THE RELATIONSHIP BETWEEN INTERNAL PARASITIC INFECTION OF GOATS AND SELF-MEDICATION USING GARLIC

by

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A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science
with a Major in Integrated Agricultural Sciences
December 2021

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DEDICATION

I would like to thank my amazing family for allowing the opportunity to further my education and for their constant support.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr Benavides, for allowing me to work with her through the last few years. I am grateful for her introducing me to parasitology and herd management as I have fell in love with the field. I would also like to thank Dr. Wagner and Dr. Sudhakaran for being on my thesis committee and their guidance during my time at Texas State University.

I would also like to thank everyone who help me with the feeding trials, collections, and maintain the care of the herd. This includes Brynn Thomas, Chris Thomas, Hunter Eichman, Reese Watson, Jaci Nix, and Esperanza Manqueros. I could not have completed my research and master’s degree with you all.

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
FEC	Fecal egg count
PCV	Packed cell volume
GIN	Gastrointestinal nematodes
SAC	S-allyl cysteine
USDA	United States Department of Agriculture
C	Control
G	Garlic
NC	No choice
S	Switch from garlic to control

ABSTRACT

Haemonchus contortus, is a gastrointestinal nematode common in small ruminants and is a major cause of economic loss in livestock enterprises. Progressive anthelmintic resistance of *Haemonchus contortus* is the most limiting factor in effective control of this parasite. The utilization of botanical supplements with suspected anthelmintic activity for treatment of *Haemonchus contortus* is gaining popularity. *Allium sativum,* commonly known as garlic, is known for having multiple health benefits and has demonstrated limited anthelmintic properties. While these botanicals can be administered by producers directly, an alternative could be through passive administration, which would be considered a self-medication method. While there is some evidence for self-medication in goats, data is limited. Therefore, it is hypothesized that goats will self-medicate with *A. sativum* when *H. contortus* infection is high. The objective of this study was to determine if goats were willing to consume feed treated with *A. sativum* and if that willingness correlated with elevated levels of *H. contortus* infection. This longitudinal study aimed to evaluate feeding behavior of goats during periods of high and low *H. contortus* infection, as determined by fecal egg counts (FEC). Twenty-three feeding trials with 11 goats were conducted from December to June with three garlic inclusion levels (0.148 g garlic/g feed, 0.298g garlic/g, feed 0.446g garlic/g feed) to determine feed preference and its relationship to FEC. Fecal samples were collected before every trial for determination of FEC using the modified McMaster procedure. During the trials each goat was observed individually for 2-mintues to determine feed choice: consuming feed with no garlic (C), continuously switching between garlic treated feed and control (NC), consuming the garlic feed (G) and switching from the garlic feed to the control feed (S) The results indicated that the inclusion level of 0.298g garlic/g feed was associated with the choices that included garlic (G and S) when animals had higher FEC. This suggests a possible therapeutic self-medicating strategy in goats with elevated FEC and may be an alternative treatment method for *H. contortus* infection in goats.

Keywords: Anthelmintics; Garlic; *Haemonchus contortus*; Self-Medication

I. INTRODUCTION

Currently, the global meat goat industry is estimated be worth 400 million dollars annually (ABA, 2020). In the United States, Texas is the largest producer of goats and holds 30% of the goat inventory. The meat stock goat population in Texas, as of 2018, is 795,000 head making up 86% of the total goat inventory in the state (USDA, 2018). In 2019, Texas witnessed a 3% increase in the goat population with a 4% price increase due to increase demand for goat products (Russel et. al., 2020).

In the United States, meat goats are rarely the primary animal raised by livestock producers, but they add value to producers by controlling noxious plants and vegetation other livestock species do not consume (Glimp et. al., 1995). Furthermore, the cost of meat produced from goats is higher per pound compared to other red meat species which further adds value to incorporating goats into a producer's operation (Glimp et. al., 1995). Comparative to other livestock species, goat production startup and input cost are lower with less labor require to maintain a herd (Riley et. al., 2018). Data collected by the United States Department of Agriculture (USDA) reported the goat industry is steadily increasing as producers discover the versatility of goats as producers of meat, wool, and milk along with being effective browsers (NAHMS et. al., 2020). To maintain the increase of growth in the goat industry, producer-friendly outreach would improve access to changes in production and effective management.

In small ruminant production, gastrointestinal nematodes are the leading cause of global economic loss (NAHMS et. al., 2020). Use of anthelmintic drugs is the primary method of controlling parasitic infection. Treatment plans surrounding parasite control are centered around reducing population in a host using commercial anthelmintic drugs causing an epidemic known as anthelmintic resistance. Anthelmintic resistance occurs when internal parasites develop various degrees of resistance to anthelmintic (deworming) drugs by overuse of anthelmintics causing loss susceptible receptor (Shalaby et. al., 2013). Although this increasing resistance negatively effects herd health, the conventional use of anthelmintics in livestock operations is the primary management strategy. *Haemonchus contortus*, is a gastrointestinal nematode that significantly impedes the efficiency and yields of goat producers (Machen et. al., 1998). Adaptations developed over time, such as short prepatent period, prolific nature, and rapid genetic mutations from short generational periods, provides *Haemonchus contortus* to swiftly increase anthelmintic resistance.

Producer awareness and prevention management practices show promise in reducing fatalities and economic loss from anthelmintic resistance and parasitic infections. Identifying additional management practices can assist producers in effectively combating anthelmintic resistance. One practice gaining popularity is the discovery of the anthelmintic properties of various plant species. Although producers could self-administer botanical alternatives, there is a potential for goats to self-select for these alternatives. Self-medication in goats could reduce labor cost for producers, along with aiding in controlling parasitic infection. The purpose of this study is to determine if goats can self-medicate using garlic as a botanical alternative to commercial anthelmintics to control instances of internal parasitic infection.

II. REVIEW OF LITERATURE

Haemonchus contortus

Internal parasites account for 22.7% of goat mortality in the United States (NAHMS, 2020). Throughout the centuries, parasites have evolved to infect nearly every phylum of animals and many plant groups (Roberts et. al., 2005). A parasite lives to benefit from the nutritional gains of their host reducing the nutrient availability for their host (Roberts et. al., 2005). As the parasite population grows, the host's immune response is trying to combat the infection weakening the host (Roberts et. al., 2005). In livestock, parasitic infection generally causes average daily gain to decrease due to the loss of nutrients that can be absorbed by the host. However, these effects vary widely depending on parasite characteristics.

Parasitic infections are readily transmissible throughout livestock herds due to parasites' evolution for proficiently infecting populations. Long term viability of parasites is dependent on the region and climate. Morphological features and lifecycles evolve over time to equip parasite species with the mechanisms required for infecting host populations (Roberts et. al., 2007). Understanding mechanisms behind parasite infections and their lifecycles could assist producers in establishing management strategies that effectively control parasite infection.

Gastrointestinal parasites are nematodes (commonly called worms) that have evolved to inhabit and thrive in the digestive tract of their host (León et. al., 2019). In livestock production there are different types of gastrointestinal nematodes that cause production loss through animal disease, parasite management cost, and animal mortality. In small ruminants, goats and sheep, *Haemonchus contortus* is the primary nematode of concern, because of its tendency to thrive within its host with few clinical signs before death (Muchiut et. al., 2018). Due to the evolutionary advantages exhibited by *Haemonchus contortus* nematode, management practices and therapeutic anthelmintic treatments are critical for controlling parasite infections.

H. contortus, commonly known as the barber pole worm, is highly pathogenic and harmful to small ruminant herd health (Waller et. al., 2004). *H. contortus* is arguably the most economically important internal parasite in small ruminants due to financial losses inflicted on producers (Schwarz et. al., 2013). Producer’s economic loss is derived from the failure to thrive in goats infected with *H. contortus*. Anemia and edema (bottle jaw) are prominent symptoms in small ruminants with *H. contortus* infection. These symptoms are caused by the loss of nutrients the host can utilize due to 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. The ability of *H. contortus* to prevail in varying climates is due to epigenetic regulations and genetic diversity. The extreme level of genetic diversity is created by both a large census population and the high fecundity of females (Salle et. al., 2019). The hot and humid climate of southern United Sates promotes high *H. contortus* infection rates (Terrill et. al., 2012).

