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Haemonchosis: dealing with the increasing threat of the barber's pole worm

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Abstract

Haemonchus contortus is a trichostrongyle nematode parasite of sheep and goats, and worldwide is considered to be the most important parasite of these species. It has a similar lifecycle to other parasitic trichostrongyle gastrointestinal nematodes, but it has a markedly higher fecundity, a preference for higher temperatures and a short pasture development time, which makes it epidemiologically different. Similarly, because of its blood-feeding habit the disease produced is distinct from parasitic gastroenteritis. This article summarises the differences in biology and control of *H. contortus* to other gastrointestinal nematodes of sheep, and covers specific control measures such as the use of FAMACHA® scoring, use of closantel and nitroxynil, the *H. contortus* vaccine, the effect of copper oxide wire particles, and the potential for breeding haemonchosis-resistant sheep and other future developments in *H. contortus* control.

Haemonchus contortus (often called the barber's pole worm) is a haematophagous trichostrongyle nematode parasite of sheep and goats. Unlike other common trichostrongyle parasites, it mainly causes disease through associated blood loss. Worldwide *H. contortus* is the most important nematode parasite of small ruminants (Waller and Chandrawathani, 2005). As a result of this importance it has served as the model gastrointestinal nematode (GIN) for the genome project (Laing et al, 2013). It is often described as a 'tropically adapted' worm, but this description is misleading as it is a major pathogen in countries with very cold winters, such as Canada (Barrere et al, 2013), Sweden (Lindqvist et al, 2001) and Estonia (Tähepõld, personal observation). In the UK it has been found on 50% of sheep farms (Burgess et al, 2012). Within recent years there have been increasing reports of haemonchosis within southern England, and the combination of anthelmintic resistance and changing climate would seem to make this trend likely to continue (Rose et al, 2016).

The biology of *Haemonchus contortus*

Although the lifecycle of *H. contortus* is superficially similar to that of many other GIN, it has a significantly different epidemiology to the other GIN species commonly dealt with in UK livestock. Integrated management of this parasite therefore requires an understanding of the factors that influence the survival and development of its life stages ([Figure 1](#)).

Figure 1. The basic lifecycle of *H. contortus* is similar to that of other parasitic gastro-intestinal nematodes of sheep. Major points of difference is the egg production being several orders of magnitude larger, the rapid development from egg to L3 when conditions are suitable and the ability of ingested larvae to undergo hypobiosis in the abomasal mucosa overwinter.

Adult worms

Adult worms are 2–3 cm long and reside in the abomasum of their host, where they feed on blood obtained using the lancet in their buccal capsule. They have a host preference for sheep and goats, although they can infect cattle ([Hogg et al, 2010](#)), deer and camelids, and in sub-tropical regions, the closely related *Haemonchus placei* is a significant parasite of cattle ([Jacquiet et al, 1998](#); [Achi et al, 2003](#); [Jabbar et al, 2014](#); [Taylor et al, 2015](#)). Adult worms have an average lifespan of approximately 50 days, and the female worms are extremely fecund, producing 1300–7000 eggs per worm per day ([Getachew et al, 2007](#); [Saccareau et al, 2017](#)), compared with a range of 0–350 eggs per worm per day in *Teladorsagia circumcincta* ([Stear and Bishop, 1999](#)).

From eggs to infective third-stage larvae (L3)

Eggs are passed in faeces and must develop through L1 and L2 stages before reaching the infective L3 stage. This development requires a minimum temperature of 9°C ([Crofton, 1965](#)), with optimum development at 25–37°C ([O'Connor et al, 2006](#)). Compared with other GIN species in UK livestock, these developmental stages are rapid, taking just 16 days at 10°C, 6.4 days at 20°C and 3.5 days at 30°C ([Smith, 1990](#)). This short development phase,

combined with the high fecundity of individual worms allows the rapid expansion of populations under optimal conditions, which can lead to the rapid development of clinical disease on farms that have not experienced problems in the past ([Figure 2](#)).

Figure 2. The optimal temperature for the balance of larval development and survival is higher for *Haemonchus contortus* than for other parasitic gastrointestinal nematodes of small ruminants. The survival of the worm at lower temperatures is notably poorer than other trichostrongyles. The shading indicates the suitability of temperature for the accumulation of infective larvae. The palest shading indicates the limits for larval development. The darker shading indicates more favorable temperature ranges, with the optimal temperature range indicated by the deepest colour.

As livestock actively avoid areas of pasture contaminated by faeces, infective L3, must translocate away from the faecal pat in order to be ingested. To do this, they require a film of free water to travel in: if long-term humidity has been high, then light rainfall is sufficient to allow this, whereas after periods of drought, heavier rainfall is required ([Wang et al, 2014](#)). These results are consistent with the authors' clinical experience of outbreaks in southern England during heat waves or when heavy rainfall has followed warm, dry periods.

Eggs, first stage larvae (L1) and second stage larvae (L2) are vulnerable to temperature fluctuations and to desiccation; however in temperate climates, they are largely shielded from these by the more constant microclimate within the faecal pat ([O'Connor et al, 2006](#)). These stages are also very vulnerable to low temperatures, with cool-temperate field studies in Australia suggesting eggs only remain viable for several days after deposition ([Barger et al, 1972](#); [Sakwa et al, 2003](#)), therefore long-term survival of eggs, L1 and L2 seem unlikely under UK conditions. L3 are more resistant to variations in environmental conditions; however, they do not tend to survive over winter in Northern Europe, although this may change if winters become milder with climate change ([Rose et al, 2015](#)).

As the metabolic rate of L3 is temperature dependent and they have no means of feeding (mouthparts covered by the cuticle), this larval stage also has a shorter lifespan at higher temperatures ([O'Connor et al, 2006](#)). In tropical climates, the combination of rapid development and short longevity at high temperatures may be useful for generating clean grazing by rotational grazing ([Waller, 1997](#)), and a study in a cool temperate region of Australia found rotational grazing with a rest period of 103 days was effective at controlling *H. contortus* populations ([Colvin et al, 2008](#)). However, rotational grazing patterns commonly seen in the UK (approximately 4-week rest periods) are unlikely to produce significant decay of pasture larval levels.

