Vol. 13(1), pp. 58-70, January-June 2021
DOI: 10.5897/JPVB2020.0405
Article Number: B2E34D166758
ISSN: 2141-2510

http://www.academicjournals.org/JPVB

Journal of Parasitology and Vector Biology

Full Length Research Paper

Haemonchosis: A review on dreaded strongylosis that affects the zootechnical performance of sheep

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Received 21 November, 2020; Accepted 29 March, 2021

Haemonchosis is a parasitosis that affects the abomasum of small ruminants, especially sheep. It is a disease that affects temperate as well as tropical and subtropical regions and can infest animals of any age, resulting in a significant loss of income to farmers. *Haemonchus contortus* is the parasite responsible for haemonchosis in small ruminants. It is haematophagous and causes serious diseases that decimate the herds of farmers. In view of the consequences of this pathology, an in-depth study has been carried out to gather available information on sheep haemonchosis in order to recommend efficient and sustainable alternative control methods for adoption. The study was carried out using online databases, Semantic scholar to search for articles in order to synthesize existing knowledge, identify gaps in knowledge about this disease and propose perspectives for future research. All articles found were critically read and analysed for inclusion in this literature review article. The review synthesized and analyzed all articles found and included in the study using keywords entered in the online databases. Shortcomings were noted and proposals for non-chemical and sustainable control of sheep haemonchosis were suggested and discussed in view of the damage created by the chemical anthelmintics commonly used by farmers.

Key words: Gastrointestinal strongyle, *Haemonchus contortus*, trichostrongylidae, cosmopolitan, sheep, anthelmintic, zootechnical performance.

INTRODUCTION

Small ruminants are domestic animals of great economic and social importance world and help rural populations manage food shortages. Their health is an issue for the world in general and for Africa in particular because they

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are a renewable source of income (FAOSTAT, 2013) and allow some farmers to increase their economic capital and others to manage themselves to escape impoverishment. Among the many parasitoses that affect the development and zootechnical performance of sheep, haemonchosis is the most insidious and dangerous (Fabiyi, 1987; Achi et al., 2003) given the parasite's spoliating action and its ability to trigger the production of anticoagulant in the infested animal causing small haemorrhages at the anchorage point while it reaches another site of attachment on the animal (Chermette, 1982). Sheep, although robust, trypanotolerant and known to be resistant to internal parasitism (Soudré et al., 2018), are the most affected by this pathology due to their mode of rearing (grass-fed) by exploiting pastures infested with parasite free-forms during favourable climatic periods (Aumont et al*.,* 1991). It is a mainly tropical and subtropical disease that can infest sheep of all ages and result in significant loss of income to farmers (Emery et al*.,* 2016). The parasite involved is *Haemonchus contortus* (Rudolphi, 1803) Cobb, 1898, parasite of the abomasum of small ruminants including sheep (Hoberg and Zarlenga, 2016). It is a widespread parasite in many countries of the world in Africa and Europe (Hoste et al., 2015) with predominance in tropical countries, warm and humid regions (Aumont et al., 1997). As an haematophagous parasite (Fentahun and Luke, 2012; Almeida et al*.,* 2018), its prevalence in the West African sub-region is estimated as 82.6% in sheep (Hounzangbé-Adoté, 2005) and 92.5% in Benin. It has been a serious threat to the development of sheep production for years (Salifou, 1996). Its pathogenicity is due to this mode of haematophageal nutrition which leads to a severe anaemia syndrome (to differentiate from fasciolosis, anaplasmosis and/or babesiosis), to a loss of milk production (liev et al*.,* 2017; Swarnkar and Singh, 2018). The parasitic infestation causes a disruption of the digestive functions leading to a reduction of the degradation of dietary proteins, changes in metabolism and malabsorption of nutrients that can promote the secondary infections by altering the bacterial flora (Sylvestre and Cabaret, 2001). The infested animal also exhibits signs of diarrhea, impaired reproductive capacity, anorexia, weight loss and degradation of wool quality (Emery et al*.,* 2016). Studies conducted by Hounzangbé-Adoté (2001) and Doeschl-Wilson et al. (2011) on the socioeconomic and health impact of parasitosis in small ruminants have raised haemonchosis as a pathology to be feared in sheep. It is therefore necessary to gather information on the clinical picture of sheep haemonchosis in a single document and to propose alternative control solutions.

METHODOLOGY

The internet platform called Semantic scholar was used in this study to ascertain the state of progress of research on sheep haemorrhagic disease. It lists all forms of publication dealing with the research topic and is associated with the search engines PubMed, BMJ Journal, Microsoft Academic and Springer Nature. This internet platform is designed to highlight the most important and influential articles and to identify links between them. It also provides data on the number of publications per author, per year and per type of publication as well as the specific field of research. In this study, the available data on the number of publications per year, the number of publications per author and per type of publication were exported to Microsoft Office Excel 2016 for statistical processing and graphing using GraphPad Prism 8.4.3 software. The graphs make it possible to assess the progress of research work over time on haemonchosis in sheep and the types of publications that go with it. After analysis of the data available on Semantic scholar, we note that the first publication on "Haemonchosis" was recorded in 1931, published by Fourie (1931) and entitled "The haematology and pathology of haemonchosis in sheep". There is a wide range of data available on the platform (Figure 1) with more results and keywords in English than in French (35500 results found for "ovine Haemonchosis" against only 625 for "Haemonchose chez les ovins"). The search with the keywords in French gives fewer results. This is most noticeable with the keywords "Haemonchosis" and "Haemonchose" where the results obtained are 567 and 10 publications respectively. This led us to make much more use of documents written in English. The following related search terms: pathology, causative agent, distribution, pathogenicity, pathophysiology, symptom, zootechnical performance and natural or synthetic anthelmintics were associated with the main keywords "ovine* haemonchosis*" or "sheep* haemonchosis*" and *H. contortus*. We then proceeded to filter and delete articles that did not fit the objectives, those dealing with both "Haemonchosis in sheep and goats" as well as articles with repeated data during the search. Publications other than journals, books or articles were also removed. All articles searched for and those with experimental, peer-reviewed results available in search engines at the time of the search have been analysed and critically reviewed. Upstream, the selection of articles was guided by reading the titles and abstracts of the different publications.

RESULTS

For this review, a total of 567 publications were obtained on the pathology "Haemonchosis", of which 275 (48.50%) appeared in the last ten years (2011-2021) and 165 (29.10%) in the last five years (2016-2021). The publication peak was recorded in 2017 with 42 publications either 7.41% of total publications (Figure 2) and decreased in the following years. This shows how topical this pathology has been over the last five years. However, when specifying the pathology, 490 were not relevant for haemonchosis in sheep and a total of 64 publications were retained exclusively for ovine haemonchosis using the specific keywords "ovine* haemonchosis*" or "sheep* haemonchosis*".