Adult *H. contortus* worms reach a size of 10-30 mm in the abomasum and the egg size is 80µm x 45µm (Foreyt et. al., 2013). The adults live in the abomasum, known as the “true stomach” of small ruminants, to feed on blood and mucus within this compartment of the abomasum (Foreyt et. al., 2013). *H. contortus* uses a single dorsal tooth to cut the tissue of the host allowing the parasite to feed freely on blood (Sendow, 2003). Digestive enzymes produced by the pharyngeal glands and intestinal epithelium of the nematode allows for digestion of the consumed blood and mucus (Sendow, 2003). The ingestion of blood into the digestive tract, along with the white ovaries of *H. contortus* female larvae exhibits color pattern of adult worms akin to a barber pole,giving the worm their common name, the barber pole worm.

The life cycle of H. contortus is often divided into roughly five stages as the nematode grows from eggs into adult worms. The prepatent period of parasites is the period between infection of the parasite and demonstration of parasitic infection in the host's body (Sendow, 2003). *H. contortus* has a prepatent period of 17-21 days (Machen et. al., 1998). Unfavorable climatic conditions to *H. contortus* eggs and larvae occurs in low temperatures and limited rainfall. 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. During this time, the worm undergoes shedding and molting of their cuticles until they mature into infectious 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 blades of grass (Machen et. al., 1998). L3 parasites use the dew or moisture that condenses in the mornings to move up the grass blades to increase chances of consumption by the definitive host. Once entering the host, L3 larvae mature into L4 larvae and attach themselves to the abomasum and begin to feed on the blood of the small ruminant and mature into adult worms (Machen et. al., 1998, Figure 1).

As adults, the worms will differentiate into male or female and begin sexual reproduction. The adult females are prolific and able to produce up to 10,000 eggs a day which are released from the host in their fecal matter quickly contaminating pastures (Kearney et. al., 2016). Adult *H. contortus* consumes up to 0.5 ml of blood per worm each day and there may be thousands of adult worms in the abomasum consuming blood, causing severe anemia resulting in serious production losses (Kearney et. al., 2016). The lifecycle of *H. contortus* occurs over a 21-day period with the first symptoms of infection starting 18 to 21 days post initial infection. Adult *H. contortus* nematodes have an average lifespan of 3 to 6 months where they are highly prolific and feed on the definitive host's blood. The lifespan and reproductive proficiency of *H. contortus* allows the parasite to thrive and rapidly infect their definitive hosts.

The increased egg production at the beginning of spring from a lifecycle adaptation of *H. contortus* is detrimental to small ruminant herd health. This is an adaptation *H. contortus* has evolved known as hypobiosis. The adult nematodes stay dormant in their host during winter when eggs and larvae are not able to survive outside the host (Machen et. al., 1998). The goal is to ensure survival of the parasite in unfavorable winter months. Hypobiosis begins during September and October when the parasite does not feed, lay eggs, or cause damage to their host (Machen et. al., 1998). *H. contortus* will resume development once the doe or ewe gives birth and warmer weather arrives. *H. contortus* will begin to produce large numbers of eggs that will be shed into the pasture to infected adults and vulnerable newborn kids (Machen et. al., 1998). When the does or ewes release high volumes of eggs and kept closely with their kid, parasitic infection of kids is inevitable. Goat kids are highly susceptible to parasitic infection because of their limited immune response (Sendow, 2003). Understanding the mechanisms of hypobiosis of *H. contortus* creates a predictable timeline of instances of elevation parasitic infection for small ruminant producers.

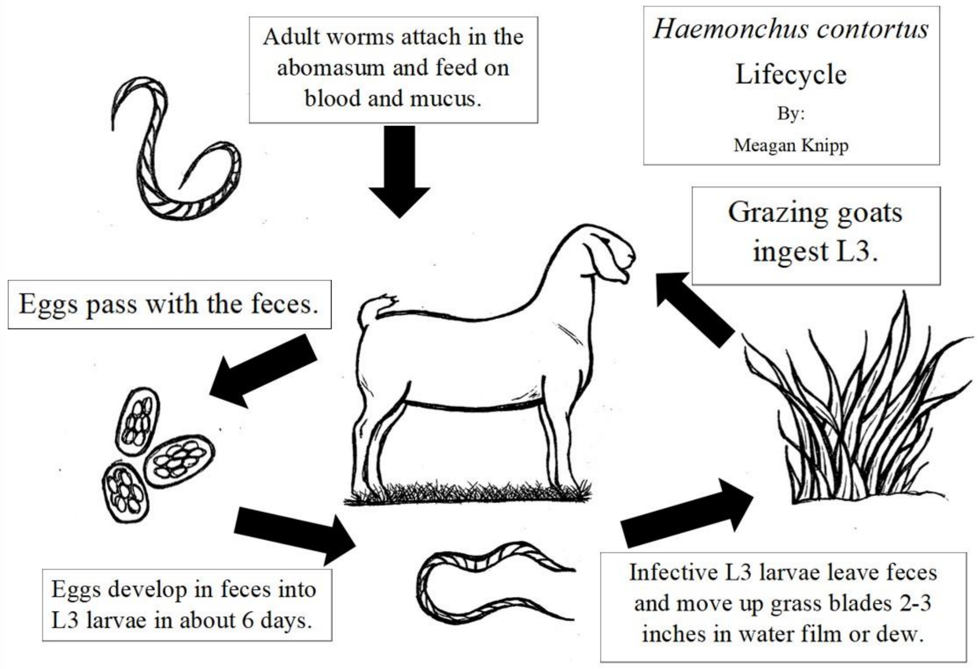

Figure 1. *Haemonchus contortus* Lifecycle. The larval lifecycle begins when the eggs are shed in the feces (L1). The larvae continue to grow and shed their cuticle with each subsequent growth stage (L2 – L3). Larvae first become infectious at the L3 stage.

The prolific reproduction of female *H. contortus*, their well-adapted lifecycle, and ease in infecting their definitive host lets parasite populations quickly infiltrate a herd. Early detection and management are crucial to prevent mortality from *H. contortus* infection. *H. contortus* causes acute anemia in kids, edema (bottle jaw), diarrhea, weak and listless behavior, chronic weight loss in adults, and death if left untreated. Anemia isa reliable indication of *H. contortus* infection as the L4 larvae and adult nematodes feed on the blood in the abomasum. However, accurately testing for anemia requires blood samples being run at a laboratory or veterinarian clinic. Observable symptoms in a herd (weight loss, lethargic behavior, etc.) can be used to identify infection but can also be symptoms of other diseases and may potentially be overlooked in a production setting.

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. Diagnosis of *H. contortus* infection through standard fecal egg count (FEC) can be correlate with the adult worms present 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). The FEC method is the cornerstone of strategic parasite control and eggs excretion is used to determine parasite load (Levecke et. al., 2012).

The use of FEC to establish strategic deworming decisions assists in reducing 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). The typical method for FEC is the modified McMaster method. McMaster slides are unique in allowing the evaluator to calculate the number of eggs per gram (EPG) in the feces (Zajac et. al., 2014). This method entails mixing a fecal 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 to be pipetted into the McMaster slide. 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 feces unlike most other nematodes (Roeber et al., 2013). Further, using a FEC reduction test (FECRT) is also valued by producers to track parasite populations in their herd post anthelmintic treatment (Waller et. al., 1997). 7 to 10 days after treatment another FEC is ran determine parasite load still in the animal. From there a producer can determine resistance within their herd and plan their anthelmintic treatments accordingly.

Use of FAMACHA© testing is also used to determine anemia in goats (Burke et. al., 2007). Famacha© scoring is conducted by observing the color of the sheep or goat's ocular conjunctiva coloration to determine anemia in the animal. Bright red or pink are typical of healthy animals while pale pink or white is an indication the animal is anemic. With *H. contortus* consuming the blood of their host, Famacha© testing allows for checking anemia out in the field rather than testing blood samples. The Famacha© system recommends anthelmintic drugs administered when the animal is reading at four or five on the scale (Mahieu et. al., 2007). The use of this testing allows the amount of drenching to decline by only treating infected individuals further decreasing the input cost of the producers (Mahieu et. al., 2007). The research also stated that the use of Famacha© can be an effective culling method in removing animals in repetitively poor condition from the herd (Mahieu et. al., 2007). This is an effective technique in management of small ruminants allowing producers to reduce the time and money they invest in their herds.

