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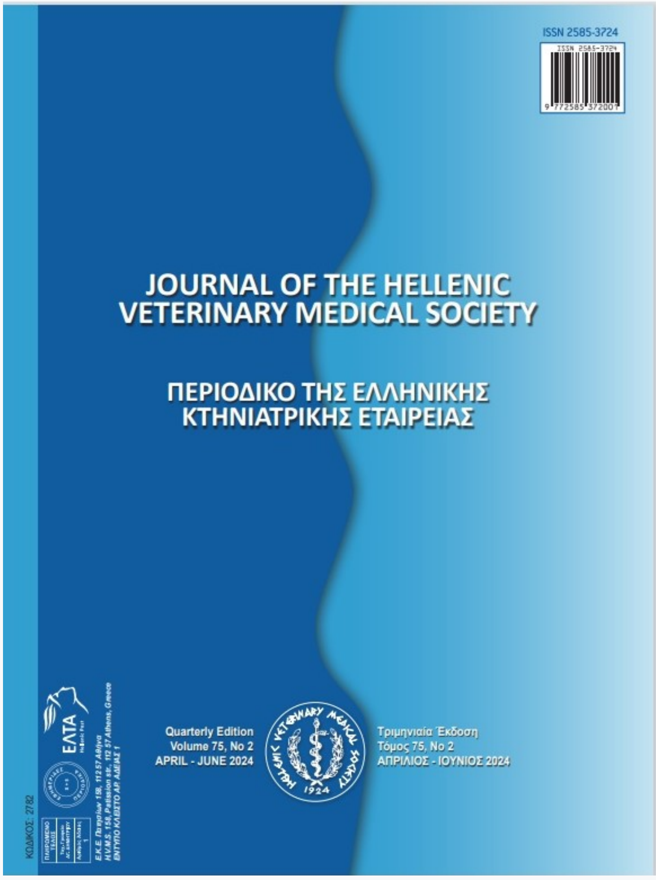


**Haemonchus contortus infection of goats and the use of anthelmintic natural alternative : An updated review**

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# *Haemonchus contortus* infection of small ruminants and the use of garlic as an anthelmintic natural alternative: An updated review

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**ABSTRACT:** *Haemonchus contortus (H. contortus) is a gastrointestinal nematode (GIN) common in small ruminants and is a significant cause of economic loss in livestock enterprises. Progressive anthelmintic resistance of H. contortus is the most limiting factor in effective control. The utilization of these natural materials for treating H. contortus is gaining popularity. This review aims to shed light on the prevalence of H. contortus in goats and possible control strategies to overcome such problems by using Allium sativum (garlic).*

**Keywords**: *Haemonchus contortus; Small ruminants; Garlic; Natural alternative; Parasitic infection.*

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## INTRODUCTION

*Haemonchus contortus* is considered a major blood-feeding nematode of the abomasum in sheep and goats, leading to severe anemia, weight loss, and low productivity (Schweizer et al., 2016; Vieira et al., 2017). *H. contortus* has a high propensity to develop anthelmintic resistance (Kotze and Prichard 2016); therefore, the efficacy for effective treatment of *H. contortus* becomes lower, causing a significant economic loss (Brasher et al., 2023). In turn, recent studies have focused on using alternatives to parasite control (Hegazy et al., 2022). So, using medicinal plants may be an alternative parasite control to reduce the frequency of anthelmintic treatments and anthelmintic residues in animal products (Besier et al., 2016).

As previously reported, garlic has antimicrobial, antioxidant, antihypertensive parasiticidal, larvicidal, and fungicidal properties (Worku et al., 2009, Zhong et al., 2019). Antiparasitic and anthelmintic activities of garlic have been studied in mice (Erol et al., 2008), rabbits (Toulah and Al-Raw, 2007), female Boer goats (Worku et al., 2009), and fish (Hyun Kim et al., 2019 and Yildiz et al., 2019). *Coriandrum sativum* L. (*C. sativum*) belongs to the Apiaceae family. Extract from seeds of *C. sativum* has many pharmacological effects (Inupala et al., 2023). It has anti-diabetic, anti-hyperlipidemic, and antioxidant activities (Sahib et al., 2013). The alcoholic extract of *C. sativum* was reported to have a protective effect against hymenolepis nana infection in mice (Hosseinzadeh et al., 2016).

