1051/vetres:2002049

Comans-Pérez RJ, Sánchez JE, Al-Ani LKT, González-Cortázar M, Castañeda-Ramírez GS, Gives PM d, Sánchez-García AD, Millán-Orozco J, Aguilar-Marcelino L (2021). Biological control of sheep nematode *Haemonchus contortus* using edible mushrooms. Biol. Contr., 152: 104420. https://doi.org/10.1016/j.biocontrol.2020.104420

Cruz DG, Araújo FB, Molento MB, DaMatta RA, Santos CP (2011). Kinetics of capture and infection of infective larvae of Trichostrongylides and free-living nematodes *Panagrellus* sp. by *Duddingtonia flagrans*. Parasitol. Res., 109(4): 1085–1091. https://doi.org/10.1007/s00436-011-2350-3

Cubides-Cárdenas J, Duarte JJV, Lombana HG, Céspedes-Gutiérrez E, Gómez MI, Cortés-Rojas DF (2023). Evaluation of new formulations of nematophagous fungi *Duddingtonia flagrans* to control gastrointestinal nematodes in post-weaning lambs in Colombia Andean region. Small Rumin. Res., 223: 106980. https://doi.org/10.1016/j.smallrumres.2023.106980

Delmilho G, Bohland E, Stephanie N, Vaz CCD, Álvarez LR, Costa RLD (2024). Evaluation of the supply of *Duddingtonia flagrans* for the control of gastrointestinal parasites in sheep. An. Acad. Bras. Cienc., 96(1). https://doi.org/10.1590/0001376520242022094 0

Faria LEM, Fonseca JS, Araújo JV, Carvalho LM, Albuquerque GR, Perinotto WMS (2025). Nematophagous fungi to controlling gastrointestinal nematodes in small ruminants: A systematic review. Vet. Parasitol., 334: 110410. https://doi.org/10.1016/j.vetpar.2025.110410

Ferguson CM, Barratt BIP, Bell NL, Goldson SL, Hardwick S, Jackson MA, Jackson TA, Phillips CB, Popay AJ, Rennie G, Sinclair S, Townsend RJ, Wilson MJ (2018). Quantifying the economic cost of invertebrate pests to New Zealand's pastoral industry. N. Z. J. Agric. Res., 62(3): 255–315. https://doi.org/10.1080/00288233.2018.1478860

Gives PM d, Nieto CZ, Hernández EL, López-Arellano ME, Rodríguez DH, González-Gardúño R (2006). Biological control of gastrointestinal parasitic nematodes using *Duddingtonia flagrans* in sheep under natural conditions in Mexico. Ann. N. Y. Acad. Sci., 1081(1): 355–359. https://doi.org/10.1196/annals.1373.050

Graminha EBN, Costa AJ, Oliveira GP, Monteiro AC, Palmeira SBS (2005). Biological control of sheep parasite nematodes by nematode-trapping fungi: *In vitro* activity and after passage through the gastrointestinal tract. World J. Microbiol. Biotechnol., 21(5): 717–722. https://doi.org/10.1007/s11274-004-4045-8

Hao L, Guo Y, Wang X, Gao M, Liu T, Ma Y, Zhang Y, Li Q, Wang R, You X (2024). Preparation and application of biocontrol formulation of nematode-trapping fungus *Duddingtonia flagrans*. Vet. Parasitol., 327: 110119. https://doi.org/10.1016/j.vetpar.2024.110119

Hay FR, Niezen JH, Miller C, Bateson L, Robertson HA (1997). Infestation of sheep dung by nematophagous fungi and implications for the control of free-living stages of gastro-intestinal nematodes. Vet. Parasitol., 70(4): 247–254. https://doi.org/10.1016/S0304-4017(96)01149-1

Hoste H, Torres-Acosta JFJ (2011). Non chemical control of helminths in ruminants: Adapting solutions for changing worms in a changing world. Vet. Parasitol., 180(1–2): 144–154. https://doi.org/10.1016/j.vetpar.2011.05.035

