Liver flukes and lungworms in Zambian goat herds: occurrence and related deworming practices

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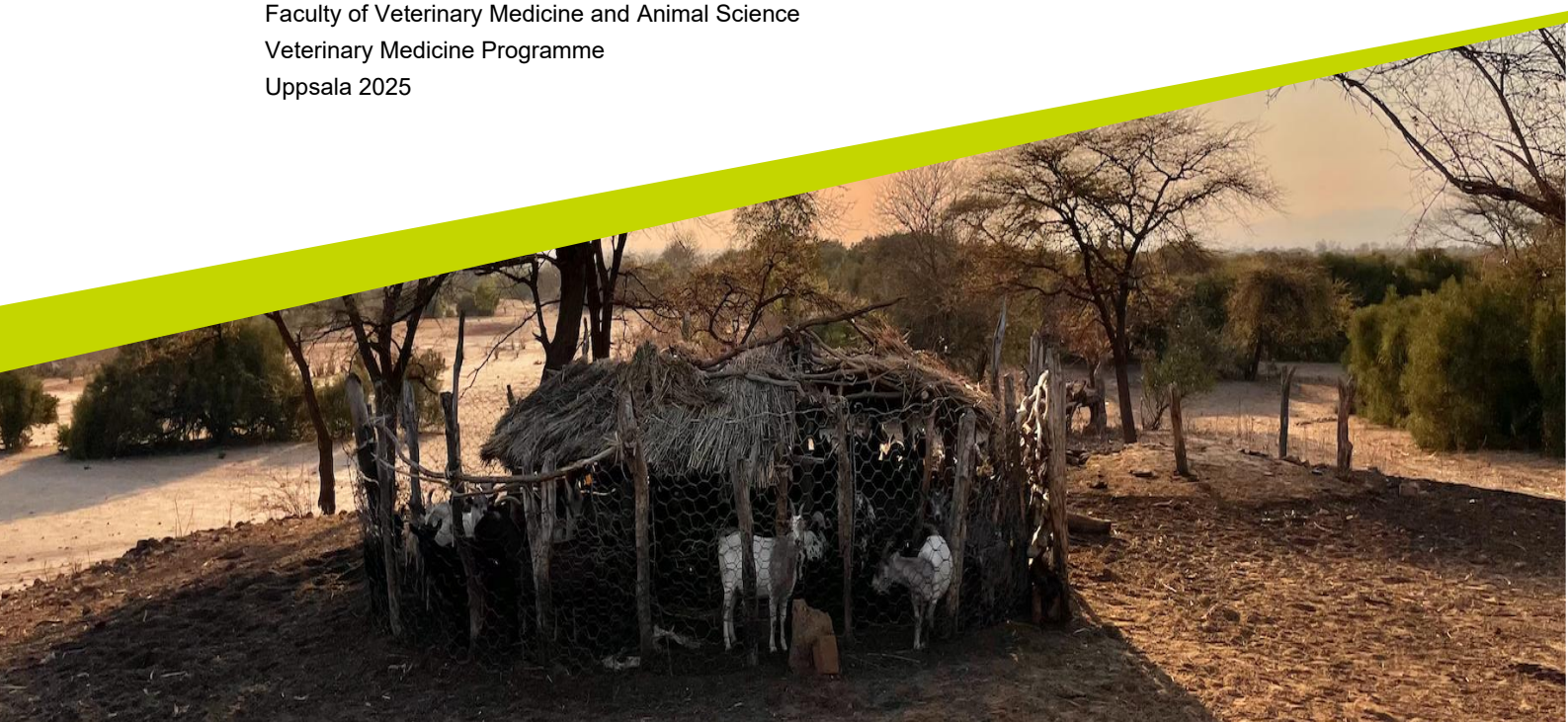

Liver flukes and lungworms in Zambian goat herds: occurrence and related deworming practices

Leverflundra och lungmask i zambiska getbesättningar: förekomst och relaterade avmaskningsrutiner

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Abstract

Goats are very important livestock in Zambia as they can alleviate poverty by providing both food and a source of income for an increasing number of rural families. While helminth infections (e.g. liver flukes and lungworms) are listed by the Zambian Ministry of Fisheries and Livestock as one of the biggest concerns affecting goats in this area, their occurrence in Zambia has not yet been studied. Additionally, information on anti-parasitic treatment is scarce in rural areas of Zambia, often leading to none or insufficient deworming strategies.

The objective of this study was to determine the occurrence of liver flukes and lungworms, and to identify current deworming strategies, in goat herds in the Southern and Central provinces of Zambia. A total of 182 and 169 faecal samples from goats were pooled and examined for liver fluke and lungworms respectively. Sedimentation was used to extract and analyse liver fluke eggs, and out of the 19 pooled samples, only one sample (5.3%) contained eggs from the liver fluke. Baermann's funnel method was used to recover L1 larvae from lungworms, however, no lungworms were found in any of the samples. The most used antiparasitic drug in both provinces was ivermectin followed by albendazole and levamisole, with treatment intervals ranging from 1-12 times per year. Due to the low occurrence of liver fluke and no findings of lungworm L1 larvae, no correlation between treatment strategy and occurrence of liver fluke or lungworm could be made.

This study still confirmed the presence of liver flukes in the Central region of Zambia and suggests that most households lack adequate treatment strategies against the parasite. While lungworms were not detected in the study area, it is likely attributed to issues with sample storage rather than their absence in Zambian goat herds. The findings of this study can serve as a starting point for further research on the prevalence of liver flukes and lungworms in goats in Zambia. Moreover, by highlighting the challenges faced by Zambian goat owners in selecting effective deworming practices, this study emphasizes the importance of making treatment information accessible to rural households.

Keywords: liver fluke, lungworm, goats, Zambia, occurrence, prevalence, deworming, deworming practices, treatment

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1. Introduction

Goats play a very important role in the lives of many Zambian households as they provide a source of income and food for the families that raise them. The number of goats in Zambia was 5.5 million in 2023, with over 99 percent being raised by households rather than establishments such as commercial farms (Ministry of Fisheries and Livestock 2022; 2023). The number of Zambian households that raise goats is increasing, with 723,740 households in 2023, compared to the 593, 870 the previous year. This increase could be the cause of increased market participation among small holder livestock farmers in Zambia, where goats receive growing attention because of their unique ability to alleviate poverty, especially in harsh climatic conditions (Fischer *et al*. 2020). The leading purpose for raising goats has been for selling/income (around 80% in both 2022 and 2023) followed by consumption for meat (Ministry of Fisheries and Livestock 2022; 2023).

Goats play a vital role for smallholder farmers in rural areas by maintaining food security and economic livelihoods (Monau *et al.* 2020). However, the production from the goats is heavily influenced by the health of the animals. Disease was reported as the leading constraint affecting the Zambian goat-raising households (37.4% in 2023 and 48.6% in 2022), followed by theft and inadequate feed (Ministry of Fisheries and Livestock 2022; 2023). The highest reported disease affecting these goats was in 2022 helminthiasis, which in 2023, came in third place of the most reported diseases after mange and cowdriosis (heartwater).

Helminthiasis is a disease caused by a group of parasitic worms called helminths. They have a cosmopolitan distribution, but their symptoms are often less noticeable compared to other livestock diseases, which makes helminthiasis frequently overlooked in veterinary care (Hansen & Perry 1997). Amongst these worms we find liver flukes (*Fasciola* spp.) and lungworms (*Dictyocaulus filaria*, *Protostrongylus rufescens* and *Muellerius capillaris*), which are the species studied in this research.

Even though they are overlooked parasites, both liver fluke and lungworm can cause severe illness. Liver flukes can result in weight loss, anaemia or sudden deaths (Martins & Verocai 2024), and lungworms can cause parasitic bronchitis and are a predisposing factor for secondary bacterial or viral infections causing pneumonia in kids and lambs (López & Martinson 2017). These diseases are a risk to animal welfare, and in the case of *Fasciola* spp., cause major economic impacts on livestock all around the world (Martins & Verocai 2024).

Even though helminthiasis was proven by the Ministry of Fisheries and Livestock to be one of the leading concerns affecting Zambian goats, the survey does not specify which species of helminth parasites were identified, or their respective prevalences. Meaning helminths other than liver fluke and lungworm might have been contributing factors. Furthermore, no other publications can be found regar-

ding the prevalence and treatment plans to control liver fluke or lungworm in Zambian goats, making it a difficult task for the goat-raising households to assess the risk of infection and battle potential infection with correct treatment. Therefore, this study aims to analyse the occurrence of liver flukes and lungworms in goat herds in Zambia, and related treatment strategies.