Early 4th-stage larvae and hypobiosis

After ingestion, L3 moult to become early 4th stage larvae (EL4): these may then either immediately carry on developing through to adult worms, or may arrest their development and undergo hypobiosis until conditions favour further development. This hypobiosis allows the parasite to persist from season to season, despite the limited survival of the free-living stages ([Taylor et al, 2015](#)). This feature of the lifecycle is of particular clinical relevance, as it may allow the transmission of *H. contortus* onto an uninfected holding through the purchase of stock if they are not given quarantine treatments, and it may lead to unexpected clinical disease because of the sudden development of hypobiotic larvae (e.g. at lambing time) ([Sargison et al, 2007](#)). This latter disease pattern is commonly seen in countries with cold winters, where on-pasture survival over winter is impossible ([Waller et al, 2004](#)). These severe disease outbreaks may occur without noticeable elevations in the faecal worm egg counts the preceding summer and autumn (Tähepõld, personal observation). It is also of great significance to the development of anthelmintic resistance, as hypobiotic EL4 may represent the only in refugia population present on a farm during periods of poor L3 survival.

Haemonchosis

Aetiopathogenesis

The disease caused by *H. contortus* is related to its blood feeding. On average, each worm consumes 0.05 ml per day, but the amount can vary from 0.005 to 0.17 ml ([Clark et al, 1962](#)). The worms themselves consume blood, but the blood loss continues after the worm detaches from the feeding site. In addition to the buccal lancet, the feeding is aided by the secretion of calreticulin by the worm, which impairs blood clotting and the immune response to the worm ([Suchitra and Joshi, 2005](#)). The majority of clinical signs, therefore, relate to the loss of blood protein and red blood cells.

Other impacts include an increase in the rumen outflow rate, and a decrease in digestion along the gastrointestinal tract as a whole, and loss of amino acids through the action of the worms ([Rowe et al, 1988](#)). The developing larvae in the gastric glands cause local distension and the loss of parietal cells ([Jackson and Coop, 2007](#)).

Diagnosis

Clinical signs

As the infective larval stages are also haematophagous, the clinical signs can occur before egg-shedding begins. The clinical signs all relate to blood loss, but the time course of the disease process, and thus the clinical signs observed, are influenced by worm burden.

The most consistent clinical sign is pallor, as a result of anaemia. In hyperacute cases (e.g. when animals ingest a very large number of larvae in a short period) this is directly related to frank blood loss. In more chronic cases it may reflect loss of red blood cells outstripping the rate of production, or exhaustion of the regenerative capacity. The anaemia and blood loss also results in tachycardia and hyperpnoea and weakness. Heart sounds and pulse quality may reflect the lower viscosity of the blood ([Figure 3](#)).

Figure 3. The clinical signs of haemonchosis relate to blood loss, among the most notable of which is pallor. This is most reliably appreciated in the ocular mucous membranes, and this forms the basis of the FAMACHA® scoring system.

Weight loss, lethargy and poor fleece quality also occur as a result of the blood loss. The loss of blood protein results in submandibular oedema. Diarrhoea is not a feature of haemonchosis; faeces may be scanty and dark.

The packed cell volume (PCV) falls in affected animals, and hypoalbuminaemia is also a feature. Faecal occult blood is also found in haemonchosis, but the usefulness as a diagnostic tool under field conditions is questionable (Rodriguez et al, 2015).

Post-mortem examination

At post-mortem examination, external signs that are indicative of haemonchosis include pallor of the mucous membranes, submandibular oedema and poor body condition. Internally the blood is often watery, and there may be ascites and increased pericardial fluid. There may be pallor of the liver. The abomasal contents are often dark brown and foetid. Adult worms can be detected with the naked eye, with the characteristic 'barber's pole' appearance. The abomasal lining may be oedematous. Dark-red petechiae (indicating points of attachment) may be seen, as may nodular changes to the mucosa ([Figure 4](#)).

Figure 4. Post-mortem features include emaciation, watery blood, dark, foetid abomasal contents, petechiation of the abomasal mucosa (a) and worms within the abomasal contents. Adult worms may be seen with the naked eye attached to the mucosa, identifiable by the characteristic red-and-white striped barber's pole appearance (b).

Faecal worm egg count

As the infective larval stages are also haematophagous, the clinical signs can occur before egg-shedding begins. Because of the high fecundity of *H. contortus*, worm egg counts where this species predominates are often notably high. Counts in the thousands or tens of thousands may be seen where a heavy *H. contortus* burden is present.

Egg morphology (Christie and Jackson, 1982) and the morphology of L3 larvae (Van Wyk and Mayhew, 2013) can be used to identify *H. contortus* eggs, but both methods require considerable skill on the part of the operator, and the latter requires significant time to culture the larvae and the resultant relative numbers of the larvae of different species will be affected by differential egg survival and larval hatch.

It has been discovered that peanut agglutinin (PNA) binds to *H. contortus* eggs but not those of other trichostrongyles. Consequently, fluorescent-labelled PNA can be used as the basis of an assay to determine the percentage of eggs in a sample that are *H. contortus* (Jurasek

et al, 2010). This is a useful, and relatively inexpensive and quick method for determining if, for example, high faecal worm egg counts are due to *H. contortus* infection. It is currently offered commercially by several laboratories in the UK.

Treatment

H. contortus is susceptible to the available broad-spectrum anthelmintics (benzimidazoles, levamisole, macrocyclic lactones, monepantel and derquantel) (Jackson and Coop, 2007). Benzimidazoles, macrocyclic lactones and monepantel are effective against the hypobiotic larval stages (Stein et al, 2010); levamisole is not (Sargison et al, 2007).

In addition to these broad-spectrum anthelmintics, *H. contortus*, by virtue of its haematophagy, is also susceptible to other compounds, specifically those that bind to blood proteins. Those available in the UK, in products licensed for use in sheep, are closantel and nitroxylin. As they have a prolonged residence time, because it is protein bound, there is a degree of persistent activity (Hall et al, 1981). As they are dependent on the feeding activity of the worm to be effective, they are not effective against hypobiotic stages. Equally, the therapeutic indices of these compounds are narrow and accurate dosing to bodyweight is required to avoid toxicity.

When considering the need for treatment, as well as choice of anthelmintic compound, the occurrence of anthelmintic resistance should be considered (see section below).

Prevention and control

The majority of *H. contortus* control is similar to that of the control of parasitic gastrointestinal nematodes in general. All that holds true of pasture management, the correct use of anthelmintic drugs, the impact of good nutrition in enabling sheep to mount an effective immune response to the parasite, the potential anthelmintic properties of certain forages (e.g. chicory, *Lespedeza* spp.) are as true for *H. contortus* as they are for parasitic gastroenteritis (PGE)-causing nematodes. Consequently, in this section we shall focus in particular on the areas where control must differ from general control of GINs.