### *Haemonchus contortus*

Internal parasites comprise 22.7% of goat mortality in the USA (Nahms, 2020). Throughout the centuries, parasites have evolved to infect a wide range of animal species and many plant groups (Roberts et al., 2013). Parasites live and obtain nutrition at the expense of their host, with harmful effects for the latter (Roberts et al., 2013). In livestock, parasitic infection causes a decrease in the average daily gain of the host due to nutritional losses (Soliman et al., 2022). However, these effects vary widely depending on parasite characteristics.

The long-term viability of parasites depends on locality and climate, and the evolution of morphological characteristics and life cycles gives Parasite species the means to infect their host (Roberts et al., 2013). Understanding the mechanisms behind parasite infections and their lifecycles could assist farmers in establishing effective management strategies to limit gastrointestinal tract infections. Gastrointestinal nematode parasites inhabit and thrive in the digestive tract of small ruminants (León et al., 2019). In livestock, parasitism by gastrointestinal nematodes (GINs) can adversely affect animals' productivity, and in high-intensity infection cases, death occurs; moreover, extra costs are needed for drugs and veterinary assistance (Attia et al. 2022). One of the major GINs that parasitize goats and sheep is *H. contortus,* with few clinical signs to be present before death (Muchiut et al., 2018).

*H. contortus*, the barber pole worm, is highly pathogenic and arguably harmful to small ruminants due to financial losses inflicted on producers (Waller et al., 2004; Schwarz et al., 2013). Losses owed to the thrive-failure. Anemia and oedema (bottle jaw) are prominent symptoms in small ruminants with *H. contortus* infection (Aboshady et al., 2023) due to nutrient losses the host can utilize as the nematode consumption strategy (Sendow, 2003). *H. contortus* is most prominent in tropical and subtropical climates, but considerable economic loss is found in temperate climates (Naeem et al., 2021). The ability of *H. contortus* to prevail in varying climates is due to epigenetic regulations and genetic diversity (Naeem et al., 2021). The extreme genetic diversity level is created by a large census population and the high fecundity of females (Salle et al., 2019).

The hot and humid climate of the southern United States promotes high *H. contortus* infection rates (Terrill et al., 2012). Adult *H. contortus* worms reach a size of 10-30 mm in the abomasum using a single dorsal tooth to cut the host's tissue, allowing the Parasite to feed freely on blood and mucus and digested through the enzymes produced by the pharyngeal glands and intestinal epithelium of the nematode with the egg size is 80μm x 45μm (Sendow, 2003; Foreyt et al., 2013). The ingestion of blood into the digestive tract and the white ovaries of *H. contortus* female larvae exhibit the color pattern of adult worms akin to a barber pole, the barber pole worm. The life cycle of *H. contortus* worms has roughly five stages as the nematode grows from eggs into adults. The prepatent period of parasites is the period between infection of the Parasite and the demonstration of parasitic infection in the host's body (Sendow, 2003) is 17-21 days (Machen et al., 1998). Unfavorable climatic conditions for *H. contortus* eggs and larvae occur in low temperatures and limited rainfall (Naeem et al., 2021). When eggs are released from the host in fecal matter, the eggs hatch and develop in the soil before reentering the host. *H. contortus* thrives in moist, warm climates where soil bacteria are plentiful for larvae growth.

The juvenile-stage larvae (L1, L2, and L3) develop outside the host and feed on soil bacteria (Naeem et al., 2021). During this time, the worm undergoes shedding and molting of its cuticles until they mature into infective larvae (L3) (Machen et al., 1998). Sheep and goats, the definitive host for *H. contortus,* are infected with L3 when the host consumes the larvae from a high point on the blades of grass (Machen et al., 1998). L3 uses the dew that condenses in the mornings to move up the grass blades to increase the chances of consumption by the definitive host (Machen et al., 1998). Once entering the host, L3 larvae mature into L4 larvae, attach themselves to the abomasum, feed on the blood, and mature into adult worms (Machen et al., 1998). The adults will differentiate into male or female and begin sexual reproduction. The adult females are prolific (produce up to 10,000 eggs a day released from the host in their faecal matter), quickly contaminating pastures (Kearney et al., 2016). Adult *H. contortus* consumes up to 0.5 ml of blood per worm daily, causing severe anemia and serious production losses (Kearney et al., 2016). The life-cycle occurs over 21 days, with the first symptoms of infection starting 18 to 21 days post-initial infection (Figure 1).

