

MAKERERE



UNIVERSITY

**PREVALENCE AND HOST RELATED RISK FACTORS OF
HAEMONCHOSIS IN SHEEP IN NAKAPELIMORU
SUBCOUNTY, KOTIDO DISTRICT, NORTH
EASTERN UGANDA**

BY

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BVM V

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OCTOBER, 2026

DECLARATION

I, **Owiny Ernest Desire**, declare that the information in this research report is my original work. It has not been submitted for any academic award in any other university or institution of higher learning.

Signature:  Date: 2/10/2026

This research has been conducted under the supervision and guidance of my supervisor. The resulting report is submitted with her approval.

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DEDICATION

With deep gratitude and high pleasure, I dedicate this research report to my beloved parents, Mr. Okello Godfrey Olirus and Mrs. Awidi Graceline Okello, for their unwavering love, financial sacrifice and constant encouragement that enabled me to complete this course and this special project. I also dedicate this work to my dear siblings and friends whose moral support and motivation kept me focused throughout the academic journey.

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TABLE OF CONTENTS

DECLARATION	i
DEDICATION	ii
ACKNOWLEDGEMENTS.....	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES.....	viii
ABSTRACT.....	ix
CHAPTER ONE	1
INTRODUCTION.....	1
1.1 Background.....	1
1.2 Problem statement.....	2
1.3 Objectives of the study.....	3
1.3.1 General objective.....	3
1.3.2 Specific objectives.....	3
1.3 Research questions.....	3
1.5 Significance and justification of the study	3
CHAPTER TWO	5
LITERATURE REVIEW	5
2.1 Biology and pathophysiology of <i>Haemonchus contortus</i>	5
2.1.1 Taxonomy and morphology	5
2.1.2 The pathophysiology and pathogenesis	5
2.1.3 Life cycle	7
2.2 Epidemiology of ovine haemonchosis	7
2.3 Factors influencing larval intensity of <i>H. contortus</i> in tropical and semi-arid zones	8
2.3.1 intrinsic factors.....	8
2.3.2 Extrinsic factors.....	9

2.4 Parasitological diagnostic techniques	10
2.4.1 Fecal egg recovery via floatation	12
2.4.2 Sheep coproculture and larval development	12
2.4.3 The Baermann technique	13
2.4.4 Morphological identification of infective third-stage larvae of <i>Haemonchus contortus</i>	13
2.5 Management of ovine haemonchosis in sheep flocks	14
2.5.1 Prevention and control	14
2.5.2 Treatment	14
CHAPTER THREE	15
MATERIALS AND METHODS	15
3.1 Study area	15
3.2 Study design	16
3.3 Study population	16
3.4 Sample size determination	17
3.5 Eligibility criteria	17
3.5.1 Inclusion criteria	17
3.5.2 Exclusion criteria	17
3.6 Data collection procedure	17
3.6.1 Fecal sample collection	17
3.6.2 Sample preparation for fecal culture and larval identification	18
3.7 Data management and statistical analysis	20
3.8 Ethical considerations	20
CHAPTER FOUR	21
RESULTS	21
4.1 Attributes of the sampled sheep	21
4.2 Prevalence of strongyles and <i>Haemonchus</i> in sheep from Nakapelimoru sub-county, Kotido district	21

4.3 Occurrence of strongyles and <i>Haemonchus</i> by parish from Nakapelimoru sub county, Kotido district.....	21
4.4 Factors associated with haemonchosis in sheep from Nakapelimoru sub county, Kotido district.....	22
4.5 Diagnostic photomicrographs of parasite stages.	23
CHAPTER FIVE.....	25
DISCUSSION	25
CHAPTER SIX.....	29
CONCLUSION AND RECOMMENDATIONS	29
6.1 Conclusion.....	29
6.2 Recommendations.....	29
REFERENCES	30
APPENDICES	35
Appendix I: The 12 parishes of Nakapelimoru subcounty	35
Appendix II: Criteria for aging the sheep used	36
Appendix III: Body condition scoring of the sheep	37

LIST OF TABLES

Table 1: Attributes of the sampled sheep	21
Table 2: Prevalence of Strongyles and <i>Haemonchus</i> among the sampled sheep	21
Table 3: Association between host-related risk factors and haemonchosis in the sampled sheep.....	22

LIST OF FIGURES

Figure 1: Administrative boundary map of Kotido District highlighting Nakapelimoru Subcounty (3° 1' 0" N, 34° 13' 0" E) alongside surrounding subcounties.	16
Figure 2: Prevalence of strongyle-type eggs and <i>Haemonchus contortus</i> in the sampled sheep by parish.....	22
Figure 3: Photomicrograph of a strongyle-type egg (red arrow) identified during fecal egg floatation (100× total magnification) [By Owiny Ernest Desire]	23
Figure 4: Photomicrograph of a third stage <i>Haemonchus contortus</i> larva (red arrow) following coproculture (100× total magnification)[By Owiny Ernest Desire].....	
Figure 5: Photomicrograph showing the posterior end of <i>Haemonchus larva</i> (red arrow) with a bend end (100× total magnification)[By Owiny Ernest Desire]	24

ABSTRACT

Haemonchus contortus is widely acknowledged as one of the most pathogenic gastrointestinal nematodes causing significant economic losses in small ruminant production systems. A cross-sectional study was conducted in Nakapelimoru sub-county, Kotido district, North Eastern Uganda to determine the prevalence and associated host-related risk factors of haemonchosis in sheep. Fecal samples were collected from 355 randomly selected sheep across three parishes (Kopsang, Kalobor, and Lookorok) and examined using the simple test tube floatation method and coproculture. The overall prevalence of strongyle eggs was 49.58 % (176/355) while the specific prevalence of *Haemonchus contortus* confirmed via coproculture and larval identification was 25.35 % (90/355). Statistical analysis using the Chi-square test revealed no significant association ($P > 0.05$) between *Haemonchus* infestation and host risk factors including sex ($P = 0.958$), age ($P = 0.650$) and body condition score ($P = 0.841$). These findings indicate that *Haemonchus contortus* is widespread across the sheep population regardless of individual host attributes emphasizing the critical need for broad-based, whole-flock control and prevention strategies within this pastoral system.

CHAPTER ONE

INTRODUCTION

1.1 Background

Haemonchosis, an infection caused by the nematode parasite, *Haemonchus contortus* is widely acknowledged as a primary contributor to anemia in small ruminants across numerous countries globally (Flay et al., 2022). *Haemonchus species* are also frequently identified among the most common gastrointestinal nematodes leading to severe implications for ruminant populations. These implications include significant economic losses in terms of meat and milk production, reduced offspring growth, compromised health, welfare, nutritional status, diminished reproductive success and increased expenses for prevention and treatment. Furthermore, it can predispose the animals to other diseases (Arsenopoulos et al., 2025). In Nakapelimoru subcounty, sheep are also a significant livestock, with their presence notably contributing to the local agricultural landscape. The sheep stand out as the most frequently slaughtered livestock for meat in this area.

A standardized cross-sectional survey conducted between 2012 and 2013 as part of the GLOWORM project gathered data from three pilot areas in Ireland, Switzerland and Italy. The survey revealed an overall prevalence of *Haemonchus contortus* in sheep farms throughout Europe to be around 56%. However, regional variations were observed with some countries reporting significantly higher prevalence rates. For instance, Switzerland showed 77%, Italy 73% and Ireland 4% (Rinaldi et al., 2015).

In Daronta, Afghanistan, a study conducted in various restaurant abattoirs in Nangarhar indicated an overall haemonchosis prevalence in sheep of 22.66%. The prevalence rate was higher in sheep less than 1 year old (27.27%) compared to those aged 1-2 years (22.44%) and more than 2 years (14%). Additionally, the sex-wise prevalence of Haemonchosis was greater in females (30.61%) than in males (18.81%) (Amarkhil et al., 2023).