One major area of difference is that unlike the situation which pertains with other GIN species, whereby adult female sheep (outwith the peri-partum) seem to be relatively unaffected, thanks to an effective immune response, adult ewes can be clinically affected and even die from haemonchosis. In the authors' experience, haemonchosis is often first detected on farm as a result of morbidity and mortality among ewes, with the problem presumably being curtailed in the lambs by the worm control strategies already applied to them to control PGE. Consequently, one of the first parts of *H. contortus* control is to ensure that some form of monitoring for haemonchosis is applied to the whole flock.

Anthelmintic resistance and *H. contortus*

Although there is limited published evidence for anthelmintic resistant *H. contortus* in the UK, resistance is widespread globally, with reports of resistance against benzimidazoles, levamisole, macrocyclic lactones (including moxidectin) and monepantel within Europe (reviewed in Rose et al, 2015), plus against abamectin/derquantel and closantel in Australia

([Rolfe et al, 1990](#); [Sales and Love, 2016](#)). Resistance is thought to develop rapidly as a result of high genetic diversity, polyandrous mating, the enormous biotic potential of individual worms, and anthelmintic treatments at times of limited pasture in refugia populations ([Besier, 2001](#); [Gilleard, 2013](#)). It is therefore vital that flock health plans should consider the risks of the introduction of *H. contortus* onto uninfected holdings, and all efforts should be made to control this parasite sustainably on endemic farms.

Sustainable control of haemonchosis

As noted above, anthelmintic resistance is as much a problem for the control of haemonchosis as it is for the control of all other GINs. The principles of sustainable control are also the same: diversify control away from the reliance on anthelmintics; reduce the use of anthelmintics as much as possible without compromising production, health or welfare; and ensure that the use of anthelmintics is done in such a way as to avoid the selection of resistant strains of nematodes.

Prevention of the introduction of *H. contortus* onto holdings where it is not already present will be achieved through suitable quarantine treatments (Sustainable Control of Parasites in Sheep (SCOPS) recommends both monepantel and derquantel/abamectin) on arrival, including withholding animals from pasture for 48 hours after treatment and then turning out onto dirty pasture.

Sustainable control strategies that apply equally to haemonchosis as to PGE include:

Grazing strategies to reduce exposure of sheep to larvae (e.g. cograzing with cattle, use of clean grazing for lambs)

Use of faecal worm egg counts (FWECS) to determine the need for treatment

The preservation of an in refugia population through either leaving a percentage of animals untreated at each treatment, or moving the timing of treatment relative to movement

Correct dosing technique, using correctly stored product, with well-maintained and calibrated equipment, at the correct dose rate for the weight of the animals being treated

Targeted selective treatment strategies based on lamb growth rates

The use of bioactive forages.

Readers are urged to consult the SCOPS website for more details (www.scops.org.uk).

FAMACHA® scoring and targeted selective treatment

The pallor as a result of haemonchosis-induced anaemia has been used as the basis of the FAMACHA® (Faffa Malan Chart) scoring system. Developed in South Africa ([Van Wyk and Bath, 2002](#)), the conjunctiva of the lower eyelid is compared to a chart and the depth of colour scored on a 5 point scale (1-red to 5-white). The conjunctiva must be used as other mucous membranes have been found to be less reliable indicators, being affected by pigmentation etc. The correlation between FAMACHA® score and PCV, and between

FAMACHA® score and faecal egg count (FEC), has been found to be reliable ([Kaplan et al, 2004](#)) ([Figure 5](#)).

Figure 5. Demonstration, in a goat kid, of the technique for examining the conjunctival surface of the lower eyelid, the basis of FAMACHA® scoring.

As there are other causes of anaemia a high FAMACHA® score alone cannot be used to diagnose haemonchosis, however, once haemonchosis has been confirmed, FAMACHA® scoring is an extremely useful tool for the development of sustainable control strategies. By identifying the worst affected animals clinically, it allows treatment of those animals that will benefit most from treatment, while leaving unaffected animals untreated. The majority of animals will require no or only one treatment in a season, with only a minority requiring more than one ([Van Wyk and Bath, 2002](#)). Scoring up to every 10 days is recommended in South Africa.

This is known as targeted selective treatment, and reduces selection pressure for resistance by preserving a large in refugia population in untreated animals, while simultaneously avoiding production loss by identifying and treating the affected animals. There is evidence that adopting this approach reduces anthelmintic usage, but with no impact on productivity ([Leask et al, 2013](#)). Some studies have found that FAMACHA® scoring over-predicts animals affected by haemonchosis ([Kaplan et al, 2004](#)), whereas others found that it lacks sensitivity and emphasised the importance of proper training of scorers and regular scoring ([Di Loria et al, 2009](#); [Reynecke et al, 2011](#)), but it still reduces anthelmintic usage relative to blanket treatment approaches.

The authors' current practice, in the UK, is to recommend FAMACHA® scoring of adult sheep on farms with haemonchosis problems every 4 weeks throughout the summer months

(May–October) with treatment of animals with scores 4 and 5 with a narrow-spectrum product to target *H. contortus* specifically e.g. closantel or nitroxynil. (Lamb treatments are determined by FWECS or growth rates, and a broad-spectrum anthelmintic is usually recommended, unless clinical haemonchosis seen in lambs, because of the likely contribution of other pathogenic trichostrongyles to lamb FWECS).

During outbreak situations, e.g. when deaths are reported, then treatment of animals with a score 3 is also recommended. Feedback from clients to one of the authors (Crilly, personal observation) is that in the first FAMACHA® scoring session (usually instigated due to the diagnosis of haemonchosis at post-mortem examination) up to 60% of sheep require treatment (i.e. are score 3, 4 or 5), but when FAMACHA® scoring is done routinely less than 20% of ewes require treatment at each scoring session (i.e. are scores 4 or 5).

As most of the research on the use of FAMACHA® scoring has been done elsewhere, assessment of the validity of FAMACHA® scoring under UK conditions and with UK sheep breeds would help place this potentially very useful tool in its proper context.

Barbervax

H. contortus is the target of the first nematode vaccine for sheep. The vaccine was developed at the Moredun Research Institute ([Fitzpatrick, 2013](#)) and is currently marketed in Australia (as Barbervax; Wormvax, DPIRD, Albany, Western Australia) and South Africa (as Wirevax; Wormvax, DPIRD, Albany, Western Australia). It uses native antigen from the gut of the worm. Due to this being a hidden antigen (not normally exposed to the sheep's immune system) there is no natural boosting of the immune response, so relatively frequent administration of booster doses is required. The recommended initial course is three 1 ml doses subcutaneously, followed by booster doses every 6 weeks during the risk period. In subsequent years a single injection before the risk period is required, followed by 6 weekly boosters (www.barbervax.com).