Adult *H. contortus* have an average lifespan of 3-6 months (Kearney et al., 2016). Their lifespan and reproductive proficiency allow *H. contortus* to thrive rapidly and infect their definitive hosts. The increased egg production at the beginning of spring from a life-cycle adaptation of *H. contortus* is detrimental to small ruminant health (Machen et al., 1998), known as "hypobiosis". The adult stays dormant in the host during winter when eggs and larvae cannot survive outside the host (Machen et al., 1998). Hypobiosis begins during September and October when the Parasite does not feed, lay eggs, or cause damage to its host (Machen et al., 1998).

*H. contortus* will resume development once the doe or ewe gives birth and warmer weather arrives (Machen et al., 1998). *H. contortus* will begin to produce large numbers of eggs shed into the pasture to infected adults and vulnerable newborn kids (Machen et al., 1998). Because of their limited immune response, goat kids are highly susceptible to parasitic infection (Sendow, 2003). Understanding the mechanisms of hypnosis of *H. contortus* creates a predictable timeline of instances of elevation parasitic infection for small ruminant producers. Early detection and management are crucial to prevent mortality from *H. contortus* infection. *H.contortus* causes acute anaemia in

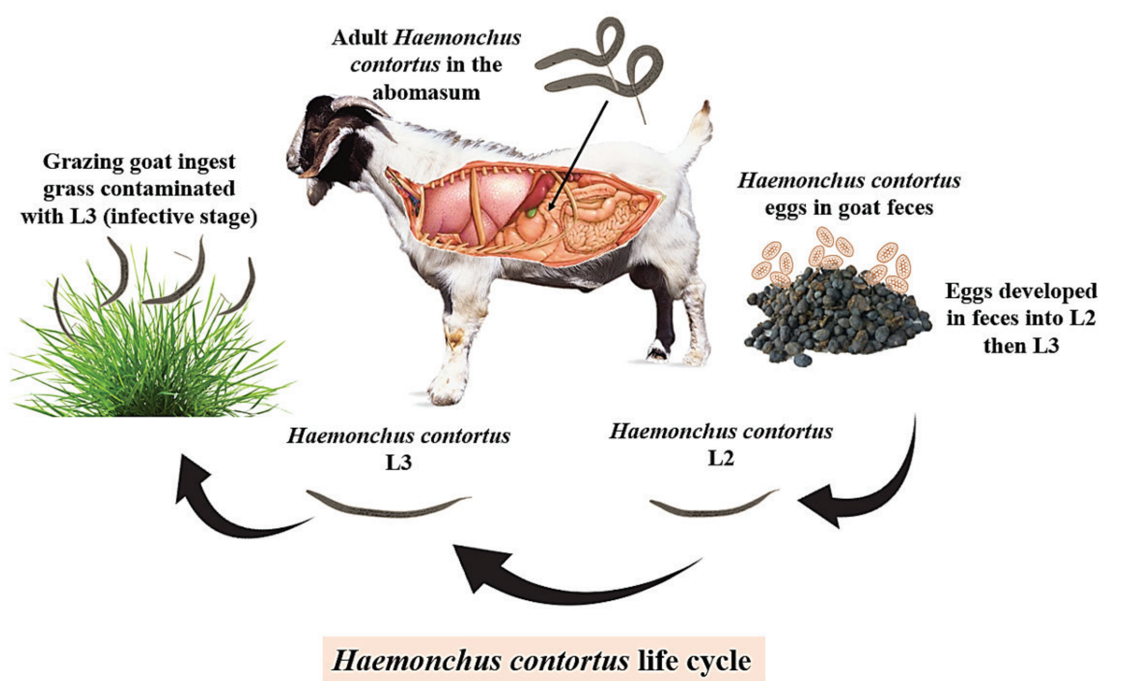


**Figure 1:** life cycle of *Haemonchus contortus* in goats.

kids, oedema (bottle jaw), diarrhoea, weak and listless behaviour, chronic weight loss in adults, and death if left untreated (Yin et al., 2013).