SHEEP HAEMONCHOSIS

Haemonchosis is a helminthosis caused by *H. contortus*. It is one of the gastrointestinal strongyle of ruminants belonging to the family Trichostrongylidae. Strong red stomach strongylid, *H. contortus* is a large parasite, easily

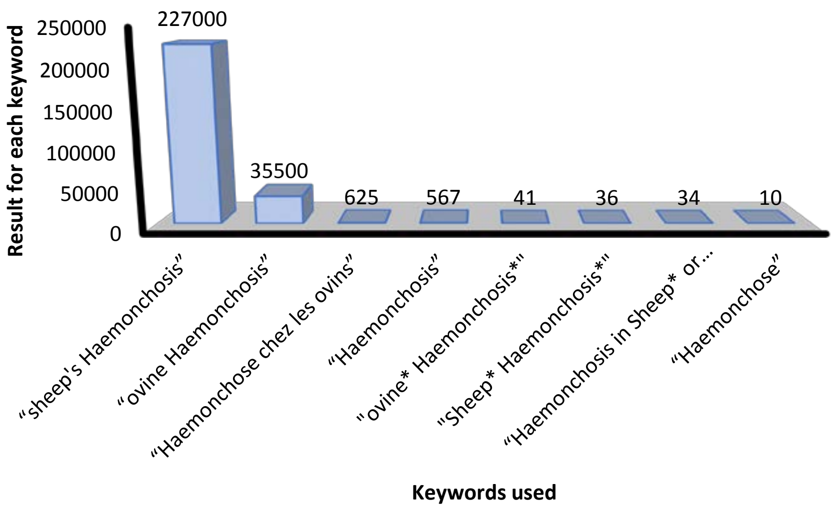

Figure 1. Search results on the Semantic scholar platform with keywords in French and English.

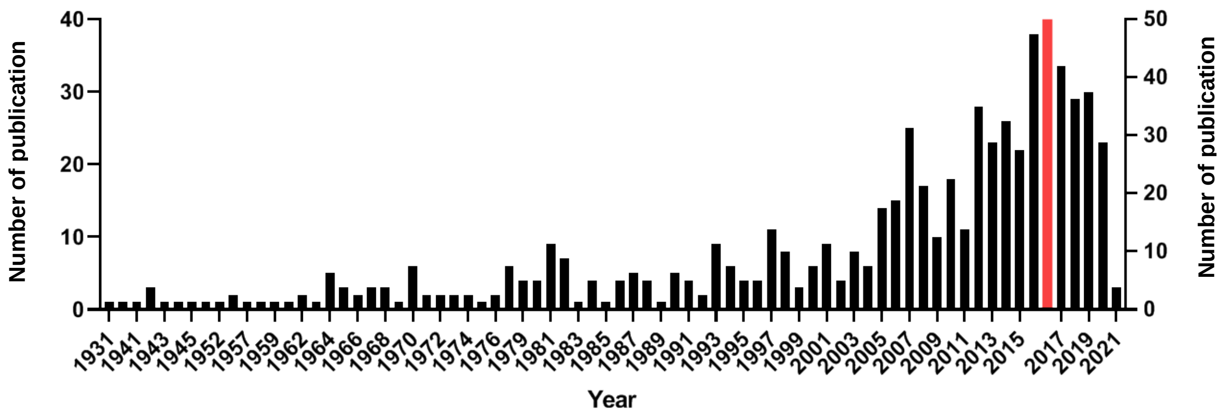

Figure 2. Number of publications per year on haemonchose over the period 1931 to 2021

visible to the naked eye. The female, in its fresh state, is recognizable to the naked eye thanks to its red digestive tract surrounded by two white spirals (genital cords). Under a microscope, the supravulval tongue can be observed. At the level of the mouth capsule, there is a dorsal tooth which allows the parasite to puncture the host tissues. The male is only recognizable under the microscope and has a copulatory bursa with harpoon-shaped spicules (Figure 3).

The parasite: Systematics, morphology and evolutionary cycle

Systematics (Durette-Desset and Chabaud, 1993)

H. contortus, parasite responsible for sheep haemonchosis belongs to:

Phylum: Nemathelminths
Class: Nematodes
Sub-Class: Secernentea
Order: Strongylida
Sub-order: Trichostrongylina
Super-Family: Trichostrongyloidae
Family: Trichostrongylidae
Sub-Family: Haemonchinae
Genus: *Haemonchus*

In domestic ruminants, the genus *Haemonchus* includes four recognized species: *H. contortus* (Rudolphi, 1803) found in sheep and goats; *Haemonchus similis* (Travassos, 1914), *Haemonchus placei* (Place, 1893) found in cattle and *Haemonchus longistipes* (Raillet and Henry, 1909) for camels. Eight other species of *Haemonchus* exist, namely: *H. Bedford*, *H. vegliai*, *H. mitchelli*, *H. lawrencei*, *H. dinniki*, *H. krugeri*, *H. horaki* and

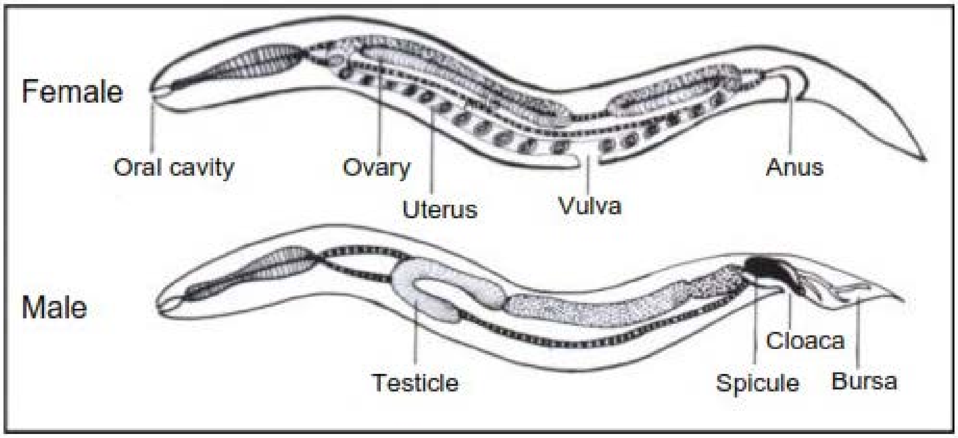

Figure 3. Anatomy of male and female *Haemonchus contortus.*
Source: Urquhart et al. (1996).

Figure 4. *Haemonchus contortus* worm in the abomasum.
Source: Kaplan (2006).

H. okapiae (Hoberg et al*.,* 2004).

Morphology

H. contortus, commonly known as the "red stomach worm" or "wireworm", is the largest common parasite of abomasum and the most prolific. It is also the most pathogenic relative to other gastrointestinal parasite, especially during periods of heat waves (Hoste et al., 1997). Strictly haematophagous, its morphology is similar to that observed in *H. longistipes* (Raillet and Henry, 1909), a dromedary parasite.

Adult worm: In the adult stage, *H. contortus* grows to 10-35 mm long and 0.4-0.6 mm wide. It is readily identifiable by its specific location in the abomasum of small ruminants and by its uniform pinkish-brown coloration due to haematophagy (Figure 4).