In Ethiopia's Wukro region, the overall prevalence of *H. contortus* in sheep was found to be 40.9% which was responsible for the loss of production in sheep. The high prevalence was more common in medium body condition and young animals which necessitates increased attention when designing the control programs. Similarly, the prevalence among male sheep was notably high. This was attributed to the practice of the society and ethical

point of slaughtering of the male animals, as most of the female animals were kept for breeding purposes (Gebresilassie & Afera Tadele, 2015).

In the Moroccan region of Gharb, a random selection of 1154 sheep from various farms, pastures and abattoirs revealed a prevalence of 23.92%. Notably, the prevalence was higher in females (30.98%) compared to males (15.63%). An analysis by age group indicated that the prevalence of haemonchosis was 6.25% in young animals and 43.22% in aged sheep. When considering body condition, the maximum prevalence (80.83%) was observed in animals with poor body condition, followed by those with moderate body condition (34.26%) while the lowest infection rate (6.88%) was noted in animals with good body condition (Brik et al., 2019a).

In North Western Nigeria, the prevalence of *H. contortus* in sheep was found to be 85% which is notably higher than that in goats (78%). The peak prevalence of this gastrointestinal parasite in small ruminant production systems typically occurs during the late rainy season. Such infestations are a leading cause of production losses (Josiah et al., 2015) and are a concern globally, beyond Uganda.

A cross sectional study in Soroti abattoir, Uganda, determined the prevalence of Haemonchosis in sheep to be 43.5% (Walyomo, 2024). Another cross-sectional study examining Haemonchosis in Small Ruminants Under Traditional Husbandry Systems in Apac District, Northern Uganda reported a prevalence of 73.3% and 70.6% observed using faecal egg identification and coproculture techniques, respectively. This explains the low productivity of small ruminants in Apac. This study also highlighted a significantly higher proportion of sheep than goats which had *H. contortus* eggs in their faeces. This suggests that sheep are more susceptible to *H. contortus* infections than goats. This may be because sheep tend to graze very close to the ground where infective nematode larvae are increasingly present raising their chances of picking up infective larval stages. Conversely, goats are frequently observed browsing on shrubs and small trees above the ground where infective larvae are comparatively fewer (Opeto et al., 2024). Currently, there is no specific study on sheep Haemonchosis in Kotido hence the need for such research in this area.

1.2 Problem statement

Haemonchosis is a major cause of illness in small ruminants in Uganda, similar to other tropical and subtropical regions globally (Nabukenya et al., 2014). Haemonchosis causing

parasites are also one of the most common and fatal pathogenic gastrointestinal nematodes of small ruminants causing significant economic losses particularly in low income nations (Opeto et al., 2024). Haemonchosis as a disease causes loss of income to farmers (Dansou et al., 2021) directly through production losses due to weight loss and potentially death of infested animals. These consequences of haemonchosis to the sheep which is the most slaughtered livestock for meat in Kotido district would lead to food insecurity causing widespread hunger and malnutrition particularly among the children and the elderly. Therefore, understanding the prevalence of haemonchosis in sheep in this area is crucial for the pastoralists and veterinary professionals to develop effective control strategies against *Haemonchus* in order to prevent food insecurity hence the need for this study.

1.3 Objectives of the study

1.3.1 General objective

To determine the prevalence and host related risk factors of Haemonchosis in sheep in Nakapelimoru subcounty, Kotido district, North Eastern Uganda.

1.3.2 Specific objectives

- i. To determine the overall prevalence of *Haemonchus contortus* infection in sheep in Nakapelimoru subcounty, Kotido district.
- ii. To determine the host related risk factors associated with *Haemonchus contortus* infection in sheep in Nakapelimoru subcounty.

1.3 Research questions

1. What is the overall prevalence of *Haemonchus contortus* infection in sheep in Nakapelimoru subcounty, Kotido district?
2. What host-related risk factors are associated with *Haemonchus contortus* infection in sheep in Nakapelimoru subcounty?

1.5 Significance and justification of the study

Sheep farming forms the foundation of rural economies in developing countries, but its advancement is significantly hindered by Haemonchosis (Muhammad et al., 2021). This disease leads to production losses primarily through morbidities and mortalities in severely infested animals and increases expenses for medication and treatment (Opeto et al., 2024).

This study intends to provide clear data on the occurrence of haemonchosis in sheep within Nakapelimoru subcounty, Kotido district located in North Eastern Uganda. The insights gained will assist the pastoralists and the veterinary professionals in planning and implementing suitable strategies for the prevention and control of haemonchosis thereby reducing its impact on the sheep in this subcounty. This research also aligns with the United Nations Sustainable Development Goal Two (Zero Hunger) which aims to end hunger, achieve food security and improve nutrition and promote sustainable agriculture by 2030 among the United Nations' member states including Uganda.

CHAPTER TWO

LITERATURE REVIEW

2.1 Biology and pathophysiology of *Haemonchus contortus*

2.1.1 Taxonomy and morphology

The parasite *H. contortus*, which is the primary cause of Haemonchosis in sheep is classified within the Kingdom: Animalia, Phylum: Nematelminths, Class: Nematodes, Sub-class: Secernentea, Order: Strongylida, Sub-order: Trichostrongylina Super-Family: Trichostrongyloidea, Family: Trichostrongylidae, Sub-family: Haemonchinae, Genus: *Haemonchus*. Within the domestic livestock, the *Haemonchus* genus has four recognized species: *H. contortus* in sheep and goats, *Haemonchus placei* and *H. similis* found in cattle, *H. longistipes* for camels (Dansou et al., 2021; Tilahun, 2021).

Morphologically, *Haemonchus contortus* adult worms are relatively large (2-3 cm) (K. Arsenopoulos et al., 2021) with males measuring 10-20 mm and females reaching 18-30 mm in length. A defining feature of the female parasite is the distinctive appearance of its white uterus spiraling around the blood filled red intestine which creates a pattern often referred to as the “barber’s pole” appearance (Selemon, 2018). On the other hand, male worms are typically red in colour. While the male bursa is visible to the naked eye, microscopic examination reveals that males possess long spicules barbed near tips and an asymmetrical dorsal ray within the bursa.

In sheep, the vulval flap in female worms is commonly linguiform in shape. Both sexes feature cervical papillae located on the head as well as a small lancet situated within the buccal cavity. This lancet serves as a critical mechanism by which the parasites injure the abomasal mucosa (K. Arsenopoulos et al., 2021; Dansou et al., 2021; Taylor et al., 2015).

2.1.2 The pathophysiology and pathogenesis

The pathophysiology of haemonchosis and its associated clinical signs are primarily driven by the anemia that develops as a consequence of the parasite’s blood feeding activity. Blood loss begins with the development of the fourth-stage larvae and the anemia typically becomes detectable 10 – 12 days post infection (Besier et al., 2016b). Research indicates that an infected sheep may lose approximately 0.05 ml of blood per worm daily and

therefore an animal infected with 5000 *H. contortus* could experience a daily blood loss of roughly 250 ml (Dansou et al., 2021).

The severity of the disease is closely linked to the number of *H. contortus* that establish in the host as there is a strong correlation between the parasite burden and the volume of blood lost. The overall outcome of this infection depends heavily on the rate of intake of infective larvae, their stage of development, the age and size of the infected sheep and the host's response that is the immune response and the animal's capacity to replace lost blood (Flay et al., 2022). Depending on the intensity of the infection and the host response, haemonchosis is categorized into a continuum of three general syndromes; hyperacute, acute and chronic.

Hyperacute haemonchosis is an uncommon form where healthy animals die suddenly from severe haemorrhagic gastritis due to burdens of up to 30,000 *H. contortus* in the abomasum.

In the more typical acute form, anemia develops over a relatively longer period with death occurring within 4-6 weeks of infection in animals harbouring burdens of 2000 – 20,000 worms. This initial anemia is followed by a progressive decline in packed cell volume (PCV) which generally occurs about two weeks after infestation subsequently leading to bone marrow decompensation that is further exacerbated by the loss of iron and protein until the animal dies. At necropsy, affected carcasses appear pale, often displaying marked ascites and submandibular edema which reflects the hypoproteinemia caused by the parasite's blood feeding activity. Furthermore, the blood may appear watery and fail to clot while the abomasal mucosa is frequently edematous showing blood flecked mucus and visible signs of parasite attachment.