Anaemia isa reliable indication of *H. contortus* infection as the L4 larvae and adult nematodes feed on the blood in the abomasum (Foreyt et al., 2013; Poli et al., 2023). The ability to diagnose *H. contortus* infection presents challenges due to the broad symptoms the Parasite causes, but there are diagnostic tests to solidify infection in a small ruminant herd (Levecke et al., 2012). Diagnosing *H. contortus* infection through standard faecal egg count (FEC) can be correlated with the adult worms in the abomasum (Foreyt et al., 2013). FEC (using proper fecal float solution and McMaster slides) is a standard, consistent method of determining parasite load intensity in an animal (Levecke et al., 2012) and is considered the cornerstone of strategic parasite control and eggs excretion is used to determine parasite load (Levecke et al., 2012).

Using FEC to establish strategic deworming decisions reduces internal parasitic infection and anthelmintic resistance (Scare et al., 2017). FEC is a common and effective method to evaluate the parasite load within an individual animal and a herd (Zajac et al., 2014). McMaster slides are unique in allowing the evaluator to calculate the number of eggs per gram (EPG) faeces (Zajac et al., 2014). This method entails mixing a faecal sample with specialized solutions that cause heavier debris in the sample to sink and the lightweight eggs to float to the surface. This allows the eggs to become isolated on the top of the solution pipetted into the McMaster slide (Zajac et al., 2014). The number of eggs observed in the specialized slide quantifies the infection status of the individual. There is a positive relationship between the number of adult *H. contortus* in the abomasum of the ruminant and the EPG in the faeces, unlike most other nematodes (Roeber et al., 2013).

Further, using an FEC reduction test (FECRT) is also valued by producers to track parasite populations in their herd post-anthelmintic treatment (Waller et al., 1997). Another FEC is run 7 to 10 days after treatment to determine whether parasite load is still in the animal. Producers can determine resistance within their herd and plan their anthelmintic treatments accordingly. FAMACHA© testing is also used to determine anaemia in goats (Burke et al., 2007). FAMACHA© scoring is conducted by observing the colour of the sheep or goat's ocular conjunctiva coloration to determine anaemia in the animal (Burke et al., 2007). Bright red or pink are typical of healthy animals, while pale pink or white indicates the animal is anaemic. With *H. contortus* consuming the blood of their host, FAMACHA© testing allows for checking anaemia out in the field rather than testing blood samples (Mahieu et al., 2007), where it recommends anthelmintic drugs to be administered when the animal is reading at four or five on the scale (Mahieu et al., 2007). The research also stated that using FAMACHA© can be an effective culling method in removing animals in repetitively poor conditions from the herd (Mahieu et al., 2007) to reduce the time and money they invest in the herds. The reliability of FAMACHA© scoring has been analyzed in goat populations. Packed Cell Volume (PCV) and FAMACHA© score were compared in a study conducted by Glaji et al. (2014). The results concluded that using FAMACHA© scoring to determine anaemia level was reliable, namely for a FAMACHA© score of five (Glaji et al., 2014). For small producers with limited resources, using FAMACHA© is a great tool to identify potential *H. contortus* infection (Van Wyk and Bath, 2002). There can also be inaccuracies when categorizing the different levels because of the subjective nature of the test (Van Wyk and Bath, 2002).