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. Results concluded that use of FAMACHA© scoring to determine anemia level was reliable namely for a FAMACHA© score of five (Glaji et. al., 2014). For small producers with limited resources, use of FAMACHA© is a great tool to quickly identify potential *H. contortus* infection.

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 anemia from other factors outside *H. contortus* infection including nutritional deficiencies. Furthermore, Famacha© was intended use being for sheep rather than goats. 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 reliability of the test on young animals (Van Wyk and Bath, 2002). With these limitations, Famacha© can still be a useful management tool for small ruminant producers.

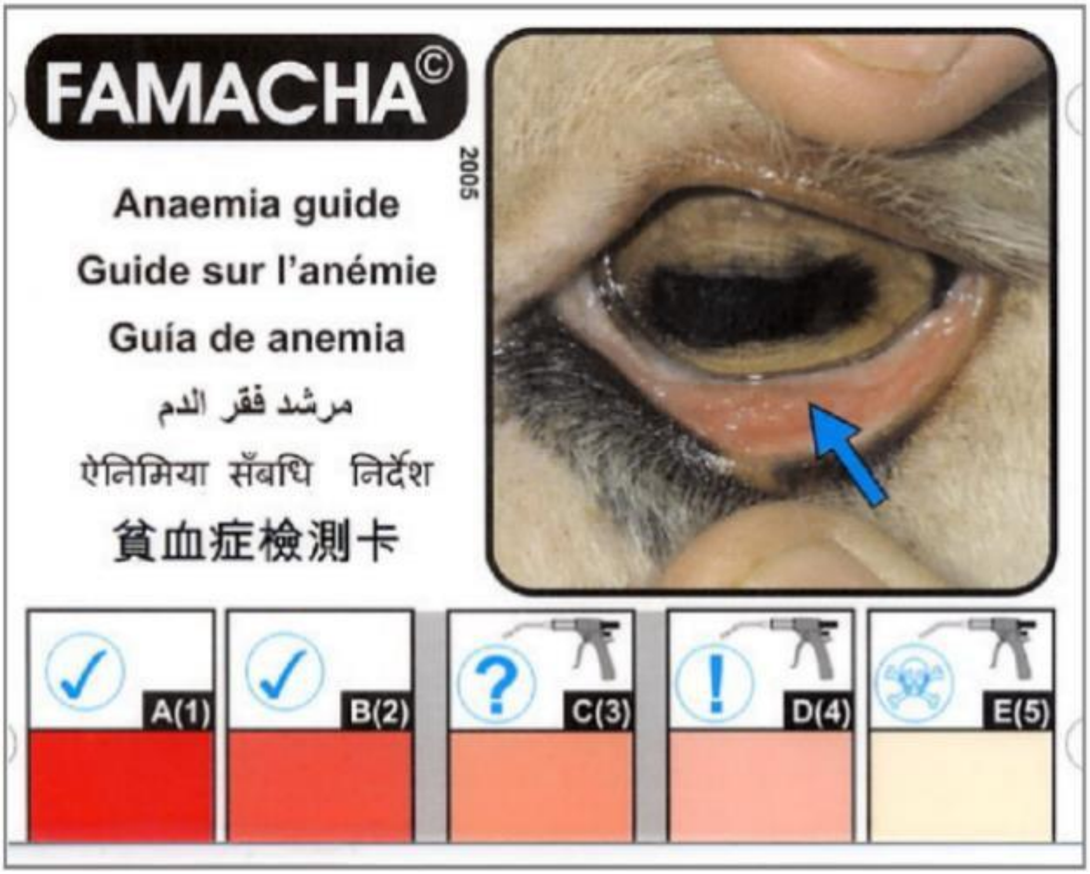

Figure 2. FAMACHA Score Card. Source. Van Wyk and Bath, 2002.

There are many challenges to eradicating *H. contortus* infections from small ruminant herds. Efficient reproduction, short generation periods, and ability to quickly become resistant to the various anthelmintic drugs contribute to the nematode thriving in small ruminants. However, the greatest challenge currently facing small ruminant producers is increasing incidence of anthelmintic resistance in *H. contortus* populations.

Anthelmintic Resistance

Introduction of anthelmintics in the mid-20th century aided in reducing losses from parasitic infection, but with unexpected consequences. Anthelmintic resistance is a genetically transmitted loss of sensitivity to a drug in worm populations that were previously sensitive to the same drug (Köhler et. al., 2001). The genetic mutation creates parasite varieties that persist in livestock populations, creating epidemics and induced innovation of new deworming drugs to combat resistant parasites (Köhler et. al., 2001). The major mechanisms parasites use to become resistant to anthelmintics is through receptor loss or decreasing the target site for the given dewormer (Köhler et. al., 2001). Adoption of strict quarantine measures and a combination drug strategy are two effective methods of preventing and reducing 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. Maintaining anthelmintic efficiency starts at knowing the mechanisms behind *H. contortus* resistant abilities.

Nematode genetic diversity and the genetic composition of their mitochondrial DNA (mtDNA) creates rapid responses to changes in their environment. Nematode mtDNA is the component that undergoes high rates of mutation 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 a population and between populations: *H. contortus* demonstrates great genetic diversity in both types further allowing for 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.

There are five major components of *H. contortus* that give them the ability to generate resistance to a wide variety of anthelmintic drugs. 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 in small ruminant herds who are most susceptible to *H. contortus* creating opportunity for new anthelmintic alternatives for producers.

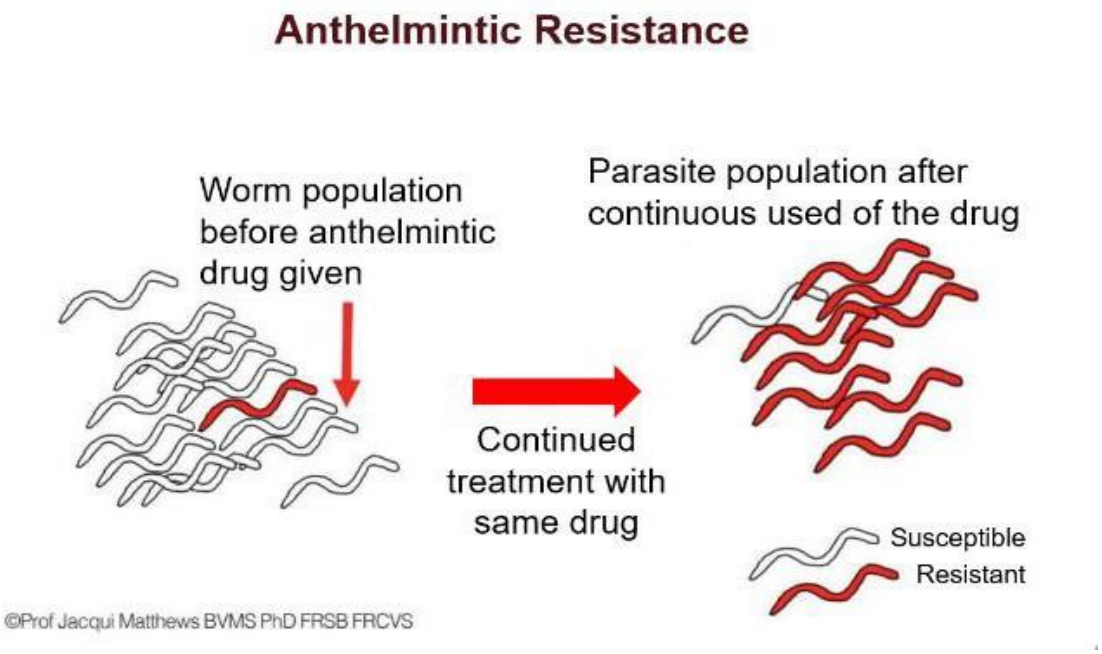

Figure 3. Mechanism of Anthelmintic Resistance. When parasites are exposed to sub-lethal levels of anthelmintic, they survive and can pass on their resistant genetics tofuture generations (Matthews, 2012).