Chronic haemonchosis is the most frequent presentation where sheep may ingest lower numbers of *H. contortus* resulting in infections that go unnoticed or occurs in environments that are unsuitable for the development of infective larvae during less favourable periods or in regions where effective control measures are implemented to prevent acute haemonchosis (Flay et al., 2022). Chronic form of haemonchosis is responsible for significant production losses due to high morbidity. Clinical signs in these cases include cachexia, weight loss, hyporexia and asthenia as well as diarrhea with black-coloured stool (Besier et al., 2016b; Dansou et al., 2021; Selemon, 2018).

2.1.3 Life cycle

Under optimal environmental conditions that is high humidity and temperature between 25°C and 30°C (Dansou et al., 2021), parasite eggs can reach the infective third stage larvae (L3) in just four days. Low humidity and dessication rapidly kill eggs and larvae. The L3 larvae are particularly hardy because they retain the protective cuticle from their second stage making them the most resilient free-living form. After emerging from the faeces into the soil, they migrate randomly both horizontally and vertically up the grass sward independent of free water. These L3 larvae do not feed but rely on internal energy stores for survival. Once a susceptible sheep ingests the L3 larvae, the parasites undergo their first parasitic molt to become fourth stage larvae (L4) by the third day of infection. At this stage, it is common during a long dry period (tropical zones) or in winter (temperate zones) for the larvae to become embedded in the digestive mucosa to delay their development until the rainy season or spring which is known as larval hypobiosis (Dansou et al., 2021; Flay et al., 2022). Between days 7 and 9, a second molt occurs as the L4 transitions into the fifth larval stage (L5). Around days 10 to 11 just before the final ecdysis, the immature L5 develop a lancet within their buccal cavity which they use to burrow into the gastric pits of the abomasum. This lancet allows them to cut the abomasal tissue and induce haemorrhages before ingesting the leaking blood. The L5 larvae then mature into adult forms, continue feeding and begin sexual differentiation and reproduction. Finally between days 12 and 15, adult female noted for their high biotic potential start producing eggs to continue the cycle (Besier et al., 2016a; Flay et al., 2022). *Haemonchus contortus* in sheep lays around 5000 – 15000 eggs per day. (Bhat et al., 2023).

2.2 Epidemiology of ovine haemonchosis

Haemonchus contortus also known as the barber's pole worm is a helminth parasite of the abomasum of ruminants and in particular sheep and goats. It is the most economically important and pathogenic helminth parasite of small ruminants in the warm tropical and subtropical regions of the world. High rainfall and temperatures promote rapid hatching of eggs on pasture and hence increased contamination (Mushonga et al., 2018). Due to the continually high temperatures, most locations within the tropics support the development of *H. contortus* and the presence of this nematode relates almost entirely to rainfall (Besier et al., 2016b). *Haemonchus contortus* survives throughout the dry season as hypobiotic fourth-stage larvae in the abomasal mucosae, a survival mechanism that may be less

pronounced in regions with shorter dry periods. Lack of moisture especially during the dry season is a crucial limitation for survival and development of larval populations, which are thus favoured only during the short rainfall periods (K. Arsenopoulos et al., 2021). Under climate change scenarios, variability in temperature and rainfall is predicted to increase so the effect of short-term climatic conditions on larval availability e.g. following brief rainfall events and the modifying influence of pasture microclimate, could significantly alter transmission patterns. The pasture microclimate strongly affects the fecal moisture content with shade and long grass both significantly slowing drying and increasing the survival of *H. contortus* parasites (Wang et al., 2018). Optimal conditions for egg hatching and larval development of *H. contortus* occur at ambient vegetation microclimate of 22°C to 26°C and humidity that is close to 100%. During the dry weather, larvae may remain in dessicated faeces and only emerge after rain leading to an infection surge (Flay et al., 2022).

2.3 Factors influencing larval intensity of *H. contortus* in tropical and semi-arid zones

2.3.1 intrinsic factors

Haemonchus contortus is a notably prolific, blood consuming parasite. Its capacity to generate vast quantities of eggs throughout its life time gives *H. contortus* an advantage over other parasites in that it can swiftly contaminate pastures and persist within small ruminant hosts through a cycle of constant and rapid reinfection (Selemon, 2018).

Nature of the host

Breed; Various sheep breeds demonstrate differing levels of vulnerability to gastrointestinal parasitic infections. This variation is clearly shown in more resistant sheep through lower fecal egg counts (FEC), decreased total worm burdens, delayed parasite development and reduced worm fecundity (Selemon, 2018; Shrivastava et al., 2022).

Age, sex and reproductive status; Beyond genetic influences, animals of different ages and sex respond differently to parasitic challenges under similar management conditions. Generally, young animals are more vulnerable to parasitic diseases than adults. This is largely attributed to immunological hypo-responsiveness or an underdeveloped active immunity during early life and it is not merely a result of insufficient exposure to pathogens to trigger an immune response (S. A.-A. Mohamed et al., 2024; Selemon, 2018).

In the work of Gauly et al. (2006) and Selemon (2018), it is noted that male animals shed significantly higher quantities of fecal eggs, harbored greater number of *H. contortus* worms and exhibited more anaemia compared to their female counter parts. Furthermore, it was observed that castration improved the resistance of male lambs to the point that their fecal egg counts (FEC) were lower than those of the female lambs, pointing toward the influence of sex-related hormones.

The phenomenon known as the peri-parturient rise (PPR) in nematode egg production is also a critical factor in the epidemiology of gastrointestinal nematodes in sheep. This is due to a temporary decline in acquired immunity or immunosuppression during the period surrounding parturition and throughout lactation. Specifically the PPR in FEC begins 2 to 4 weeks before lambing and persists into the post parturient lactation period (Gowda, 2016; Selemon, 2018).

2.3.2 Extrinsic factors

Climate; Climatic conditions significantly influence the progression of infection by *H. contortus*. Tropical and sub-tropical regions provide the ideal combination of warmth and humidity necessary for the survival of and the subsequent infection of ruminants (K. V. Arsenopoulos et al., 2021). Specifically, the eggs of *H. contortus* hatch and larvae develop most effectively when ambient micro-climate temperatures remain between 22°C and 26°C with humidity levels nearing 100% (Flay et al., 2022). Microclimates created by shade and long grass play a vital role in slowing the dessication of faeces. This moisture retention facilitates greater larval migration and increases the likelihood of transmission (Wang et al., 2018).

Management factors; Sheep grazing freely in open pastures characterized by woody vegetation and shrubs generally exhibit a lower risk of infection with *H. contortus* larvae. This reduced likelihood is often attributed to the environmental conditions of semi-arid regions where the sparse distribution of forage and nature of the vegetation may be less conducive to the survival and transmission of infective larvae compared to lush, damp pastures. A significant correlation exists between veterinary intervention and infection rates that is sheep that do not receive regular antihelminthic treatments face a substantially higher risk of Haemonchosis than those under routine veterinary care i.e. deworming (Opeto et al., 2024). The risk is exacerbated by high stocking densities particularly at communal water points. These localized areas of high animal concentration promote heavy pasture

contamination and increases the frequency of larval ingestion directly leading to higher prevalence and increased larval intensity within the flock (Mushonga et al., 2018; Titcomb et al., 2021).

Nutrition; A good plane of nutrition is a critical determinant in enhancing both the resilience and resistance of sheep against gastrointestinal nematode infections. Nutrition significantly influences the clinical outcome of parasitism by increasing the ability of the host to maintain productivity and cope with the adverse physiological effects of the parasite (resilience) and improve the immunological capacity to limit the establishment, development and fecundity of the parasite (resistance) (Selemon, 2018). Well-fed animals often remain reasonably productive and typically require fewer anti-helminthic interventions compared to their undernourished counterparts. Conversely, sheep in poor body condition generally exhibit a higher prevalence of infection. This is particularly evident in regions like Karamoja where animal feed resources are frequently scarce and insufficient to meet nutritional demands throughout the year. In these semi-arid environments, the lack of consistent high quality forage increases the susceptibility of the flock leading to higher larval intensities and widespread prevalence of haemonchosis (Alkadir & Ayana, 2024; Selemon, 2018).

