

Review

Prevalence, effects and alternative control methods of *Haemonchus contortus* in small ruminants: A review

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Small ruminants farming is a traditional activity mostly practiced by local populations in developing countries since several centuries. Nowadays, due to many biotic and climatic factors, it faces various problems which damage smallholders' income especially those related to gastrointestinal parasites. In opposite to the chemical drugs use in controlling those parasites, medicinal plants have been investigated with fewer side effects on both the meat quality and the environment. This current study aimed at reviewing *Haemonchus contortus* prevalence in small ruminants across the world and present medicinal plants that have been investigated in the last decades. *H. contortus* is identified as the most significant nematode parasite in small ruminants due to its high prevalence reported by many studies. Its presence in small ruminants results in a loss of feed absorption and disturbance of nutrient metabolism, which lead to poor performance and significant economic loss in the herds, especially in rural areas of developing countries. For the past decades, its control was mainly based on the use of chemical anthelmintics; whose use has been limited due to several factors like the irrational and misuse. Recently, the use of medicinal plants has been identified as alternatives methods of its control with conclusive results. Parts of plants or the whole plants of several plant species were reported to be relevant to control *H. contortus* infection in small ruminants such as: *Bridelia ferruginea*, *Mitragyna inermis*, *Combretum glutinosum*, *Hagenia abyssinica*, *Chenopodium ambrosioides*, *Leucaena leucocephala*, *Phytolacca icosandra*, *Eucalyptus staigeriana*, *Carica papaya*, *Newbouldia laevis* and *Zanthoxylum zanthoxyloides*.

Key words: Economic losses, gastrointestinal nematodes, chemical anthelmintics, medicinal plants, poor performance.

INTRODUCTION

Small ruminants are essential in subsistence agriculture owing to their exceptional adaptability in difficult

environmental conditions. They provide raw materials for the agro-industries and their manure is used as a source

of biogas (Adua and Hassan, 2016) and fertilizer for promoting crop production. Additionally, they perform key sociocultural functions that are hardly quantifiable in monetary terms; for example, their use for rituals and sacrifices, in or during festivities, and as insurance against poor harvests (Hassan et al., 2013) and are also used for teaching and research. Despite all these benefits, the sector receives little attention and faces various challenges, mainly feed and health problems, particularly those related to gastrointestinal nematodes that are very detrimental to livestock (Hounzangbe-Adote et al., 2005). *Haemonchus contortus* infections are commonly identified as the most significant (Emery et al., 2016; Jamalm et al., 2016) with significant rates of growth and milk yield reduction in small ruminants in tropical environments leading them to production losses in herds, especially grass-fed small ruminants (Andrea et al., 2011). Several studies carried out in small ruminants revealed the existence of polyparasitism with strongyles and prevalence rates of digestive strongyles, especially *H. contortus* (Salifou, 1996; Attindehou et al., 2012; Adua and Hassan, 2016). As a direct consequence, both the carcass yield of these animals and the income of the small farmers are decreasing. In some areas, particularly in the tropics and subtropics where environmental conditions are ideal for the development and transmission of the nematode parasite, frequent use of synthetic anthelmintics has been successful in solving the problem of nematodes (Knox et al., 2006; Torres-Acosta and Hoste, 2008). In parallel with increasing and not always reasoned use of these chemicals, parasites have become increasingly resistant to anthelmintics. In addition, the high cost, limited availability of these chemicals and the drug residues in final products and the environment following their use are other factors that discourage many farmers from using them in some emerging countries (Knox et al., 2006).

Faced all these challenges, it becomes essential to develop new methods to control parasitism. Indeed, improvement of animal nutrition through feed supplements and the use of medicinal plants have been identified as alternatives adapted to the financial means and socio-cultural environment of the populations (Wabo et al., 2012). Recent studies have revealed the anthelmintic effect of several medicinal plants in the control of gastrointestinal nematodes parasites, especially *H. contortus* in small ruminants that can be considered when designing parasites control programmes. Therefore, this current study aims to present an overview of the prevalence and the effects of *H. contortus* on small ruminants' production (growth and milk production), then to summarize studies conducted on some medicinal plants with anthelmintic properties

tested against *H. contortus*.

MORPHOLOGY AND BIOLOGICAL CHARACTERISTICS OF *H. CONTORTUS*

Also called the Barber's pole worm (Brightling, 2006), *Haemonchus* is a gender of gastrointestinal parasite belonging to the class of Nematoda, the family of Trichostrongylidae and the sub-family of Haemonchinae. The gender counts three species such as: *H. contortus*, *Haemonchus placei* and *Haemonchus longistipes*. *H. contortus* (Figure 1) has been reported to affect goats, sheep and cattle (Sutherland and Scott, 2010), *H. placei* affects mostly cattle (Taylor et al., 2007; Sutherland and Scott, 2010) and *H. longistipes* affects dromedary (Urquhart et al., 1996). *H. contortus* is the main species of strongyle found in small ruminants in tropical areas of Africa, Central America, Southeast Asia and subtropics in Australia and South America (Alowanou, 2016). Measuring about 15 to 30 mm long, an adult *H. contortus* male is shorter than the female. *H. contortus* male is characterized by its copulatory bursa formed of two large lateral lobes and a small asymmetrically positioned dorsal lobe (Morales and Pino, 1987). Female parasites have a reddish digestive tube containing ingested blood, spirally surrounded by two white genital cords (Getachew et al., 2007). *H. contortus* is a hematophagous strongyle located in the abomasum of small ruminants. This characteristic leads to a greater pathogenicity compared to other gastrointestinal nematodes (Penicaud, 2007). In fact, as a blood-sucking parasite, it absorbs the blood of the fine capillary vessels of the digestive mucosa of animals, which can cause more or less severe anemias. In addition, the female is extremely active in terms of spawning with excretion of about 5000 to 7000 eggs/day (Coyne and Smith, 1992).