A goat or sheep could also display anaemia from other factors outside *H. contortus* infection, including nutritional deficiencies. Furthermore, FAMACHA© was intended for sheep rather than goats (Van Wyk and Bath, 2002). The ocular conjunctiva coloration range in goats is smaller, creating difficulty in accurately scoring goats. There is also a difference in ocular conjunctiva coloration in adult sheep or goats compared to lambs or kids, reducing the test's reliability and reducing the test's reliability on young animals (Van Wyk and Bath, 2002). With these limitations, FAMACHA© can still be a useful management tool for small ruminant producers. There are many challenges to eradicating *H. contortus* infections from small ruminant herds. Efficient reproduction, short generation periods, and quickly becoming resistant to the various anthelmintic drugs contribute to the nematode thriving in small ruminants (Van Wyk and Bath, 2002). However, small ruminant producers' greatest challenge is increasing anthelmintic resistance in *H. contortus* populations.

**Anthelmintic Resistance**

Introduction of anthelmintics in the mid of $20^{th}$ century aided in reducing losses from parasitic infection (Köhler et al., 2001). Anthelmintic resistance is a genetically transmitted loss of sensitivity to a drug in worm populations that were sensitive to the same drug (Köhler et al., 2001). The genetic mutation creates parasite varieties that persist in livestock populations, creating epidemics and inducing innovation of deworming new medicines to combat resistant parasites. The major mechanisms parasites use to become resistant to anthelmintics are receptor loss or decreasing the target site for the given dewormer (Köhler et al., 2001). Adopting strict quarantine measures and a combination drug strategy effectively prevent and reduce anthelmintic resistance (Shalaby et al., 2013).

Although there are many anthelmintic drugs to use against *H. contortus,* widespread anthelmintic resistance in small ruminant herds significantly reduces the options for parasite treatment (Prichard et al., 2001). Maintaining anthelmintic efficiency starts with knowing the mechanisms behind *H. contortus*-resistant abilities. Nematode genetic diversity and their mitochondrial DNA (mtDNA) genetic composition create rapid responses to environmental changes. Nematode mtDNA is the component that undergoes high mutation rates, creating resistance. The mutation rate of *H. contortus* is up to ten times higher than the rate seen in vertebrates (Prichard et al., 2001). Genetic diversity can be observed within and between populations: *H. contortus* demonstrates great genetic diversity in both types, further allowing them to be a highly successful parasite (Gilleard et al., 2016).

Understanding the methods behind *H. contortus* anthelmintic resistance will support new ways to control the parasitic population in small ruminants. Five major components of *H. contortus* allow them to generate anthelmintic resistance. These are changing the molecular target for a given drug, induction of metabolic changes to remove or prevent activation within the Parasite, increasing expression of the target gene for the drug (which then requires an increased concentration to elicit the desired effect), altering the distribution of the drug within the Parasite and complete replacement of the target protein in the Parasite (Kotze et al., 2016). The versatility of *H. contortus* in generating rapid resistance to traditional anthelmintic drugs. Active parasite management practices are necessary for small ruminant herds most susceptible to *H. contortus,* creating new anthelmintic alternatives for producers.

Anthelmintic resistance is observable worldwide and detectable in every anthelmintic group (Salem et al., 2022). To reduce the resistance, the dosage of a commercial anthelmintic should be selected for the heaviest infected animal to ensure underdosing does not occur (Machen et al., 1998). Using ineffective compounds should be avoided to prevent further parasitic population growth. Treating an animal and returning them to heavily infested pastureland will immediately cause reinfection. So, it is critical to practice grazing/pasture rotation in an anthelmintic resistance management plan (Machen et al., 1998; Muchiut et al., 2018). *H. contortus* eggs and larvae can survive in the soil for multiple weeks during ideal conditions. Regular pasture rotations are recommended to allow larvae to die off (Muchiut et al., 2018; Herath et al., 2021).

Supported management techniques against anthelmintic resistance will allow small ruminant producers to reduce the loads of resistant parasites in livestock herds. The potential for alternative anthelmintic options would give producers another option for controlling parasite loads and limiting anthelmintic resistance. Anthelmintic resistance in a goat herd was observed over thirty months to understand further the mechanisms and potential of the anthelmintic drug to be effective again (Zajac et al., 2000). *H. contortus* was resistant to ivermectin, levamisole, and fenbendazole drugs, resulting in death due to parasite infection. However, altering administration practices allowed certain drugs to become effective again (Machen et al., 1998; Zajac et al., 2000; Muchiut et al., 2018; Herath et al., 2021).