Its anterior end has well-developed cephalic papillae and consists of a conical mouth capsule blank containing a small lancet (Figure 5a). The lancet is actually a vestigial perforating tooth that parasites acquire just before their last moult. It allows them to reach the lumen of the blood capillaries of the mucous membrane (Bentounsi, 2001). The male is smaller (10 to 20 mm) and has a caudal bursa at the posterior end of his body with a gubernaculum and two spicules in Y form that are used to identify him (Figure 5b). The female is larger (20-30 mm), tapered at the posterior end, and has a white ovary wrapped around the blood-filled digestive tract (Figure 5c), giving it a characteristic "hookworm" appearance

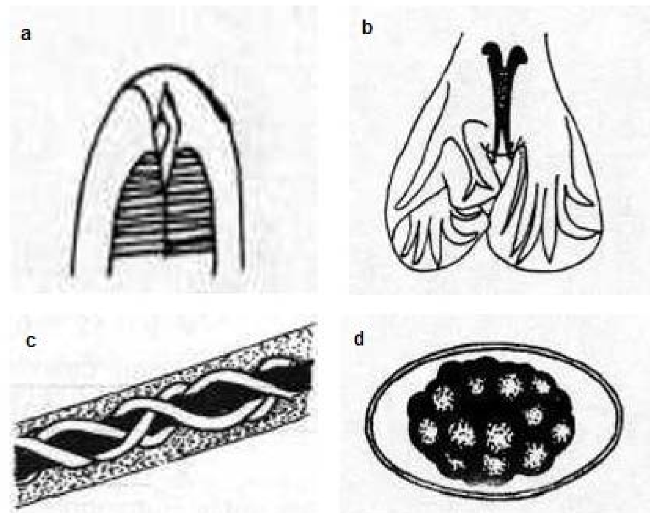

Figure 5. *Haemonchus contortus*. (a) Anterior end of *H. contortus* with neodont formations in lateral view. (b) Male posterior end of *H. contortus* presented the spicules and the caudal bursa. (c) Adult female of *H. contortus* with genital cords female. (d) *Haemonchus contortus* eggs.
Source: Bussieras and Chermette (1991, 1995).

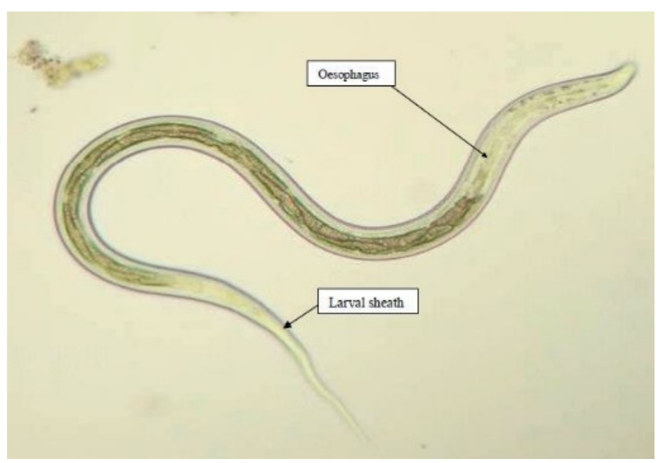

Figure 6. Third-stage larva of *H. contortus* from coproculture.
Source: Mahmoud et al. (2017).

(Bentounsi, 2001).

Eggs: The eggs of *H. contortus* are 80 to 100 µm length and 40 to 50 µm width with a thin, light-yellow oval-shaped shell with a smooth surface, lined inside with a thin yolk membrane, containing a greyish morula which does not fill the entire shell (Bussiéras and Chermette, 1995). They contain a large number of indistinct blastomeres, filling almost the entire egg. They are elliptical in shape, regular and wide, with broad, rounded, almost equal poles and even, highly rounded side walls (Figure 5d).

Larvae: L3 infesting larvae, with an average length of 800 µm, are characterized by a small oral cavity, a 16-cell intestine and a double cuticle (Figure 6).

Evolutionary cycle

The life cycle of *H. contortus* is monoxenous (Figure 7), comprising two life phases: a free phase in pastures, characterized by the development of eggs to the larval L3 stage, (exogenous phase) and a parasitic phase in the host abomasum (endogenous phase) manifested by the

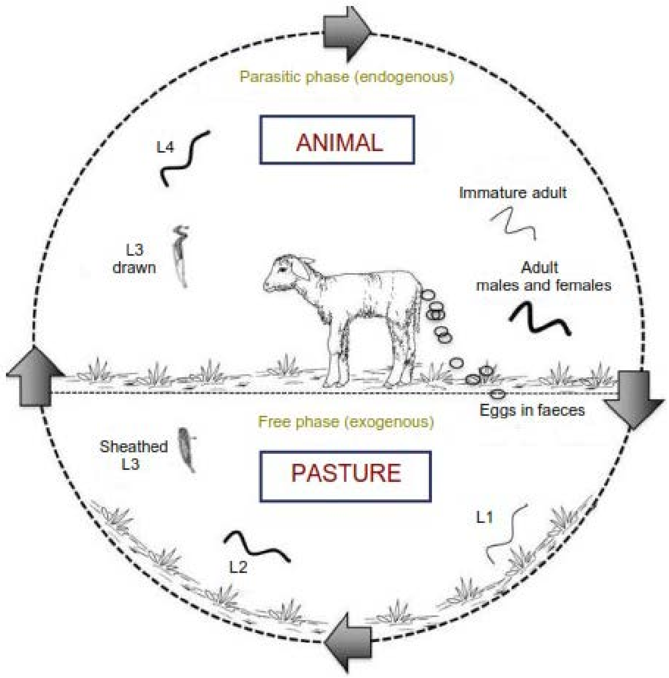

Figure 7. Life cycle of *Haemonchus contortus.*
Source: Hoste et al. (2018).

development of the parasitic stages, L4 larvae, juveniles and adults (Jacquiet, 1997).

Exogenous phase: The free stage of the cycle begins when eggs laid by female worms are disposed of with the faeces of an artificially or naturally infested animal. The eggs spread over the grassland, embryo and hatch into first-instar larvae (L1) when environmental conditions are favourable, that is, high humidity and temperature between 25 and 30°C (Urquhart et al., 1996). L1 larvae actively feed on waterborne microparticles and microorganisms through a "rhabdoid" type valvular apparatus on their oesophagus, and then moult into L2 larvae, which in turn feed in the same way, and then moult into L3 or infesting larvae. L3 larvae have a strongyloid oesophagus without a valvular apparatus. They do not feed and can survive on nutrients acquired and stored in their intestinal cells during the first two larval stages. They are surrounded by a protective sheath, which corresponds to the exuviate of the previous larval stage and gives them a greater or lesser resistance to desiccation factors. The L1 and L2 stages are not very resistant in the external environment (their evolutionary period is 2 days and their survival is only possible in a humidity-saturated environment with a favourable temperature and a sufficient quantity of oxygen) unlike the eggs and the L3 stages. Depending on the environmental conditions, L3 can survive on pasture for several months in temperate zones thanks to their glycogenic and lipid reserves, whereas in tropical or subtropical zones, their survival is of the order of a few weeks (Urquhart et al., 1996).