H. contortus is an extremely prolific parasite possessing different strategies for evading unfavorable environmental conditions and immune reactions of the host. Due to its unique ability for producing eggs in large number during its lifetime, *H. contortus* has an important advantage over other parasites. In that, it can easily contaminate grazing areas and may survive in its hosts through frequent and rapid re-infections. In addition, because the degree of infectivity varies significantly according to the *H. contortus* isolates, studies concluded on the importance to take in to account the parasite genetic diversity in various agro-ecological zones (Aumont et al., 2003) in all prevention and control measures. These above factors justify its high pathogenicity which is a requirement to the treatment and control of this parasite in small ruminants (Can, 2015)

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Figure 1. Microscopic view (x 200) of sheathed infesting larvae (L3s) of *H. contortus*. Source: Brunet (2008).

(Figure 1).

LIFE CYCLE OF *H. CONTORTUS*

The life cycle of a parasite, like every living thing, describes the whole development process of its life which follows a certain pattern designated under the term life cycle. As regards *H. contortus*, the life cycle is deemed as a direct life cycle which comprise two phases: a parasitic phase that takes place in the host, and a free-living phase that takes place in the external environment (Walken-Brown et al., 2008; Solaiman, 2010) (Figure 2). According to Ballweber (2004), *H. contortus* life development may generally take 2 to 4 weeks to complete after infection. Walken-Brown et al. (2008) described *H. contortus* life cycle in seven stages: the egg stage, four larvae stages (L1, L2, L3, and L4), and two adult stages, although the sexually immature adult stages are sometimes named L5. In the development process, the adult female mates with a male and lays the fertile

eggs in the digestive tract of the host. Through defecation, those eggs are freely released into the environment by the host. With favorable environmental conditions, the eggs hatch to free-living L1 (Bush et al., 2001; Brightling, 2006), which at their turn, moult to the L2 stage. Both L1 and L2 stages larva feed on bacteria within the host faeces (Walken-Brown et al., 2008). Then, the L2 stage partially changes into the L3 stage, which is unable to feed on bacteria due to its envelope (Bush et al., 2001). So, the amount of energy left after the L2 stage determines the survival of the L3 larvae (Brightling, 2006). The ingestion of the L3 by the host is then necessary to complete their life cycle. Thus, the L3 larvae leaves the faeces, migrates up grass leaves in the pasture, and remains suspended, during the morning dew (Brightling, 2006). After its ingestion by the host, the L3 larvae then changes into L4 that then enters the abomasum mucous of the host to advance into L5 which later becomes sexually mature in the gastrointestinal tract of the host (Walken-Brown et al., 2008). When adults of *H. contortus* attains maturity, they mate, and begin laying