One dose regimen of Fenbendazole did not decrease fecal egg counts (FECs). So, to maintain effective control of *H. contortus*, two doses of fenbendazole over 12 hours were administered, thus reducing FECs by 92%. The same fenbendazole treatment was administered the following year, but effectiveness fell by 57% after constant use. Given both orally and SC, ivermectin improved from a 57% reduction in FECs to 70% and 90% the following year (Zajac et al., 2000).

Similar results were observed by Muchiut et al. (2018) to recover the effectiveness of fenbendazole for intensive sheep production. Using refugia and introducing a susceptible parasite population from artificially infected lambs, fenbendazole efficacy on *H. contortus* over the 16-month post-population period increased to 97.58% (Muchiut et al., 2018). Results demonstrated the effectiveness of an anthelmintic drug by altering traditional management strategies. Commercial anthelmintics are shown to function on a single component of *H. contortus*. Botanical alternatives are believed to elicit a response through several complex structures that would prevent the high resistance seen in commercial anthelmintics (Abongwa et al., 2017). Anthelmintic rotation via thorough management records is vital in limiting the Parasite's ability to become resistant. This is largely due to the positive correlation between drenching frequency and farm resistance (Kettle et al., 1983).

Refugia in parasitology refer to when a potential host or environment is left untreated with anthelmintic drugs to maintain effectiveness (Muchiut et al., 2018; Hodgkinson et al., 2019). Exploiting refugia can delay the evolution of anthelmintic resistance in small ruminants. In typical management strategies, parasite control largely depends on broad-spectrum anthelmintic, which kills susceptible nematodes while leaving resistant genotypes to infect pastureland. Minimizing the use of anthelmintic drugs by utilizing refugia can allow for crossbreeding between susceptible and resistant genotypes, diluting the population of resistant nematodes. The success of refugia on anthelmintic resistance is dependent on the parasite population within the given host.

Factors include a parasite percentage with resistant alleles, genetic diversity, mechanisms of gaining resistant alleles (whether alleles are dominant or recessive), the parasite species within the host, and frequency of an anthelmintic (Hodgkinson et al., 2019). Further, understanding the life-cycle and environmental influences on the parasite species will help improve the effectiveness of refugia. Using botanical products with anthelmintic properties can aid refugia strategies by limiting commercial drugs (Hodgkinson et al., 2019).

Reducing the need for anthelmintics through active herd management will prevent reinfection and restrict the development of anthelmintic resistance. They offer forages to herds raised off the ground to reduce the consumption of larvae that live in the soil, along with pasture rotations if feasible for the producer (Waller et al., 2004; Muchiut et al., 2018). Reduction of stocking rates, increasing grazing area available, short-term rotational grazing, and moving to zero grazing are also recommended to reduce the chances of parasitic infection (Waller et al., 2004). These strategies, along with the use of FAMACHA© testing and taking FEC, will reduce parasite numbers in the herds and decrease the number of anthelmintic drugs to control the parasites (Van Wyk and Bath et al., 2002; Waller et al., 2004).

Effective herd management can reduce input costs by requiring fewer anthelmintic drugs to treat parasites while allowing for more productive, healthy animals (Waller et al., 2004) and limited anthelmintic resistance. Although these management practices are effective, they may not be feasible for every producer.

**Alternative Anthelmintics**

The threat of anthelmintic resistance in small ruminants is a growing problem. So, the potential for using alternatives such as nutraceuticals for controlling parasite infections. Nutraceuticals are parts of a plant or food with medical or health benefits, including disease prevention. Secondary metabolites in plants or forages can benefit animals because some compounds have antiparasitic properties (Torres-Acosta et al., 2008). Investigating the use of certain plants, such as garlic, on parasite control and anthelmintic resistance could potentially lead to low-cost, low-input effective methods of parasite management. Garlic has been known for its health benefits for humans, such as lowering blood pressure, cholesterol, and glucose concentrations and preventing arteriosclerosis. Garlic consumption is inversely correlated with the risk of some cancers (Tsai et al., 2012). Current data suggests the anthelmintic properties of garlic is from thiosulfate (Lima et al., 2012).