Endogenous phase: The parasitic phase begins with the ingestion of the infesting L3 by a host during grazing. In the rumen, L3 larvae of *H. contortus* are first released from their sheath by the chemical composition of the ruminant abomasum and pH (Hertzberg et al., 2002). This release is accompanied by the impregnation of the environment with the shedding fluid, which has a high antigenicity and in turn stimulates the shedding of other L3 larvae (Bartley et al., 2003). The drawn L3 larvae then penetrate into the culottes of the glands of the mucosa of the abomasum, mainly in the fundal region where they moult into L4 larvae. These larvae penetrate more or less deeply into the glands of the digestive wall or into the spaces between the intestinal villi. At this stage, it is common in winter (in temperate zones) or during a long dry period (in tropical zones) for the larvae to become embedded in the digestive mucosa and delay their development: this is known as "larval hypobiosis" or "delayed development" of the larvae. The larvae do not resume their normal development until the spring or the following rainy season. The L4 larvae obtained after moulting the L3s, in turn moult in the digestive wall to reach the juvenile stage (immature males and females) sometimes referred to as stage 5 or pre-adult stage and then the adult stage. The passage to the adult stage corresponds to the acquisition of sexual maturity. After fertilization, females lay eggs that are excreted in the host feces and become a new source of pasture contamination. The period between ingestion of infesting larvae and the first egg laying by female worms is the pre-patent period and infested sheep may die during this period (Emery et al., 2016).

Notable characteristics of the life cycle of this parasite, which makes it one of the most feared

i) Eggs, excreted in faeces, have an optimum temperature for development of 20-30°C; embryonated eggs are more resistant than non-embryonic eggs; however, they do not develop when the temperature is too low (Coyne and Smith, 1992) resulting in high mortality in the egg stage in areas where winter temperatures are below 5°C.
ii) Infesting larvae are relatively resistant in the external environment, especially to desiccation, due to the presence of lipids in their intestinal cells.
iii) *H. contortus* has a high propensity to arrest development at the L4 stage, which is considered by some authors as the main means of overwintering survival in temperate regions, and by others as the result of acquired host resistance.

Pathophysiology of sheep haemonchosis

Pathogenicity of the parasite

Blood-sucking nematode, *H. contortus*, causes a decrease in cell volume, body weight and wool quality as well as a decrease in erythrocyte and lymphocyte levels. It has been shown that an infected sheep loses about 0.05 ml of blood per worm per day (Clark et al., 1962; Ijaz et al., 2009) and therefore would lose about 250 ml of blood per day if infected with 5000 *H. contortus*. Moreover, the female is extremely active in terms of oviposition compared to other species, with an average production of 5000-7000 eggs per day (Coyne et al., 1991; Coyne and Smith, 1992), which makes this parasite more pathogenic (Hounzangbé-Adoté et al., 2005). This characteristic counterbalances the mortality of eggs excreted in faeces, especially when climatic conditions are not favourable for their development. Its pathogenicity is essentially associated with its spoliating action on the host, that is, its haematophagous feeding mode, which causes anaemia (extreme pallor of the mucous membranes), the evolution of which is rapidly fatal in case of massive infestation (Hoste et al., 1997). It is also related to the local traumatic effect caused by the larval stages during the intramucosal parasite phase and by the adult stages during feeding, leading to weight loss. Disruption of abomasal digestive functions (altered mucosal permeability, altered secretory functions, impaired motor skills and abomaso-duodenal flow) is responsible for reduced dietary protein degradation and malabsorption, which can lead to secondary infections (Chermette, 1982; Sylvestre and Cabaret, 2001).

Symptoms of sheep haemonchosis

Occasional blackish diarrhea is the calling sign of haemonchosis. Three forms of sheep haemonchosis have been described (Chermette, 1982):

i) Superacute haemonchosis: is an uncommon form occurring in healthy animals which then die suddenly from severe haemorrhagic gastritis;

ii) Acute haemonchosis: is a typical form characterized by anaemia (Figure 8) with a progressive fall in haematocrit usually occurring about two weeks after infestation, followed by bone marrow decompensation, aggravated by loss of protein and iron, until the animal dies. This form is usually fatal within 1 to 6 weeks (Table 1).

iii) Chronic haemonchosis: is the most frequent and responsible for significant production losses due to high morbidity. This form appears in an insidious way and creates in the animal a state of cachexia, hyporexia, misshapenness and even asthenia (Iliev et al. 2017). The infested animal no longer follows the herd and presents diarrhea with stools coloured black (presence of digested blood). Chronic haemonchosis is also often associated with blood symptoms with hypochromic microcytic anaemia leading to subglossian oedema (Figures 9 and 10).

Lesions

The general lesions are those of anaemia and cachexia in the chronic forms. The local lesions concern the digestive tract. They are inconspicuous and the affected animal may have haemorrhagic lesions of the abomasum and small ulcers (Figure 11) that mark the points of attachment of the worms and the haemorrhages they cause when they become detached (Bentounsi, 2001). Inflammatory lesions of the wall such as congestion, mucus hypersecretion, mucosal hypertrophy and oedema of the submucosa as well as whitish nodules (1 to 2 mm in diameter) indicating the presence of encysted larvae may also be present (Mage, 1998).

Geographical distribution of sheep haemonchosis

The geographical distribution of sheep haemonchosis is worldwide because of its great capacity to adapt to climatic variations. The parasite involved is cosmopolitan. It is the main species found in sheep in tropical Africa with

Figure 8. Anemia in a young animal with haemonchosis.
Source: Saminathan et al. (2015).

Table 1. Clinical picture of acute haemonchosis.

General symptoms	Prostration (animals no longer have a hock), dyspnea, cachexia, loss of wool
Blood Signs	Spectacular fall in red blood cell count; hypochromic and microcytic anemia, 30-50% decrease in haemoglobin and haemosiderin levels.
Local symptoms	Intense pallor of the conjunctival, buccal, vulvo-vaginal mucous membranes, which become white-porcelain, also visible on thin-skinned areas that are discoloured; appearance of oedema in declining areas.
Evolution: It is variable	- In the weakest animals, it is fatal in 1 to 6 weeks... - In others, immune and self-healing phenomena may bring temporary improvement. - In addition, the infested suckler ewes are then in agalaxia, which leads to the death of the lambs due to malnutrition without the lambs even being parasitized.

Source: Chermette (1982).

a prevalence of 87.1% in Nigeria (Fakae, 1990); 40.9% in Ethiopia (Gebresilassie and Tadele, 2015). This makes it the most pathogenic parasite in the country. It is also one of the main gastrointestinal nematodes of the Argentinean pampas (Suarez and Busetti, 1995), New Zealand (Vlassof et al., 2001) but also Australia with a prevalence of 78.05% (Bott et al., 2009). In Guadeloupe and Martinique, the prevalence of sheep haemonchosis is between 80 and 100% (Aumont et al., 1997). In China, it is estimated at 78.30% (Wang et al., 2006); 9.3% in Iran (Tehrani et al., 2012) and 42.67% in Pakistan (Ijaz et al., 2009). The parasite responsible for this disease has adapted to conditions ranging from tropical zones to cold and mountainous regions (Newton, 1995; Waller, 1997) because even at latitudes close to the arctic circle, its presence can be noted with, for example, 37% of Swedish flocks affected (Lindqvist et al., 2001); less than 10% of sheep in central France affected (Cabaret et al., 2002) and 41% in Canada (Mederos et al., 2010).