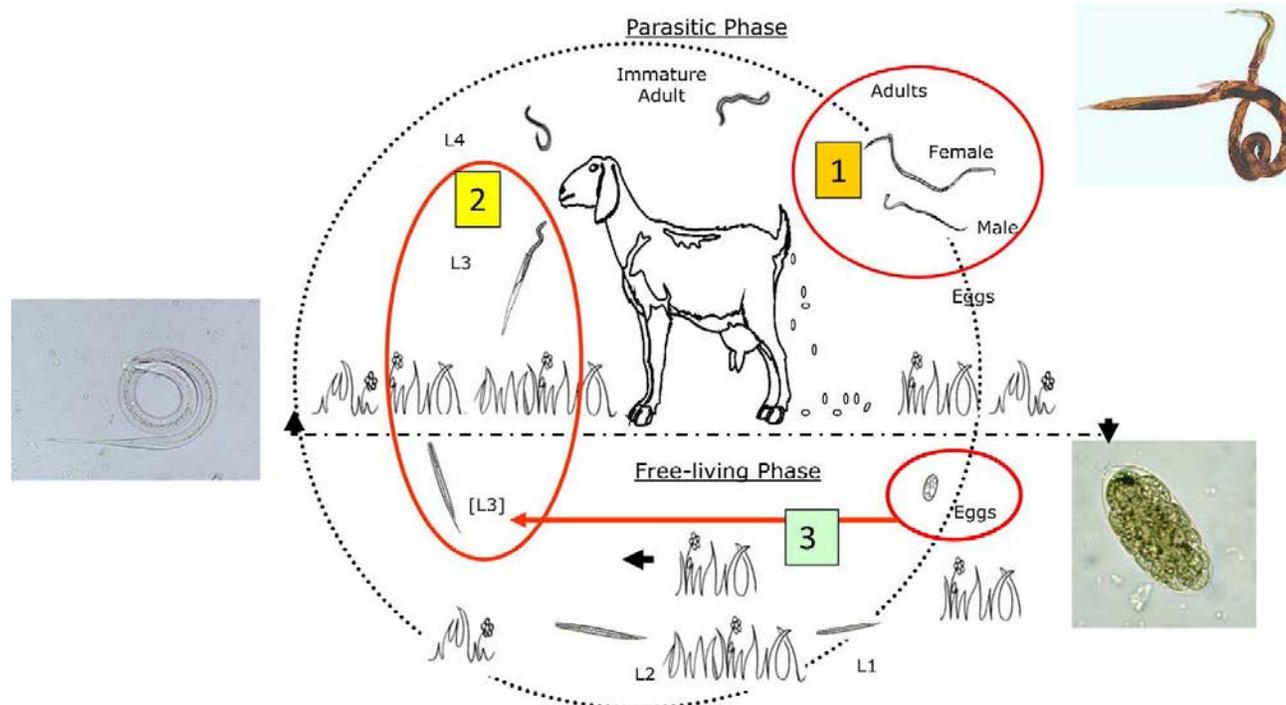


Figure 2. Life cycle of *H. contortus* in small ruminants. (1) Hatching of eggs and evolution of larvae from stage 1 to stage 3 by successive moults. (2) Ingestion of infesting lava (L3s) by small ruminants on pasture. (3) Reproduction of adult worms inside small ruminants and excretion of eggs.

Source: Hoste et al. (2015).

eggs inducing a new cycle.

FACTORS INFLUENCING *H. CONTORTUS* DEVELOPMENT

Many previous studies reported external factors that influence the patterns of *H. contortus* development. Indeed, temperature, rainfall, humidity and vegetation cover are environmental factors which influence Gastrointestinal Nematodes (GINs) development (Selemon, 2018). El-Ashram et al. (2017), early, had revealed a direct correlation between the harshness of gastrointestinal nematodes problems and rainfall during the wet periods of the year where livestock are raised in the developing countries. Furthermore, Attindehou et al. (2012) also reported, in Benin Republic, a significant association of the haemonchosis rates with the season; the minimum and maximum infection rate respectively 36.06% in January (a dry month) and 79.41% July (a very wet month). Definitely, this seasonal trend of prevalence of these parasitic infections will assist in preparing appropriate control strategies, that will be beneficial for goats rearing and industry (Singh et al., 2015). Beside these environmental factors, many other factors have also been reported to influence parasitic infections in small ruminants: the nutrition (Bricarello et al., 2005; Knox et al., 2006), the management practices such as

overcrowding, poor management and hygiene (Olanike et al., 2015), the differential management practices (Mandonnet et al., 2003), the drug treatments (Barnes et al., 2001), the genetic factors that provide natural resistance to the host like the breed of host (Chaudary et al., 2007; Saddiqi et al., 2011; Solomon-Wisdom and Matur, 2014; Singh et al., 2015), the age of the host (Solomon-Wisdom et al., 2014; Singh et al., 2015) and the sex of the host (Attindehou et al., 2012; Olanike et al., 2015; Poddar et al., 2017). Contrary to all the above factors, Attindehou et al. (2012) reported no significant difference in relation to animal's age, origin, sex or species, even if animals less than a year old and especially goats were mostly infected. Finally, both the body weight and reproductive status of the host, according to Tasawar et al. (2010), influence the parasitic infection development due to the development of acquired immunity with gradual increase in weight along with age of the animals.

PREVALENCE OF *H. CONTORTUS* IN SMALL RUMINANTS

H. contortus is a serious nematode in small ruminants and has been found as a dominant parasite of goat and sheep among the nematodes (Jamalm et al., 2016). Several parasitological surveys carried out in many

regions of Africa have shown convincing results regarding the prevalence of gastrointestinal nematodes in small ruminants' herds. Indeed, in Benin Republic, 55.56% of the examined animals were infested by *H. contortus*; and the monthly trend of infections showed that in all areas, haemonchosis is endemic with no significant differences in terms of origins or species (Attindehou et al., 2012). According to the same study, the minimum and maximum recorded *H. contortus* infection rate was respectively of 16.9% in January (a dry month) and 88.7% in July (a very wet month). In Nasarawa State (Nigeria), Adua and Hassan (2016) reported an overall nematodes infection rate of 32.40 and 17.01% in Red Sokoto goats and West African Dwarf goats respectively. According to the same study, the prevalence rate of nematodes infection was 22.45 and 17.82% in Red Sokoto goats while West African Dwarf goats had 14.58 and 8.33% in young and adults respectively. In addition, in the same country, Olanike et al. (2015) reported in Ibadan, 75.85% small ruminants positive for gastrointestinal parasites with the higher prevalence of 54.25% in Red Sokoto breed and the lower prevalence of 21.5% in West African Dwarf breed. According to the results of the same study, 22.75 and 10.5% Red Sokoto and West African Dwarf breeds respectively had mixed helminths (*Strongyle spp*, *Strongyloides spp* and *Coccidia spp*) and protozoa infections (Olanike et al., 2015). In the Plateau region of Togo, Bonfoh et al. (1995) reported a *H. contortus* prevalence up to 82%. Later, in peri-urban area of Sokodé, in Togo, approximatively the same prevalence rate of gastrointestinal nematodes in small ruminants was recorded (88% represented by *Haemonchus* sp. and *Trichostrongylus* sp.) with a negative effect of the season. In a similar way, in urban and peri-urban areas in Maroua, Far North of Cameroon, Ngambia Funkeu et al. (2000) have reported the presence of five species of parasitic nematodes: *Haemonchus*, *Trichostrongylus*, *Cooperia*, *Oesophagostomum* and *Strongyloides papillosus* with a predominance of *Trichostrongylus* and *Haemonchus* respectively in dry and rainy season. This same study revealed a prevalence of 27 to 31% for these two species depending on the age of the sheep without any significant influence of sex. An epidemiological investigation of small ruminants parasites in the southern forest zone of Ivory Coast carried out by Oka et al. (1999) has revealed a parasite fauna which consisted of nine species of nematodes with a predominance of *Trichostrongylus colubriformis* (89.7%) and *H. contortus* (84.1%) in terms of prevalence. Furthermore, in Eastern Ethiopia, Sissay et al. (2007), reported a prevalence of 60% in small ruminants. This is below the results of Mengist et al. (2014) who recorded an overall prevalence of *H. contortus* of 71.03% with prevalence in sheep and goat up to 67.57 and 71.39% respectively in and around Finoteselam, Ethiopia. According to the same study, the prevalence of haemonchosis was higher in males (73.22