The antiparasitic properties of garlic have been evaluated in numerous species with variable results (Waag et al., 2010). The most abundant thiosulfinate in garlic is allicin, created by the interaction with a non-protein amino acid, alliin, and the enzyme alliinase (Waag et al., 2010). The therapeutic effects of allicin are suggested to be from metabolites that interact with metabolic pathways releasing disulfides, allyl sulfides, and other various metabolites (Rosen et al. 2001). A metabolite, known as S-allyl cysteine (SAC), is highlighted as a potential anthelmintic alternative based on its half-life of 10 hours in the bloodstream, which would lead, leading *H. contortus* to consume treated blood (Kodera et al., 2002). Current findings of SAC anthelmintic properties present limited effects on FEC in goats (Burke, 2009).

A study of the effect of garlic thiosulfate, allicin, on *Schistosoma mansoni* worms in mice sought to cause damage to the worm's tegument (Lima et al., 2012). At higher concentrations of allicin, 15 & 20 mg/ml, allicin caused the greatest damage to the tegument of the adult worms (Lima et al., 2012). In contrast, data gathered on the efficiency of allicin for *Ascaridia galli* infection in chickens showed no improvement in infected chickens. Also, it showed that allicin is not an effective alternative to fenbendazole (Velkers et al., 2011). Conversely, the effects of garlic on GINs in sheep demonstrated positive effects on their treated population (Zhong et al., 2019). The findings concluded that 50 g/kg garlic powder for 84 days resulted in increased growth performance in lamb infected with GINs from feed digestion, rumen fermentation, and the health status due to the lower parasite load (Zhong et al., 2019). Azra et al. (2019) tested different concentrations of garlic on hatching inhibition of *H. contortus* eggs in the abomasum of small ruminants, where the highest concentration (100%) showed the largest mortality rate of 67% of *H. contortus* eggs. In contrast, a 50% concentration resulted in a 50% mortality rate of eggs. Garlic demonstrated therapeutic effects on the larvae of small ruminants, although the mode of treatment needs to be explored (Azra et al., 2019). Further, research by Masamha discovered reduced FEC counts when dosing sheep with raw garlic juice compared to a commercial anthelmintic. Four different concentrations of garlic juice were used, with the highest concentration, 80%, matching strongyle percent reduction of the commercial anthelmintic, Valbazen (Masamha et al., 2010). These studies support garlic as an effective natural anthelmintic for GINs in small ruminant herds (Masamha et al., 2010; Azra et al., 2019; Zhonget al., 2019).

When investigating garlic's control over GIN infection in small ruminants, results varied for Burke et. (2009); water was used as control. In contrast, garlic juice or three garlic bulbs were used as the treatments for Spanish goat kids. The water and garlic juice were administered with a stomach tube, and the garlic bulbs were fed to the kids. The results indicated neither the garlic juice nor the bulbs reduced FEC for acute GIN infection (Burke et al., 2009). Strickland et al. 2009 also recorded a lack of response to garlic for GIN in wether lambs. A commercial dewormer was administered to the control group, and garlic for the treatment group. While the commercial dewormer effectively controlled GIN, garlic presented with no effect on the infection level and reduced body condition, indicating adverse effects for small ruminants consuming garlic (Strickland et al., 2009).

Based on previous work, garlic has exhibited conflicting effects on parasite mortality in the animal and parasites studied. There is potential for using garlic as an alternative anthelmintic for small ruminant producers. Still, the inconsistent results do not suggest garlic is an effective anthelmintic alternative. Further evaluation of the anthelmintic properties of garlic will be beneficial to understand the potential of substituting conventional anthelmintic drugs with botanical alternatives.

**Self-Medication**

There is evidence that animals may voluntarily choose to consume plant products with pharmaceutical properties. This is commonly known as self-medicating. Self-medicating may provide an additional strategy for *H. contortus* control in small ruminant operations (Khalil et al., 2023). Self-medicating has been observed in primates to alleviate symptoms of GIN (Huffman et al., 2002). In a study by Huffman, apes were observed bitter pith chewing on the plant *Vernonia amygdalina*. Researchers observed apes consuming small amounts that contributed insignificant nutritional benefits. Before consuming *V. amygdalina,* the apes were observed to have a noticeable drop in appetite, malaise, diarrhea, and constipation. These symptoms correlated with high levels of nodule worm infection. Individuals visibly recovered from the symptoms within 20-24 hours of post-pitch chewing (Huffman et al., 2002).