HEALTH IMPACTS OF HAEMONCHOSIS AND ZOOTECHNICAL PERFORMANCE OF SHEEP

Raising small ruminants, especially sheep, is an important element of farming systems because, apart from the

Figure 9. State of cachexia caused by *Haemonchus contortus.*
Source: Ferrer et al. (2002).

Figure 11. Ulcerative lesions on the abomasum by *Haemonchus contortus.*
Source: Mage (1998).

Figure 10. Sign of the bottle (Subglossian edema) in a Haemonchosis-infested lamb.
Source: Ferrer et al. (2002).

production function it plays, it contributes to the smooth running of cultural and customary activities of populations through baptism, marriage and/or funeral ceremonies and brings an economic boost to households. The appearance of haemonchosis directly affects the viability of the animal, limits the expression of the zootechnical performance of animals on farms and causes enormous economic damage through production losses (Jabbar et al., 2006). The disease influences both the quantity and quality of production directly affecting the zootechnical characteristics of infested animals (Urquhart et al., 1996). Indeed, haemonchosis causes haematological and biochemical disorders of the host. The classic clinical picture reveals a deterioration in the general condition of the animal (prostration), severe anaemia, weight loss (cachexia) due to loss of appetite and malabsorption as a result of abrasion of villi and destruction of enterocytes. Digestive disorders (diarrhoea) may also occur. Infested lambs are stunted and lose their market value if treatment does not immediately follow the infestation (Hoste et al., 2006). Adult animals see their reproductive and production potential altered, which affects milk production and growth. The disease causes considerable economic losses at the animal and herd level. It is therefore urgent that alternative solutions be found to limit or even stop the damage caused by this sheep disease since the usual control methods (synthetic anthelmintics) used by farmers have shown their limitations through the emergence of cases of resistance and the chemical residues left by these anthelmintics in the environment and animal products (meat, milk).

Diagnosis

The diagnosis of sheep haemonchosis is made as next described.

Epidemioclinical diagnosis

In sheep farming, the appearance between June and September of clinical signs such as anaemia, subglossian oedema, loss of appetite, prostration associated with mortality, are signs of haemonchosis (Durrani et al., 2007). Lambs are affected before adults (Live et al., 2017).

Coprological diagnosis

Coproscopy allows the detection of *H. contortus* eggs and their count expressed as number of eggs per gram (EPG) of faeces in order to have a good idea of the parasite infestation. It consists of developing the eggs collected in the faeces into infesting larvae which then allows the identification of the parasite. The faeces must be sufficiently rich in eggs, collected from several animals and in fairly large quantities. For this diagnostic method, two quantitative methods are often used: the Mac Master slide flotation enrichment method and the Ovassay flotation enrichment method. Baermann's method can be used to search for larvae after evolution in coproculture (Zarlenga et al*.,* 2016).

Necropsy diagnosis

In the presence of mortality, the use of autopsy is of great interest. It should be carried out immediately after the death of the animal. Examination of the abomasal lining reveals parasites and characteristic lesions: exudative congestion and haemorrhagic foci on the abomasal mucosa (Bentounsi, 2001). The wall of the abomasal cavity appears to be moving due to the presence of visible worms. The female has a typical appearance, her gastrointestinal tract is red, surrounded by two white spirals and the observation of small ulcers on the abomasal lining of the abomasal cavity may help in making the diagnosis.

Prevention of sheep haemonchosis

Prevention against sheep haemonchosis requires good pasture management, that is, prolonged resting (several months) of a plot of land allows partial decontamination; reserving healthy meadows (new, mowed, cultivated) for lambs or ewes that are sponge-fed; avoiding overgrazing (grass that is too short leads to a high ingestion of larvae). The aim of this practice is to minimize contact between susceptible animals and infesting larvae on pastures (Hoste et al., 2004). Mixed or alternate grazing between different species (small ruminants and cattle or small ruminants and horses) helps to reduce the infesting character of a pasture. Thus, prevention of this disease requires good maintenance of the animals through sufficient protein and quality feed, as undernutrition increases the animals' susceptibility to parasitic infestations (Louvandini et al., 2006). Sufficient and balanced feeding thus improves possible resistance and partially compensates for malabsorption. Finally, the adoption of a good treatment schedule is also a means of preventing sheep haemonchosis.

Treatment of sheep haemonchosis

Because of the pathogenicity of haemonchosis, it should be targeted if the frequency of anaemia and diarrhoea is abnormally high. Monitoring the colour of the ocular mucous membranes by the FAMACHA® method makes it possible to estimate anemia in order to implement targeted treatment in adult animals. In this case, the administration of iron and vitamin B12 is recommended. The treatment depends on the phase of the parasite cycle. During the free phase, non-medical control is much more adopted through grazing management (use of hay meadows, alternation of hosts of different species), biological control through the use of nematophagous fungi (Chandrawathani et al., 2002). As for the parasitic phase, vaccination, complementary animal nutrition and especially the repeated use of chemical anthelmintics are the most commonly used means of treatment for sheep haemonchosis. The most commonly used anthelmintic molecules include fenbendazole, levamisole and ivermectin. These molecules belong to the large families of broad-spectrum anthelmintic molecules that are benzimidazoles, imidazothiazoles and macrocyclic lactones, to which is added the family of salicylanilides active against haematophageal parasite (Martin, 1997). Of course, the various chemical anthelmintics used by breeders and agro-breeders can have an effect on the parasite phase, but their use has limitations. Indeed, their use is not recommended for lactating female animals and in organic agriculture (Cabaret, 2004). In addition, the presence of drug residues in animal products worries consumers (FAO, 2003) as well as the appearance and emergence of cases of resistance in the parasite population largely calls into question their effectiveness and use. Resistance exists in many countries and is a public health problem. This situation means that news alternatives control methods such as the use of medicinal plants with anthelmintic properties should be explored and encouraged. This alternative offers the prospect of non-chemical means of control, which are inexpensive and above all accessible to farmers and agro-pastoralists with little purchasing power (Hounzangbé-Adoté, 2001; Hoste et al., 2008).