Anthelmintic resistance is observable worldwide and the extent of resistance is detectable in every anthelmintic group. To reduce this resistance, the dosage of a commercial anthelmintic should be selected for the heaviest animal of the group to ensure underdosing does not occur (Machen et. al., 1998). Proper method for dosing small ruminants with anthelmintic drugs is through oral administration: other methods such as subcutaneous injections, pour-on and feed additives should be avoided (Machen et. al., 1998). The use of ineffective compounds should be avoided for preventing 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 anthelmintic resistance management plan (Muchiut et. al., 2018; Machen et. al., 1998). *H. contortus* eggs and larvae can survive in soil for multiple weeks during ideal conditions and regular pasture rotations are recommended to allow for larvae in the soil to die off (Herath et. al., 2021; Muchiut et. al., 2018). Use of supported management techniques against anthelmintic resistance will allow small ruminant producers to reduce loads of resistant parasites in livestock herds. The potential for alternative anthelmintic options would give producers another option for controlling parasite loads and limit instances anthelmintic resistance.

Anthelmintic resistance in a goat herd was observed over a thirty-month period to further understand 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 (Zajac et. al., 2000; Herath et. al., 2021; Muchiut et. al., 2018; Machen et. al., 1998). The anthelmintics were given in monthly intervals during grazing periods. Three anthelmintics were given to the population and dosages were increased when resistance was detected. Due to high resistance, levamisole was removed from the rotation over a twelve-month period (Zajac et. al., 2000). Once brought back into use, susceptibility to the drug was restored.

Fenbendazole did not decease fecal egg counts (FECs) if only one dose was given. To maintain effective in controlling *H. contortus*, two doses of fenbendazole over a twelve- hour period were administered, and reduced FECs by 92%. The following year the same fenbendazole treatment was administered but, after constant use, effectiveness fell by 57%. Ivermectin, given both orally and subcutaneously, improved from 57% reduction inFECs to 70% and 90% respectively the following year (Zajac et. al., 2000). Similar results were observed by Muchiut et. al. to recover effectiveness of fenbendazole for an intensive sheep production. By 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 ability to recreate effectiveness in 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 response through several complexstructures that would prevent high resistant seen in commercial anthelmintics (Abongwaet al. 2017).

Use of anthelmintic rotation via thorough management records is a vital method in limiting the parasite’s ability to become resistant. This is largely due to the positive correlation between drenching frequency and the presence of resistance on farms (Kettle et. al., 1983). In addition to anthelmintic rotation, there are other management practices that have demonstrated effectiveness in controlling resistant parasite populations in herds.

A dynamic approach for controlling parasite infection is essential to break the dependence on anthelmintic drugs. Management strategies should be tailored and individualized to meet a given production's needs. Practices that can be used to effectively manage parasites include pasture management/rotation, refugia, and breeding and selecting for resilient/resistant individuals (Kearney, 2016). Refugia in parasitology refers to when a potential host or environment are left untreated with anthelmintic drugs to maintain effectiveness (Muchiut et. al., 2018 and Hodgkinson et. al., 2019). Exploiting refugia can delay evolution of anthelmintic resistance in small ruminant herds. In typical management strategies, parasite control is largely dependent on use of broad spectrum anthelmintic which kill susceptible nematodes while leaving resistant genotypes to infect pastureland. Minimizing use of anthelmintic drugs by utilizing refugia can potentially allow for crossbreeding between susceptible and resistant genotype diluting the population of resistant nematodes. Success of refugia on anthelmintic resistance is dependent on the parasite population within the given host. Factors include percentage of the parasite population with the resistant alleles, genetic diversity of the parasite population, mechanisms of gaining resistant alleles (whether alleles are dominant and recessive), the parasite species within the host, and frequency an anthelmintic drug is given (Hodgkinson et. al., 2019). Further, understanding the lifecycle and environmental influences on the parasite species will aid in improving effectiveness of refugia. Use of botanicals products that have anthelmintic properties has the potential to aid in refugia strategies by limiting the use of commercial anthelmintic drugs. Small ruminant producers incorporating refugia in their management strategies will benefit from lower instances anthelmintic resistance.

Reducing the need of anthelmintics through active herd management will prevent reinfection and restrict development of anthelmintic resistance. Offering forages to herds raised off the ground to reduce consumption of larvae that lives in the soil along with pasture rotations if feasible for the producer (Waller et. al., 2004; Muchiut et. al., 2018; Machen et. al., 1998). Reduction of stocking rates, increasing grazing area available, short term rotational grazing, and moving to zero grazing are also recommended to reduce chances of parasitic infection (Waller et. al., 2004). These strategies along with 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 (Waller et. al., 2004; Van Wyk and Bath et. al., 2002). Effective herd management can reduce input costs by requiring less anthelmintic drugs to treat for parasites while also allowing for more productive, healthy animals (Waller et. al., 2004). Although these management practices are effective, they may not be feasible for every producer. Adoption of these methods along potential alternative anthelmintics will support herd health through limited anthelmintic resistance.

Alternative Anthelmintics

With the threat of anthelmintic resistance in small ruminants a growing problem, there has been increased interest in the potential for using alternatives such as nutraceuticals for controlling parasite infections. Nutraceuticals are parts of a plant or food that has medical or health benefits including the prevention or treatment of disease. Secondary metabolites in plants or forages can benefit animals because some compounds being found to have antiparasitic properties and positive effects on host resilience (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. Clinically, it has been demonstrated to lower blood pressure, cholesterol, and glucose concentrations, as well as prevent arteriosclerosis. Garlic consumption is inversely correlated with the risk of some cancers (Tsai et. al., 2012). Current data suggests anthelmintic properties of garlic is from thiosulfinates (Lima et. al., 2012). 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 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 blood stream which would lead *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).

The antiparasitic properties of garlic have been evaluated in numerous species with variable results. A study of the effect of a garlic thiosulfate, allicin, on *Schistosoma mansoni* worms in mice sought to determine if damage can be caused to the tegument of the adult worms (Lima et. al., 2012). At higher concentrations of allicin, 15 and 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 on infected chickens with allicin compared to infected control chickens (Velkers et. al., 2011). This study concluded that allicin does not present as an effective alternative to fenbendazole (Velkers et. al., 2011).

Conversely, the effects of garlic on gastrointestinal nematodes (GIN) 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 (Zhong et. al., 2019). This is due to the lower parasite load within the lambs at the end of the trial (Zhong et. al., 2019). Azra et. al. tested different concentrations of garlic on hatching inhibition of *H. contortus* eggs that were removed from adult female nematodes in the abomasum of small ruminants. The highest concentration at 100% showed the largest mortality rate of 67% of *H. contortus* eggs. A concentration of 50% resulted in a mortality rate of 50% of *H. contortus* eggs. Garlic demonstrated therapeutic effects on the larvae from small ruminants although 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 when 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 the use of garlic asan effective natural anthelmintic for GINs in small ruminant herds (Zhong et. al., 2019; Azra et. al., 2019; Masamha et. al., 2010).

Results varied for Burke et. al. when investigating garlic's control over GIN infection in small ruminants. Water was used as a control while 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 garlic bulbs reduced FEC for acute GIN infection (Burke et. al., 2009). Strickland et. al. 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 was effective at controlling 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 on the animal and parasite studied. There is potential for using garlic as an alternative anthelmintic for small ruminant producers, but the inconsistent results do not suggest garlic to be an effective alternative anthelmintic. 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

One limitation of current literature surrounding garlic as an anthelmintic is that the animals used were administered the garlic treatment, rather than it being provided as a free-choice feedstuff. There is some 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.

Self-medicating has been observed in primates to alleviate symptoms of GIN. In astudy by Huffman, apes were observed bitter pith chewing on the plant *Vernonia amygdalina*. Researchers observed apes consuming small amount that contributed insignificant nutritional benefits. Before consuming *V. amygdalina,* the apes were observed to have a noticeable drop in appetite, malaise, diarrhea, and constipation. Thesesymptoms correlated with high levels of nodule worm infection. Within 20-24 hours postpith chewing, individuals visibly recovered from the symptoms (Huffman et. al 2002).

These observations strongly supported the hypothesis that bitter pith chewing alleviatedparasite infections in apes and provided some evidence of self-medicating behavior.