2. Literature review

2.1 Zambia's climate and geography

Zambia is a land-locked country in southern Africa with a subtropical climate (World Bank Group 2021). The country is divided into 10 provinces which consist of 81 districts (Central Province Provincial Administration 2022). The provinces are (in no apparent order): Southern, Muchinga, Lusaka, Northern, Eastern, Central, Luapula, Western, North-Western and Copperbelt. Parts of the country is on the Central African plateau with altitudes from 1000 to 1600 meters above sea level and are run through by large rivers as the Zambezi, Chambeshi and Kafue which form expansive wetlands. These wetlands are used by livestock as grazing areas.

The year in Zambia can be divided into three seasons: the hot wet season ranging from November to April, the cool and dry season from April to August and the hot and dry season from August to November (Akayombokwa & Mukanda 1998). At a monthly minimum, temperatures range from about 10 ºC in June and July, and up to 30 ºC in October and November. November to March is marked by heavy rainfalls that varies from 700 mm in the south to 1500 mm in the north. On the main basis of rainfall, Zambia can be divided into three agroecological regions. Agroecological region I include the semi-arid parts of Zambia, mainly the Luangwa, Lunsemfwa and Zambezi valleys, and the Sesheke low altitude plateau and Senanga. These areas are characterized by high temperatures and low amounts of rain, resulting in a short growing season. Droughts are common and represent a challenge for small scale farmers in these areas. Agroecological region II includes the entire plateau that stretches from Eastern, Central and Lusaka provinces to the Western and Southern province. These areas have more rainfall than the first agroecological region. Lastly, agroecological region III is known for its high amounts of rainfall and covers the Northern, Luapula, Copperbelt, North-Western and some parts of the Central provinces.

Poverty is widespread over the country affecting 64.3 percent of the population in 2022 (World Bank Group 2024). Adding to this, the whole country has recently been affected by major droughts, especially in the years of 2015-2018 which has increased the inhabitant's vulnerability to food shortages and challenges to meet minimum food needs (ACAPS n.d). Furthermore, food insecurity is expected to worsen and estimated to affect 5.8 million people from October 2024 to March 2025 as the country as recently as February 2024 declared a state of disaster because of a drought.

2.2 Goats, sheep and helminths

Goats and sheep are two species that are often grouped in the veterinary field, and most of the available information about helminth infections in ruminants are about cattle and sheep. However, due to differences in anatomy and grazing behaviours, sheep and goats differ when it comes to infection rates and antiparasitic treatment (Jacobs 2015). As goats are often kept in extensive husbandry systems, they are less exposed to infection. This is due to them being browsers rather than grazers. Goats are known to be more resilient to parasite infection than sheep, although heavy worm burdens can still cause disease. Goats tend to have a weaker immune response against intestinal nematodes and can continue to shed eggs throughout their lives. Also, anthelmintic resistance tends to develop more rapidly in goats than sheep, often due to unintentional underdosing of anthelmintics when treating parasites because of their faster metabolization of the drugs.

2.3 Liver flukes – *Fasciola hepatica* and *Fasciola gigantica*

Fasciola hepatica and *Fasciola gigantica* are hepatic parasitic flatworms that infect goats, sheep, cattle, water buffalo, wild animals and humans (Martins & Verocai 2024). *Fasciola* spp. causes the disease fasciolosis, found on all five continents. Due to the disease being widespread, it has a significant impact on the livestock industry and nearly USD 3 billion per year is lost globally due to losses in production and treatment costs. Also, the World Health Organisation (WHO) has now recognised fasciolosis as a human neglected tropical disease due to *Fasciola* spp. being a zoonotic parasite, infecting humans through consumption of contaminated water plants (World Health Organization 2021; Martins & Verocai 2024). Fasciolosis in animals and humans predominantly occurs in developing countries, where the liver fluke has been estimated to infect around 2,4 million people alongside the many animals infected every year (Martins & Verocai 2024), making it an important parasite to study in the face of animal and human welfare.

2.3.1 Morphology

F. hepatica and *F. gigantica* are morphologically similar. They both are “leaf-like” hermaphrodites with a broad and flattened spine- covered body, as seen in Figure 1 (Li & Liu 2024).

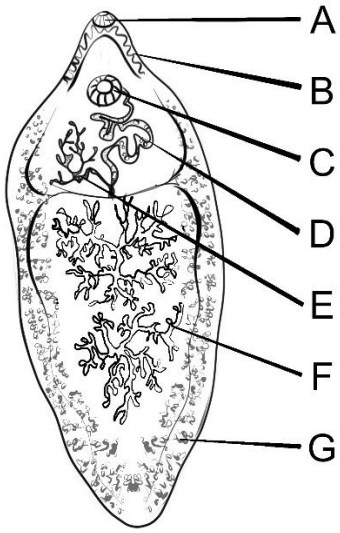

Figure 1. An adult liver fluke with important morphological structures. A: oral sucker. B: caeca. C: ventral sucker. D: uterus. E: ovary. F: testes. G: vitelline (egg-shell secreting) gland. Source: Author's illustration.

The adult *F. hepatica* measures up to 30 mm in length and is found in the bile ducts of its final host (Centers for Disease Control and Prevention (CDC) 2019). Its eggs are large, spanning from 130-145 µm in length, and 70-90 µm in width (Thienpont *et al.* 2003). The shape of the egg is a nearly regular ellipse with similar poles and symmetrical barrel-shaped walls on the sides (Li & Liu 2024). The shell is thin and the contents of the egg are granular with a yellow to brown colour that fills the whole egg (Fig. 2). An operculum, a "lid" on one of the poles, can be visible on one end of the egg.

Figure 2. A Fasciola hepatica *egg. Source: Author's photograph.*

Adults of *F. gigantica* are larger, measuring up to 75 mm in length with eggs being generally bigger in size but otherwise very similar to the ones of *F. hepatica*

(CDC 2019). Due to morphologic overlap, egg size cannot reliably distinguish between the *F. gigantica* and *F. hepatica.*

2.3.2 Lifecycle

The *F. hepatica and F. gigantica* have similar life cycles (Hansen & Perry 1997). The life cycle of *Fasciola* spp. starts with the egg that is passed in the faeces of its host (Jacobs 2015). Outside of the host body the faeces contribute to warmth and moisture which aids the development of a miracidium (a ciliated stage). This development will only happen if there is a film of water present and if the egg is exposed to light of the correct intensity. The miracidium then seeks its intermediate host - a snail- and does so with the help of its cilia with which it moves forward. When in contact with the snail the miracidium secretes an enzyme which enables it to penetrate the snail's body.

In sub-Saharan Africa, two lymnaeid species are involved in the transmission of *Fasciola* spp. Firstly, an amphibious snail *Galba (*formerly *Lymnaea) truncatula* that lives close to the edge of slow moving or stagnant water (Hansen & Perry 1997) and is known as an intermediate host of *F. hepatica* (Kendall 1954, as cited in Kendall 1965). It has a wide range and is, besides sub-Saharan Africa, found in Europe and north Asia (Kendall 1965). *L. truncatula* can also serve as an intermediate host of *F. gigantica* in the East and Central African highlands (Kusiluka & Kambarage 1996). The second snail, *Lymnaea natalensis* is an intermediate host of *F. gigantica* and preferers habitats with deeper waters (Hansen & Perry 1997). *L. natalensis* is found in tropical countries (Phiri 2004) with an optimum temperature for survival and development at 15-25 degrees (Kusiluka & Kambarage 1996).

In the snail's hepatopancreas the miracidium goes through three stages of asexual replication (Jacobs 2015). Firstly, the miracidium develops into a sporocyst. The structure of the sporocyst is sac-like where cloning is done multiple times to form more sporocysts. These then develop to rediae, a fluke-like larval stage which produces the next larval stage, the cercariae. One miracidium that enters a snail can turn into 600 or more cercariae, the speed depending on the temperature inside the snail. The moment the cercariae leaves the host can vary anywhere between five weeks to a few months depending on temperature and moisture (Abott *et al.* 2009). When the moist period of the year arrives the cercariae leaves the snail (Jacobs 2015). With its heart shaped body and tail the cercariae swims through water and films of moisture onto vegetation where it adheres and encysts, becoming a metacercaria. The metacercaria sits on a piece of vegetation and has a tough protective wall, where it will remain until it is eaten by its final host (e.g. goat or sheep).