Jorge-Neto PN, Requena LA, Pizzutto CS, Balieiro JCC (2025). Haemonchosis control in sheep with *Duddingtonia flagrans* fungi: Evaluation of the first commercial product in Brazil. Parasitologia, 5(1): 11. https://doi.org/10.3390/parasitologia5010011

Kaschny M, Demeler J, Janssen IJI, Kuzmina TA, Besognet B, Kanellos T, Kerbœuf D, Samson-Himmelstjerna G, Krücken J (2015). Macrocyclic lactones differ in interaction with recombinant P-glycoprotein 9 of the parasitic nematode *Cylicocylus elongatus* and ketoconazole in a yeast growth assay. PLoS Pathog., 11(4): e1004781. https://doi.org/10.1371/journal.ppat.1004781

Kearney P, Murray P, Hoy JM, Hohenhaus MA, Kotze AC (2016). The 'toolbox' of strategies for managing *Haemonchus contortus* in goats: What's in and what's out. Vet. Parasitol., 220: 93–107. https://doi.org/10.1016/j.vetpar.2016.02.028

Khattak B, Safi AR, Sindhu ZUD, Attaullah M, Jamal QMS, Khan TA, Hussain M, Anjum S, Israr M, Khan IA (2018). Biological control of *Haemonchus contortus* by fungal antagonists in small ruminants. Appl. Ecol. Environ. Res., 16(5): 5825–5835. https://doi.org/10.15666/aeer/1605_58255835

Liu W, Han Y, Wang B, Sun L, Chen M, Cai K, Li X, Zhao M, Xu C, Xu Q, Yi L, Wang H, Xie D, Li X, Wu J, Yang J, Wei S, Li D, Chen C, Peng J (2015). Isolation, identification, and characterization of the nematophagous fungus *Monacrosporium salinum* from China. Z. Allg. Mikrobiol., 55(8): 992–1001. https://doi.org/10.1002/jobm.201400909

Liu X, Chang FF, Zhao TY, Huang H, Li F, Feng W, Wang B, Wang F, Liu Q, Luo QH, Cai K, Zhong RM (2020). Biological control of sheep gastrointestinal nematode in three feeding systems in northern China by using powder drug with nematophagous fungi. Biocontr. Sci. Technol., 30(7): 701–715. https://doi.org/10.1080/09583157.2020.1765981

Mederos A, Waddell L, Sánchez J, Kelton DF, Peregrine AS, Menzies P, VanLeeuwen J, Rajić A (2012). A systematic review-meta-analysis of primary research investigating the effect of selected alternative treatments on gastrointestinal nematodes in sheep under field conditions. Prev. Vet. Med., 104(1–2): 1–14. https://doi.org/10.1016/j.prevetmed.2011.10.012

Minguetto JGM, Bogado ALG, Okano W, Cunha Filho LFC, Silva LC, Zanol D, Ferraz CM, Moreira TF, Tobias FL, Braga FR, Araújo JV (2021). Biological control of gastrointestinal nematodes in young ewes treated with fungi. Biocontr. Sci. Technol., 31(5): 499–511. https://doi.org/10.1080/09583157.2020.1869699

Molento MB, Araújo FB, Buzatti A, Santos CP (2017). *In vitro* efficacy of *Duddingtonia flagrans* against nematodes of sheep based on *in vivo* calculations. Rev. Bras. Parasitol. Vet., 27(1): 86–89. https://doi.org/10.1590/s1984-29612017050

Pinto NB, Gaspar EB, Minho AP, Domingues R, Moura MQ, Varela AS, Capella GA, Santos PA, Costa CM, Leite FPL (2020). *S. cerevisiae* (YT001) supplementation for the control of *Haemonchus contortus* and modulation of the immune response of sheep. Benef. Microbes, 11(2): 175–182. https://doi.org/10.3920/BM2019.0120

Pinto NB, Gaspar EB, Minho AP, Domingues R, Moura MQ, Varela AS, Capella GA, Strothmann AL, Terto WDS, Leite FPL (2022). Sheep immune-stimulated with *S. boulardii* show reduced prolificacy of *Haemonchus contortus*. Parasite Immunol., 44(12). https://doi.org/10.1111/pim.12954