%) and adult animals (71.43%). The high rate of prevalence of infection among the goats could be attributed to poor management practices and lack of veterinary services in the area (Osakwe and Anyigor, 2007). A prevalence assessment of *H. contortus* infections in Goats in Nyagatare District (Rwanda) showed that 75.7% of the small ruminants had *H. contortus* eggs in faeces with a prevalence rate of 71.8% in goats (Mushonga et al., 2018). Moreover, a 12 months period of survey in the local abattoir of Nyala town, South Darfur State, Sudan revealed 85% of slaughtered goats harbored both adults and immature worms of *H. contortus* (Abakar, 2002) while an overall prevalence of *H. contortus* eggs of 12.1% with a 95% CI ranging from 7.97 to 16.23% has been reported in Khartoum State (Sudan) by Boukhari et al. (2016).

Other recent studies conducted on goats in the rest of the world, particularly in Madhya Pradesh (India) concluded that *H. contortus* was the most predominant parasite followed by *Trichostrongylus* sp., *Oesophagostomum* sp., *Strongyloides* sp. and *Bunostomum* sp. Of the 960 faecal samples of goats examined, 94.48% were found positive for one or more gastrointestinal parasitism viz., coccidian (82.4%), strongyle (69.27%), amphistomes (22.71%), *Strongyloides* (9.17%), *Trichuris* (3.85%), *Moniezia* (3.02%), *Schistosoma* (2.29%) and *Fasciola* sp. 1.77% (Singh et al., 2015). Furthermore, various others studies had earlier reported the high prevalence rates of gastrointestinal parasites in goats, especially *H. contortus*, from Indonesia (89.4%) (Widiarso et al., 2018) and different parts of India like 88.23% prevalence of helminthes in Nagpur (Maske et al., 1990), 90.05% from Jabalpur (Lalbiaknungi, 2002), 96% in Tarai region of Uttarakhand (Pant et al., 2009). In Markhor of Chitral Gol National Park, a prevalence rate of 40% of *H. contortus* has been recorded by Jamalm et al. (2016) against 56-61% prevalence that has been recorded for the parasite in goat in previous studies especially in the Potohar area of Pakistan (Chaudary et al., 2007) and 77.7% Jehangirabad District Khanewal, Punjab, Pakistan recorded by Tasawar et al. (2010). Furthermore, Adhikari et al. (2017) reported a polyparasitism with the higher prevalence for *H. contortus* of 13.89% in goats of Western Chitwan of Nepal. According to the same study, *H. contortus* was more prevalent in non-dewormed (40.32%) than in dewormed (5.26%). Finally and in agreement with the previous reports, *H. contortus* has been reported, in the region of Valle de Lerma (northwestern Argentina), by Suarez et al. (2013) to be the most prevalent nematode species.