In the final host the metacercaria sheds its shell and turns into an immature fluke that migrates through the small intestines and through the liver to its predi-

lection site, the bile ducts (Jacobs 2015). In the ducts it matures to an adult fluke, sexually reproduces and starts producing eggs. Given the presence of both uterus, ovary and testicles adult flukes can auto-fertilize themselves, although cross-fertilization is the most common form of sexual reproduction (Rokni 2014). The eggs are laid and passed through the faeces where the embryonating and hatching are dependent on light, oxygen and a suitable temperature between 20-25 degrees (Kusiluka & Kambarage 1996). If conditions are under 10 degrees or over 35 no development can occur.

Migration

After being swallowed by its host, the immature fluke of 0.1 mm in length takes around one week to penetrate the small intestine wall and migrate to the liver across the peritoneal cavity (Jacobs 2015). After that it takes 6-7 weeks to meander through the liver parenchyma while growing to about 10 mm. The migration is destructive and contributes to the clinical signs observed in the host. The fluke then enters the bile ducts and continues growing by sucking blood and grazing the mucosa, causing further tissue damages and clinical signs in the host. Ten to 12 weeks after infection the adult *F. hepatica* starts to lay eggs. The prepatent period of *F. hepatica* is 8-12 weeks, and for *F. gigantica* 12-16 weeks (Li & Liu 2024).

2.3.3 Clinical signs

The manifestations of fasciolosis are often mild but can be divided into two phases in the final host: the acute phase which accounts for the immigration of the immature flukes, and the chronic phase caused by the damage done by the fluke residing in the hepatic biliary ducts (Miller *et al.* 2012). In sheep, disease and even death occur in individuals of all ages. Information on symptoms regarding goats specifically is scarce.

Acute fasciolosis is caused by large numbers of metacercariae being ingested over a short period of time, and later on, large numbers of immature flukes migrating through the liver (Jacobs 2015). There is a delay of 2-6 weeks from infection to onset of clinical signs due to the damage of the smaller immature flukes being negligible. The migrating worms are larger and cause a lot of damage in their migration, with liver tissue being destroyed and blood vessels ruptured (Jacobs 2015), leading to clinical signs such as anorexia, weakness, colic-like symptoms and anaemia in goats and sheep (Miller *et al.* 2012).

A heavy infection (over 500 metacercariae) in sheep that are not eliminated in the initial acute phase may lead to a subacute disease later on where they start to lose weight, become anaemic and also die (Jacobs 2015).

Chronic fascioliasis is caused by a relatively smaller number of metacercariae ingested over a longer period where the host survives the acute migration phase of the immature fluke (Jacobs 2015). In cattle with chronic infection, extensive hepa-

tic fibrosis and hyperplasia of the biliary ducts can be observed, where the risk of developing fibrosis increases with the number of liver flukes present (Marcos *et al.* 2007). With the hepatic damages caused by the fluke together with consumption of the host's blood, symptoms like a loss of appetite and anaemia can be observed, causing long-term clinical signs such as suboptimal growth, weight-loss and deteriorating milk production (Jacobs 2015).

2.3.4 Epidemiology

The distribution of *F. hepatica* is mostly confined to wetter temperate regions whereas *F. gigantica* is found in more tropical (Jacobs 2015) to subtropical climates (Centers for Disease Control and Prevention (CDC) 2019). In the sub-Saharan countries of Africa, *F. gigantica* is the most common cause of fasciolosis (Kusiluka & Kambarage 1996). However, in the highland areas of Ethiopia, Kenya, north-eastern and south-western Tanzania, Lesotho and South Africa, *Fasciola hepatica* has been shown to be a significant cause of fasciolosis too.

The studies done on the prevalence of liver fluke in goats in different countries in Africa are limited. In Egypt, the recorded prevalence of adult *F. hepatica* recovered from goats in slaughterhouses was 3.5 percent (Khalafala 2020). In Ethiopia *Fasciola* spp. was studied with routine post-mortem examination and the overall prevalence was 13.6 percent (Abdulhakim & Addis 2012) in goats. In Kenya a retrospective study on slaughter records and condemned goat livers showed a prevalence of *F. gigantica* was 6.6 percent (Mungube *et al.* 2006).

The prevalence of fasciolosis in Zambian goats is not easy to determine from literature. No studies have been found that investigates the prevalence of liver fluke in Zambian goats, sheep or buffalo. However, there are some studies done on cattle, most recently by Phiri (2004) and Phiri *et al*. (2006). In the first study (Phiri 2004), the cumulative prevalence of *F. gigantica* was 59.4 percent (n=677) in Zambian cattle in the Kafue and Zambezi river basins. Using a method of both coprological examination and liver inspection, it was proved that *F. gigantica* was a widespread parasite in cattle in Zambia at that time. In the second study (Phiri *et al*. 2006), mixed infections of *F. gigantica* and amphistomes in the Central, Southern and Western provinces of Zambia was analysed in cattle presented for slaughter, and the results showed a 80.0 percent prevalence in the Southern, 66.4 percent in the Western and 16.3 percent in the Central province. A seasonality of *F. gigantica* in cattle was seen as well. The prevalence of *F. gigantica* was at its highest in the post rainy season (Marsh to May) and at its lowest during the cold and dry season (in June to August according to this author).

Zambia's increasing human population needs more land for agricultural crops, often at the expense of traditional grazing areas (Phiri 2004). This means that the pressure on available grazing areas increases leading to livestock being forced to less suitable areas. These might include areas infested with lymnaeid snails and

contaminated with *F. gigantica* or *F. hepatica* metacercariae. Additionally, the grazing areas are forced closer to parks and reserves meaning livestock are grazing on land used by wild animals, meaning risks of further transmission of the disease within and between species.

2.3.5 Diagnostics, treatment and prophylaxis

Diagnostics

Diagnosing liver flukes in goats is traditionally done through coprological examination by sedimentation (Miller *et al.* 2012). Because the fluke eggs are dense and heavy, they will sink to the bottom when submerged in water and can be collected for identification. Faecal sedimentation is considered a gold standard in detection of fasciolosis in individual animals (Aftab *et al.* 2024). The method is inexpensive, however it has low sensitivity compared to other diagnostic methods and, because of the prepatent period of *Fasciola* spp. being around 10-12 weeks, this form of diagnosis is only useful in patent infections. The sensitivity of the test is also affected by factors such as host age, faecal water content and amount of faeces tested per sample (Sabatini *et al.* 2023). When parasite burden is low, or during the migration of the immature flukes, this test can be a poor indicator of infection (Miller *et al*. 2012).

Differentiation between eggs of *F. hepatica* and *F. gigantica* can be done through a mitochondrial DNA duplex PCR, which is a sensitive tool that accurately differentiates between the two *Fasciola* species in areas where they overlap in distribution (Le *et al.* 2012).

Liver fluke-specific antibody ELISAs (enzyme-linked immunosorbent assays) serves as an alternative to sedimentation and are routinely used for diagnosing indirectly antibodies against liver fluke in sheep and cattle (Sabatini *et al.* 2023). There are ELISAs developed for diagnosing liver fluke in goats which rely on the detection of *F. hepatica* (Martínez *et al.* 1996) and *F. gigantica* (Gupta *et al.* 2011) specific antibodies in goat serum. There are also copro-antigen ELISAs developed for detection of *F. hepatica* antigen in goat faeces (Villa-Mancera *et al.* 2016). Both serum and copro-antigen ELISAs have high sensitivity compared to coprological examination (Charlier *et al*. 2008), and has a major advantage in the detection of early infection as coprological examination cannot detect immature migrating stages (Sabatini *et al.* 2023). However, serum ELISAs can be used from approximately 3-4 weeks post infection while coproantigen ELISA can be used from approximately 8-10 weeks post infection in livestock.

Liver inspection can also identify *Fasciola* spp. and provides a highly accurate diagnosis from approximately two weeks post infection in livestock, however it is not a practical option in herd or flock management as it can only be carried out post-mortem (Sabatini *et al.* 2023). During necropsy or slaughter, the mature and

immature flukes are then found in the liver and bile ducts in both acute and chronic cases (Miller *et al.* 2012). In Zambia, the major method of diagnosing liver fluke is through liver inspection at abattoirs, and secondly through faecal sedimentation (Chilundu, J., UNZA, pers. comm., 2024).