A sterile immunity does not result, infection is not completely prevented, but the worm burden is reduced and worm egg output is suppressed ([Teixeira et al, 2019](#)). Vaccinated lambs shed 80% fewer eggs than unvaccinated lambs in one study ([Bassetto et al, 2018](#)); ewe egg shedding was reduced by 87% and worm burden by 79%, with the peri-parturient rise also suppressed ([Teixeira et al, 2019](#)). This effect leads to lower levels of pasture contamination and so reduced challenge. As the efficacy is dependent on the immune response of the sheep, nutrition plays a key role. Good nutrition of sheep is required to get maximum benefit from the vaccine ([Bassetto et al, 2018](#)).

The vaccine is not currently available in the UK but may be imported under a special import certificate.

Breeding haemonchosis-resistant sheep

In tropical and sub-tropical areas where *H. contortus* is the major nematode pathogen of sheep, native breeds show greater resistance to infection, both in terms of reduced worm egg output, decreased impact of infection on PCV, and better maintenance of production

compared with 'improved/commercial' breeds ([Mugambi et al, 1997](#); [Aumont et al, 2003](#); [Amarante et al, 2004](#); [Alba-Hurtado et al, 2010](#)). This appears to be because of a greater and more rapidly activated immune response to the worms, with higher levels of mucosal mast cells, eosinophils and leukocytes in the abomasal mucosa of 'resistant' compared with 'susceptible' breed lambs; more rapid tissue repair may play a role in some breeds ([Bricarello et al, 2004](#); [Shakya et al, 2009](#); [Guo et al, 2016](#)).

It should be possible to breed for more resistant sheep, both through conventional methods such as crossing with more resistant breeds ([Amarante et al, 1999](#); [Li et al, 2001](#)), selection of stock for breeding on the basis of phenotypic measures such as FEC ([Woolaston, 1992](#)), weight gain in the face of challenge or PCV/FAMACHA® score ([Burke and Miller, 2008](#); [Riley and Van Wyk, 2009](#); [Pereira et al, 2016](#)) or, more recently, through the identification of genetic markers of resistance to haemonchosis and the use of these for the selection of breeding animals ([Estrada-Reyes et al, 2019](#); [Haehling et al, 2020](#)).

Copper oxide wire particles

Copper oxide wire particles (COWP) are often used as a method of copper supplementation, through administration orally, contained in a capsule. They have been found to reduce the worm burden of sheep infected with *H. contortus* ([Soli et al, 2010](#); [Schweizer et al, 2016](#)). The impact is greatest when the COWP are administered after infection is established ([Waller et al, 2004](#); [GalindoBarboza et al, 2011](#)). Other forms of copper supplementation do not have the same effect.

One of the concerns with use of COWP in control of haemonchosis is the risk of copper toxicity. Administration of even small amounts (1 g and 0.5 g) of COWP were found to still have an impact on FWEC ([Burke and Miller, 2006](#)); but caution is still advisable.

Forecasting of pasture larval contamination

As discussed above, a combined understanding of grazing history, local weather conditions and parasite epidemiology can be useful for judging how quickly free-living GIN larvae will both develop and persist on pasture, and therefore contribute to the general risk assessing of pasture on farms. However, there are many complex factors that affect pasture and faecal micro-climates, therefore it is not possible to make accurate, specific risk assessments without sophisticated modelling ([Wang et al, 2018](#)). Such modelling has been used to predict changes in *H. contortus* distribution across Europe ([Rose et al, 2016](#)), and has recently been expanded to include other parasitic species ([Vineer et al, 2020](#)). It would be of great value if this could be adapted to provide regional forecasting for *H. contortus*, as is already performed for *Nematodirus battus* (www.scops.org.uk/forecasts/nematodirus-forecast). In addition, there is enormous potential to combine this modelling with the increasing wealth of on-farm data (e.g. pasture mass measurements, individual animal bodyweights, GPS/drone tracking of livestock) with satellite monitoring of grasslands ([Ali et al, 2016](#)) to generate truly integrated approaches to sustainable parasitology, land management and food production.

How molecular techniques may aid in haemonchosis control

The recent application of deep amplicon sequencing to elucidate the species composition of gastrointestinal nematode populations (the 'nemabiome'), has enabled researchers to quantify the relative proportions of different parasite species at much higher throughput than using traditional parasitological techniques ([Avramenko et al, 2015](#)). These techniques were recently applied to ovine faecal samples from across Great Britain and revealed the relative abundance of *H. contortus* to be very low on the majority of farms, but to be greater than 50%, a small number of farms. This study also highlighted regional variation in *H. contortus* abundance, with a greater number of farms in England having high levels, than in Wales or Scotland ([Redman et al, 2019](#)).

Deep amplicon sequencing methods have also been applied to quantify single nucleotide polymorphisms (SNPs) associated with benzimidazole resistance in *H. contortus* and other nematode species ([Avramenko et al, 2019](#); [Sargison et al, 2019](#)). Significant further work has also narrowed down the regions of the *H. contortus* genome associated with resistance to macrocyclic lactones, levamisole and monepantel ([dos Santos et al, 2019](#); [Doyle et al, 2019](#); [Niciura et al, 2019](#)). These technologies offer great promise for further research into the genetics of anthelmintic resistance and field studies to monitor its emergence and spread, as has already been performed for benzimidazole resistance in *Haemonchus* spp. in Pakistan ([Ali et al, 2019](#)).

Further work has also been performed to develop loop-mediated isothermal amplification (LAMP) assays that are able to identify the presence of *Haemonchus* spp. eggs ([Melville et al, 2014](#)) and the presence of benzimidazole resistance SNPs in *H. contortus* ([Tuersong et al, 2020](#)). These techniques are particularly promising for practitioners as they are performed at ambient temperature with minimal equipment, and may be transferred to lateral flow devices for point of care testing, as has been described for the diagnosis of resistance mutations in malaria ([Yongkiettrakul et al, 2017](#)).

Conclusion

Haemonchosis has become a more important problem in the UK over recent years and given likely climatic changes and the spread of anthelmintic resistance this trend is likely to continue. As a result of the differences in the epidemiology of *H. contortus* and in the pathobiology of haemonchosis compared with PGE, it requires a separate approach to other pathogenic GINs of sheep. Fortunately, there are some unique tools available for the control of haemonchosis, and given its worldwide importance as a parasite of small ruminants, further research into haemonchosis is likely to be relatively extensive.

KEY POINTS

Haemonchus contortus is a globally important trichostrongyle nematode of sheep and goats, and climate change may lead to it becoming a more important parasite in the UK.