2.4 Parasitological diagnostic techniques

The comprehensive diagnosis of haemonchosis relies on an integration of clinical observation, postmortem findings, diagnostic laboratory tests and advanced molecular methods.

Clinical signs and symptoms

Severe anaemia is the hallmark sign because the primary pathognomonic manifestations of this disease are directly linked to the blood feeding activity of adult helminths and immature larvae within the host's abomasum. This anaemia is commonly evaluated in the field using the **FAMACHA system** (Faffa Malan Chart) (Seyoum et al., 2018), a highly sensitive five – point scoring scale that correlates ocular conjunctival paleness from a healthy red – pink (score 1) to a severe life threatening paleness (score 5). This system is particularly effective in endemic tropical and subtropical climates. Beyond conjunctival paleness, advanced infestations manifest as submandibular edema, marked declines in milk yield or partial agalactia, generalized physical weakness and the passage of scant, firm and dark coloured

faeces due to melena, all this resulting in severe production and economic losses across the flock (K. Arsenopoulos et al., 2021; Besier et al., 2016b).

Postmortem findings

Post-mortem examinations provide a rapid and accurate means of diagnosing Haemonchosis infestations (Besier et al., 2016a). In cases of hyperacute haemonchosis, diagnosis relies on identifying massive populations of adult *Haemonchus* species within the abomasum alongside macroscopic observation of petechiae haemorrhages on the organ's gastric mucosa. When examining carcasses affected by acute haemonchosis, the animals typically present as severely anemic, characterized by pale mucous membranes, ascites and submandibular edema. This is due to the hypoproteinemia caused by the blood sucking activity of the parasites. Furthermore, the blood within the carcass may fail to clot properly and the gastric mucosa is full of petechiae haemorrhages with visible parasites still attached. Ultimately it is important to note that these distinct postmortem findings are generally not indicative of chronic haemonchosis (K. Arsenopoulos et al., 2021; Regassa et al., 2024).

Diagnostic laboratory tests

Laboratory diagnosis of *Haemonchus* infestation relies on qualitative methods like the Teleman method and quantitative approaches such as the modified McMaster method to detect and count eggs in fecal samples (Besier et al., 2016a; Seyoum et al., 2018). The structural characteristics of *Haemonchus* eggs lack genus-specific distinctiveness hence identifying them at genus level through standard microscopy is highly challenging and practically inapplicable (K. Arsenopoulos et al., 2021).

Advanced molecular methods

Molecular technologies like Polymerase Chain Reaction (PCR) are now being utilized for precise genus and species identification (K. Arsenopoulos et al., 2021). These techniques can isolate and distinguish individual species by targeting distinct genetic markers within their ribosomal DNA across a variety of strongylid nematodes. These PCR assays operate by amplifying DNA collected directly from nematode eggs in fecal samples, from fecal DNA or from isolated individual larvae. Real-time PCR has also shown potential for calculating overall worm burdens offering a promising alternative that could eventually

replace both traditional fecal egg counts and manual species identification procedures (K. Arsenopoulos et al., 2021; Besier et al., 2016a).

2.4.1 Fecal egg recovery via floatation

The fundamental principle of the floatation method relies on the specific gravity of the medium used. When fecal samples are suspended in a solution with a higher specific gravity than that of the helminth eggs, the eggs will float to the surface. Nematode and cestode eggs float in a liquid with a specific gravity of 1.10 – 1.20. Typically, floatation solutions for nematode and cestode ova are prepared using sodium chloride or magnesium sulphate though sugar solutions are sometimes utilized. These saturated solutions are prepared in advance, stored and their specific gravity is verified prior to use (Taylor et al., 2015).

Regarding the **Simple test tube floatation procedure**; approximately 3g of fecal material is mixed thoroughly with 50 ml of floatation fluid in a container using a stirring device such as a tongue blade. The resulting suspension is passed through a tea strainer into a second container. This suspension is then transferred into a test tube and placed in a test tube rack. The test tube is filled to create a convex meniscus at the rim where a cover slip is carefully placed. After standing for 20 minutes, the coverslip is removed with the adhering drop of fluid and immediately placed onto a microscope slide for examination at 10× magnification (J. Hansen & B. D. Perry, 1994).

2.4.2 Sheep coproculture and larval development

Coproculture is intended to provide an optimal environment for the hatching of helminth eggs and their subsequent development into the infective third-stage larvae (L3) (J. Hansen & B. D. Perry, 1994). Charcoal or dried, sterile bovine faeces are commonly used for this process. To prepare the sterilized bovine faeces, the bovine fecal material is heated to 70 °C to eliminate any existing helminth eggs and then ground into a fine powder.

To initiate the culture, collected faeces should be broken up finely using a stirring tool. The mixture must maintain a moist, crumbly consistency; water should be added if sample is too dry while charcoal or the sterile bovine faeces should be incorporated if the sample is excessively wet. The cultures are maintained at room temperature for 14 to 21 days to allow the larvae to reach the infective stage. Alternatively, if an incubator is available, cultures can be kept at 27 °C for 7 to 10 days with water added regularly every 1 to 2 days to

maintain moisture. Larvae are then recovered using the Baermann technique (J. Hansen & B. D. Perry, 1994; Taylor et al., 2015).

2.4.3 The Baermann technique

The Baermann technique is employed to isolate infective larvae from fecal cultures for diagnostic identification. The procedure begins by fitting a short piece of tubing, closed at one end with a clamp or spring clip onto the stem of an appropriately sized funnel supported by a stand. Approximately 5 – 10g of fecal culture is weighed and placed on a double layer of cheesecloth which is then shaped into a “pouch” and secured with a rubber band. A supporting stick is fixed beneath the rubber band to suspend the pouch within the funnel and the surplus cheesecloth is trimmed. The funnel is filled with lukewarm water until the fecal material is submerged and the apparatus is left to stand for 24 hours or overnight at room temperature. During this time, larvae actively migrate out of the fecal material and collect by gravity in the stem of the funnel.

For final examination, 10 – 15 ml of fluid is drawn from the funnel stem into a test tube and left to settle for 30 minutes. The supernatant is removed with a Pasteur pipette and a small aliquot of the remaining fluid is transferred to a microscope slide. A drop of iodine is added and the sample is covered with a coverslip and examined at 10× magnification to identify third-stage larvae (L3) of *Haemonchus contortus* (J. Hansen & B. D. Perry, 1994; Taylor et al., 2015).

2.4.4 Morphological identification of infective third-stage larvae of *Haemonchus contortus*

The infective third-stage larvae (L3) of *Haemonchus contortus* can be identified by specific anatomical features including the presence of 16 intestinal cells and a narrow rounded head. These larvae also possess a medium sheath tail which is kinked along with a pointed tail. The L3 larvae also have a filaroid oesophagus (J. Hansen & B. Perry, 1994; Taylor et al., 2015).

2.5 Management of ovine haemonchosis in sheep flocks

2.5.1 Prevention and control

Effective control of *H. contortus* requires strategies that break the parasite's lifecycle through a combination of antihelminthic treatments, sound animal husbandry and diligent pasture management.

Proper pasture rotation is essential as it provides sufficient time for larvae on the pasture to die before animals return to graze while also allowing the grasses to grow to a height higher than the larvae can climb (K. Arsenopoulos et al., 2021; Selemon, 2018). Additionally, alternate grazing with different host species and the rotation of grazing with cropping can provide economic advantages when combined with traditional antihelminthic use. However, in many parts of Africa, communal pastoral systems often do not allow for the regulated grazing necessary to minimize exposure to infective larvae. Beyond these measures, preventing the disease requires maintaining animal health through the provision of quality feed and sufficient protein (Dansou et al., 2021).