Treatment

There is often no consensus on the correct treatments of liver flukes (Fairweather *et al.* 2020; Castro-Hermida *et al.* 2021) and due to a rise in drug resistant flukes, properly administering and monitoring treatment efficacy is of great importance in order to maintain the efficacy of the available anthelmintic drugs (Fairweather *et al.* 2020). Goats have a uniquely faster metabolization and elimination of drugs compared to sheep (Hennessy *et al.* 1993) and need to be treated with higher drug doses (Hennessy 1994) to avoid generating more drug-resistant flukes.

Studies regarding efficiency of anti-fluke drugs have been mostly done on cattle or sheep. However, the efficiency of triclabendazole (benzimidazole), albendazole (benzimidazole) and clorsulon (sulphonamide) have been assessed in goats (Castro-Hermida *et al.* 2021). The most effective drug on the market for controlling fluke is triclabendazole. This drug kills all stages of *F. hepatica*, both early and late immature and mature life stages (94.9% after four weeks post-infection and 99.2-100% from 8-16 weeks post infection with a dosage of 10 mg/kg) in goats (Martínez-Moreno *et al.* 1997). Triclabendazole is also effective on juvenile *F. gigantica* with the same treatment (killing 100% of juvenile flukes within three days post treatment) (Shareef *et al.* 2014). Because of the high efficacy of triclabendazole and a following worldwide high usage of the drug, there are concerning reports of widespread resistant fluke populations around the world (Castro-Hermida *et al.* 2021). Albendazole and clorsulon also show therapeutic effects against adult *F. hepatica* in goats with treatment efficacies of 100% of clorsulon (15 mg/kg) (Sundlof *et al.* 1991), and 95.9% for albendazole (15 mg/kg) when treated 14 weeks after infection (Foreyt 1988).

There is reported albendazole resistance in *Fasciola hepatica* in sheep in Argentina (Sanabria *et al.* 2013), Spain (Álvarez-Sánchez *et al*. 2006) and Sweden (Novobilský *et al.* 2016) and as for clorsulon, a flock of sheep in Spain were found to be resistant to treatment in 2013 (Martínez-Valladares *et al.* 2014). Anthelmintic resistance in liver flukes has not been investigated in Zambia.

In treating liver flukes, the drug of choice in different countries and regions likely depends on what products are available there and the current regulations in the area. Seasonal prevalence of fasciolosis needs to be determined in the area for treatment timing to account for seasonal trends. A treatment option provided for eliminating *F. gigantica* in Zambian cattle is to treat the entire heard in the beginning of dry season (October), then treat exposed animals and repeat treatment

at the beginning of the post-rainy season (April) (Phiri 2004). In areas like Kafue or Zambezi flood plains, a third treatment might be necessary in e.g. June or July.

The solution to the growing resistant populations could be alternative treatments, such as the development of a vaccine for the control of fasciolosis in goats (Toet *et al.* 2014). While there are reports of this being developed for cattle and sheep, nothing has yet been commercialised. However, it is considered to be an applicable tool in the future.

Prophylaxis

Prophylactic measures for fasciolosis are done with the use of dewormers, controlling or eliminating the intermediate host and environmental control (Castro-Hermida *et al.* 2021).

2.4 Lungworms (*Dictyocaulus filaria, Protostrongylus rufescens* and *Muellerius capillaris)*

Lungworms are bursate nematodes that live in the lungs of their hosts (López & Martinson 2017). In small ruminants *Dictyocaulus filaria*, *Protostrongylus rufescens* and *Muellerius capillaris* are the relevant species. These are found worldwide, most commonly infecting goat kids and lambs, causing parasitic bronchitis (López & Martinson 2017).

Dictyocaulus filaria, also called the large lungworm, inhabits the lumen of the upper respiratory tract in the trachea or bronchi (Miller *et al.* 2012). It has a high pathogenicity and is most known to cause bronchitis in younger goats and sheep. *Protostrongylus rufescens*, commonly referred to as the "red lungworm", is found within the small bronchioles in the lungs and has an intermediate pathogenicity with an often subclinical infection in small and wild ruminants. *Muellerius capillaris*, known as the nodular lungworm, is supposedly the least pathogenic of the three (Miller *et al.* 2012) and lives in terminal alveolar ducts and bronchioles of the lungs in goat and sheep where they usually do not cause clinical signs, but can cause secondary bacterial pneumonias (López & Martinson 2017).

2.4.1 Morphology

Dictyocaulus filaria

Adults: white and threadlike, female: 43-112 mm with a conical, tapered tail, male: 25-80 mm long and has a short bursa (Panuska 2006).

L1 larva: 550-580 µm, dark-grey intestinal granules, protruding protoplasmic knob, blunt (Thienpont *et al.* 2003) and straight (Miller *et al.* 2012) tail (Fig. 3).

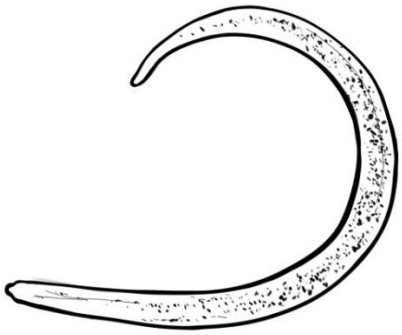

Figure 3. L1 larva of Dictyocaulus filaria*. Source: Author's illustration.*

Protostrongylus rufescens

Adults: grey-white, 16-40 mm (Abott *et al.* 2009).

L1 larva: 320-400 μm, no protoplasmic knob, waving, pointed tail (Fig. 4) and fine granules (Thienpont *et al.* 2003).

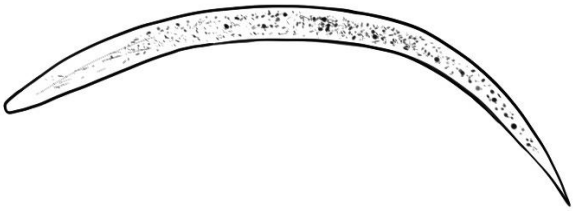

Figure 4. L1 larva of Protostrongylus rufescens*. Source: Author's illustration.*

Muellerius capillaris

Adults: very small and white, female: 19-23 mm, male: 11-12 mm and a posterior end coiled in 11-13 spirals (Panuska 2006).

L1 larva: small 300-320 μm: no protoplasmic knob, tail is kinked (Fig. 5) and ends in a dorsal spine, fine granules (Thienpont *et al.* 2003).

Figure 5. L1 larva of Muellerius capillaris*. Source: Author's illustration.*

2.4.2 Lifecycle

Dictyocaulus filaria

D. filaria has a direct lifecycle (Christensen 2020a). The adults of the *D. filaria* live and lay eggs in the bronchi of the lungs. The eggs are then coughed up by the goat and swallowed. While moving through the digestive system the eggs hatch and the first larval stages (L1) are then passed with the host's faeces. Outside the body, the larva then feeds off the food particles in the faeces and develops into the second larval stage.

After 7-10 days (Delano *et al.* 2002) the larva then moults into the third and infectious larval stage (L3) (Christensen 2020a). This is done when conditions are moist and at a temperature of about 27 °C. This larva can lay inactive for months in moist conditions and is resistant to low temperatures (meaning it can survive infectious in pastures during cold seasons). However, they can only survive a few days in dry conditions. Infection takes place when another goat grazes in the pasture contaminated by L3 larvae and ingests it.

In the host the larvae travel to the intestine and penetrate through the intestinal wall where they migrate to the lymph nodes and develop into the fourth larval stage (L4) six days after infection (Panuska 2006). Here they shed their protecting cuticle, and the larvae then make their way to the blood through the lymph vessels (Christensen 2020a). In the blood they are transported to the right side of the heart and migrate to the lungs. In the lung the larvae migrate through the capillaries and enter the bronchi. About 12 days after infection where the larvae can arrest development and lay latent, or mature to adult worms (after about four weeks) and start laying eggs (Panuska 2006).

Peak larval output occurs 39-57 days after infection. The shortest prepatent period for *D. filaria* is around 5 weeks (Delano *et al.* 2002).