EFFECTS OF *H. CONTORTUS* INFECTIONS ON SMALL RUMINANTS' PRODUCTION

Information on the effects of *H. contortus* infections on

small ruminant production mostly concern milk production (both the yield and quality). And even in this context, compared to dairy cows, effects of *H. contortus* infections on dairy goats and sheep are not well documented. However, several decades ago, while comparing milk yield in ewes orally infected with 2500 *H. contortus* larvae weekly during pregnancy and lactation, Thomas and Ali (1983) reported a striking weight loss and reduction of sheep milk yield by 23%. This result was then greater than 2.5% to 10% milk yield reduction that had been recorded by Hoste and Chartier (1993) from machine-milked goats infected three times with *H. contortus* L3 larvae at 50-day intervals. But recent studies have revealed greater reduction rates than these previous ones. Indeed, in Italy, a study involving untreated naturally infected and anthelmintic-treated animals has revealed significantly effect of GINs infections on milk production, with the highest milk yield recorded in the treated goats (Rinaldi et al., 2007). More recently, in Argentina, Suarez et al. (2017) reported a significant difference in the mean total milk production between treated ($399.5 \text{ L} \pm 34.0 \text{ L}$) and untreated goats ($281.6 \text{ L} \pm 37.5 \text{ L}$), amounting to 41.8% increase in total milk yield. The same study also revealed a post-partum peak in egg count and a negative effect of gastrointestinal nematodes (GINs) on milk yield, even with moderate infections. In addition, studies have gone further by assessing the effects of those GINs infections on the lactation length in small ruminants. Considering milk production of the whole period in naturally infected goats in France, Chartier et al. (2000) reported a significant effect of GINs infections on the lactation period length with a longer duration of lactation in the high protein diet treated group compared to the group treated with normal protein diet (301.5 vs. 294.9 days) and a similar tendency for the total milk yield. According to Suarez et al. (2009), anthelmintic treatment positively affects the length of the milking period with regard to the length of the milking period of untreated dairy sheep. The same way, Suarez et al. (2017) revealed, in goats instead, a significant negative effect of the GIN infections on the milking period length of the goats after kidding (262.3 ± 9.8 days and 223.3 ± 10.8 days respectively for treated and untreated goats). These different results could explain the positive correlation between the GINs infections treatment and the persistence increase in milk yield in dairy goats, ranging from 7.4 to 18.5% with respect to control values observed by Rinaldi et al. (2007). The same study (Rinaldi et al., 2007) highlighted the deteriorating effect on milk quality caused by nematode infections, when they observed that 29.9% lower fat, 23.3% lower protein and 19.6% lower lactose contents in milk from the untreated goats than that from the control group. However, these findings were not in accordance with Hoste and Chartier (1993) who previously had reported no changes in fat and protein contents between infected and uninfected dairy goats. This might be due to the high level of resistance development in the GINs that occurred more recently in

small ruminants herds and reported by several studies in small ruminants (Kaplan and Vidyashankar, 2012; Torres-Acosta et al., 2012b; Geurden et al., 2014; Besier et al., 2016). Finally, in Pakistan, Muhammad et al. (2011) estimated the effect of haemonchosis on milk yield and goats weight respectively up to 29 and 27% reduction.

Losses due to *H. contortus* infections are related to productivity performances, particularly to decrease in body weight that can range from 20 to 60% (Kawano and Yamamura, 2001). These losses could be explained by the loss of appetite (reduction of voluntary feed intake), diarrhoea, anemia and reduced growth (Khan et al., 2008) and disturbance in the nutrient metabolism that cause young *H. contortus*. In overall, Muhammad et al. (2011) estimated losses due to haemonchosis in sheep and goats at 10-20% reduction of the production.

In disease pathogenesis, anorexia or depression of voluntary feed intake is properly recognized as a critical factor that is capable of revealing largely the response to imbalance of nutrition during gastrointestinal nematodes infection (Sahoo et al., 2011). Even in subclinical infections, anorexia is present (Sykes and Greer, 2003), and may account for around 40 to 90% production losses detected during intestinal parasitism (Greer, 2008). According to Sahoo et al. (2011), in a parasitized animal, anorexia occurrence is as a result of the different factors, viz: a) triggered by the parasite itself for its own advantage; b) reduction of voluntary feed intake is aimed at starving the parasites; c) in the host, it helps in promoting an effective immune response; and d) anorexia affords the host an opportunity to choose diets that minimize infection risk. According to both the nutrient contents of feed offered to parasitized animals and the number of established parasites present, Petkevicius (2007) revealed voluntary feed intake reductions varying from 6 to 50% which, according to Greer (2008), could be understood to be the cost of the developing immune response. Feed intake of parasitized animals usually returns toward normality as animals acquire resistance to infection (Sahoo et al., 2011). More recently, on artificial infection with 15 000 third-stage larvae of *H. contortus* given as three divided doses, Tonin et al. (2014) concluded on progressive degradation of physiological condition; weakness, lethargic and pale state; and depressed feed intake of crossbred Corriedale lambs.

On the other hand, one of the key features of GINs infection, such as *H. contortus* infection is an increased loss of endogenous protein into the gastrointestinal tract, partly due to plasma protein leakage and partly because of increased production of muco-protein and sloughing of epithelial cells into the alimentary tract (Petkevicius, 2007; Sahoo et al., 2011). A substantial amount of these proteins are redigested before absorption at sites distal to infection; however, subsequent recycling of digested nutrients would result to additional energy expense by the small ruminants (Knox et al., 2006). The quantity of nutrients reabsorbed endogenously depends on the distal

tract (whether there is adequate compensatory absorptive capacity or the lesions position (whether they are in the anterior) (Coop and Kyriazakis, 2001). A proportion that is not resorbed is either further digested in the large intestine or waits to be excreted in the faeces, absorbed as ammonia and excreted as urea in the urine and can therefore constitute a major drain to the infected animals' overall nitrogen economy (Knox et al., 2006). In parasitized animals, nutrients diversion from production towards specific proteins synthesis for replacement, repair, and reaction to the gut wall damage, to whole blood or plasma loss as well as to mucus production can inflict a significant drain on resources that otherwise would have contributed to fiber, bone, milk and muscle synthesis (Liu et al., 2003; Sahoo et al., 2011). For instance, according to Liu et al. (2003), an additional 17g/day Metabolisable Protein (MP), which is equivalent to 0.57, 0.71, and 0.14 of the MP requirement, is respectively needed for growth, late pregnancy, and early lactation as compensation for losses owing to GINs infection. According to Colditz (2003), GINs adult and larval stages incidence in the gastrointestinal tract leads to inflammation and activation of the acute phase response to infection and occurs locally and systemically. These responses may cause significant drain on the nutritional resources at the disposal of the animals along with protein redirection away from other body processes (Knox et al., 2006).