2.5.2 Treatment

Treating sheep haemonchosis typically involves the use of antihelmintics such as albendazole (5mg/kg), fenbendazole (5mg/kg), oxfendazole (5mg/kg), levamisole (7.5mg/kg), ivermectin (0.2mg/kg), moxidectin (0.2mg/kg) and closantel (10mg/kg) (Besier et al., 2016a; Selemon, 2018). Given the widespread emergence of resistance to these conventional antihelmintics, there is a growing need to explore and encourage alternative control methods. For instance, medicinal plants with antihelminthic properties against *H. contortus* in animals such as garlic (*Allium sativum*) which makes the host's digestive tract healthier because it possesses known antibacterial properties (Dansou et al., 2021; Shrivastava et al., 2022).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was carried out in Nakapelimoru subcounty, Kotido district, Karamoja region, Uganda in February, 2026. Geographically, the subcounty is located at latitude 3° 1' 0" N and longitude 34° 13' 0" E. The area experiences an annual rainy season extending from April to August, yielding approximately 519 mm of rainfall per annum, with daily temperatures ranging from 20°C to 35°C annually. According to the National Population and Housing Census 2024 data, Nakapelimoru subcounty had a population of about 13,502 people, comprising 6,168 males and 7,334 females. The subcounty is home to the Jie people of Karamoja, who practice pastoralism as their primary livelihood.

Administratively, Nakapelimoru subcounty comprises 12 parishes. Guided by the subcounty veterinary extension team, three parishes within Nakapelimoru subcounty were purposively selected for sample collection that is Kopsang, Kalobor, and Lookorok. These specific parishes were selected because they represented the highest sheep population densities within the subcounty. Also, sample collection was strategically synchronized with an active government veterinary campaign during which sheep were being vaccinated against Peste des Petits Ruminants (PPR), and goats against both PPR and Contagious Caprine Pleuropneumonia (CCPP). Utilizing these active, centralized vaccination aggregation points allowed for efficient access to a high volume of animals and ensured a broad, representative sampling of sheep across the diverse pastoral herds in Nakapelimoru subcounty.

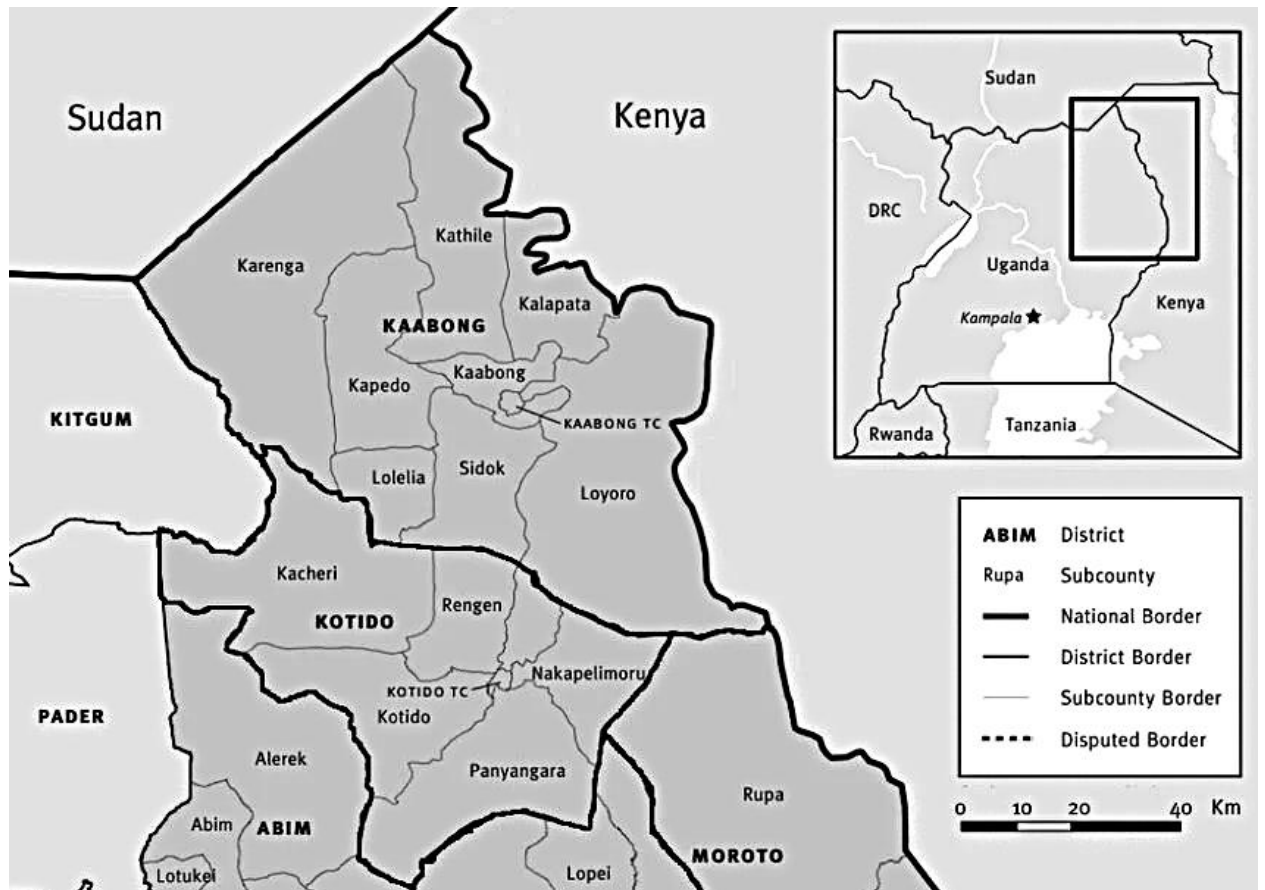


Figure 1: Administrative boundary map of Kotido District highlighting Nakapelimoru Subcounty ($3^{\circ} 1' 0''$ N, $34^{\circ} 13' 0''$ E) alongside surrounding subcounties.

Source: (Parvez Butt, 2017)

3.2 Study design

A cross sectional study using random sampling was conducted in February 2026 to determine the prevalence of haemonchosis and its association with host-related risk factors in sheep owned by the pastoralists in Nakapelimoru subcounty. Before individual sample collection, data regarding the specific location (parish) as well as host-related risk factors including sex, age, and body condition score (BCS) of each sheep were obtained and recorded directly on the label of each corresponding sample container.

3.3 Study population

The study population were sheep of different sexes, ages and body condition scores kept on the pastoral system of management with no or minimal access to veterinary services.

The majority of sheep in Nakapelimoru subcounty are the indigenous sheep which are adapted to the climatic and environmental conditions of this area.

3.4 Sample size determination

The sample size (n) for the study population was determined using the formula for prevalence studies (Daniel & Cross, 2018);

$$n = \frac{Z^2 P(1-P)}{d^2}$$

Considering a 95% confidence interval (CI), 5% desired absolute error (d) and 50 % expected level of prevalence (P) of *H. contortus* among the sheep in the study since there was no previous study specifically in the study area. This yielded a minimum sample size of 384.16 which is approximately 384 sheep. However, due to limited financial resources, a final total of 355 fecal samples were successfully collected across the three parishes - Kopsang (n = 102), Kalobor (n = 169) and Lookorok (n = 84) and processed for parasitological analysis.

3.5 Eligibility criteria

3.5.1 Inclusion criteria

Only sheep from flocks managed and primarily residing within the geographical boundaries of Nakapelimoru sub-county were included in the study. Additionally, eligibility was restricted to sheep whose owners provided verbal informed consent following a detailed explanation of the study objectives and sampling procedures prior to fecal collection.

3.5.2 Exclusion criteria

Severely debilitated, moribund or highly stressed sheep were excluded from sampling to promote animal welfare and ensure handler safety.