Amit also proposed that goats could select for 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, which have demonstrated anthelmintic properties (Amit et. al., 2013). However, tannins also impair protein metabolism, creating a toxic tradeoff for the animals consuming it. The objective of this research was to determine the possibility of goats selecting this forage when infected with GIN (Amit et. al., 2013). *P. lentiscus*, *Phillyrea latifolia*, and clover hay was offered to infected and non-infected goats and their selections were recorded. The two different breeds, Mamber and Damascus, differed in forage selection strategies. The Damascus goats demonstrated a prophylactic strategy, eating a significant amount of *P. lentiscus* often. 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 suggest subtle trade-offs between the roles of *P. lentiscus* as a food, a toxin, and a medicine. These results suggest that goats may have the potential to select for 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 ruminant herds. The potential use of natural forage in a region with high levels of 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 in tannins (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, but consumption lowered as GIN infection decreased in the parasitized population demonstrating small ruminant's ability to self-medicate with tannin-rich forage. Goats ina similar study on using plant tannins as an anthelmintic showed decrease in *H. contortus* infection with use of the forage *A. karoo* added to feed (Kahiya et. al., 2003). Although condensed tannins contain the ability to control parasitic infection the do cause adverse effects if fed in high concentrations (Kearney et. al, 2016). Adverse effects are by reduced feed intake and feed 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 the availability of protein. This would suggest that browsers would avoid consumption of condensed tannin plants, but small ruminants actively seek out these plants. This can be attributed to the medical properties the plants possess indicative of self-medicating in small ruminants. There is a high potential for using botanical alternative for parasite control in small ruminants as pervious research has shown. Alterative 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.

In goats, the variety of their forage consumption could increase the chances of ingesting secondary compounds while browsing. This idea of self-selection for plants containing secondary compounds has the potential of being a sustainable parasite management strategy (Kearney, 2016). Use of the wide range of management practices, such as FEC, selective breeding, 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 further benefit small producers by adding to their wide range of strategies available.

III: OBJECTIVES

The proposed work hypothesizes that goats will self-medicate using garlic, a plant containing anthelmintic properties, when they are naturally infected with *H. contortus*. The two objectives are: to determine the relationship between the selection for garlic and FEC, and to determine if goats select to consume plants with anthelmintic properties when they have elevated levels of *H. contortus* infection. Previous studies suggest that goats with a higher FEC - indicative of a greater parasite infection - will select to consume pelleted feed supplemented with garlic due to its anthelmintic properties. A positive correlation between the selection for garlic and FEC is also expected.

IV. JUSTIFICATION

The current literature on the anthelmintic potential of garlic on *H. contortus* is conflicting, while the research on self-medication in small ruminants. The minced garlic selected for this study is anticipated to contain high concentrations of allicin, the most abundant thiosulfate in garlic with proven medicinal benefits in other species. Self-medication in goats presents on opportunity for less intensive management for internal parasitic infection by reducing labor inputs comparatively to deworming with commercial anthelmintic drugs.

V. RESEARCH VALUE

The proposed work has the potential to aid producers in developing strategies for further mitigation of parasite infections in their herd by using an alternative anthelmintic like garlic. Determining if a goat will self-medicate has the potential to lower labor input in a goat operation by providing a hands-off approach to parasite control. Further, the use of garlic in a parasite control program will reduce the use of traditional anthelmintic drugs such as Fenbendazole. Small ruminant producers will benefit from decreasing inputs that will simultaneously increase production yield. The use of garlic is also an organic method of parasite control that could assist in organic operations. By using garlic as an alternative to anthelmintic drugs, anthelmintic resistance may also be reduced, thus improving parasite loads in a population.

Theoretically, goats with a higher FEC, indicating a higher parasite infection, will select for the garlic treatment feed due to the anthelmintic properties. It is also expected that there will be a positive correlation between the selection for garlic and FEC.

VI. METHODOLOGY

Population

The goat herd at the Freeman Center, located in Hays County, San Marcos, Texas, was the population for the research. The animals used in this study were 11 Spanish-Boer crossbred goats at 1 year of age. The goats had access to 2.93 hectares of native forage and were supplemented with a trace mineral block and coastal hay. The goats had continuous access to fresh water. This project was approved by the Texas State Institutional Animal Care and Use Committee (IACUC), protocol number 5826.

Weekly Samples

The weekly sample collection for this study consisted of fecal samples, body weight, appearance observations, and behavioral changes. Collections assisted in establishing animal health for the goats in the study. Weekly fecal samples were collected to establish baseline herd FECs. Upon establishment of baseline herd FEC parameters, garlic feeding trials were initiated. Weekly samples continued throughout the experiment to correlate FECs with feed choice of individual goat. If a goat’s FEC was higher than 30-egg average or if the animal presented abnormal symptoms, the goat/s were pulledfrom the study and treated. They were returned to the study once they regained their health.

For fecal collections, a trained sample collector collected the weekly fecal samples by placing 1 finger of a gloved and lubricated hand into the rectum of the goat to remove several fecal pellets. After collecting the fecal pellets, the glove was inverted, knotted, and labelled with the goat’s identification number. The samples were placed in a cooler and FEC analysis was conducted within a 24-hour period.

FEC was determined using a modified McMaster procedure for each weekly fecal sample collected (Zajac, 2014). The fecal samples were processed within 24 hours of the collection. 2g of crushed fecal matter was removed from each sample and mixed with 28mL of magnesium sulfate fecal float (specific gravity: 1.20 to 1.27). After 5 minutes, the samples were strained and left undisturbed for another 5 minutes before being loaded into a McMaster slide. Three separate sections of a McMaster slide were used for each goat to determine the average FEC. *H. contortus* eggs counted in each McMaster blue square were recorded totaling to three numbers for each goat. The three counts for each goat were added together and divided by three to find the average FEC. If the average FEC of a given goat was above critical limits based on age, they were treated with necessary anthelmintic drug.

Feeding Trial

The experiment was conducted from December through June of 2021. Over this time, different amounts of a commercialized *A. sativum* product (Chef Cuisine Minced Garlic, Majestic Foods Inc., Libertyville, IL) were offered to the goats. The first 6 trials consisted of 67.5g of minced garlic per 453.6g of pelleted feed (0.148 g garlic/g feed) (Dumor Goat Pellets, Purina Mills, St. Louis, MO). The next 11 trials consisted of 0.298g garlic/g feed followed by another 6 trials consisting of 0.446g garlic/g feed. This increasing inclusion of garlic aided in establishing a refusal incidence.

To maintain consistency of the feed in both treatment and control, equal amounts of corn oil were added to control (non-supplemented) samples. Separate mixing utensils were utilized to mix the treatment and control samples. A mock feeding trial was conducted to determine ideal observation time. After a two-minute period, the goats were observed to be set on their selected feed choice. Overthe course of the feeding trials a two-minute observation period was used to document feed choice and behavior of the goats.

For each feeding trial, the goats were initially corralled in a pen as a group. Two ground feeders, one with the treated feed and one with the control feed, were placed in an isolation pen side by side. A single goat was placed into the pen with the feeders and allowed to choose freely between the two bowls. Placement of the treated and control bowls was switched for every trial to minimize selection bias based on feed location. The goat was observed over the course of two minutes to determine if the choice for a given feed was reliable and definitive. Any switching between the feeds was recorded. The observer took note of the goat’s selection and any abnormal behavior observed. Choice for each goat was recorded under four different categories: control choice (C) for when the goat selected for the control feed only; garlic choice (G) for when the goat selected for the garlic treated feed only; no choice (NC) was assigned to goats when they switched continuously between the control and garlic treated feed; and switch (S) was assigned to goats that switched from the garlic treated feed to the control feed without switching back.

Once the two minutes concluded, the goat was removed from the pen and allowed to rejoin the herd. After each goat observation the control and treatment feed were remeasured and remixed as needed to maintain consistency. Throughout the trials, the goats were monitored for any abnormal behavior, such as self-isolation, lethargy, and panting.