The lifecycle of *H. contortus* is similar to other gastrointestinal nematodes (GINs), with the exception of overwintering hypobiosis of L4 larvae; it is the high fecundity of the female and

the different temperature preferences of this species that produces epidemiological differences.

Disease is due to blood loss caused by the haematophagy of this parasite; the disease course ranges from hyperacute to chronic.

Mechanisms for the treatment and control of parasitic gastroenteritis (PGE) will also be effective in controlling haemonchosis, but the haematophagy means that other treatment options are also possible, e.g. closantel and nitroxynil.

Important developments in *H. contortus* control include the FAMACHA scoring system and the Barbevax vaccine; further advances in forecasting and molecular techniques for the identification of species and resistant strains of nematodes may further aid in *H. contortus* control.

- Achi YL, Zinsstag J, Yao K, Yeo N, Dorchie P, Jacquet P. Host specificity of *Haemonchus* spp. for domestic ruminants in the savanna in northern Ivory Coast. **Vet Parasitol.** 2003;116(2):151–158. doi:[https://doi.org/10.1016/S0304-4017\(03\)00258-9](https://doi.org/10.1016/S0304-4017(03)00258-9)
- Alba-Hurtado F, Romero-Escobedo E, Muñoz-Guzmán MA, Torres-Hernández G, Becerril-Pérez CM. Comparison of parasitological and productive traits of Criollo lambs native to the central Mexican Plateau and Suffolk lambs experimentally infected with *Haemonchus contortus*. **Vet Parasitol.** 2010;172(3-4):277–282. doi:<https://doi.org/10.1016/j.vetpar.2010.05.001>
- Ali I, Cawkwell F, Dwyer E, Barrett B, Green S. Satellite remote sensing of grasslands: from observation to management. **J Plant Ecol.** 2016;9(6):649–671. doi:<https://doi.org/10.1093/jpe/rtw005>
- Ali Q, Rashid I, Shabbir MZ, Aziz-Ul-Rahman, Shahzad K, Ashraf K, Sargison ND, Chaudhry U. Emergence and the spread of the F200Y benzimidazole resistance mutation in *Haemonchus contortus* and *Haemonchus placei* from buffalo and cattle. **Vet Parasitol.** 2019;265:48–54. doi:<https://doi.org/10.1016/j.vetpar.2018.12.001>
- Amarante AFT, Craig TM, Ramsey WS, El-Sayed NM, Desouki AY, Bazer FW. Comparison of naturally acquired parasite burdens among Florida Native, Rambouillet and crossbreed ewes. **Vet Parasitol.** 1999;85(1):61–69. doi:[https://doi.org/10.1016/S0304-4017\(99\)00103-X](https://doi.org/10.1016/S0304-4017(99)00103-X)
- Amarante AFT, Bricarello PA, Rocha RA, Gennari SM. Resistance of Santa Ines, Suffolk and Ile de France sheep to naturally acquired gastrointestinal nematode infections. **Vet Parasitol.** 2004;120(1-2):91–106. doi:<https://doi.org/10.1016/j.vetpar.2003.12.004>
- Aumont G, Gruner L, Hostache G. Comparison of the resistance to sympatric and allopatric isolates of *Haemonchus contortus* of Black Belly sheep in Guadeloupe (FWI) and of INRA 401 sheep in France. **Vet Parasitol.** 2003;116(2):139–150. doi:[https://doi.org/10.1016/S0304-4017\(03\)00259-0](https://doi.org/10.1016/S0304-4017(03)00259-0)
- Avramenko RW, Redman EM, Lewis R, Yazwinski TA, Wasmuth JD, Gilleard JS. Exploring the gastrointestinal “nemabiome”: deep amplicon sequencing to quantify the species composition of parasitic nematode communities. **PLoS One.** 2015;10(12):e0143559. doi: <https://doi.org/10.1371/journal.pone.0143559>

-
- Avramenko RW, Redman EM, Melville L et al.. Deep amplicon sequencing as a powerful new tool to screen for sequence polymorphisms associated with anthelmintic resistance in parasitic nematode populations. **Int J Parasitol.** 2019;49(1):13–26. doi:<https://doi.org/10.1016/j.ijpara.2018.10.005>
 - Barger IA, Benyon PR, Southcott WH. Simulation of pasture larval populations of *Haemonchus contortus*. **Proc Aust Soc Anim Prod.** 1972;9:38e42
 - Barrere V, Falzon LC, Shakya KP, Menzies PI, Peregrine AS, Prichard RK. Assessment of benzimidazole resistance in *Haemonchus contortus* in sheep flocks in Ontario, Canada: comparison of detection methods for drug resistance. **Vet Parasitol.** 2013;198(1-2):159–165. doi:<https://doi.org/10.1016/j.vetpar.2013.07.040>
 - Bassetto CC, Almeida FA, Newlands GFJ, Smith WD, Castilhos AM, Fernandes S, Siqueira ER, Amarante AFT. Trials with the *Haemonchus* vaccine, Barbervax®, in ewes and lambs in a tropical environment: nutrient supplementation improves protection in periparturient ewes. **Vet Parasitol.** 2018;264:52–57. doi:<https://doi.org/10.1016/j.vetpar.2018.11.006>
 - Besier B. Re-thinking the summer drenching program. **Journal of the Department of Agriculture, Western Australia, Series 4.** 2001;42(1):6–9.
 - Bricarello PA, Gennari SM, Oliveira-Sequeira TCG, Vaz CMSL, Gonçalves de Gonçalves I, Echevarria FAM. Worm burden and immunological responses in Corriedale and Crioula Lanada sheep following natural infection with *Haemonchus contortus*. **Small Rumin Res.** 2004;51(1):75–83. doi:[https://doi.org/10.1016/S0921-4488\(03\)00188-3](https://doi.org/10.1016/S0921-4488(03)00188-3)
 - Burgess CGS, Bartley Y, Redman E, Skuce PJ, Nath M, Whitelaw F, Tait A, Gilleard JS, Jackson F. A survey of the trichostrongylid nematode species present on UK sheep farms and associated anthelmintic control practices. **Vet Parasitol.** 2012;189(2-4):299–307. doi:<https://doi.org/10.1016/j.vetpar.2012.04.009>
 - Burke JM, Miller JE. Evaluation of multiple low doses of copper oxide wire particles compared with levamisole for control of *Haemonchus contortus* in lambs. **Vet Parasitol.** 2006;139(1-3):145–149. doi:<https://doi.org/10.1016/j.vetpar.2006.02.030>
 - Burke JM, Miller JE. Use of FAMACHA system to evaluate gastrointestinal nematode resistance/resilience in offspring of stud rams. **Vet Parasitol.** 2008;153(1-2):85–92. doi:<https://doi.org/10.1016/j.vetpar.2008.01.029>
 - Christie M, Jackson F. Specific identification of strongyle eggs in small samples of sheep faeces. **Res Vet Sci.** 1982;32(1):113–117. doi:[https://doi.org/10.1016/S0034-5288\(18\)32448-2](https://doi.org/10.1016/S0034-5288(18)32448-2)
 - Clark CH, Kiesel GK, Goby CH. Measurements of blood loss caused by *Haemonchus contortus* infection in sheep. **Am J Vet Res.** 1962;23(96):977–980
 - Colvin AF, Walkden-Brown SW, Knox MR, Scott JM. Intensive rotational grazing assists control of gastrointestinal nematodosis of sheep in a cool temperate environment with summer-dominant rainfall. **Vet Parasitol.** 2008;153(1-2):108–120. doi:<https://doi.org/10.1016/j.vetpar.2008.01.014>
 - Crofton HD. Ecology and biological plasticity of sheep nematodes. I. The effect of temperature on the hatching of eggs of some nematode parasites of sheep. **Cornell Vet.** 1965;55:242–250