3.6 Data collection procedure

3.6.1 Fecal sample collection

Fecal samples were collected per rectum from young and adult sheep of all sexes. The age of the sheep were determined based on inspection of the teeth as young (≤ 1 year) and adult (> 1 year) as in *Appendix II*. Body condition score of each sheep was determined based on

the level of fat and muscle cover under and around the vertebrae in the lumbar region as in *appendix III* and grouped as 1 (Poor), 2 (average) and 3 (good) according to Morgan et al. (2006). Faecal pellets (13 – 15) were scooped from the rectum of each sheep using a gloved finger in animals restrained in a standing position. Each collected fecal sample was placed inside a primary polythene bag which was securely tied and labeled with the animal's host-related data including sex, age, and body condition score using masking tape and a permanent marker. To ensure a leak-proof and biosecure layer, this primary bag was then enclosed within a secondary polythene bag. The double-packed samples were subsequently grouped into a larger polythene bag labeled with the specific parish and date of collection and immediately placed inside an insulated cool box containing ice packs for safe field preservation. Upon return from the field, the samples were stored in a refrigerator at 4°C at the Kotido district local government Production cold chain office in order to arrest parasite development before being transported back in an iced cool box for subsequent coproculture and analysis at the Parasitology Laboratory within the College of Veterinary Medicine, Animal Resources and Biosecurity (CoVAB) at Makerere University, Uganda.

3.6.2 Sample preparation for fecal culture and larval identification

At the laboratory, each of the 355 fecal samples was processed using a qualitative simple test tube floatation technique. Briefly, a 3g aliquot of fecal material was macerated and thoroughly mixed with 45 mL of saturated sodium chloride solution using a wooden tongue depressor. The resulting suspension was filtered through a sieve into a clean container to remove coarse debris and then poured into a test tube until a convex meniscus formed at the rim. A coverslip was carefully placed over the meniscus and the tube was allowed to stand undisturbed in a rack for 20 minutes to permit the eggs to float to the surface. The coverslip was then vertically lifted with the adhering drop of fluid placed onto a clean microscope slide and examined under a light microscope at 10×10 magnification for the presence of strongyle eggs. Samples confirmed positive for strongyle eggs were subsequently set aside for coproculture to isolate and identify third-stage infective larvae.

The fecal culture was as follows; the remaining fecal samples were grouped into 10 groups that is males, females, young, adults, Poor BCS, Average BCS, good BCS, Kopsang, Kalobor and Lookorok. In each of the groups, pooling of equal amounts from the respective individual fecal samples was done to make a total composite weight of 20g for the culture. The 20g for each group was finely broken up using a wooden tongue depressor to facilitate

aeration. To ensure an optimal environment for egg hatching and larval development, the moisture level was carefully monitored; a few drops of water were added if the faeces were too dry whereas charcoal powder was incorporated if the sample was excessively wet. This adjustment maintained a consistently moist, crumbly texture throughout the mixture preventing anaerobic conditions. Using an incubator, the fecal cultures were kept at 27 °C for 7 days to allow all the larvae to reach the infective third stage larvae (L3) with water added regularly every 2 days to maintain moisture (J. Hansen & B. Perry, 1994).

Each of the completed coprocultures were processed using the Baermann technique to harvest the third-stage larvae. The Baermann apparatus was left undisturbed overnight at room temperature to allow active larvae to migrate out of the fecal culture and settle at the funnel stem. The following day, a 7 mL aliquot of fluid was drawn from the funnel stem into a test tube and allowed to sediment for 30 minutes. The supernatant was carefully aspirated using a Pasteur pipette, leaving the remaining fluid with larvae at the bottom. 2 ml of this remaining sediment was transferred to a clean gridded petri dish with a marker and stained with 2 drop of iodine for immobilization and visualization of the larvae. Microscopic examination at 10×10 magnification and identification of third stage infective larvae of was done according to J. Hansen and B. D. Perry (1994) and Lloyd (2017). The proportion of *Haemonchus contortus* in each of the 10 groups was determined by microscopically examining the petri dish and comparing the total number of identified *Haemonchus* larvae against the overall number of strongyle larvae counted within the sample. These proportions were then used to get the exact number of positive cases for host related risk factors of haemonchosis.

The overall *Haemonchus contortus* prevalence of 25.35% was derived directly from the cumulative parish-level laboratory analyses. Across the three study sites in Nakapelimoru sub-county, coproculture and diagnostic identification confirmed 26 positive cases in Kopsang parish (n = 102), 43 positive cases in Kalobor parish (n = 169) and 21 positive cases in Lookorok parish (n = 84). Summing these positive cases across the three parishes yielded 90 total *Haemonchus* positive animals (26 + 43 + 21 = 90). Dividing these 90 cases by the total study sample size of 355 sheep (102 + 169 + 84 = 355) established the overall study prevalence of 25.35% ($[90 / 355] \times 100$).

3.7 Data management and statistical analysis

All data collected during the study were initially entered, cleaned, and coded in a Microsoft Excel spreadsheet, which was also utilized to generate graphical representations of the data. The cleaned dataset was then exported to STATA version 14.2 for formal statistical analysis. The descriptive statistics including the overall and group-specific prevalences of *Haemonchus* and strongyles were expressed as percentages alongside their corresponding 95% confidence intervals (CI). The overall prevalence of haemonchosis was calculated using the following formula:

Overall prevalence of Haemonchosis (%) = Number of positive sheep/Total number of sheep sampled (n) * 100.

To determine the association between the host-related risk factors (sex, age, and body condition score) and *Haemonchus* infestation, a Chi-square test was employed. Statistical significance was set at $P < 0.05$. Since the bivariate Chi-square test revealed no statistically significant association ($P > 0.05$) between any of the host-related risk factors investigated and haemonchosis, further multivariate statistical modelling (such as logistic regression) was not pursued.

3.8 Ethical considerations

Formal verbal permission to conduct the research was obtained from the local leadership and the head of the veterinary team in Nakapelimoru sub-county. Prior to any data collection, voluntary verbal informed consent was obtained from all participating sheep owners and herders following an explanation of the study objectives. All animals were handled humanely and with minimal stress during data and sample collection; specifically, sheep were gently restrained in a standing position by one handler while per-rectal fecal pellet collection was performed swiftly to avoid unnecessary distress.

CHAPTER FOUR

RESULTS

4.1 Attributes of the sampled sheep

A total of 355 sheep were sampled across Nakapelimoru subcounty to evaluate host-related factors as summarized in Table 1 below.

Table 1: Attributes of the sampled sheep

Attribute	Frequency (n)	Percent (%)
Sex		
Male	153	43.1
Female	202	56.9
Age category		
Young	278	78.3
Adult	77	21.7
Body condition score		
1 (Poor)	30	8.5
2 (Average)	271	76.3
3 (Good)	54	15.2

4.2 Prevalence of strongyles and *Haemonchus* in sheep from Nakapelimoru sub-county, Kotido district

Parasitological evaluation was conducted on fecal samples from the 355 sheep to assess overall infection rates. Table 2 summarizes the prevalence and 95% confidence intervals for strongyle -type eggs and *Haemonchus contortus*.

Table 2: Prevalence of Strongyles and *Haemonchus* among the sampled sheep

Helminth	N	Prevalence, n (%)	95% CI
Strongyles	355	176 (49.58)	44.3 – 54.9
Haemonchus	355	90 (25.35)	20.9 – 30.2

4.3 Occurrence of strongyles and *Haemonchus* by parish from Nakapelimoru sub county, Kotido district

Spatial distribution of infection was analyzed across the study area to determine variations in parasite burden. Figure 2 shows the comparative prevalence of strongyle-type eggs and *H. contortus* by parish.