Muellerius capillaris and Protostrongylus rufescens

M. capillaris and *P. rufescens* have indirect life cycles and require a molluscan (snail or slug) intermediate host (Miller *et al*. 2012). The species of snail or slug that works as an intermediate host in Africa, and more specifically Zambia remains less documented than in other parts of the world. *M. capillaris*' lifecycle will be focused on, however *P. rufescens'* lifecycle is similar.

Adult *P. rufescens* and their eggs are found in the small bronchioles of the lungs where the eggs hatch (Miller *et al.* 2012). The adult lungworm of *M. capillaris* lay their eggs inside nodules of the lung tissue (Miller *et al*. 2012). After hatching the larva (L1) leaves the nodule and moves into the interior of the alveoli (Christensen 2020b). The *M. capillaris* L1 larvae then migrates up the trachea and are coughed up and swallowed to the oesophagus from where they

then migrate through the digestive system (Christensen 2020b). The L1 larvae are then passed with the faeces.

Outside the host's body, the larvae can live freely in faeces or soil and are most active at moderate temperatures between 17-27 °C (Christensen 2020b). The larvae can survive fairly dry conditions until they can find and penetrate the body of their intermediate host, a snail or slug (Panuska 2006). In the snail or slug the larvae develop to the second stage, and after two weeks develop into the third stage (L3). In the snail the L3 can stay throughout the life of the snail in waiting for the snail to be accidentally eaten by its final host. In its final host the larva then develops into the fourth larval stage and migrates to the small intestine and penetrates the lymph nodes. From the lymph nodes the larvae migrate through the blood into the heart and finally to the lungs. In the lung alveolus the larvae can either undergo arrested development and lay latent in the lung, or mature to the adult stage where they mate and lay eggs and repeated. The prepatent period for *M. capillaris* is 5-6 weeks (Sauerländer 1988) in sheep the cycle. The prepatent period for *P. rufescens* cannot be found by this author.

2.4.3 Clinical signs

The pathogenicity of lungworms is amongst other things influenced by the quantity of ingested infectious larvae, the animals' immune systems robustness and where the lungworms are located in the respiratory tract (Ballweber 2021).

Dictyocaulus filaria

Infection with *D. filaria* is the most pathogenic of the lungworms usually affecting young goats and sheep (Miller *et al.* 2012). Goats do not develop as strong immunity as sheep, and they are more susceptible to re-infections (Wilson 1970). The worm causes bronchitis and clinical signs include cough, nasal discharge, tachypnoea, anorexia, chronic fever and weight loss (Miller *et al.* 2012). Anaemia of unknown pathogenesis and secondary bacterial pneumonia is also common in infected animals (López & Martinson 2017).

Protostrongylus rufescens

Infection with *P. rufescens* is often subclinical, however it can be pathogenic for goat kids and lambs causing mucopurulent nasal discharge, anorexia, diarrhoea and weight loss (López & Martinson 2017).

Muellerius capillaris

Infection with *M. capillaris* causes few clinical signs in goats (Miller *et al.* 2012). The adult worm is confined within its location in the lungs and therefore seldom causes problems for the goat (Christensen 2020b). However, symptoms arise mainly due to the migrating larvae. The larvae cause damage in the lining of the

alveoli when migrating to the trachea, which can cause pneumonia or allergic reaction in the host. Heavy infection can cause lung weakness and secondary infections.

2.4.4 Epidemiology

The infectivity of pastures depends on the presence of infective (L3 stage) larvae and suitable climatic conditions (Kusiluka & Kambarage 1996). While a cool and damp environment is suitable for the development of the *D. filaria* L3 stage larva, dry conditions can result in the inhibition of the larvae in the lungs of its host. For *M. capillaris* and *P. rufescens* the presence of intermediate hosts, whose epidemiology is dependent on factors like moisture, is vital for their infectivity (Kusiluka & Kambarage 1996).

Around the world, lungworms are considered ubiquitous (Rose 1973). There is however not much to be found in the literature about the prevalence of lungworms in goats in Africa, and not a single study can be found concerning the prevalence of lungworms in any domesticated animal species in Zambia. However, one post-mortem study on helminth parasites in the endemic Kafue lechwe antelope showed a nine percent (n=65) prevalence of *D. filaria* in the Kafue wetlands (involving the Central, Southern and Lusaka provinces) in Zambia (Phiri *et al.* 2011).

The data available on prevalence of lungworm in small ruminants in Africa are mostly originating from northern African countries, especially Ethiopia where *Muellerius capillaris* is said to be the most common lungworm in sheep (López & Martinson 2017). Studies have also been done in Egypt, the Ivory coast and DR Congo. There are also very few studies on potential intermediate hosts of *M. capillaris* and *P. rufescens* in Africa, making it difficult to evaluate the potential prevalence of lungworm in Zambia.

In a study conducted in Wolaita Zone, Southern Ethiopia, all three lungworms were found in goats and sheep using a modified Baermann's method, with an overall prevalence of the three lungworms being 36.5 percent (Tessema *et al.* 2024). *D. filaria* was the predominant lungworm species infecting the small ruminants, followed by *P. rufescens*. In the study, the proportion of lungworm infection was higher in sheep than goats (43.34% and 26.42% respectively) and the reason was believed to be differences in grazing behaviour. Also in the study, small ruminants were 70.4 percent less likely to be infected by lungworm if kept in lowland areas in Ethiopia than in highlands due to a warmer climate and lower moisture levels in the lowlands.

A study of the ovine lungworm prevalence in Nile delta, Egypt, found an overall prevalence of 4.5 percent through identifying lungworms in lungs at slaughter houses, where *D. filaria* constituted all of the lungworm findings (Ali *et al*. 2018).

In DR Congo, *M. capillaris* was the only type of nematode found in the lungs of young and adult goats with a prevalence of 32 percent (Cabaret & Chartier 1989). And, in goats raised in the municipality of Lubumbashi in DR Congo, *Dictyocaulus* spp. was found in 88.6 percent of the population (Ipungu *et al.* 2017).

2.4.5 Diagnostics, treatment and prophylaxis

Diagnostics

Diagnosing lungworm infection is done by finding the first larval stages (L1) in fresh faeces using the Baermann technique (Miller *et al.* 2012). The L1 larvae migrate from fresh faeces submerged in water, reaching the bottom of a funnel and are then analysed and the species identified by microscopy. The test had a very high sensitivity in calves when at least 30 g per individual were analysed for *Dictyocaulus viviparus* (Eysker 1997). To minimise false negative results, Baermannisation should be done on freshly collected faeces as *D. filaria* is very liable in storage and 60-70 percent of larvae die within 24 hours (even if kept at 4°C) (Rode & Jørgensen 1989).

A diagnostic ELISA kit is also available to detect antibodies against *Dictyocaulus* spp., however, it is developed for cattle and so far has a restricted geographical availability (UK and Netherlands) (Sabatini *et al.* 2023). Both ELISA and Baermann require the presence of adult worms, meaning that they will only show positive results from days 23-28 post-infection and later on resulting in a diagnostic gap where no results can be obtained.

Diagnosing infection can also be done by finding adult lungworms in pathological samples, during necropsy or at slaughter (Delano *et al*. 2002). This is the method most commonly used in Zambia, while detection of L1 in faeces using Baermann's funnel method is not a routine diagnostic method (Chilundu, J., pers. comm., 2024).

Treatment

Treatment protocols as well as the anthelmintic drugs used to control lungworm infection differ around the world depending on availability of products and the country's regulations.

There is no available literature/documentation describing the approved anthelmintic drugs and general dosages for treating lungworm in goats (or sheep) in Zambia. Globally, few anthelmintic drugs are approved specifically for goats (Delano *et al*. 2002), meaning that treatments are often done "off label". However, albendazole (benzimidazole), fenbendazole (benzimidazole) or ivermectin (macrocyclic lactone) can be used for treating all three lungworm species (Miller *et al*. 2012). Because of the often mild symptoms caused by *M. capillaris*, affect-

ted animals often go untreated. However, repeated treatment or higher doses might be needed to eliminate immature stages of *M. capillaris* (Miller *et al.* 2012). Three to five times the normal dosage of benzimidazoles is said to be effective against *M. capillaris* (the efficacy of this dosage in goats is not specified) (Hansen & Perry 1997). Levamisole (benzimidazole) is also used in the treatment against lungworm, however it is reported as not as effective against some larval stages (especially arrested larvae) (Jacobs 2015). Furthermore, a study in Iran showed low levels of efficacy of levamisole (and albendazole) in *D. filaria* and *M. capillaris* in goats as a result of a growing drug resistance (Abdollahzadeh *et al.* 2024).