Finally, the analysis of the situation on the economic plan designates *H. contortus* as the most economically vital gastrointestinal nematode in its main endemic zones (Perry et al., 2002; Mcleod, 2004) mainly owing to the common occurrence and potential for substantial rates of mortality in small ruminants. Animal losses vary significantly between seasons, years and regions, contingent on environmental conditions as well as control measures' effectiveness, including anthelmintic resistance impact (Besier et al., 2016). Although it is difficult to assess the impact of chronic *H. contortus* infection, and also critically significant in wide grazing situations where routine monitoring is seldom conducted, Muhammad et al. (2011) ascribed considerable loss to the reduced value of animal production. For example, in Australia, gastrointestinal nematodes cost the sheep industry \$369 million annually or around 8.7% of its total value (Sackett et al., 2006). All these results revealed the negative interaction between small ruminants and nematode (Hoste et al., 2010), and could justify the fact that, even at moderate burdens, GIN control should not be neglected in small ruminants production.

CONTROL OF GASTROINTESTINAL NEMATODES PARASITES IN SMALL RUMINANTS

Use of chemical anthelmintics

Anthelmintics have continued to be the bedrock of many

GIN control programmes in grazing animals owing to their ease of use, low cost, and lack of real alternative options (Kenyon and Jackson, 2012). However, in many countries, the resistance of gastrointestinal parasites to chemical anthelmintic is an increasing burden and poses real concern to numerous countries (Kaplan and Vidyashankar, 2012; Torres-Acosta et al., 2012b; Geurden et al., 2014). Anthelmintics resistance is an increasing challenge not only in small ruminants (Kaplan and Vidyashankar, 2012) but also in cattle (Cotter et al., 2015) and horses (Nielsen et al., 2014). GINs resistance to the three classes of anthelmintics (macrocyclic lactones, nicotinic agonists, and benzimidazoles) has become recurrent globally, since the foremost case of resistance was identified in the early 1960s (Fleming et al., 2006; Kaplan and Vidyashankar, 2012; Cotter et al., 2015). Moreover, in single nematode strains, multiple resistance remains a concern (Taylor et al., 2009; Geurden et al., 2014). Nevertheless, GINs resistance levels against anthelmintics may vary between areas (Torres-Acosta et al., 2012b).

As regards anthelmintic resistance of GIN in goats, since the very first reported cases in different areas of the world like New Zealand (Kettle et al., 1983), Australia (Barton et al., 1985), France (Kerboeuf and Hubert, 1985), this challenge has become globally prevalent as in sheep (Fleming et al., 2006; Jackson et al., 2012; Chandra et al., 2015). In Australia and South America, there is particularly high prevalence; however, in Europe there are increasing reports of elevated prevalence (Váradí et al., 2011). Though both goats and sheep are infected with the same nematode species (Hoste et al., 2008), parasites in goats seem to be more resistant to chemical drugs, especially in large flocks characterized by high stocking rates, industrial schemes of production, and frequent treatment based on anthelmintics. Thus, resistance to chemical anthelmintic is assumed to be more frequent in goats' parasites than in sheep (Váradí et al., 2011). According to Jackson et al. (2012), this low sensitivity to anthelmintics in goats parasites primarily results from difficulties in ascertaining the precise dose of drugs in goats as compared to sheep. A number of anthelmintics are registered for use in sheep, but in goats, they are used off-licence. Thus, goats treatment at the recommended dose rates of sheep led to routine underdosing which reduces the efficacy of the drug used and partly explains the high prevalence of anthelmintic resistance of parasites in goats in comparison with sheep (Hoste et al., 2011).

To retain anthelmintics effectiveness for a prolonged period, a detailed comprehension of the factors that are likely to initiate anthelmintic resistance of GINs is necessary. As a result, there is need for appropriate approaches implementation and development that will slow or impede possible resistance (Leathwick et al., 2015). Resistance development in GINs against anthelmintic may be influenced by many factors, e.g. those listed in Table 1.

Table 1. Factors influencing the development of resistance in GINs against anthelmintics.

Authors	Factors
Bartley (2008), Falzon et al. (2013), and Torres-Acosta and Hoste (2008)	Lack of quarantine of newly introduced animals
Torres-Acosta and Hoste (2008)	Treatment of all the animals in the herd
Bartley (2008), Falzon et al. (2013), and Jackson et al. (2012)	Under-dosing of the drugs
Falzon et al. (2013), and Torres-Acosta and Hoste (2008)	Use of the same family of anthelmintic drugs for prolonged period
Bartley (2008), Falzon et al. (2013, 2014), and Jackson et al. (2012)	Frequency of treatment
Falzon et al. (2014)	The use of long-acting anthelmintics

Alternatives control methods

Elimination of the source of contamination of animals

The purpose of the depletion of the source of contamination is to block the biological cycle of gastrointestinal nematodes (GINs) by controlling the infestation of grazing and thus minimizing the risk of contact between sensitive hosts and L₃s larvae (Paolini et al., 2004; Heckendorn, 2007). Various methods of grazing management exist to achieve this goal. These methods are based on three main principles: prevention, evasion and dilution (Pomroy, 2006). Prevention is to put healthy animals on clean pastures (free of L₃s) while evasion involves transferring treated animals with anthelmintics from contaminated pastures to clean pastures. Finally, the last principle is to dilute the infestation of grazing.