These observations supported the hypothesis that bitter pith chewing alleviated parasite infections in apes and provided evidence of self-medicating behavior. Amit also proposed that goats select plants when their GIN counts are high. A Mediterranean shrub known as *Pistacia lentiscus* has anthelmintic properties and can help alleviate symptoms caused by GIN. *Pistacia lentiscus* contains tannins, demonstrating anthelmintic properties (Amit et al., 2013). However, tannins also impair protein metabolism, creating a toxic trade-off for consuming animals. This research aimed to determine the possibility of goats selecting this forage when infected with GIN (Amit et al., 2013). *P. lentiscus*, *Phillyrea latifolia,* and clover hay were offered to infected and non-infected goats, and their selections were recorded. The two breeds, Mamber and Damascus, differed in forage selection strategies. The Damascus goats demonstrated a prophylactic strategy, often eating a significant amount of *P. lentiscus*. On the other hand, the Mamber breed employed a therapeutic strategy, eating *P. lentiscus* only when there was a precise need. The selection made by the animals suggests subtle trade-offs between the roles of *P. lentiscus* as a food, a toxin, and a medicine.

These results suggest that goats may potentially select plants with anthelmintic properties, but further research is required to fully understand the mechanisms behind their choices (Amit et al., 2013). Several other studies have also used plants with different levels of tannins to control parasitic infection (Athanasiadou et al., 2000; Kahiya et al., 2003; Lisonbee et al., 2009). The condensed tannins are an alternative to commercialized anthelmintic drugs and could reduce resistance in small ruminants (Githiori et al., 2006). The potential use of natural forage in a region with high tannins could reduce production inputs while improving herd health. It has been shown that sheep with access to forages high in tannins have lower GIN infection than sheep with access to forages low (Niezen et al., 1996). Parasitized sheep and non-parasitized sheep were observed to determine the influences tannin-rich plants had when allowed to self-medicate (Lisonbee et al., 2009).

Parasitized sheep consumed more of the tannin-rich forage for the first 12 days, and still, consumption lowered as GIN infection decreased in the parasitized population, demonstrating small ruminant's ability to self-medicate with tannin-rich forage (Kahiya et al., 2003). Goats in a similar study on using plant tannins as an anthelmintic showed a decrease in *H. contortus* infection with the use of the forage *A. karoo* added to feed (Kahiya et al., 2003). Although condensed tannins can control parasitic infection, they cause adverse effects if fed in high concentrations (Kearney et al., 2016). Some of these adverse effects are reduced feed intake and digestibility, which lowers production yield. In herbivores, they cause the mucous membranes, mouth, and tongue to dry. When digested, the tannins disrupt the microorganisms in the digestive tract of ruminants and bind with protein, reducing protein availability (Kearney et al., 2016).

## CONCLUSION

As previous research has shown, there is a high potential for using a botanical alternative for parasite control in small ruminants. Alternative botanicals from condensed tannin plants could alleviate the adverse effects caused by ingesting high amounts of tannins. Small producers could use these advancements to reduce the need for commercial anthelmintic drugs and mitigate resistance in parasite populations while maintaining production levels. Using allicin would also have a beneficial action against the internal parasites and *H. contortous*. Also, nano preparation of garlic would be evaluated in small ruminants. In goats, the variety of their forage consumption could increase the chances of ingesting secondary compounds while deworming. This idea of self-selection for plants containing secondary compounds could be a sustainable parasite management strategy. The wide range of management practices, such as FEC, selective breeding, pasture rotation, and rotational anthelmintic, can be manipulated to meet current needs feasibility by small ruminant producers. Although these management tactics are viable in any production, investigating additional, novel strategies for parasite control could benefit small producers by adding to their wide range of available strategies.

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