Prophylaxis

Prophylactic measures are done through strategic deworming and pasture management (Hansen & Perry 1997). For the control of *D. filaria* in goats vaccination is also an option where attenuated larvae are administered in two doses, four weeks apart (Sharma 1994). It is said to be able to provide a strong immunity against *D. filaria* infection (Hansen & Perry 1997).

2.5 Available information on helminth control in Zambia

The amount of available information online on local recommendations for treating helminths in animals in Zambia is scarce. In a manual on goat production in Zambia (Els *et al*. 2019) the use of anthelmintics for the treatment of parasites is discussed. However, it lacks practical treatment advice, i.e. does not specify the indication for treating individual animals or herds, the dose and/or the intervals treatments are supposed to be given. However, the manual does mention the importance of using a drug that is safe to use for goats and using an effective dosage (again no specific dosages are recommended). Changing dewormers regularly to prevent resistance and to eliminate several types of worms is also advised. Examples given of anthelmintics for farmers to have at home are (amongst others) albendazole, triclabendazole, and a combination of praziquantel, levamisole, closantel and ivermectin although indication for their usage is not given.

3. Material and methods

3.1 Description of the study area and study population

The study was conducted as a part of a longitudinal study on climate-sensitive diseases in goats in Zambia. Sampling was done in the Central and Southern provinces of Zambia from September to mid-November 2024 (Fig. 6). The provinces were chosen thorough stakeholder consultation.

In the provinces twenty households were selected through snowball sampling. The households from the Southern province (n=10) were located in the agroecological region I. In the in the Central province, n=5 households were in the agroecological region II and n=4 in the agroecological region III. In one sampled household the location could not be confirmed.

On the chosen farms, 10 goats over one year of age were randomly selected. The goats used in this study were of local breeds and kept under extensive husbandry arrangement systems. In daytime, the goats foraged in extensive pastures, often alongside sheep and/or cattle. During the study period a drought had been affecting the country since January 2024.

Figure 6. The approximate locations of sampled areas (grey dots) in the Central province (green stripes) and Southern province (red stripes) of Zambia. Author's marking of the provinces on a map from https://sv.wikipedia.org/wiki/Fil:Zambia_provinces_named.png with permission to use according to GNU Free Documentation License.

3.2 Study design

The study was a cross-sectional study and was carried out from September to November 2024 to estimate the occurrence of liver flukes and lungworms and determine current treatment strategies against them, in Zambian goat herds.

3.3 Data collection

3.3.1 Animal data collection

Data containing the age, sex and body condition score was collected by clinical examination or by asking the owner. The owner was also questioned about their routines for deworming, how often the herd was treated and which drugs were used. Body condition scoring was done with a goat-specific scoring method, categorising the goats between the scores 1-5 according to Villaquiran, Gipson, Merkel, Goetsch, and Sahlu (2007).

3.3.2 Parasitological data collection – coprological sampling

In the southern province sampling was done in the morning before the goats were let out of their enclosures for the day. From the herd (usually around 20-30 individuals in total) 10 goats above one year and older were randomly selected for sampling.

The faeces were collected rectally through digital palpation. The faeces were then collected in plastic tubes (ca 50 ml) and labelled with the household ID and the number of the individual (1-10). If blood was spotted on the glove, the rectal sampling was discontinued. If the rectum was empty, no faecal sample was taken from that goat, and the number of samples were lowered.

Faecal samples were kept in a cooling box with ice packs and were then transferred to a refrigerator after all the households were sampled for the day. At the end of the sampling week, the samples were then transported to the lab at the University of Zambia in Lusaka (UNZA) and kept in a refrigerator until analysing (around 3-12 days).

Simultaneously to the faecal sampling jugular blood sampling was done and the goat's mouths and teats were searched for signs of Orf (farmyard pox). If signs were found e-swab sampling was done. The skin of the goat was searched for signs of mange, in case skin lesions were detected a deep skin scraping was made. Those samples were part of other studies and will not be presented in this study.

The goat owners did not get any compensation for their contribution to this study. However, the test results for the herd will be reported after the study is finished.

3.4 Parasitological examination

3.4.1 Sedimentation

For information about the uses and aim of this method see the subheading Diagnostics on page 18. Pooling of the five individuals was done with two grams of faeces making it 10 g in total per sample. Two pooled samples from every household were created. If there were not enough individual samples (e.g. rectum was empty when sampling) to form two pooled samples with five individuals in every sample, the amount of individual samples was reduced to four or three per pooled sample and the amount of faeces from each individual sample increased (if possible) to make 10 g in total.

The ten grams of faeces was homogenised in tap water and passed through a sieve (of large mesh size) and collected in a bowl (50 ml). The contents in the sieve were discarded and the filtered suspension was passed through another sieve (approximately 150 µm, this second sieve-moment of the sedimentation was only performed for the samples collected from the Central province, as the sieve was not available when samples from the Southern province were examined) and transferred to a cone shaped beaker. The suspension was diluted with tap water to a volume of 500 ml. The suspension was then left for five minutes to allow the fluke eggs to sediment. The supernatant was after that decanted and the sediment re-suspended in 500 ml water. The process was repeated twice and after the last decantation the final sediment (ca 15 ml) was transferred to a milk tube and stored in a refrigerator (+4° Celsius) for further microscopical examination.

When analysing the samples, the supernatant was removed with a pipette, leaving around five millilitres in the bottom. The sediment was then mixed with a pipet with the remaining supernatant and spread out on a microscopic slide.

From the samples collected from the Southern province two slides from every sample were analysed for liver fluke in a microscope at 4x - 10x magnification. The limited amount of microscopical investigations was due to the fact that sediment samples from the Southern province contained a large amount of sand. From the Central province, due to an additional sieve being used the amount of sediment was much cleaner and less sand was present, which made it possible to analyse more slides in the limited time available (n=3).

The samples containing the most sand (n=4), were sedimented once instead of thrice before being transferred to a milk tube in an attempt to leave some larger pieces of vegetation and therefore prevent the sand from occluding the vision. Three drops from the suspension were then added to a microscopic slide with three drops of water. For those four samples, three slides per sample were analysed.

3.4.2 Baermann's funnel method

For information about the aim of the method see the subheading Diagnostics on page 25. Two grams of faeces from five individuals was weighed and ground in a beaker, making it two pooled samples from every household, and a total of 10 g faeces per sample (if the number of individuals sampled from a farm were too few to form two pooled samples containing five samples each, four or three samples were pooled instead using more faeces each to reach 10 g in total). The amount of faeces that could be used from the Southern province was less than from the Central region. Meaning that the samples from the Central province were instead pooled with 1,2 g from every individual to a total of six grams.

A funnel stand was made from a cardboard box with holes made with scissors standing on the side. Silicone tubes were added to plastic funnels and put in through the cardboard stand and a plastic clamp was attached to the bottom of the tubes (Fig. 7 & 8). The funnels were filled with tap water. The samples were added to a double layer of gauze cloth which was then folded and tied to a pouch. A wooden stick was threaded through the top of the pouch and the pouch containing the faecal matter was then submerged in the water of the funnel (Fig. 4). The samples were then left for six hours allowing for the L1 larvae to migrate out of the faeces and sink to the bottom. After six hours the suspension at the bottom of the tubes were collected in milk tubes. The samples were centrifuged at 1200 rpm for three minutes to concentrate potential L1s. The supernatant was then removed and the remaining suspension was pipetted out on a microscopic slide. The samples were then analysed for identification of L1. All the sediment was analysed and the results noted. If a live larva was found a drop of iodine was added to kill the larva and stain it.

Figure 7. The setup of Baermann's funnel method. Source: Author's photograph.

Figure 8. Funnels containing faecal samples and water. Source: Author's photograph.

4. Results

4.1 Detection of liver fluke eggs (sedimentation)

A total of eighty-six samples from 10 households were taken from goats in the Central province of Zambia. Out of the 19 pooled samples, one sample was positive for eggs of the liver fluke (Table 1). Ninety-six samples from 10 households were taken in total from goats in the Southern province. Out of the 20 pooled samples, no samples were positive for fluke eggs.

Table 1. The occurrence of liver fluke eggs in pooled faecal goat samples in the Central province (n=19) and Southern province (n=20) of Zambia.