Improvement of the host resistance

The improvement of the host resistance may be done by two ways: selection of genetically resistant animals and improvement of the host diet.

Selection of genetically resistant animals

The selection of animals resistant to gastrointestinal nematodes (GINs) is a long-standing approach to reduce the use of synthetic anthelmintics (Pomroy, 2006), as such selection would theoretically reduce host infestations and gradually decrease pasture contamination. Genetic variability in GINs resistance has been reported either between breeds or between individuals of the same breed (Bishop and Morris, 2007). Selection of resistant animals may also present some limitations such as the risk of increased host susceptibility to other pathogens (Gruner et al., 1998) or an adverse effect on productivity (Stear and Murray, 1994; Gray, 1997). In addition, these resistant animal selections remain long-term programmes that must take into account local breeding conditions, availability of breeds, and breeding objectives (Pomroy, 2006).

Improvement of the host diet

Gastrointestinal nematodes (GINs) cause severe disruption of digestive physiology and induce an increase in the host's dietary requirements to overcome the strong disturbances of protein and energy metabolism (Hoste et al., 2005). On the basis of this observation, it has been suggested that an improvement in the feed ration to cover the additional needs associated with the presence of nematodes would contribute to improving the host's response to parasitism, particularly when corrections are made. In general, it has been shown that protein metabolism is far more affected by gastrointestinal parasitism than energy metabolism (Coop and Kyriazakis, 1999). As a result, the studies have focused on the benefits of protein supplementation. The notion of immuno-nutrition has been suggested because improving the diet leads to greater resilience by reducing the consequences of subclinical infestations and improved resistance (Hoste et al., 2008).

Use of medicinal plants

For centuries, medicinal plants and their extracts have been employed in treatment of diseases in man as well as animals (Akhtara et al., 2000; Hounzangbe-Adote et al., 2005; Athanasiadou et al., 2007). Worldwide, anthelmintic resistance occurrence in GIN populations has inspired investigation pertaining to plants and their extracts' usage as a substitute approach for controlling GINs in ruminants. These medical plants are reasonably inexpensive, generally accepted by small landholders and available locally (Athanasiadou et al., 2007; Hoste et al., 2011). Thus, several review works have already been conducted on use of medicinal plants as a substitutive means for controlling GINs in ruminants (Akhtara et al., 2000; Athanasiadou et al., 2007; Hoste et al., 2011). Table 2 summarizes information on some of these plants that have been used in the recent studies for controlling *H. contortus* infection in small ruminants.

CONCLUSION

This current study attempted to provide an overall view

Table 2. Medicinal plants used in controlling gastrointestinal parasites, especially *H. contortus* infection in small ruminants.

Plant species/materials	Parts used/Mode	Dose tested	Infection methods	Type of test	Authors
<i>Hagenia abyssinica</i>	Whole plants	20, 40, and 60g/goat	Natural infection	<i>In-vivo</i>	Abebe et al. (2000)
<i>Chenopodium ambrosioides</i>	Oil and fresh ground plant	Single dose of the oil at 0.1, 0.2, 0.4 ml/kg Body-Weight (BW)	Artificial infection with pure <i>H. contortus</i>	<i>In-vivo</i>	Ketzis et al. (2002)
<i>Crassocephalum crepidioides</i>	Aqueous leaves extract	75 to 2400 µg/ml	Three development stages of <i>H. contortus</i> (eggs, larvae and worms)	<i>In-vitro</i>	Bogning et al. (2016)
<i>Ananas comosus</i> , <i>Momordica charantia</i> , <i>Eugeni caryophyllus</i> , and <i>Azadirachta indica</i>	Ethanol extracts from fresh leaves, seeds and bark.	100 mg/kg BW	Natural infection	<i>In-vivo</i>	Sujon et al. (2009)
<i>Aloe ferox</i>	Crude aqueous extracts of leaves	20 mg/ml	Eggs and larvae of <i>H. contortus</i>	<i>In-vitro</i>	Maphosa et al. (2010)
<i>Leonotis leonurus</i>	Crude aqueous extracts of leaves	1.25 mg/ml (egg hatch) and 1.25 mg/ml (larvae development)			
<i>Elephantorrhiza elephantine</i>	Crude aqueous extracts of roots	2.5 mg/ml (egg hatch) and 1.25 mg/ml (larvae development)			
<i>Allium sativum</i>	Commercial garlic juice and fresh garlic bulbs	3 garlic buds or garlic juice with 1:1 dilution of 99.3% formula Garlic Barrier, Garlic (Research Labs, Inc., Glendale, CA)	Natural infection	<i>In-vivo</i>	Burke et al. (2009a)
<i>Zanthoxylum zanthoxyloides</i>	Fagara leaves	Three-day administration of Fagara	2500 third-stage larvae of <i>H. contortus</i>	<i>In-vivo</i>	Hounzangbe-Adote et al. (2005)
Commercial herbal dewormer Formula 1: <i>Artemisia absinthium</i> , <i>Allium sativum</i> , <i>Foeniculum vulgare</i> , <i>Juglans nigra</i> , and <i>Stevia rebaudiana</i> Formula 2: <i>Cucurbita pepo</i> , <i>Artemisia vulgaris</i> , <i>Allium sativum</i> , <i>Foeniculum vulgare</i>	Formula 1 and 2	19 g/goat	Natural infection	<i>In-vivo</i>	Burke et al. (2009b)
<i>Azadirachta indica</i> , <i>Artemisia absinthium</i> , and <i>Nicotiana tabacum</i>	Extracts from leaves of <i>N. tabacum</i> , <i>A. indica</i> , and whole dry plant of <i>A. absinthium</i>	200 mg/pound BW	Artificially infected with 80% <i>H. contortus</i> and 20% <i>Trichostrongylus spp</i>	<i>In-vivo</i>	Worku et al. (2009)
<i>Eucalyptus staigeriana</i>	Essential oil	500 mg/kg BW	Natural and artificial infection	<i>In vivo</i>	Macedo et al. (2010)
<i>Agave sisalana</i>	Aqueous extract	1.7 g/kg BW	Natural infection	<i>In vivo</i>	Botura et al. (2011)
<i>Phytolacca icosandra</i>	Ethanol extract	250 mg/kg BW (dosed on two consecutive days)	Artificially infected with 3,000 <i>H. contortus</i>	<i>In vivo</i>	Hernández-Villegas et al. (2012)
<i>Leucaena leucocephala</i>	Protein extracts	109.95 mgP gMF ⁻¹	Artificially infected with viable larvae of ages 2 to 3 months	<i>In vivo</i>	dos Santos Soares et al. (2015)
<i>Newbouldia laevis</i> and <i>Zanthoxylum zanthoxyloides</i>	Acetonic and ethanolic extracts	150, 300, 600 et 1200 µg/mL	L ₃ s larvae of <i>H. contortus</i>	<i>In vitro</i>	Olounladé et al. (2011)