-
- Di Loria A, Veneziano V, Piantedosi D et al.. Evaluation of the FAMACHA system for detecting the severity of anaemia in sheep from southern Italy. **Vet Parasitol.** 2009;161(1-2):53–59. doi:<https://doi.org/10.1016/j.vetpar.2008.12.002>
 - Dos Santos JML, Vasconcelos JF, Frota GA et al.. Quantitative molecular diagnosis of levamisole resistance in populations of *Haemonchus contortus*. **Exp Parasitol.** 2019;205:107734. doi: <https://doi.org/10.1016/j.exppara.2019.107734>
 - Doyle SR, Illingworth CJR, Laing R et al.. Population genomic and evolutionary modelling analyses reveal a single major QTL for ivermectin drug resistance in the pathogenic nematode, *Haemonchus contortus*. **BMC Genomics.** 2019 Dec;20(1):218. doi: <https://doi.org/10.1186/s12864-019-5592-6>
 - Estrada-Reyes ZM, Tsukahara Y, Amadeu RR et al.. Signatures of selection for resistance to *Haemonchus contortus* in sheep and goats. **BMC Genomics.** 2019;20(1):735. doi: <https://doi.org/10.1186/s12864-019-6150-y>
 - Fitzpatrick J. Barbervax, a potential commercial vaccine for *Haemonchus contortus*: background, mechanism of action and efficacy studies with housed lambs. In Proceedings WAAVP congress (pp. 25-29): 2013
 - Galindo-Barboza AJ, Torres-Acosta JFJ, Cámara-Sarmiento R et al.. Persistence of the efficacy of copper oxide wire particles against *Haemonchus contortus* in sheep. **Vet Parasitol.** 2011;176(2-3):201–207. doi:<https://doi.org/10.1016/j.vetpar.2010.11.012>
 - Getachew T, Dorchies P, Jacquet P. Trends and challenges in the effective and sustainable control of *Haemonchus contortus* infection in sheep. **Review. [Review]. Parasite.** 2007;14(1):3–14. doi:<https://doi.org/10.1051/parasite/2007141003>
 - Gilleard JS. *Haemonchus contortus* as a paradigm and model to study anthelmintic drug resistance. **Parasitology.** 2013;140(12):1506–1522. doi:<https://doi.org/10.1017/S0031182013001145>
 - Guo Z, González JF, Hernandez JN et al.. Possible mechanisms of host resistance to *Haemonchus contortus* infection in sheep breeds native to the Canary Islands. **Sci Rep.** 2016;6(1):26200. doi: <https://doi.org/10.1038/srep26200>
 - Haehling MB, Cruvinel GG, Toscano JHB et al.. Four single nucleotide polymorphisms (SNPs) are associated with resistance and resilience to *Haemonchus contortus* in Brazilian Morada Nova sheep. **Vet Parasitol.** 2020;279:109053. doi: <https://doi.org/10.1016/j.vetpar.2020.109053>
 - Hall CA, Kelly JD, Whitlock HV, Ritchie L. Prolonged anthelmintic effect of closantel and disophenol against a thiabendazole selected resistant strain of *Haemonchus contortus* in sheep. **Res Vet Sci.** 1981;31(1):104–106. doi:[https://doi.org/10.1016/S0034-5288\(18\)32531-1](https://doi.org/10.1016/S0034-5288(18)32531-1)
 - Hogg R, Whitaker K, Collins R et al.. Haemonchosis in large ruminants in the UK. **Vet Rec.** 2010;166(12):373–374. doi:<https://doi.org/10.1136/vr.c1509>
 - Jabbar A, Cotter J, Lyon J, Koehler AV, Gasser RB, Besier B. Unexpected occurrence of *Haemonchus placei* in cattle in southern Western Australia. **Infect Genet Evol.** 2014;21:252–258. doi:<https://doi.org/10.1016/j.meegid.2013.10.025>
 - Jackson F, Coop RL. Gastrointestinal helminthosis. In: Aitken ID, ed. **Diseases of sheep**, fourth edition. Blackwell Publishing. 2007: pp. 185–195