Origin	*n* (sampled individuals)	*n* (pooled samples, 3-5 individual samples per pooled sample*)	No. of positive pooled samples	Occurrence, percentage of positive pools (%)
Central province	86	19	1	5,3
Southern province	96	20	0	0
Total	179	39	1	2,6

*3 individual samples per pooled sample, n=3, 4 individual samples per pooled sample, n=7, 5 individual samples per pooled sample, n=19.

4.2 Detection of lungworm larvae (Baermann's funnel method)

Eighty-three samples from 10 households in the Southern province of Zambia were analysed to determine the occurrence of lungworms. Out of the 20 pooled samples, no samples were positive for lungworm. Eighty-six samples from 10 households in the Central province of Zambia were analysed and out of the 19 pooled samples, none of them were positive for any of the lungworms.

4.3 Deworming practices

Information about deworming practices (antiparasitic treatment) were collected through interviewing the owners in the different households at the time of sampling, their answers are shown in Table 2 and summarised in Table 3. Seventy-five percent of the households used a form of antiparasitic treatment for their goats. Out of the 10 households in the Southern province, ivermectin was the most used drug for deworming, followed by albendazole. The intervals in which the drug was given ranged from 2-12 times a year. In the Central province ivermectin was the most used drug as well, followed by albendazole and levamisole, with treatment intervals ranging from between 1 to 3-4 times per year. On two farms the

drug used for deworming was unknown. The whole herd was often dewormed and not individual animals.

Table 2. Deworming practices (if they do/do not have a deworming practice, drug used and treatment intervals) used by the households in the Southern province (n=10) and Central province (n=10) in Zambia.

Origin	Household ID	Antiparasitic treatement	Drug	Interval (times per year)
Southern province	2H	No	-	-
	3H	Yes	Unknown	12
	4H	Yes	Albendazole	4
	5H	Yes	Ivermectin	4-6
	7H	Yes	Albendazole	3
	8H	Yes	Albendazole + Ivermectin	2
	12H	Yes	Ivermectin	12
	14H	No	-	-
	15H	No	-	-
	17H	Yes	Ivermectin	2
Central province	18H	Yes	Albendazole	1
	19H	Yes	Albendazole	3-4
	21H	Yes	Unknown	Unknown
	25H	Yes	Ivermectin + Levamisole	3
	26H	No	-	-
	27H	Yes	Levamisole	2
	28H	Yes	Ivermectin	2
	29H	Yes	Ivermectin	2
	31H	No	-	-
	32H	Yes	Ivermectin	2

Table 3. A summary of deworming practices (total amount of households, number of households that do/do not have a deworming practice, drug used and treatment intervals) used by the households in the Southern province (n=10) and Central province (n=10) of Zambia.

	No. households	Deworming practice		Drug used					Interval (times per year)							
		Yes	No	Ivermectin	Albendazole	Levamisole	Mix	Unknown	1	2	3	3-4	4	4-6	12	Unknown
Total	20	15	5	6	4	1	2	2	1	6	2	1	1	1	2	1

5. Discussion

5.1 Liver flukes

This study detected an occurrence of liver fluke eggs in the Central province with a prevalence of 5.3 percent, whereas no fluke eggs were found in the Southern province. The overall prevalence of liver fluke was 2.6 percent which was lower than the prevalence of studies conducted in other African countries such as Kenya, Ethiopia and Egypt. As no previous studies on liver fluke prevalence in goats in Zambia were available, there is no data to compare present results with. However, in the study by Phiri *et al.* (2006), fasciolosis was proven to be a widespread disease in cattle in Zambia and found a much higher prevalence of fasciolosis in cattle in the Southern and Central provinces. The lower prevalence rate in goats in the Central and Southern provinces compared to cattle could be because of i) differences between the species as goats are browsers rather than grazers, ii) the sampled herds within Southern and Central province were in different proximity to water reservoirs and intermediate hosts, and iii) climatic/seasonal conditions during the sampling period (i.e. the drought experienced by the country at the time of sampling) might have directly affected the *Fasciola* spp. different developmental stages.

The detection of liver fluke eggs in the Central province and not the Southern could be explained by the positive farm being in agroecological region III which has more rainfall compared to the Southern region that is located in the agroecological region I, which is more prone to droughts. However, due to major challenges in storing samples from the Southern province and upholding the cool chain, a possibility that the liver fluke eggs hatched before examination must be taken into consideration. The samples from the Southern region were also analysed on two and not three microscopic slides due to the samples containing large quantities of sand, meaning less material was analysed than the samples in the Central province. Other reasons could be that light and/or immature infections is difficult to find through sedimentation, and that the sampled goat herds were kept far from each other, meaning that there is probably not much contact between herds and therefore lower risk of transmission of the liver fluke.

The species of liver fluke found was probably *Fasciola gigantica* as it is the most common fluke in that part of Africa, and also the species found in cattle in Southern and Central province in Zambia. Beyond lacking access to proper molecular techniques, with the low occurrence of liver fluke eggs, it was not considered relevant to identify the liver fluke species. However, to identify what species of liver fluke occur in Zambian goats would be an interesting aim for future studies.

5.2 Lungworms

This study did not detect any lungworm infection in the whole study area. This should however not be interpreted as if lungworms do not occur in goats in those areas, as *D. filaria* has been found in Zambian antelopes in the Central and Southern province in a study before this, and the sample storing method during this study was not ideal. Compared to other countries, as all three species occur in Ethiopia and *D. filaria* has been studied in goats in Egypt and DR Congo, the difference in prevalence rates between countries could depend on differences in geographical location affecting elevation, temperature, humidity and rain.

Beyond the factor of antiparasitic-treatment (which is discussed further down) being a reason for its absence, climatic/seasonal conditions during the sampling period could be a contributing factor, since the development of free-living larvae is dependent on lower temperatures, higher humidity and rainfall compared to those that occurred during the sampling period (dry season with an ongoing drought). Furthermore, errors in storage and examination technique could be a contributing factor where the larvae might have died before analysing. For example, the *D. filaria* larvae are very liable to storage conditions, where most larvae die within 48h even when refrigerated, and the Baermann's funnel method could not be run until 3-12 days after sampling. Meaning most larvae could have died before analysing was finished. Furthermore, as lungworm typically affects younger individuals, the study population of animals above one year of age could have contributed to no positive samples being found. There was also a challenge of insufficient amounts of faecal material for both the sedimentation and Baermann's funnel method.

As there was another study also using the collected faecal matter for this study, the available amounts of materials per diagnostic method were low, resulting in the samples having to be pooled (three to five individual samples per pooled sample). With less faeces per individual being used when analysing the pooled samples, the sensitivity was lowered as there is a risk that positive samples were missed.

5.3 Deworming practices

Three types of drugs were used for deworming in the Southern and Central province of Zambia: ivermectin, albendazole and levamisole. Ivermectin was the overall most used anti-parasitic drug and is active against all considered lungworms, but not liver flukes. The second most used drug was albendazole which is effective against adults of *Fasciola* spp. as well as lungworms. The last drug used was levamisole which is active against lungworms but not liver fluke.

This means that out of the 15 households stating to have a deworming practice, eight households did not have use a flukicide, and counting in those households

with absence of deworming practices, this figure increased to 13 (out of 20 households). The deworming practice on the only farm where fluke eggs were detected was with ivermectin and levamisole three times per year, thus not treating liver fluke which explains the positive result. The underlying reason for few households testing positive for liver fluke despite 65 percent of households not using a flukicide is unknown but could be attributed to factors earlier discussed (page 36).

Thirteen out of the 15 households with deworming practices used drugs that were effective against lungworms, which correlates with the negative results from this study. However, even amongst the five households without any deworming practices, none were positive for lungworm larvae, making it likely that the negative results could have been affected by other factors.

The reported deworming practices varied significantly between farms, and no apparent consensus on treatment strategies amongst the households was observed. Due to the low occurrence of liver fluke and lungworm there was not enough information to discern any correlation between deworming practices and occurrence. To do that, better understanding about the true occurrence needs to be studied. Furthermore, when questioning about deworming practices, no information about the most recent treatment was known, nor the dosages used when deworming, which would have been interesting to identify.

A potential bias in this study could be response bias where participants could have answered questions of deworming practices based on what they thought the interviewer wanted them to answer (e.g. saying they dewormed when in fact they did not).