DISCUSSION

Paper selection

The literature on haemonchosis is linked to *H. contortus*, the parasite responsible for the pathology; hence circumscribing the subject and finding specific articles was the real challenge, as the parasite involved in haemonchosis affects sheep, goats and cattle as well, even though sheep are the preferred hosts of the parasite. The fact that haemonchosis is caused by this parasite led us to the exploitation of some articles dealing with this parasite, its morphology, life cycle and pathogenicity. The data obtained in this context are only those relating to the sheep species of small ruminants. All the literature on haemonchosis and *H. contortus*, only concerns sheep and the fact that we have excluded data dealing with both haemonchosis in sheep and goats may cause us to lose some relevant information on the disease. The data available in French did not provide a wide range of information for use and this may create a possible bias in the selection of articles used for this review due to the dominant use of English in the databases considered. This remark is consistent with that made by Stefani et al*.* (2013) in the systematic review study *"Land cover, land use and malaria in the Amazon: A systematic literature review of studies using remotely sensed data".*

Data on haemonchosis

This literature review shows that haemonchosis is a pathology that has a negative impact on the development of the livestock sector, particularly sheep, due to its pathogenicity and its adaptation to climatic variations (Emery et al*.,* 2016; Swarnkar and Singh, 2020). This pathology decimates herds and causes significant loss of income for smallholders. Although haemonchosis has existed for decades and several authors have directed their research towards this pathology, the definitive control of this disease remains a real challenge. There are still some gaps in its effective and efficient control. Limited attention has been given to proposals for organic, chemical-free livestock production through experimental field studies with products from plant flora. Many authors point out the dangerous and lethal aspect of this disease (Kandil et al*.,* 2015; Besier et al., 2016), especially for young animals (Live et al*.,* 2017; Dey et al*.,* 2018) but little information is available in the literature on prophylaxis although this information is important for the sustainable control of haemonchosis. With regard to the synthetic anthelmintic molecules that are currently the most widely used control method used by livestock farmers to combat this disease, few studies have been carried out on the health and environmental risks that may arise from the repeated and prolonged use of these synthetic anthelmintics on a human scale. Similarly, the emergence of cases of resistance that parasites develop to these anthelminthics (Naeem et al,. 2021), the risks linked to the presence of residues in animal products (meat, milk), the contamination of pastures, or the exposure of farmers to toxic substances have not been studied indepth. It should be noted that the emergence of resistance due to the frequent use of anthelmintics complicates control (Aumont et al*.,* 1997). As this resistance is a genetic problem owing to the transmission of the resistant trait from generation to generation (Wolstenholme et al*.,* 2004), it would be appropriate for studies to also address sheep breed species that could resist infestations of gastrointestinal parasites such as *H. contortus* over several generations. This information is important and would help farmers limit infestations in their flocks. Finally, it is essential to shed light on the ecotoxicity and consequences of the repeated misuse of synthetic anthelmintics and the dangers they pose to health, and to propose control measures based on medicinal plants. This would alleviate the economic difficulties of livestock farmers and address public mistrust of the use of chemical molecules on livestock. Over the years, many studies have been conducted on medicinal plants with anthelmintic properties, and few of them have resulted in the manufacture of improved traditional medicines. The use of medicinal plants with anthelmintic properties for the non-chemical control of this parasitosis will be a better alternative. Researchers are already relying on medicinal plants to solve the problems posed by traditional medicines in many scientific fields such as human health. It is important to extend research to the formulation of improved traditional medicines that are effective, accessible and available to meet the health care needs of livestock farmers for their sheep and thus address the environmental problems posed by synthetic anthelmintics.

CONCLUSION

Sheep haemonchosis is one of the major parasitic diseases of sheep. It induces a significant loss of productivity (in meat, milk and wool) and develops under favourable conditions (heat and humidity), resulting in a very rapid multiplication of the parasite. Infested sheep lose their appetite, weaken and become anaemic very quickly and then die if immediate and adequate treatment is not given. The use of chemical anthelmintics provides comfort to the infested animals by lowering the parasite load but leaves long-term damage to both health and the environment. It is therefore urgent that new alternative control methods such as the use of medicinal plant extracts with anthelmintic properties be found, given the galloping evolution of chemoresistance developed by parasites against synthetic anthelmintic drugs.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Achi YL, Zinsstag J, Yao K, Yeo N, Dorchies P, Jacquiet P (2003). Host specificity of *Haemonchus spp.* for domestic ruminants in the savannah in northern Ivory Coast. Veterinary parasitology (116):151-158. https://doi.org/10.1016/S0304-4017(03)00258-9.

Almeida FA, Bassetto CC, Amarante MRV, Albuquerque ACA, Starling RZC, Amarante AFT (2018). Helminth infections and hybridization between *Haemonchus contortus* and *Haemonchus placei* in sheep from Santana do Livramento, Brazil. Revista Brasileira de Parasitologia Veterinaria 27:280-288. https://doi. org/10.1590/s1984-296120180044

Aumont G, Gruner L, Berbigier P (1991). Dynamique des populations de larves infestantes des strongles gastro-intestinaux des petits ruminants en milieu tropical humide. Consequences sur la gestion des paturages. Revue d'élevage et de médecine vétérinaire des pays tropicaux pp. 123-132.

Aumont G, Pouillot R, Simon G, Hostacha G, Varo H, Barré N (1997).