Data Analysis

R-studio and JMP were used to analyze the data. The multiple regressions used were ran using R-studio. A chi-square analysis and the graphs were created in JMP. A linear regression, mixed effect regressions, and multinomial logistical regression were used to fully evaluate the data and compare the array of variables that could have influenced the selection of the goats. The multinomial logistical regression was used to evaluate the effects that multiple variables could have on the goat’s feed choice. The variables evaluated were garlic inclusion, preweaning diet, season of trial, and FEC. The linear regression model was used to evaluate the influence of the same variables on FEC of the goats. Mixed effect regressions evaluated the relationship between each individual goat and both the individual and trial to rule out error caused by random effects. Each goat’s FEC, and feed choice were used in the development of the linear regression and multinomial regression models. Significance was defined as $p<0.05$.

VII: RESULTS

Animal Health

Goat body weights throughout the experiment are presented in Table 1. Weights were categorized between winter and summer months. Significance was seen between individual goats and dates due to maturing of the kids. When categorized based on environmental season, there was no difference in body weights between goats.

Two goats were removed from the trial for a brief period due to declining body condition and high FECs. Abnormal FECs higher than 30-egg average required the animal to be removed from the trial until FECs decreased. Each was treated with albendazole to lower the FECs to a manageable level before reentering the study.

Choice

The pre-trial variables were analyzed using a linear regression model to evaluate their influence on FEC. Neither pre-weaning diet nor trial season had a significant effect on FEC. This suggests that the FECs were similar through winter to summer indicative of no hypobiosis effect. Pre-weaning diet did not contribute any effect on FECs throughout the trial. In addition to pre-trial variables, the linear regression model was also used to determine the correlation between FEC and feed choice. There was a significant interaction between the FECs and 0.298g garlic/g feed inclusion level, and the S choice. This indicated that the FECs were elevated for the animals during the of 0.298g garlic/g feed inclusion level and the switching behavior. This effect was also observed in the multinominal logistical model (Table 3). Additionally, there was a significant interaction between FECs, and the NC selection summarized by the multinominal linear regression in Table 3.

Across the entire experiment, when not accounting for garlic inclusion level, there was a significant correlation between FEC and the switch behavior ($p<0.05$). This correlation is illustrated in Figure 4. Upon accounting for garlic inclusion level, goats with elevated FECs tended to more frequently select for the garlic treatment or switch at the moderate inclusion level (0.298g garlic/g feed) seen in Figure 5. Switch behavior was slightly increased with higher FEC at the lower inclusion level (0.148 g garlic/g feed). While not statistically significant, this may be biologically relevant. At the highest garlic inclusion level (0.446g garlic/g feed) the goats tended to stay with the control feed, indicating a potential avoidance level.

Figures 5 and 6 represent the feed choice of two individual goats over the course of the trials. Both figures demonstrate the correlation between the switch and garlic behavior with elevated FECs. Goat number 40 (Figure 5) had comparatively lower FECs although the relationship with garlic consumption and raised parasitic infection is prevalent. Goat number 54 (Figure 6) had comparatively higher FECs with the same correlation observed for the garlic and switch consumption behaviors.

Table 4 and 5 illustrate the effect of several variables on choice and remove error from the random effects of individuals and trials. Significance derived from these tables are with FEC and 0.446g garlic/g feed inclusion level.

Table 1. Weight (kgs) over the trial by season analyzed with ANOVA. Average body weight did not differ between goats in each season (p>0.05).

	Winter		**Summer**
Weight Range	11.8-32.7		39-94
Average	23.1(1.46)	NS	25.7(1.53)

Table 2. Linear regression model evaluating the effect multiple variables had on FEC. Goats favored 135g inclusion and exhibited the switch behavior with higher FECs. *p<0.05

Variables	**Estimate**	**Standard Error**	**t-value**	**Pr(>t)**	
(Intercept)	3.25227	2.28946	1.421	0.156733	
0.298g garlic/g feed Inclusion	5.23192	1.45066	3.607	0.000377	***
0.446g garlic/g feed Inclusion	-0.21975	1.71652	-0.128	0.898237	
Garlic Treatment Choice	1.79963	1.17	1.538	0.125315	
No Choice	-1.56167	1.38195	-1.13	0.25957	
Switch Garlic to Control	4.50287	1.42891	3.151	0.00183	**
Synthetic Pre-Weaning Diet	0.01778	0.91576	0.019	0.984524	
Season	-0.58548	1.52894	-0.383	0.702102	

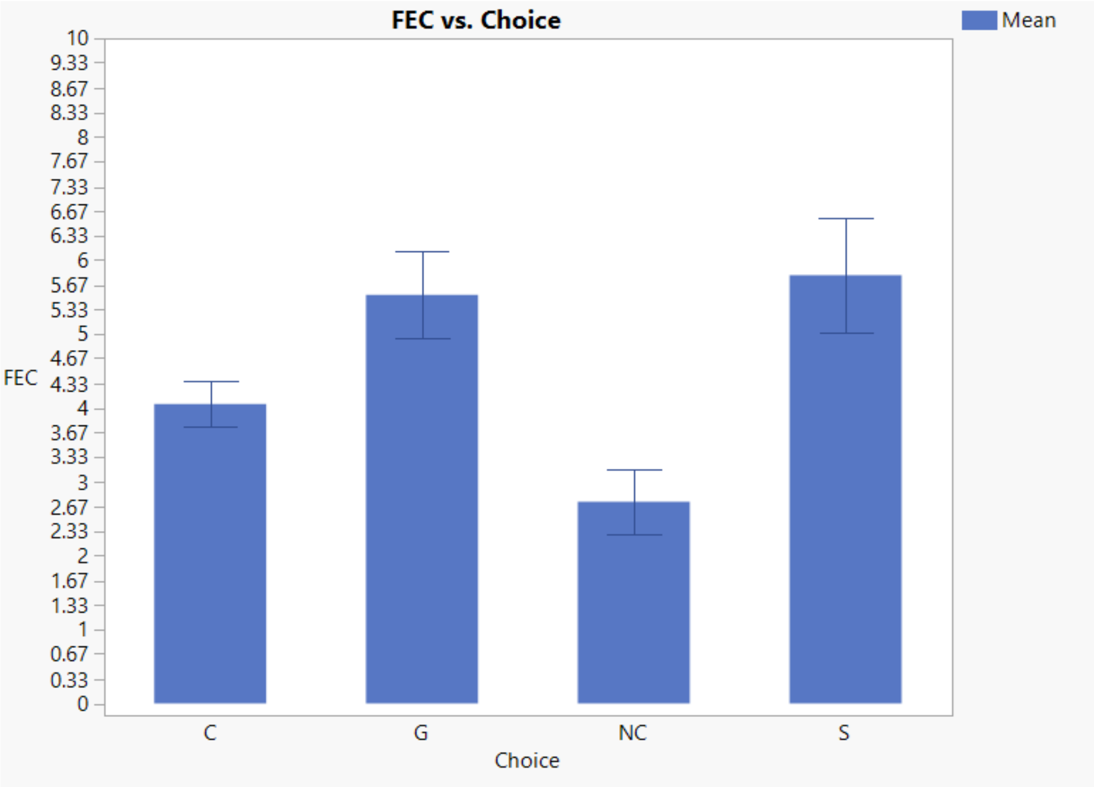

Figure 4. Influence of FEC on feed choice for all feeding trials. Over the duration ofthe experiment, goats with higher FECs exhibited the switch behavior most often, $^*p<0.05$.