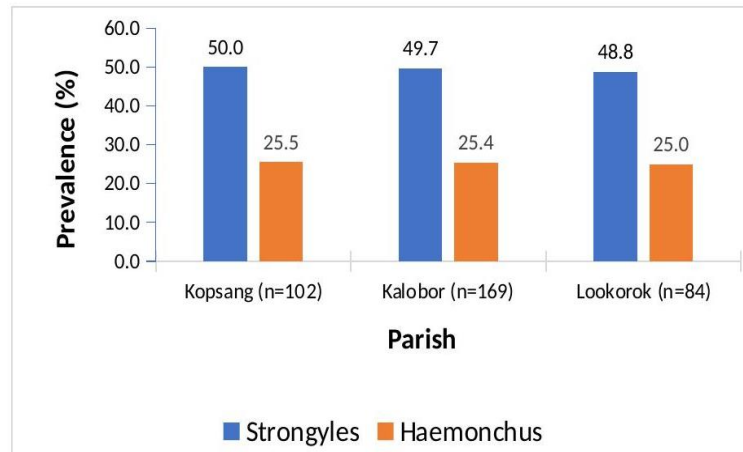


Figure 2: Prevalence of strongyle-type eggs and *Haemonchus contortus* in the sampled sheep by parish

4.4 Factors associated with haemonchosis in sheep from Nakapelimoru sub county, Kotido district

The Chi-square test was performed to assess host-related risk factors associated with haemonchosis. Table 3 presents the bivariate analysis between infection status and animal sex, age, and body condition score.

Table 3: Association between host-related risk factors and haemonchosis in the sampled sheep

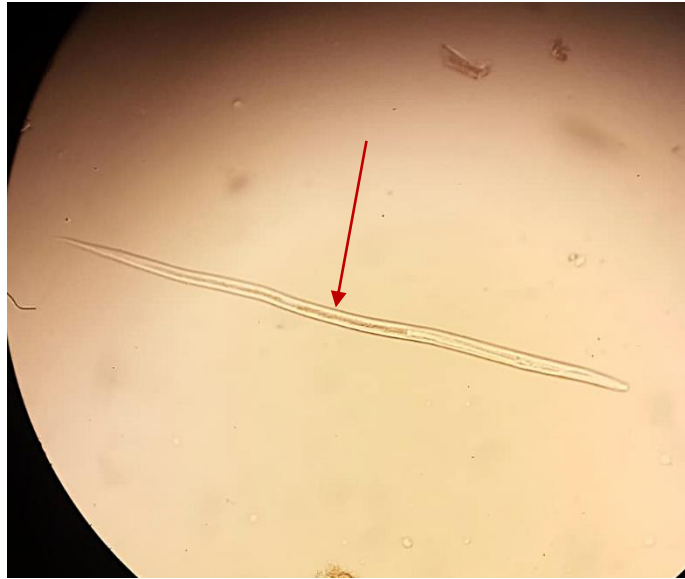
Risk factor (n=355)	<i>Haemonchus</i> infestation		Chi-squared <i>P</i> value
	Positive, n (%)	Negative, n (%)	
Sex			
Male	39 (25.5)	114 (74.5)	0.958
Female	51 (25.3)	151 (74.7)	
Age category			
Young	72 (25.9)	206 (74.1)	0.650
Adult	18 (23.4)	59 (76.6)	
Body condition score			
1 (Poor)	8 (26.7)	22 (73.3)	0.841
2 (Average)	70 (25.8)	201 (74.2)	
3 (Good)	12 (22.2)	42 (77.8)	

4.5 Diagnostic photomicrographs of parasite stages.

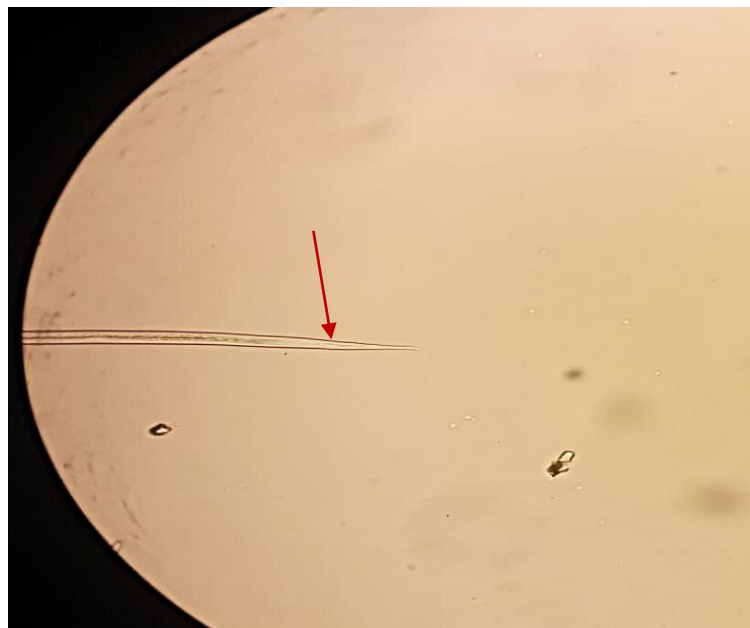
Microscopic examination was used to confirm egg morphology and L3 larval characteristics. Figures 3 through 5 show representative diagnostic photomicrographs of the recovered parasite stages.



Figure 3: Photomicrograph of a strongyle-type egg (red arrow) identified during fecal egg floatation (100× total magnification) [By Owiny Ernest Desire]



*Figure 4: Photomicrograph of a third stage *Haemonchus contortus* larva (red arrow) following coproculture (100× total magnification)[By Owiny Ernest Desire]*



*Figure 5: Photomicrograph showing the posterior end of *Haemonchus* larva (red arrow) with a bend end (100× total magnification)[By Owiny Ernest Desire]*

CHAPTER FIVE

DISCUSSION

This research study aimed to determine the prevalence of *Haemonchus contortus* and its association with host-related risk factors in sheep in the Nakapelimoru subcounty of Kotido district. Employing a cross-sectional study design, fecal samples were collected from 355 sheep, which were then processed using fecal culture technique and the Baermann technique to isolate and identify third-stage infective larvae. The results revealed an overall prevalence of 49.58% (n = 176) for strongyles and 25.35% (n = 90) for *Haemonchus contortus*. Statistical analysis using Chi-square test indicated no significant association ($P>0.05$) between *Haemonchus contortus* infestation and the selected host factors of sex, age, or body condition score.

The observed prevalence of 49.58% for strongyles and 25.35% for *Haemonchus contortus* indicates a substantial burden of gastrointestinal nematode infections among the sampled sheep in Nakapelimoru subcounty. This demonstrates that nearly half of the study population is shedding strongyle eggs while one-quarter is actively infested with *Haemonchus*. These findings highlight that *Haemonchus contortus* is a significant contributor to the total strongyle burden in the area, likely impacting the productivity and health of the local sheep flocks. Given that no significant associations were found between host factors (sex, age, body condition) and *Haemonchus contortus* infection, the results suggest that the parasite is widespread across the population regardless of individual host attributes emphasizing the need for broad-based control strategies in this pastoral system.

A primary strength of this study was the utilization of a robust sample size of 355 sheep, which ensured a high level of statistical representativeness for the sheep population in Nakapelimoru sub-county and narrowed the confidence intervals around the prevalence estimates. Although the initial target calculated was 384 samples, the final collection of 355 samples remained statistically robust for achieving all the study's stated objectives and providing reliable diagnostic data on *Haemonchus contortus* burden in the area.

This study, however, has some limitations that warrant consideration when interpreting the findings. First, sample collection was conducted exclusively during the dry season, a period when environmental desiccation reduces *Haemonchus contortus* egg viability and larval development on pasture, potentially lowering egg shedding and underestimating overall

prevalence. Second, the coproculture methodology relied on pooling individual fecal samples into group composite samples (20g) based on sex, age, body condition score and parish. While resource-efficient for group-level larval recovery, this pooling approach risks diluting samples with low egg counts and masking individual-level larval dynamics which may have contributed to a lower observed larval yield. Future studies incorporating multi-seasonal sampling and individual coprocultures are recommended to capture complete year-round parasite transmission patterns.