Parasitisme digestif des petits ruminants dans les Antilles françaises. Productions animales 10(1):79-89.
Bartley DJ, Jackson E, Johnson K, Coop RL, Mitchell GBB, Sales J, Jackson F (2003). A survey of anthelminthic resistant nematode parasites in scottish sheep flocks. Veterinary parasitology 117(1-2) :61-71. https://doi.org/10.1016/j.vetpar.2003.07.023.
Bentounsi B (2001). Parasitologie. Université Mentouri. Département Sci. Vét. el Khroub P113.
Besier R, Kahn L, Sargison N, Van Wyk J (2016). Diagnosis, treatment and management of *Haemonchus contortus* in small ruminants. Advances in parasitology 93:181-238.
Bott NJ, Campbell BE, Beveridge I, Chilton NB, Rees D, Hunt PW, Gasser RB (2009). A combined microscopic-molecular method for the diagnosis of strongylid infections in sheep. International Journal for Parasitology 39(11):1277-1287. https://doi.org/10.1016/j.ijpara.2009.03.002.
Bussieras J, Chermette R (1991). Abrégé de parasitologie vétérinaire, Fascicule I: Parasitologie générale. Polycopié 75 pp. Ecole Nationale Vétérinaire d'Alfort, Service de parasitologie.
Bussieras J, Chermette R (1995). Abrégé de Parasitologie Vétérinaire, Fascicule III: Helminthologie Vétérinaire. Polycopié 290 pp. Ecole Nationale Vétérinaire d'Alfort, Unité de Parasitologie et Maladies Parasitaires.
Cabaret J, Mage C, Bouilhol, M (2002). Helminth intensity and diversity in organic meat sheep farms in centre of France. Veterinary parasitology 105(1):33-47. https://doi.org/10.1016/S0304-4017(01)00647-1
Cabaret J (2004). Parasitisme helminthique en élevage biologique ovin : réalités et moyens de contrôle. INRAE Prod. Ani, 17(2):145-154. https://doi.org/10.20870/productions-animales.2004.17.2.3562
Chandrawathani P, Jamnah O, Waller PJ, Hoglund J, Larsen M, Zahari WM (2002). Nematophagous fungi as a biological control agent for nematode parasites of small ruminants in Malaysia: a special emphasis on Duddingtonia flagrans. Veterinary Research. 33:685-696. https://doi.org/10.1051/vetres:2002049
Clark CH, Kiesel GK, Goby CH (1962). Measurement of blood loss caused by *Haemonchus contortus* infection in 177 sheep. American Journal of Veterinary Research 23(96):977-980
Chermette R (1982). L'haemonchose ovine et ses particularités: importance et situation actuelle en France. Point Vétérinaire 13(65) :21-28.
Cobb NA (1898). Extract from MS. report on the parasites of stock.
Agricultural Gazette of New South Wales 9(3):296-321.
Coyne MJ, Smith G, Johnstone C (1991). A study of the mortality and fecundity of *Haemonchus contortus* in sheep following experimental infections. International journal for parasitology 21(7):847-853. https://doi.org/10.1016/0020-7519(91)90153-X
Coyne MJ, Smith G (1992). The development and mortality of the free-living stages of *Haemonchus contortus* in laboratory culture. International Journal for Parasitology 22(5):641-650. https://doi.org/10.1016/0020-7519(92)90013-B
Dey AR, Zhang Z, Begum N, Alim MA, Hu M, Alam MZ (2018). Genetic diversity patterns of *Haemonchus contortus* isolated from sheep and goats in Bangladesh. Infection, Genetics and Evolution 68:177-184. https://doi.org/10.1016/j.
Doeschl-Wilson AB, Davidson R, Conington J, Roughsedge T, Hutchings MR, Villanueva B (2011). Implications of host genetic variation on the risk and prevalence of infectious diseases transmitted through the environment. Genetics 188(3):683-693. https://doi.org/10.1534/genetics.110.125625
Durette-Desset MC, Chabaud AG (1993). Nomenclature of Strongylidae above the family group. Annales de parasitologie humaine et compare 68(2):111-112. https://doi.org/10.1051/parasite/1993682111 PMID: 8215111
Durrani AZ, Kamal N, Khan MS (2007). Serodiagnosis of haemonchosis in small ruminants. Global veterinary 1:1-66.
Emery DL, Hunt PW, Le Jambre LF (2016). *Haemonchus contortus*: The then and now, and where to from here? International Journal for Parasitology 46(12):755-769. https://doi.org/10.1016/j.ijpara.2016.07.001
Fabiyi AK (1987). Production losses and control of helminths in ruminants of tropical regions. International Journal for parasitology 17:435-442.
Fakae BB (1990). The epidemiology of heiminthosis in small ruminants under the traditional husbandry system in eastern Nigeria. Veterinary Research Communications 14 (5):381-391.
Food and Agriculture Organization (FAO) (2003). Residues of some veterinary drugs in animals and foods. Fao food and nutrition paper N°41/15. 6th meeting of the Joint FAO/WHO Expert Committee on Food Additives Geneva, Switzerland, 6-12 February 2003. http://www.fao.org/3/y4858e/y4858e00.htm
Fentahun T, Luke G (2012). Small ruminant haemonchosis: prevalence and associated determinants in randomly selected restaurants and hotels of Gondar Town, Ethiopia. European Journal of Applied Science 4(4):168-172.
Ferrer LM, Garcia De Jalon A (2002) Atlas de parasitologie ovine. Edn CEVA. Santé Animale pp. 37-42.
Food and Agriculture Organization (FAO) (2003). Residues of some veterinary drugs in animals and foods. Fao food and nutrition paper N°41/15. 6th meeting of the Joint FAO/WHO Expert Committee on Food Additives Geneva, Switzerland, 6-12 February 2003. http://www.fao.org/3/y4858e/y4858e00.htm
Food and Agriculture Organization Statistics (FAOSTAT) (2013). Ensuring small-scale farmers can benefit from high food prices. The implications of smallholder heterogeneity in market participation. Rome, available at www.faostat.fao.org (visited 6th November 2020).
Gebresilassie L.and Tadele B.A. (2015). Prevalence of Ovine Haemonchosis in Wukro, Ethiopia. Hindawi Publishing Corporation. ournal of parasitology research ID 635703, 5 http://dx.doi.org/10.1155/2015/635703
Hertzberg H, Huwyler U, Kohler L, Rehbein S, Wanner M (2002). Kinetics of exsheathment of infective ovine and bovine strongylid larvae *in vivo* and *in vitro*. Parasitology 125(1):65-70. https://doi.org/10.1017}S0031182002001816
Hoberg EP, Lichtenfels JR, Gibbons L (2004). Phylogeny for species of *Haemonchus* (Nematoda: Trichostrongyloidea): considerations of their evolutionary history and global biogeography among Camelidae and Pecora (Artiodactyla). Journal of parasitology 90(5):1085-1102; PMid:15562609. http://dx.doi.org/10.1645/GE-3309
Hoberg EP, Zarlenga DS (2016). Evolution and biogeography of *Haemonchus contortus*: linking faunal dynamics in space and time Advances in parasitology 93:1-30. https://doi.org/10.1016/bs.apar.2016.02.021
Hoste H, Huby F, Mallet S (1997). Helminthoses gastro-intestinales des ruminants: conséquences physiopathologiques et mécanismes pathologiques. Le point vétérinaire, numéro spécial "parasitologie des ruminants" 28:23-109.
Hoste H, Jackson F, Athanasiadou S, Thamsborg SM, Hoskin SO (2006). The effects of tannin-rich plants on parasitic nematodes in ruminants. Trends in parasitology 22(6):253-261. https://doi.org/10.1016/j.pt.2006.04.004
Hoste H, Torres-Acosta JF, Alonso-Diaz MA, Brunet S, Sandoval-Castro C, Hounzangbé-Adoté S (2008). Identification and validation of bioactive plants for the control of gastrointestinal nematodes in small ruminants. Tropical Biomedicine 25:56-72.
Hoste H, Torres-Acosta JFJ, Sandoval-Castro CA, Mueller-Harvey I, Sotiraki S, Louvandini H, Thamsborg SM, Terrill TH (2015). Tannin containing legumes as a model for nutraceuticals against digestive parasites in livestock. Veterinary parasitology 212(1-2):5-17. https://doi.org/10.1016/j.vetpar.2015.06.026
Hoste H, Torres Acosta F, Sotiraki S, Hounzangbe-Adote S, Kabore A, Costa Jr L, Louvandini H, Gaudin E, Mueller Harvey I (2018). Des plantes contenant des tannins condensés : un modèle d'alicament pour gérer les vers parasites en élevages des petits ruminants. Innovations Agronomiques 66 :19-29.
Hounzangbé-Adoté SM (2001). L'élevage face à la pharmacopée en médecine vétérinaire au sud du Bénin. BRAB 33:1-9.
Hounzangbé-Adoté S, Paolini V, Fouraste I, Moutairou K, Hoste H (2005). *In vitro* effects of four tropical plants on the intestinal parasitic nematode, *Haemonchus contortus.* Research in Veterinary Science 78(2):155-160. https://doi.org/10.1016/j.rvsc.2004.05.009
Ijaz M, Khan M, Avais M, Ashraf K, Ali M, Khan M (2009). Infection rate and chemotherapy of various helminthes in diarrhoeic sheep in and