Table 2. Contd.

<i>Moringa oleifera</i>	Infused and macerated aqueous extract as well ethanolic extract of leaves	0.625, 1.25, 2.5, 3.75 and 5 mg/ml	Fresh eggs, embryonated eggs, L ₁ and L ₂ larvae of <i>H. contortus</i>	<i>In vitro</i>	Mbogning Tayo (2014)
<i>Bridelia ferruginea</i> , <i>Mitragyna inermis</i> , <i>Combretum glutinosum</i>	Leaves extracts		Eggs, L ₃ larvae and adults worms from animals artificially infected with <i>H. contortus</i>	<i>In vitro and in vivo</i>	Alowanou et al. (2015) Alowanou (2016)
<i>Parkia biglobosa</i>	Fruit pods	3,2g/kg/jour	2000 L ₃ larvae of <i>H. contortus</i>	<i>In vivo</i>	Dedehou et al. (2015)
<i>Pterocarpus erinaceus</i>	Leaf powders	3,2g/kg/jour	2000 L ₃ larvae of <i>H. contortus</i>		
<i>Eucalyptus staigeriana</i>	Essential oil	1.35 and 5.4 mg ml ⁻¹	<i>H. contortus</i> egg and larval development	<i>In vitro</i>	Macedo et al. (2010)
<i>Agave sisalana</i> Perr.	Aqueous extract	1.7 g/kg BW for eight days	Animals naturally infected with GINs	<i>In vivo</i>	Botura et al. (2011)
<i>Carica papaya</i>	Papaya seeds in water	-	Artificially infected with <i>H. contortus</i>	<i>In vivo</i>	Burke et al. (2009a)
<i>Coriandrum sativum</i>	Crude aqueous extracts of the seeds	0.45 and 0.9 g/kg BW	Artificially infected with <i>H. contortus</i>	<i>In vitro and in vivo</i>	Egualé et al. (2007b)
<i>Khaya senegalensis</i>	Ethanolic crude extracts from the bark	125, 250 and 500 mg/kg BW	Natural infection	<i>In vitro and in vivo</i>	Ademola et al. (2004)
<i>Zingiber officinale</i> Roscoe	Crude powder, crude aqueous extracts from dry plant	1 to 3 g/kg BW	Natural infection with mixed species of GINs	<i>In vitro</i>	Iqbal et al. (2006)

about the prevalence and the methods of control of gastrointestinal nematodes parasites, particularly *H. contortus*. Several previous studies have revealed a high prevalence of *H. contortus* in small ruminants, and in goats in particular all over the world. Its development is favored by many external factors mainly the climatic factors (temperature, humidity, etc.), management practices. The presence of *H. contortus* in small ruminants is associated to many problems (weight losses and milk yield reduction) that lead to significant economic losses. Conventional control methods used by farmers during decades are no more adequate to address parasite infections in small ruminants considering their negative impacts on cattle and farmers' benefits. Medicinal plants with anthelmintic properties have been investigated and can be used as alternatives to chemicals especially for small scale farmers. Knowing, understanding and mastering these

alternatives methods might help the small ruminants' value chain actors to design appropriate control programmes adapted to the financial conditions and geographical area of small scale farmers.

ABBREVIATIONS

BW, Body weight; **FSA**, Faculty of Agronomic Sciences; **GIN**, gastrointestinal nematode/GINs; **gastrointestinal nematodes**; **LESA**, Laboratory of Ethnopharmacology and Animal Health; **MP**, metabolisable protein; **UAC**, University of Abomey-Calavi; **WAAPP**, West Africa Agricultural Productivity Project.

CONFLICT OF INTERESTS

The author has not declared any conflict of

interests.

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