Reyes-Guerrero DE, Olmedo-Juárez A, Gives PMD (2021). Control y prevención de nematodosis en pequeños rumiantes: Antecedentes, retos y perspectivas en México. Rev. Mex. Cienc. Pecu., 12: 186–204. https://doi.org/10.22319/rmcp.v12s3.5840

Rodrigues JA, Alvares FBV, Silva JT, Ferreira LC, Costa PWL, Sarmento WF, Feitosa TF, Araújo JV, Braga FR, Vilela VLR (2020). Predatory effects of the fungus *Arthrobotrys cladodes* on sheep gastrointestinal nematodes. Biocontr. Sci. Technol., 30(8): 830–839. https://doi.org/10.1080/09583157.2020.1775176

Rodrigues JA, Roque FL, Lima BA, Filho GMS, Oliveira CSM, Sousa LC, Silva ALP, Lima EF, Feitosa TF, Braga FR, Araújo JV, Vilela VLR (2022). Control of sheep gastrointestinal nematodes on pasture in the tropical semiarid region of Brazil, using Bioverm® (*Duddingtonia flagrans*). Trop. Anim. Health Prod., 54(3). https://doi.org/10.1007/s11250-022-03181-z

Rodríguez-Esquivel DL, Ocampo-Gutiérrez AY, Olmedo-Juárez A, López-Arellano ME, Hernández-Romano J, Aguilar-Marcelino L, Gómez-Rodríguez O, Gives PMD (2023). Using *Arthrobotrys oligospora* (Orbiliales) spores mixed with sterile sheep faeces for disinfesting soil micro-plots infested with *Nacobbus aberrans* (Nematoda: Pratylenchidae). Biocontr. Sci. Technol., 34(1): 96–110. https://doi.org/10.1080/09583157.2023.2297172

Rodríguez-Martínez R, Gives PM d, Aguilar-Marcelino L, López-Arellano ME, Gamboa-Ángulo M, Rosas-Saito G, Reyes-Estébanez M, García-Rubio VG (2018). *In vitro* lethal activity of the nematophagous fungus *Clonostachys rosea* (Ascomycota: Hypocreales) against nematodes of five different taxa. Biomed. Res. Int., 2018: 1–7. https://doi.org/10.1155/2018/3501827

Sagüés MF, Fusé LA, Fernández S, Iglesias L, Moreno FC, Saumell C (2011). Efficacy of an energy block containing *Duddingtonia flagrans* in the control of gastrointestinal nematodes of sheep. Parasitol. Res., 109(3): 707–713. https://doi.org/10.1007/s00436-011-2302-y

Sagüés MF, Zegbi S, Guerrero I, Fernández S, Iglesias L, Junco M, Saumell C (2020). Assessment of the efficacy *In vitro* of *Duddingtonia flagrans* isolate 03/99 in different doses of chlamydospores and faeces egg counts in faecal of sheep. Biocontr. Sci. Technol., 31(5): 443–450. https://doi.org/10.1080/09583157.2020.1849560

Sander C, Neumann SO (2025). Nematophagous fungi as biological control agents of parasitic nematodes in soils of wildlife parks. Int. J. Parasitol. Parasit. Wildl., 26: 101033. https://doi.org/10.1016/j.ijppaw.2024.101033

Santana DAD, Machado MO, Azevedo BZ, Wéber H, Sotomaior CS, Ollhoff RD (2023). Influence of probiotic supplementation on parasitological parameters in lambs. Vet. Parasitol., 318: 109934. https://doi.org/10.1016/j.vetpar.2023.109934

Saumell C, Fernández S, Echevarria FAM, Gonçalves IG, Iglesias L, Sagüés MF, Rodríguez E (2015). Lack of negative effects of the biological control agent *Duddingtonia* *flagrans* on soil nematodes and other nematophagous fungi. J. Helminthol., 90(6): 706–711. https://doi.org/10.1017/S0022149X1500098X