The current study revealed a moderate 25.35 % prevalence of Haemonchosis in sheep within Nakapelimoru subcounty likely influenced by data collection during the dry season characterized by minimal rainfall. The lack of moisture acts as a limiting factor for larval development and survival while also inducing hypobiosis in the fourth stage larvae in the abomasal mucosae which hinders egg shedding (K. Arsenopoulos et al., 2021). The moderate prevalence of Haemonchosis in this study aligns with several studies from similar environments such as M. O. S. Mohamed et al. (2024) that reported a prevalence of 30.73 % in sheep, Brik et al. (2019b) which reported 23.92 % and Amarkhil et al. (2023) which reported a prevalence of 22.66 %. This study however disagreed with other studies from comparable climates such as a study conducted by Opeto et al. (2024) which gave a much higher prevalence of 73.3 % and 70.6 % observed using fecal egg identification and coproculture techniques respectively in Apac district, Northern Uganda. Higher burdens of 43.5 % prevalence were also reported in Soroti abattoir by Walyomo (2024). Gebresilassie and Afera Tadele (2015) also reported a prevalence of 40.9 % in Wukro region of Ethiopia. While climate zones across these regions are similar, the variations in *Haemonchus* prevalence are likely driven by distinct seasonal rainfall patterns and local management practices. Differences in grazing systems, stocking densities e.g. at communal water points and the frequency of antihelmintic treatments create significant disparities in transmission intensity (Mushonga et al., 2018; Opeto et al., 2024). These site-specific environmental and husbandry factors override broad climatic classifications in determining the overall burden of Haemonchosis.

In the current study, sex had no statistically significant association with the prevalence of *Haemonchus contortus* in sheep ($P = 0.958$). This finding indicates that both the male and female sheep in Nakapelimoru subcounty are equally susceptible to haemonchosis. These results are in strong agreement with recent studies by Amarkhil et al. (2023) and S. A.-A. Mohamed et al. (2024), who similarly reported no significant difference in infection rates

between male and female sheep. The lack of a sex-based association in this study can be largely attributed to the communal grazing practices inherent to the pastoralist system of the Kotido district. Because both sexes share the same pastures and water points, they are subjected to an identical intensity of environmental exposure to infective third-stage larvae. In contrast, these findings contradict several other epidemiological surveys. Studies by Brik et al. (2019a) and Demessie et al. (2025) reported significantly higher prevalences in female sheep. They attributed this disparity to the peri-parturient relaxation of immunity during late gestation and early lactation increasing female susceptibility to gastrointestinal nematodes. The absence of this female bias in the present study suggests that the sampling period may not have coincided with peak lambing season thereby masking the effects of peri-parturient immune suppression. The results also disagree with earlier literature such as Gauly et al. (2006) and Selemon (2018) which hypothesized that males are more susceptible due to the immunosuppressive properties of testosterone.

Although age did not show a statistically significant association with *Haemonchus* infestation ($P = 0.650$), young sheep (≤ 1 year) exhibited a higher prevalence (25.9%) compared to adults (>1 year) at 23.4%. This trend is consistent with literature noting that young animals are more vulnerable to helminths due to an underdeveloped active immune system (Brik et al., 2019b; S. A.-A. Mohamed et al., 2024; Selemon, 2018). While studies such as Amarkhil et al. (2023) similarly observed higher infection rates in younger sheep, the lack of statistical significance suggests that high environmental exposure in communal pastoral systems often homogenizes infection risk across all age groups effectively overshadowing age-related immunity.

Regarding body condition score, although the association between Body Condition Score (BCS) and *Haemonchus* infestation was not statistically significant ($P = 0.841$), a clear trend emerged where poor body condition (BCS 1) showed the highest prevalence (26.7%) while good body condition (BCS 3) recorded the lowest (22.2%). This inverse relationship where lower physical health correlates with higher parasitic burden aligns with findings by Brik et al. (2019b) and Gebresilassie and Afera Tadele (2015) who similarly observed that animals with poor body condition often harbor heavier worm burdens. Such a pattern is frequently attributed to the compromised nutritional status and diminished immune resilience in undernourished animals which hinders their ability to withstand and clear infections (Alkadir & Ayana, 2024; Selemon, 2018). This observation reinforces the

understanding that poor body condition remains a critical indicator of animal susceptibility to haemonchosis.

Future research should therefore transition toward longitudinal monitoring by tracking specific indicator flocks over a 12–24 months period to map parasite prevalence trends across both wet and dry seasons. Such studies would be instrumental in capturing the critical period when *Haemonchus* larvae enter hypobiosis thereby providing a deeper understanding of the parasite's survival mechanisms in this environment. Future work should also incorporate comprehensive surveys focused on environmental and management-related risk factors specifically comparing the impact of different watering sources such as surface dams versus boreholes and documenting seasonal migration paths to further clarify the drivers of transmission in the region.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study successfully determined the prevalence of *Haemonchus contortus* and evaluated its association with host-related risk factors among sheep in the Nakapelimoru subcounty of Kotido district. The research revealed an overall *Haemonchus* prevalence of 25.35% confirming that the parasite is actively infesting a significant portion of the sheep population. Notably, the statistical analysis indicated no significant association ($P > 0.05$) between *Haemonchus* infection and host-related attributes specifically sex, age, and body condition score. These findings suggest that the parasite is widespread across the population regardless of individual host characteristics emphasizing the need for whole-flock control strategies rather than targeted interventions in this pastoral system.

6.2 Recommendations

Control programs in Nakapelimoru sub-county should adopt whole-flock deworming strategies applied across entire sheep herds rather than targeting specific sub-groups. Since *Haemonchus contortus* infestation showed no statistically significant association with sex, age or body condition score ($P > 0.05$), focusing treatment solely on vulnerable groups like young or poor-conditioned animals would leave a large reservoir of infected sheep untreated.

Local veterinary extension services should establish year-round parasite surveillance by implementing continuous diagnostic screening, including fecal floatation and coproculture, rather than limiting deworming efforts exclusively to the rainy season. Given that a 25.35% prevalence was recorded during the dry season, active parasite transmission and egg shedding persist outside primary rainfall periods requiring sustained year-round monitoring.

Further research should conduct longitudinal and microclimate studies that track indicator flocks across a 12-month cycle to assess seasonal hypobiosis patterns and evaluate communal water point contamination dynamics in Kotido district. Monitoring flocks across all seasons will overcome the limitations of a single cross-sectional study and clarify the environmental drivers of parasite transmission in this semi-arid pastoral system.

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APPENDICES

Appendix I: The 12 parishes of Nakapelimoru subcounty

1. Kopsang
2. Lookorok
3. Kalobor
4. Nakapelimoru town board
5. Kaileng
6. Watakau Central
7. Thiwakol
8. Longerep
9. Lokwakial
10. Potongor
11. Kalomugerang
12. 405 bridgate

Appendix II: Criteria for aging the sheep used

The sheep were aged based on inspection of the permanent teeth according Pitassi et al. (2022) to as below;

Permanent teeth	Age of the animal
1 st incisor pair	1 year
2 nd incisor pair	2 years
3 rd incisor pair	3 years
4 th incisor pair	4 years

Permanent incisor wear and loss are a result of advancing age in sheep (McGregor, 2011).

Appendix III: Body condition scoring of the sheep

Body condition score (BCS) was determined by palpation of the lumbar region to assess the fat and muscle cover under and around the vertebrae in this region. The standard 1-5 scoring system was used according to Kenyon et al. (2014) and Thompson and Meyer (1994).

Body condition score	Characteristics at the lumbar region
1	Spinous processes are sharp and prominent. Transverse processes are sharp and one can pass fingers under ends. Eye muscle areas are shallow with little to no fat cover.
2	The spinous processes are smooth but still prominent. The transverse processes are smooth and rounded. However, it is still possible to pass the fingers under the ends of the processes with some pressure. The eye muscle areas are of moderate depth, but have sparse fat cover.
3	The spinous processes are smooth and rounded, and individual bones can only be felt with some pressure applied. The transverse processes are also smooth and are well covered. Firm pressure is required to feel over the ends. Eye muscle area is full and covered by a moderate degree of fat.
4	With pressure applied, the spinous processes can just be detected, although the ends of the transverse processes cannot. Eye muscle areas are full with a thick covering of fat.
5	Even with firm pressure applied, the spinous processes cannot be detected. There is a depression between fat where spine would normally be felt. It is not possible to detect the transverse processes. The eye muscle areas are very full with very thick fat cover. It is possible to have significant deposits of fat cover over the rump and tail.