5.4 General reflections

In hindsight, a more effective way to study the occurrence of liver fluke and lungworm in a country where no prior studies have been done could have been to visit abattoirs and examine goat livers and lungs for identification of liver flukes and lungworms before doing coprological examinations. And, if possible, combining it with e.g. serology (ELISA) to increase the sensitivity.

The laboratory routines and specific diagnostic methods in Zambia differ significantly from Sweden. It was at times challenging to find a balance between the local practices and the analytical protocols I, the author of this paper, had practiced on at the SLU (Swedish University of Agricultural Sciences), but I am rather confident that this is not a factor that influenced the obtained results. However, any influence cannot be excluded. In an aim to battle this, faecal material from the samples could have been brought back to Sweden and analysed. However, transporting biological samples are challenging, both in the aspects of export/import regulations between Zambia and Sweden, and keeping samples viable during transportation.

This study is the first one of its kind investigating the occurrence of liver flukes and lungworms in goat herds in Zambia. However, because only the Southern and Central province was studied, the picture given is not representative of the situation countrywide. Further research is needed to investigate the overall occurrence, clinical relevance, and treatment routines regarding these parasites in Zambia.

6. Conclusion

In conclusion, this study confirms the presence of liver flukes in the Central region of Zambia and shows that most farms lack in adequate treatment strategies against the parasite. While lungworms were not detected in the study area, it is likely attributed to issues with sample storage rather than their absence in goat herds in Zambia.

This study establishes a basis for future research in the prevalence of liver flukes and lungworms in Zambian goat herds. Furthermore, by addressing the difficulties Zambian goat owners face in choosing effective deworming strategies, it highlights the critical need for accessible treatment information in rural communities.

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Popular science summary

Goats are very important for rural households in Zambia. They provide the families with economic security as they can be used for trading and income as well as providing the household with meat, milk and hides.

In a report by the Zambian Ministry of Fisheries and Livestock from 2023, a majority of Zambian goat raising households answered that one of the three leading problems affecting their goats were helminthiasis, a disease caused by parasitic worms affecting animals and humans. Parasites are organisms that live on or in other organisms where they benefit by taking nutrients from its host. The host meaning the plant, animal or human that it derives nutrients from, and often causes harm to. Amongst these parasites we find the liver fluke (Scientific name: *Fasciola*), a flat leaf-shaped parasite around 30-75 mm that lives in the liver of its host, usually goats, sheep, cattle, buffalo or on occasion, humans. The liver fluke is considered by the World Health Organisation a neglected tropical disease and is expected to infect as many as 2,4 million people around the world. Even though the liver fluke can be found in animals all around the world too, it is often overlooked in veterinary medicine because it does not frequently cause prominent symptoms compared to other diseases. However, the liver fluke can still cause severe illness, especially in sheep, where sudden deaths can occur due to the great damages on the liver caused by the fluke. In goats, the symptoms are not as well studied, but the liver fluke is a proven cause of weight loss and impaired growth. This affects the families that raise them as they might experience production losses and might not be able to sell the sick animals.

In a way to cope with the effects of liver fluke treatment can be given to the animals as part of a so-called deworming practice. In this practice the farmers treat their goats and other animals with an anti-parasitic drug at specific intervals throughout the year to minimise the risk of the goats being infected by the liver fluke and other parasites. These deworming practices are important in maintaining the health of the herd. However, information about how to treat goats is limited. What drug to choose, the amount and when to use the drug is not clearly stated in the goat manuals available to Zambian farmers, and when searching in literature globally, no consensus in treatment against liver fluke in goats specifically can be found. This makes it difficult for farmers to administer the correct treatment for their goats. Furthermore, studies have found that goats need higher doses of drugs than sheep. Which is a problem since sheep and goats are often treated the same due to them being similar in size. As a result of goats being treated with doses of drugs that are too low to fully eliminate the liver fluke, a problem with the liver flukes developing resistance to the treatment is increasing. Parasites developing resistance to treatment is a growing problem worldwide where infected animals

are treated with a drug that is not efficient in eliminating the parasite, leading to continued risk of the infection spreading in herds.

Another important parasite amongst the helminths (parasitic worms) affecting goats are lungworms. These parasites live in the lungs of its host where they usually do not cause the animal any harm. But, if younger animals are infected or the number of worms in the lungs high, the animal can show signs like coughing and a runny nose. In severe cases, animals can show signs of weight loss and develop lung infection. There are three species of lungworms that infect goats and sheep: the large lungworm (*Dictyocaulus filaria),* the red lungworm (*Protostrongylus rufescens)* and the nodular lungworm (*Muellerius capillaris)*. While not being able to infect humans, lungworms still cause problems by as it is a cause of production losses in livestock around the world. Like with the liver fluke, information on correct treatment strategies against lungworm in goats in Zambia is difficult to find and challenges with lungworms developing resistance to treatment is growing.

In Zambia no studies investigating the prevalence (the proportion of a population of animals infected by a specific parasite at a chosen time) of liver fluke or lungworm in goats has been done. With little accessible information about if the liver fluke or lungworm exist in Zambian goat herds and how to correctly treat them, this could be potentially be affecting many Zambian families.

The aim of this study was therefore to investigate the occurrence (if a specific parasite appears in a population) of liver flukes and lungworms in goat herds in Zambia and to identify the current treatment strategies used.

The study was conducted through sampling 10 goats from 20 households in two of Zambia's ten provinces: the Central and Southern provinces. The households sampled in the Southern province were in an area with low amounts of rainfall during rainy season (often occurring from November to April) and that is prone to droughts during dry season (from April to November), while the households in the Central province experience heavier rains and are not as prone to droughts. During the time of this study a major drought was affecting the whole country leading to food insecurity and power shortages.

Goats stool was sampled from ten goats from each farm and stored in refrigerators until analysing. The owners of the goats were also asked about their treatment strategies (if they had one, and if yes, with what drug and how often). The samples were then pooled, which means that stool from three to five goats were grouped together for analysing. Two pooled samples from each farm were made, making 39 pooled samples in total. These were then analysed through a method called sedimentation where the goat stool is homogenized in water and filtered through multiple sieves to remove any food particles. The solution left contained smaller particles and eggs of the liver fluke (that are excreted with the stool), and as liver fluke eggs are heavy, they will sink to the bottom of a solution with water.

The water and lighter particles could then be poured of after a couple of minutes and the eggs at the bottom collected and analysed in a microscope. From the Central province, liver fluke eggs were found in one of the pooled samples, making the prevalence 5,3 percent in the Central province. From the Southern province no eggs from the liver fluke were found.

For lungworms, the method used to analyse the samples was Baermann's funnel method which extracts the lungworm larvae (an immature life stage of the lungworm expelled trough the host's stool) from the pooled stool samples. This was done by placing the goat stool in a cloth and submerging it in a funnel filled with tap water. The funnel features a silicone tube and a clamp attached to the end. Using this method, any larvae in the stool would swim out from the cloth and sink to the bottom of the funnel and through the tube. After six hours, the clamp was removed and the water in the tube containing the larvae was collected and analysed in a microscope.

No lungworms were found in any of the samples from the studied areas.

A majority of the goat owners claimed they treated their animals on a regular basis with intervals ranging from 1-12 times a year. Amongst the drugs used, a drug called ivermectin was the most used in both Central and Southern province. This drug is efficient in treating many parasites including lungworms, however, it does not kill liver flukes. The second most used drug was albendazole which can eliminate both liver flukes and lungworms. The third and last drug was levamisole which can treat lungworms, but is not efficient in treating liver flukes, just like ivermectin. In the household where eggs of the liver fluke were found, ivermectin and levamisole were used three times a year, which can explain the positive result. For lungworm however, even though the majority of households had deworming practices capable of treating lungworm it is not believed to be the only cause of the negative test samples. As said earlier, power outage was common during the study period which resulted in challenges in properly storing the samples in a cool environment. This means that the lungworm larvae could have died due to not being kept sufficiently cool or stored for too long, which likely contributed to the negative results.

This study showed that liver fluke does occur in the Central region of Zambia, and that most farms do not have an adequate treatment strategy against them.

The findings of this study can contribute to further investigation of the prevalence of liver flukes and lungworms in goats in Zambia. Additionally, by providing a better understanding of the challenges faced by Zambian goat owners in choosing appropriate deworming practices, this study may highlight the importance of making treatment information accessible to rural households.

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