Silva A, Araújo JV, Braga FR, Frassy LN, Tavela AO, Carvalho RO, Castejon FV (2009). Biological control of sheep gastrointestinal nematodiasis in a tropical region of the southeast of Brazil with the nematode predatory fungi *Duddingtonia flagrans* and *Monacrosporium thaumasium*. Parasitol. Res., 105(6): 1707–1713. https://doi.org/10.1007/s00436-009-1613-8

Silva AR, Araújo JV, Braga FR, Alves CDF, Frassy LN (2010). Activity *in vitro* of fungal conidia of *Duddingtonia flagrans* and *Monacrosporium thaumasium* on Haemonchus contortus infective larvae. J. Helminthol., 85(2): 138–141. https://doi.org/10.1017/S0022149X10000362

Silva BF, Mauad JRC, Braga FR, Campos AK, Araújo JV, Amarante AFT (2010). Efficacy of *Duddingtonia flagrans* and *Arthrobotrys robusta* in controlling sheep parasitic gastroenteritis. Parasitol. Res., 106(6): 1343–1350. https://doi.org/10.1007/s00436-010-1805-2

Silva NCS, Lima AS, Silva CR, Brito DRB, Cutrim Júnior JAA, Milhomem MN, Costa LM (2018). *In vitro* and *in vivo* activity of hydrolyzed *S. cerevisiae* against goat nematodes. Vet. Parasitol., 254: 6–9. https://doi.org/10.1016/j.vetpar.2018.02.034

Sinott MC, Castro LLD, Leite F, Gallina T, De-Souza MT, Santos D, Leite FPL (2014). Larvicidal activity of Bacillus circulans against the gastrointestinal nematode *Haemonchus contortus* in sheep. J. Helminthol., 90(1): 68–73. https://doi.org/10.1017/S0022149X14000844

Sinott MC, Filho NAC, Castro LLD, Lorenzon LB, Pinto NB, Capella GA, Leite FPL (2012). *Bacillus* spp. toxicity against *Haemonchus contortus* larvae in sheep fecal cultures. Exp. Parasitol., 132(2): 103–108. https://doi.org/10.1016/j.exppara.2012.05.015

Szewc M, Waal TD, Zintl A (2021). Biological methods for the control of gastrointestinal nematodes. Vet. J., 268: 105602. https://doi.org/10.1016/j.tvjl.2020.105602

Tehrani MH, Shemshadi B, Shayan P, Shirali S, Panahi N (2024). Prevalence of abomasum nematode infection in sheep from north of Iran. J. Hellenic Vet. Med. Soc., 74(4): 6361–6368. https://doi.org/10.12681/jhvms.29841

Victoria MM, Martins CJL, Ignacio AL, Lanusse C, Virkel G, Lifschitz A (2022). Pharmacological characterization of geraniol in sheep and its potential use in the control of gastrointestinal nematodes. Vet. Anim. Sci., 18: 100269. https://doi.org/10.1016/j.vas.2022.100269

Waller PJ (2006). Sustainable nematode parasite control strategies for ruminant livestock by grazing management and biological control. Anim. Feed Sci. Technol., 126(3–4): 277–289. https://doi.org/10.1016/j.anifeedsci.2005.08.007

Wang B, Wang F, Xu Q, Wang K, Xue Y, Ren R, Zeng J, Liu Y, Zhang H, Wang H, Cai B, Cai K, Cao X (2016). *In vitro* and *in vivo* studies of the native isolates of nematophagous fungi from China against the larvae of *Trichostrongylides*. J. Basic Microbiol., 57(3): 265–275. https://doi.org/10.1002/jobm.201600620

Xue YJ, Li EL, Wang A, Cai K (2018). Predatory activity and passage of six nematophagous fungi species in gastrointestinal tract of *Trichostrongylide*-infected sheep. Biocontr. Sci. Technol., 28(7): 654–662. https://doi.org/10.1080/09583157.2018.1464125