-
- Jacquet P, Cabaret J, Thiam E, Cheikh D. Host range and the maintenance of *Haemonchus* spp. in an adverse arid climate. **Int J Parasitol.** 1998;28(2):253–261. doi:[https://doi.org/10.1016/S0020-7519\(97\)00185-9](https://doi.org/10.1016/S0020-7519(97)00185-9)
 - Jurasek ME, Bishop-Stewart JK, Storey BE, Kaplan RM, Kent ML. Modification and further evaluation of a fluorescein-labeled peanut agglutinin test for identification of *Haemonchus contortus* eggs. **Vet Parasitol.** 2010;169(1-2):209–213. doi:<https://doi.org/10.1016/j.vetpar.2009.12.003>
 - Kaplan RM, Burke JM, Terrill TH et al.. Validation of the FAMACHA® eye color chart for detecting clinical anemia in sheep and goats on farms in the southern United States. **Vet Parasitol.** 2004;123(1-2):105–120. doi:<https://doi.org/10.1016/j.vetpar.2004.06.005>
 - Laing R, Kikuchi T, Martinelli A et al.. The genome and transcriptome of *Haemonchus contortus*, a key model parasite for drug and vaccine discovery. **Genome Biol.** 2013;14(8):R88. doi: <https://doi.org/10.1186/gb-2013-14-8-r88>
 - Leask R, van Wyk JA, Thompson PN, Bath GF. The effect of application of the FAMACHA® system on selected production parameters in sheep. **Small Rumin Res.** 2013 Feb;110(1):1–8. doi:<https://doi.org/10.1016/j.smallrumres.2012.07.026>
 - Li Y, Miller JE, Franke DE. Epidemiological observations and heterosis analysis of gastrointestinal nematode parasitism in Suffolk, Gulf Coast Native, and crossbred lambs. **Vet Parasitol.** 2001;98(4):273–283. doi:[https://doi.org/10.1016/S0304-4017\(01\)00440-X](https://doi.org/10.1016/S0304-4017(01)00440-X)
 - Lindqvist Å, Ljungström B-L, Nilsson O, Waller PJ. The dynamics, prevalence and impact of nematode infections in organically raised sheep in Sweden. **Acta Vet Scand.** 2001;42(3):377–389. doi:<https://doi.org/10.1186/1751-0147-42-377>
 - Melville L, Kenyon F, Javed S, McElarney I, Demeler J, Skuce P. Development of a loop-mediated isothermal amplification (LAMP) assay for the sensitive detection of *Haemonchus contortus* eggs in ovine faecal samples. **Vet Parasitol.** 2014;206(3-4):308–312. doi:<https://doi.org/10.1016/j.vetpar.2014.10.022>
 - Mugambi JM, Bain RK, Wanyangu SW et al.. Resistance of four sheep breeds to natural and subsequent artificial *Haemonchus contortus* infection. **Vet Parasitol.** 1997;69(3-4):265–273. doi:[https://doi.org/10.1016/S0304-4017\(96\)01128-4](https://doi.org/10.1016/S0304-4017(96)01128-4)
 - Niciura SCM, Tizioto PC, Moraes CV et al.. Extreme-QTL mapping of monepantel resistance in *Haemonchus contortus*. **Parasit Vectors.** 2019;12(1):403. doi: <https://doi.org/10.1186/s13071-019-3663-9>
 - O'Connor LJ, Walkden-Brown SW, Kahn LP. Ecology of the free-living stages of major trichostrongylid parasites of sheep. **Vet Parasitol.** 2006;142(1-2):1–15. doi:<https://doi.org/10.1016/j.vetpar.2006.08.035>
 - Pereira JFS, Mendes JB, De Jong G et al.. FAMACHA® scores history of sheep characterized as resistant/resilient or susceptible to *H. contortus* in artificial infection challenge. **Vet Parasitol.** 2016;218:102–105. doi:<https://doi.org/10.1016/j.vetpar.2016.01.011>
 - Redman E, Queiroz C, Bartley DJ, Levy M, Avramenko RW, Gilleard JS. Validation of ITS-2 rDNA nemabiome sequencing for ovine gastrointestinal nematodes and its application to a large scale survey of UK sheep farms. **Vet Parasitol.** 2019;275:108933. doi: <https://doi.org/10.1016/j.vetpar.2019.108933>

-
- Reynecke DP, van Wyk JA, Gummow B, Dorny P, Boomker J. Validation of the FAMACHA® eye colour chart using sensitivity/specificity analysis on two South African sheep farms. **Vet Parasitol.** 2011;177(3-4):203-211. doi: <https://doi.org/10.1016/j.vetpar.2009.08.023>
 - Riley DG, Van Wyk JA. Genetic parameters for FAMACHA® score and related traits for host resistance/resilience and production at differing severities of worm challenge in a Merino flock in South Africa. **Vet Parasitol.** 2009;164(1):44–52. doi: <https://doi.org/10.1016/j.vetpar.2009.04.014>
 - Rodríguez AV, Goldberg V, Viotti H, Ciappesoni G. Early detection of *Haemonchus contortus* infection in sheep using three different faecal occult blood tests. **Open Vet J.** 2015;5(2):90–97
 - Rolfe PF, Boray JC, Fitzgibbon C, Parsons G, Kemsley P, Sangster N. Closantel resistance in *Haemonchus contortus* from sheep. **Aust Vet J.** 1990;67(1):29–3
 - Rose H, Rinaldi L, Bosco A et al.. Widespread anthelmintic resistance in European farmed ruminants: a systematic review. **Vet Rec.**
 - Rose H, Caminade C, Bolajoko MB et al.. Climate-driven changes to the spatiotemporal distribution of the parasitic nematode, *Haemonchus contortus*, in sheep in Europe. **Glob Change Biol.** 2016;22(3):1271–1285. doi: <https://doi.org/10.1111/gcb.13132>
 - Rowe JB, Nolan JV, de Chaneet G, Teleni E, Holmes PH. The effect of haemonchosis and blood loss into the abomasum on digestion in sheep. **Br J Nutr.** 1988;59(1):125–139. doi: <https://doi.org/10.1079/BJN19880016>
 - Saccareau M, Sallé G, Robert-Granié C et al.. Meta-analysis of the parasitic phase traits of *Haemonchus contortus* infection in sheep. **Parasit Vectors.** 2017;10(1):201. doi: <https://doi.org/10.1186/s13071-017-2131-7>
 - Sakwa DP, Walkden-Brown SW, Dobson RJ, Kahn LP, Lea JM. The influence of pasture microclimate on survival of *Haemonchus contortus* infective larvae in a cool temperate climate of Australia. In The 45th Annual Scientific Meeting of the Australian Society for Parasitology, Darwin. 2003: p51
 - Sales N, Love S. Resistance of *Haemonchus* sp. to monepantel and reduced efficacy of a derquantel / abamectin combination confirmed in sheep in NSW, Australia. **Vet Parasitol.** 2016;228:193–196. doi: <https://doi.org/10.1016/j.vetpar.2016.08.016>
 - Sargison ND, MacLeay M, Morrison AA, Bartley DJ, Evans M, Chaudhry U. Development of amplicon sequencing for the analysis of benzimidazole resistance allele frequencies in field populations of gastrointestinal nematodes. **Int J Parasitol Drugs Drug Resist.** 2019;10:92–100. doi: <https://doi.org/10.1016/j.ijpddr.2019.08.003>
 - Sargison ND, Wilson DJ, Bartley DJ, Penny CD, Jackson F. Haemonchosis and teladorsagiosis in a Scottish sheep flock putatively associated with the overwintering of hypobiotic fourth stage larvae. **Vet Parasitol.** 2007;147(3-4):326–331. doi: <https://doi.org/10.1016/j.vetpar.2007.04.011>
 - Schweizer NM, Foster DM, Knox WB, Sylvester HJ, Anderson KL. Single vs. double dose of copper oxide wire particles (COWP) for treatment of anthelmintic resistant *Haemonchus contortus* in weanling lambs. **Vet Parasitol.** 2016;229:68–72. doi: <https://doi.org/10.1016/j.vetpar.2016.09.011>
 - Shakya KP, Miller JE, Horohov DW. A Th2 type of immune response is associated with increased resistance to *Haemonchus contortus* in naturally infected Gulf Coast Native lambs. **Vet Parasitol.** 2009;163(1-2):57–66. doi: <https://doi.org/10.1016/j.vetpar.2009.03.052>