around Lahore. Journal of Animal and Plant Sciences 19(1):13-16.
Jabbar A, Iqbal Z, Kerboeuf D, Muhammad G, Khan MN, Afaq M (2006). Anthelmintic resistance: the state of play revisited. Life sciences 79(26):2413-2431. https://doi.org/10.1016/j.lfs.2006.08.010
Jacquiet P (1997). Les strongles digestifs des ruminants. Point Vét.(Parasitologie des ruminants) 28:20-22.
Kandil OM, Eid NA, Elakabawy LM, Abdelrahman KA, Helal MA (2015). Immunodiagnostic potency of different *H. contortus* antigens for diagnosis of experimentally and naturally Haemon- chosis in Egyptian sheep. APG 6(3):238-247
Kaplan M (2006). Update on parasite control in small ruminants: Addressing the challenges posed by multiple-drug resistant worms. September 21-23. In: Proceedings of the American Association of Bovine Practitioners. Saint Paul, MN, USA.
liev P, Prelezov P, Ivano, A, Kirkova Z, Tonev A (2017). Clinical study of acute haemonchosis in lambs, Trakia Journal of Science 15:74-78.
Lindqvist A, Ljungstrom BL, Nilsson O, Waller PJ (2001). The dynamics, prevalence and impact of nematode infections in organically raised sheep in Sweden. Acta Veterinaria Scandinavica 42(3):377-389.
Louvandini H, Veloso CFM, Paludo GR, Dell'Porto A, Gennari SM, McManus CM (2006). Influence of protein supplementation on the resistance and resilience on young hair sheep naturally infected with gastrointestinal nematodes during rainy and dry seasons. Veterinary Parasitology 137(1-2) :103-111. 137(1-2):103-111. https://doi.org/10.1016/j.vetpar.2006.01.004
Mage C (1998). Parasites des Moutons: Prévention, diagnostic, traitement. Edition France Agricole 118 p.
Mahmoud MAM, Elfadil AAM, Yagoup EA, Adam IA, Mohamed EGS, Bushara SB, Shuaib YA (2017). Epidemiological study of *Haemonchus contortus* among sheep in north Kordufan State, Sudan. International Journal of Veterinary Science 6(4):209-215.
Martin RJ (1997). Modes of action of anthelmintic drugs. Veterinary Journal 154 :11-34.
Mederos A, Fernández S, VanLeeuwen J, Peregrine A, Kelton D, Menzies P, LeBoeuf A, Martin R (2010). Prevalence and distribution of gastrointestinal nematodes on 32 organic and conventional commercial sheep farms in Ontario and Quebec, Canada (2006–2008). Veterinary parasitology 170(3-4):244-252. https://doi.org/10.1016/j.vetpar.2010.02.018
Naeem M, Iqbal Z, Roohi N (2021). Ovine haemonchosis: a review. Tropical Animal Health and Production 53:19, https://doi.org/10.1007/s11250-020-02439-8
Newton SE (1995). Progress on vaccination against *Haemonchus contortus*. International journal for parasitology 25(11):1281-1289. https://doi.org/10.1016/0020-7519(95)00065-A
Place FE (1893). Anaemic diarrhoea in young cattle. Veterinary Record 5:589.
Raillet M, Henry A (1909). Sur la classification des strongylidae. C. R. Seances Soc. Biol. 66:85-88.
Rudolphi CA (1803). Neue Beobachtungen iiber die Eingeweidewtirmer. Archiv fir Zoologie rrnd Zootomie 3:l-32.
Salifou S (1996). Nématodes et nématodoses du tube digestif des petits ruminants du Sud Bénin : Taxonomie, Epidémiologie et les facteurs de variation. Thèse de doctorat de l'Université Cheikh Anta Diop de Dakar, Sénégal P 162.
Saminathan M, Gopalakrishnan A, Latchumikanthan A, Milton AAP, Aravind M, Dhama K, Singh R (2015). Histopathological and parasitological study of blood-sucking *Haemonchus contortus* infection in sheep. Advances in Animal and Veterinary Sciences 3(2):99-108.DOI http://dx.doi.org/10.14737/journal.aavs/2015/3.2.99.108 ISSN (Online): 2307-8316; ISSN (Print): 2309-3331
Silvestre A, Cabaret J (2001). Résistance aux benzimidazoles chez les nématodes gastrointestinaux parasites de petits ruminants: diagnostic moléculaire et stratégies de traitements. 3R. 8:175-180.
Soudré A, Gréma M, Notter RD, Tapsoba ARS, Traoré A, Kaboré A, Alvarez I, Fernandez I, Sanou M, Lompo D, Sanou T, Samshuddin M, Periasamy K, Tamboura HH, Goyache F (2018). Resistance of Djallonké sheep to *Haemonchus contortus* under artificial challenge. IJBCS 12(3):1274-1285. https://doi.org/10.4314/ijbcs.v12i3.16
Stefani A, Dusfour I, Corrêa APSA, Cruz MCB, Dessay N, Galardo AKR, Galardo CD, Girod R, Gomes MSM, Gurgel H, Lima ACF, Moreno ES, Musset L, Nacher M, Soares ACS, Carme B, Roux E (2013). Land cover, land use and malaria in the Amazon: a systematic literature review of studies using remotely sensed data. Malaria Journal 12(192):1-8.
Suarez VH, Busetti MR (1995). The epidemiology of helminth infections of growing sheep in Argentina's western pampas. International journal for parasitology 25(4):489-494. https://doi.org/10.1016/0020-7519(94)00122-5
Swarnkar C, Singh D (2018). Haematological variations in visually anaemic sheep naturally infected with Haemonchus contortus in farm conditions at arid Rajasthan, Indian Journal of Animal Sciences 88:34-38.
Swarnkar C, Singh D (2020). Rhythmicity in thermal humidity index and regulation of *Haemonchus contortus* in sheep of semiarid tropical Rajasthan, Biological Rhythm Research 51:58-66.
Tehrani A, Javanbakht J, Jani M, Sasani F, Solati A, Rajabian M, Khadivar F, Akbari H, Mohammadian M (2012). Histopathological study of *Haemonchus contortus* in Herrik sheep abomasum. Journal of Bacteriology and Parasitology 3(5):144.
Travassos LP (1914). Trichostrongylinae brasileiras (2a nota prévia). Brasil-Médico 28:183.
Urquhart GM, Armour J, Duncan JL, Dunn AM, Jennings FW (1996). Veterinary parasitology. 2nd Edn. 292 pp. Oxford, UK, Blackwell Science.
Vlassof A, Leathwick DM, Heath AC (2001). The epidemiology of nematode infections of sheep. New Zealand Veterinary Journal, 49(6):213-221. https://doi.org/10.1080/00480169.2001.36235.
Waller PJ (1997). Nematode parasite control of livestock in the tropics/subtropics: the need for novel approaches. International Journal for Parasitology 27(10):1193-1201. https://doi.org/10.1016/S0020-7519(97)00117-3
Wang C, Qiu J, Zhu X, Han X, Ni H, Zhao J, Zhou Q, Zhang H, Lun Z (2006). Survey of helminths in adult sheep in Heilongjiang Province, People's Republic of China. Veterinary parasitology 140(3-4):378-382. https://doi.org/10.1016/j.vetpar.2006.04.008
Wolstenholme AJ, Fairweather I, Prichard R, von Samson-Himmelstjerna G, Sangster NC (2004). Drug resistance in veterinary helminths. Trends in parasitology 20(10):469-476. https://doi.org/10.1016/j.pt.2004.07.010
Zarlenga D, Hoberg EP, Tuo W (2016). The identification of Haemonchus species and diagnosis of haemonchosis. Advances in parasitology 93:145-180.