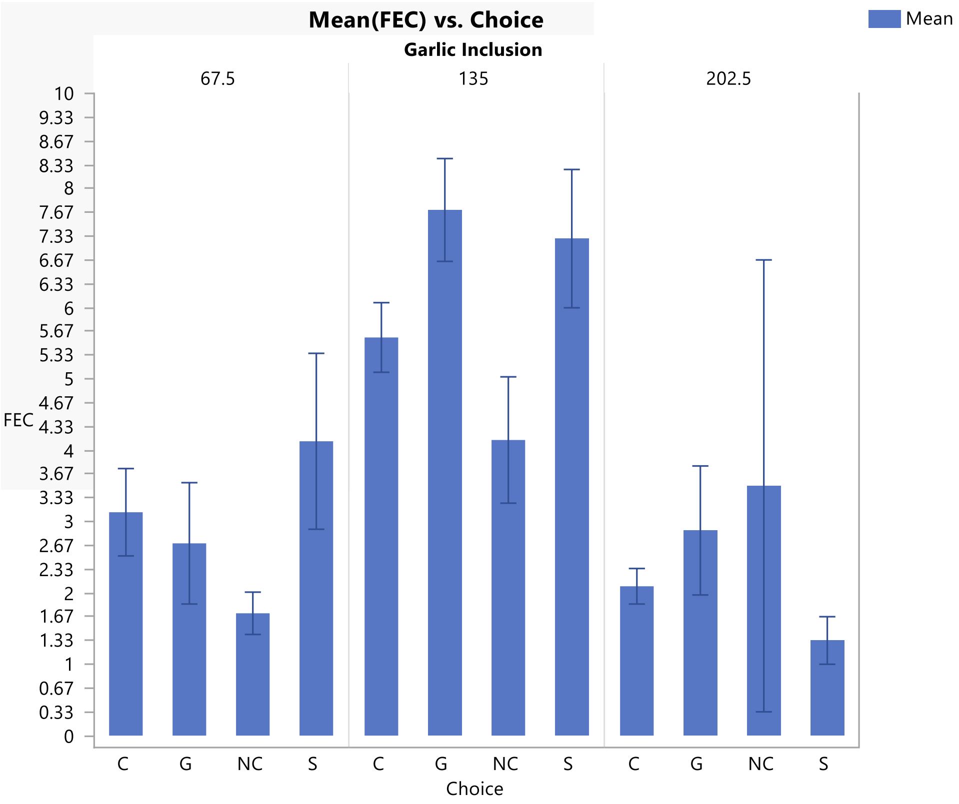

Figure 5. Influence of FEC and garlic inclusion on feed choice. Goats with thehighest FECs consumed garlic most frequently at the 0.298g garlic inclusion level (*p<0.05).

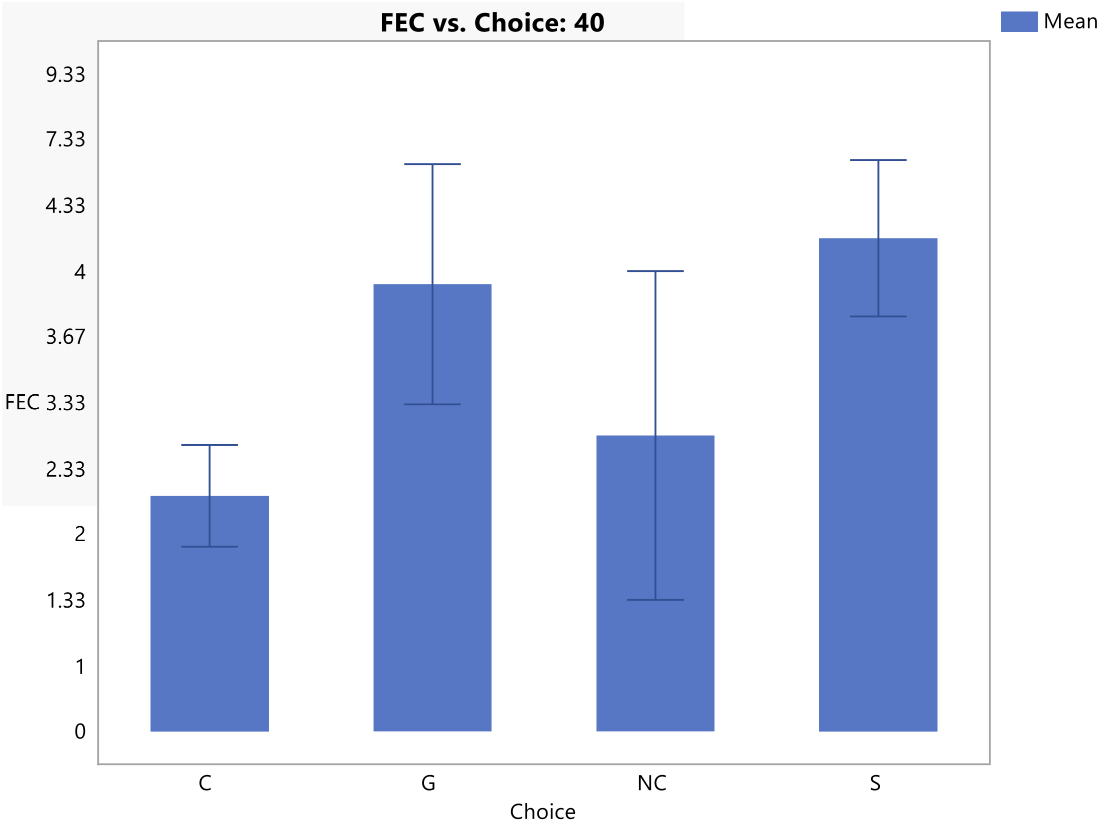

Figure 6. Average FEC for an individual goat (40) and its feed selection for the entire experiment. While this goat had lower FEC, they still elected to consume garlic with elevated FECs.

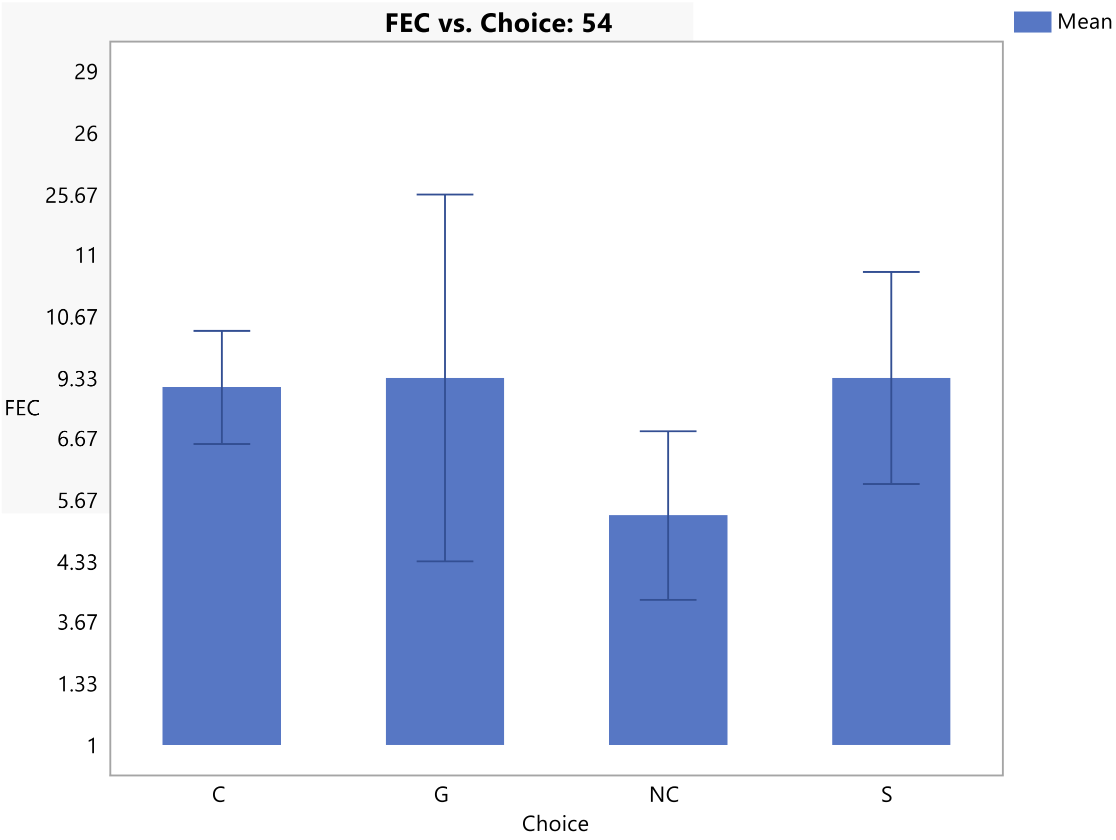

Figure 7. Average FEC for an individual goat (54) and its feed selection for the entire experiment. While this goat had lower FEC, they still elected to consume garlic with elevated FECs

Table 3. Multinomial logistical regression model evaluating the effect of multiple variables had on choice. Values: Coefficient (Standard Error).