-
- Smith G. The population biology of the free-living phase of *Haemonchus contortus*. **Parasitology**. 1990;101(2):309–316. doi:<https://doi.org/10.1017/S003118200006337X>
 - Soli F, Terrill TH, Shaik SA, Getz WR, Miller JE, Vanguru M, Burke JM. Efficacy of copper oxide wire particles against gastrointestinal nematodes in sheep and goats. **Vet Parasitol**. 2010 Feb;168(1-2):93–96. doi:<https://doi.org/10.1016/j.vetpar.2009.10.004>
 - Stear MJ, Bishop SC. The curvilinear relationship between worm length and fecundity of *Teladorsagia circumcincta*. **International journal for parasitology**. 1999;29(5):777-780. [https://doi.org/10.1016/S0020-7519\(99\)00019-3](https://doi.org/10.1016/S0020-7519(99)00019-3)
 - Stein PA, Rolfe PF, Hosking BC. The control of inhibited fourth-stage larvae of *Haemonchus contortus* and *Teladorsagia* spp. in sheep in Australia with monepantel. **Vet Parasitol**. 2010;169(3-4):358–361. doi:<https://doi.org/10.1016/j.vetpar.2010.01.012>
 - Suchitra S, Joshi P. Characterization of *Haemonchus contortus* calreticulin suggests its role in feeding and immune evasion by the parasite. **Biochimica et Biophysica Acta (BBA) - General Subjects**. 2005;1722(3):293–303. doi:<https://doi.org/10.1016/j.bbagen.2004.12.020>
 - Taylor MA, Coop RL, Wall RL. 2015. Veterinary Parasitology. Fourth Edition. Wiley: Chichester. ISBN:9780470671627
 - Teixeira M, Matos AFIM, Albuquerque FHMA, Bassetto CC, Smith WD, Monteiro JP. Strategic vaccination of hair sheep against *Haemonchus contortus*. **Parasitol Res**. 2019;118(8):2383–2388. doi:<https://doi.org/10.1007/s00436-019-06367-x>
 - Tiersong W, He L, Zhu T et al.. Development and evaluation of a loop-mediated isothermal amplification (LAMP) assay for the detection of the E198A SNP in the isotype-1 β -tubulin gene of *Haemonchus contortus* populations in China. **Vet Parasitol**. 2020;278:109040. doi: <https://doi.org/10.1016/j.vetpar.2020.109040>
 - Van Wyk JA, Bath GF. The FAMACHA system for managing haemonchosis in sheep and goats by clinically identifying individual animals for treatment. **Vet Res**. 2002;33(5):509–529. doi:<https://doi.org/10.1051/vetres:2002036>
 - van Wyk JA, Mayhew E. Morphological identification of parasitic nematode infective larvae of small ruminants and cattle: a practical lab guide. **Onderstepoort J Vet Res**. 2013;80(1):539. doi: <https://doi.org/10.4102/ojvr.v80i1.539>
 - Rose Vineer H, Verschave SH, Claerebout E et al.. GLOWORM-PARA: a flexible framework to simulate the population dynamics of the parasitic phase of gastrointestinal nematodes infecting grazing livestock. **Int J Parasitol**. 2020;50(2):133–144. doi: <https://doi.org/10.1016/j.ijpara.2019.11.005>
 - Waller PJ. Sustainable helminth control of ruminants in developing countries. **Vet Parasitol**. 1997;71(2-3):195–207. doi:[https://doi.org/10.1016/S0304-4017\(97\)00032-0](https://doi.org/10.1016/S0304-4017(97)00032-0)
 - Peter JW, Chandrawathani P. *Haemonchus contortus*: parasite problem No. 1 from tropics - Polar Circle. Problems and prospects for control based on epidemiology. **Trop Biomed**. 2005;22(2):131–137
 - Waller PJ, Rudby-Martin L, Ljungström BL, Rydzik A. The epidemiology of abomasal nematodes of sheep in Sweden, with particular reference to overwinter survival strategies. **Vet Parasitol**. 2004;122(3):207–220. doi:<https://doi.org/10.1016/j.vetpar.2004.04.007>

-
- Waller PJ, Bernes G, Rudby-Martin L, Ljungström B-L, Rydzik A. Evaluation of copper supplementation to control *Haemonchus contortus* infections of sheep in Sweden. **Acta Vet Scand.** 2004;45(3):149–160. doi:<https://doi.org/10.1186/1751-0147-45-149>
 - Wang T, Van Wyk JA, Morrison A, Morgan ER. 2014. Moisture requirements for the migration of *Haemonchus contortus* third stage larvae out of faeces. **Veterinary Parasitology.** 2014;204(3-4), 258-264. <https://doi.org/10.1016/j.vetpar.2014.05.014>
 - Wang T, Vineer HR, Morrison A et al.. Microclimate has a greater influence than macroclimate on the availability of infective *Haemonchus contortus* larvae on herbage in a warmed temperate environment. **Agric Ecosyst Environ.** 2018;265:31–36. doi:<https://doi.org/10.1016/j.agee.2018.05.029>
 - Woolaston RR. Selection of Merino sheep for increased and decreased resistance to *Haemonchus contortus*: peri-parturient effects on faecal egg counts. **Int J Parasitol.** 1992;22(7):947–953. doi:[https://doi.org/10.1016/0020-7519\(92\)90052-M](https://doi.org/10.1016/0020-7519(92)90052-M)
 - Yongkiettrakul S, Kampeera J, Chareanchim W et al.. Simple detection of single nucleotide polymorphism in *Plasmodium falciparum* by SNP-LAMP assay combined with lateral flow dipstick. **Parasitol Int.** 2017;66(1):964–971. doi:<https://doi.org/10.1016/j.parint.2016.10.024>

Website References

- www.barbervax.com. Accessed on 20th April 2020
-
- www.scops.org.uk. Accessed on 12th May 2020
 - www.scops.org.uk/forecasts/nematodirus-forecast Accessed on 19th May 2020