Variables	Multinomial Logistical Regression
Intercepts	
Garlic	0.6818 (0.98)
No Choice	752994.8 (0.80)
Switch	0.0563 (1.01)
0.298g garlic/g feed Inclusion	
Garlic	0.9293 (0.57)
No Choice	145984.4 (0.59)
Switch	0.2685 (0.70)
0.446g garlic/g feed Inclusion	
Garlic	0.5157 (0.64)
No Choice	21963.95 (0.91)
Switch	0.0681 (0.98)
FEC	
Garlic	1.0472 (0.03)
No Choice	0.8916 (0.06)

Switch	1.0712 (0.03)
Synthetic Pre-Weaning Diet	
Garlic	1.3265 (0.35)
No Choice	1.6430 (0.42)
Switch	0.9948 (0.03)
Spring	
Garlic	0.6541 (0.63)
No Choice	0.0000 (0.57)
Switch	3.2125 (0.71)
Number of Observations	251
AIC	570.2023
Residual Deviance	534.2023

Table 4. Mixed effect model intercepts evaluating goat effects.

Variables	Mixed Effect model with Goat
Intercept	3.2088 (0.95)
135g Garlic Inclusion	0.6621(0.68)
202.5 Garlic Inclusion	0.2011(0.74)
FEC	1.0331(0.02)
Synthetic Pre-WeaningDiet	1.3222(0.58)
Spring	0.5547(0.72)
Number of Observations	251
AIC	318.9
Residual Deviance	304.944

Table 5. Mixed effect model intercepts evaluating goat and trial effects.

Variables	Mixed Effect Model with Goat and Trial
Intercept	3.2103(0.95)
0.298g garlic/g feedInclusion	0.6622(0.68)
0.446g garlic/g feedInclusion	0.2011(0.75) *
FEC	1.0331(0.02)
Synthetic Pre-WeaningDiet	1.3221(0.58)
Spring	0.5545(0.72)
Number of Observations	251
AIC	320.9
Residual Deviance	304.9243

VIII: DISCUSSION

This experiment is one of the first evaluating self-medicating behavior with plant botanicals and concentrate feeding in goats. The results establish a relationship between feeding behavior of goats and their parasite burden, as characterized through FECs. The feeding behaviors most prevalent in this study that were correlated with high FECs included the consumption of garlic supplemented feed and the previously described switching behavior. This suggests that goats may choose to self-medicate with nutraceutical anthelmintic alternatives when infected with *H. contortus*. Similar behavior with other forages has been reported previously in sheep and goats. Niezen et. al., 1996 observed goats with access to forages high in tannins to have lower *H. contortus* infection than goats with access to forages low in tannin. The self-medicating behavior, observed in small ruminants, suggested that sheep and goats may have the ability to detect GIN infection, or the symptoms that result from parasitic infection. When symptoms are realized, the individuals have electively self-medicated by consuming tannin-rich forages (Amit et. al., 2013; Lisonbee et. al., 2009; Niezen et. al., 1996; Kahiya et. al., 2003).

Additionally, the significant correlation between FEC and switching behavior observed in the current study demonstrates a behavior that is similar to the self-medicating behavior observed in apes (Huffman et. al., 2003). Apes were documented consuming small portions of tannin-rich forages with no nutritional value when presenting symptoms of GIN infection. The small consumption of the tannin-rich forage was defined as a therapeutic consumption strategy. Therapeutic consumption is explained as consuming plants with pharmaceutical properties to health infection and mitigate symptoms. The apes were observed to consume the forage containing anthelmintic properties to alleviate symptoms caused by GIN infection. This could explain the consumption behavior of goats in the current experiment that may have been therapeutically consuming small amounts of the garlic feed to help alleviate symptoms of GIN before moving on to the more palatable control feed (Huffman et. al. 2003; Amit et. al.2013). By consuming small, therapeutic amounts of feed with garlic, the goats may be assessing their own condition and responding by consuming nutraceutical alternatives when needed.

Garlic consumption did not have any adverse effects on weight during the study and could promote growth by alleviating parasite burden. Increased growth performance of small ruminants, by improved feed digestion, rumen fermentation, and health status, is expected from the lower GIN in herds since parasitic infection causes anemia, lethargy, and weight loss (Zhong et. al., 2019; Lisonbee et. al., 2009). Further, the use of garlic as an anthelmintic alternative could provide producers with a practical solution to control parasitic infection. There is potential for mitigating the effects of anthelmintic resistance in small ruminant herds by incorporating anthelmintic alternatives in production (Abongwa et al. 2017; Zhong et. al., 2019).

Inclusion level of the garlic also appeared to influence the goats' selection in the current trial. The 0.298 garlic/g feed inclusion level resulted in the most consumption of garlic treated feed or switch from garlic to control (37.99% vs. 31.25 and 18.19, 0.298 vs. 0.148 and 0.446g garlic/g feed). Additionally, at the 0.298 garlic/g feed inclusion level, selection of garlic supplemented feed was the second most popular choice (51.16% vs. 23.26, C vs. G). At this inclusion level, goats did not appear bothered by the strong smell and unfamiliar texture of the garlic. At the 0.446g garlic/g feed inclusion level, most goats did not consume the garlic treated feed (81.8%, sum of C and NS choices), suggesting that the 0.446g garlic/g feed inclusion level was unfavorable in comparison to the previous two concentration levels. This could be related to previously reported behavioral responses seen in small ruminants to avoid noxious plants or insects by relating adverse consequences when ingested (Launchbaugh et. al., 1993; Mbatha, 2001; Provenza et. al., 1990; Berman et. al., 2019; Hoste et. al., 2010). This behavior is learned by the animals relating the look, taste, or smell with discomfort from consumption of plant or insect. The strong smell and taste of the garlic at the highest inclusion level could result in the avoidance behavioral response.

A limitation of the current study is the use of natural infection over artificial infection. Artificial infection would maintain consistent FEC counts over the duration of the experiment. More consistent FECs could more accurately evaluate choice related to changes in FECs. This experimental design could further assess self-medicating behavior with garlic in small ruminants and potentially correlate FEC reduction from therapeutic consumption. The drawback of using artificial infection is managing the parasitic infection to ensure the animal does not succumb to the elevated infection over the course of the trial.

The breed of goat used may also influence selection for a given feed similar to errors addressed in previous research (Amit et. al., 2013). The two breeds used in Amit's study had differing nutraceutical consumption strategies: the Damascus breed consumed *P. lentiscus* prophylactically and the Mamber breed consumed the plant therapeutically. Further investigation with different breeds and larger experimental population would establish the strategies favored by goats.

Additionally, consistently rotating the different garlic inclusion levels could potentially alter the results of the self-medicating behavior in goats. This would further determine an avoidance level particularly when the FECs are elevated in spring when *H. contortus* reproduction increases. The effects of season on FEC and the self-medicating behavior may also change with modifying the experiment by offering the different garlic inclusions from winter into summer (Machen et. al., 1998; Sendow, 2003).

IX. CONCLUSION AND RESEARCH IMPLICATIONS

In summary, the current experiment established the preference for garlic treated feed in goats with GIN infection, which is indicative of self-medicating behavior. Overall, the goats preferred consuming small doses of the garlic treated feed then switching to the control suggesting a therapeutic self-medicating strategy. In addition to the characterization of the therapeutic self-medicating strategy, this experiment also illuminated a garlic inclusion level that resulted in avoidance behavior by the goats. The inclusion level of 0.298g garlic/g feed was readily consumed by goats with elevated FECs, but once the inclusion level increased to 0.446g garlic/g feed, the goats were observed to avoid the treated feed even with elevated FECs. The avoidance of the higher inclusion rate demonstrates goats are only willing to consume garlic at a moderate inclusion level and requires further refinement of the maximum inclusion rate. Given that there is limited research on the use of garlic as a botanical anthelmintic alternative for goats through self-medication, additional exploration of the self-medicating behavior is warranted. For example, experimentally infecting goats with *H. contortus* rather than natural infection could elucidate stronger correlations between FEC and choice. Additionally, evaluating the effects of self-medicating behaviors on post-consumption FEC will also further characterize the self-medicating behavior and outcomes. Regardless, small ruminant producers could benefit from the current findings by offering garlic as a supplement to their goat herds, at a moderate inclusion level (0.298g garlic/g feed). The concept of self-medication could modify the current model of parasite management by transferring decisions to the animals themselves.

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