Chapter 7 Parasitism management in animal production system: Sustainable approaches for their control

Capítulo 7 Manejo de las parasitosis en unidades de producción animal: Métodos sustentables para su control

VARGAS-MAGAÑA, Juan José*† & DUARTE-UBALDO, Ivonne Esmeralda

Escuela Superior de Ciencias Agropecuarias Calle 53 S/N, entre 20 y 18. Col. Unidad Esfuerzo Y Trabajo No. 2. CP 24350, Escárcega, Campeche, México.

ID 1st Author: *Juan José, Vargas-Magaña* / **ORC ID**: 0000-0002-9218-3259

ID 1st Co-author: *Ivonne Esmeralda Duarte-Ubaldo* / **ORC ID**: 0000-0001-9683-1594

DOI: 10.35429/H.2021.8.117.135

J. Vargas & I. Duarte

*jjvargas@uacam.mx

N. Niño, M. Valencia and M. García. (AA. VV.) Productive System, Territory and Sustainability. Handbooks-TIII-©ECORFAN-Mexico, Guerrero, 2021.

Abstract

Despite the use of modern anthelmintics to treat and control parasitism in animal production systems, these illnesses continue affecting both animals' health and diminish production parameters. One of the most important is gastrointestinal nematodiasis which is present in temperate and tropical conditions and represents larges economic losses. The concern increases with the new nematode isolates resistant to different broad-spectrum anthelmintic families (multi-resistant isolates). In addition to social pressure to have food that is safe and that does not harm the environment. The above, leading to the development of alternative gastrointestinal nematode control methods and allows to decrease the excessive use of commercial anthelmintics, extend the useful life of these products and help to have sustainable animal production systems. However, first, this valuable information is encountered in specialized periodic journals in the English language, second due to its high cost, it is difficult to access in general for students and producers who need to know about this information for its application in production systems. A literature review was carried out about the alternative control strategies of nematodes in ruminants that have been developed worldwide with a simple explanation of their potential use, the results obtained so far, and that their dissemination free of charge to make it available to the public. The above using the access granted by the Autonomous University of Campeche to databases such as Elsevier, Springer, and Ebsco Host.

Production system, Alternative control methods, Gastrointestinal nematodes

Resumen

A pesar del uso de los modernos antihelmínticos para tratar y controlar las parasitosis en los sistemas de producción animal estas enfermedades siguen afectando a los animales y disminuyendo los indicadores productivos. Entre estas parasitosis resaltan las nematodosis gastrointestinales que se presentan en climas templados y tropicales y que año con año reportan pérdidas millonarias. Esta preocupación se ha incrementado con la aparición de cepas de nematodos resistentes a las diferentes familias de antihelmínticos de amplio espectro (multirresistentes), además de la presión social por tener alimentos inocuos y que no dañen al medio ambiente. Ante este panorama se ha desarrollado un área de métodos de control alternativo de las nematodosis que permitan disminuir el uso excesivo de antihelmínticos, prolongar su vida útil y convertir estos sistemas productivos en sustentables. Sin embargo, esta información se halla en revistas especializadas en idioma inglés y por su alto costo es de difícil acceso para estudiantes y productores que necesitan conocer esta información para su aplicación en los sistemas productivos. Se realizó una revisión de literatura sobre las estrategias de control alternativo de nematodos en rumiantes que se han desarrollado a nivel mundial, con una explicación sencilla de su uso potencial, los resultados obtenidos hasta el momento y que se logre su difusión de manera gratuita para asegurar que esté disponible para el público en general. Lo anterior usando el acceso otorgado por la Universidad Autónoma de Campeche a bases de datos como Elsevier, Springer y Ebsco Host.

Sistemas de producción, Métodos control alternativos, Nematodos gastrointestinales

Introduction

Despite the use of modern anthelmintics, some authors agreeing that parasitism, especially gastrointestinal nematodes are the most prevalent parasites in the world, these parasites are responsible for huge losses animal production system especially those based on grazing management and their control have great importance due to the growing human need for the protein of animal origin and the pressure of developed countries leading to limit the use of chemical substances that pollute the environment.

Similarly, it is recognized that in the last decades the control of these nematodes relied on the use of commercial anthelmintics. However, the inappropriate and indiscriminate use of these substances has led to the appearance of new resistant strains of these nematodes to one, two, or three of the commercial anthelmintics families existent in the market, and this resistance was rapidly extended, in such a way, their use on animal production systems is endangers.

On the other hand, there are a social concern and economical pressure which demands not only higher production they also demand efficiency, considering, animal welfare and overall, this production must be according with the environment, namely sustainable. The latter implies an adequate use of modern commercial anthelmintic and overall, the seek for non-conventional alternative methods which help to control this parasitosis

However, the chosen solution must be adapting to the regional epidemiological features and the farm conditions. In this sense, it must use a combination of management and alternative control methods to avoid economic losses and to create control schemes based on an integral parasite control management. Nevertheless, there are few pieces of literature about this topic, regularly attend to principles of parasite control by separate, regularly are of scientific cut and highest const for veterinary students and farm owners who are the persons that fight every day with this illness.

Therefore, the chapter aims to integrate the different strategies developed worldwide in one document, provide a simple explanation of its potential use at the farm level, and finally ensure the free diffusion of this information to students, farmers, and interested people.

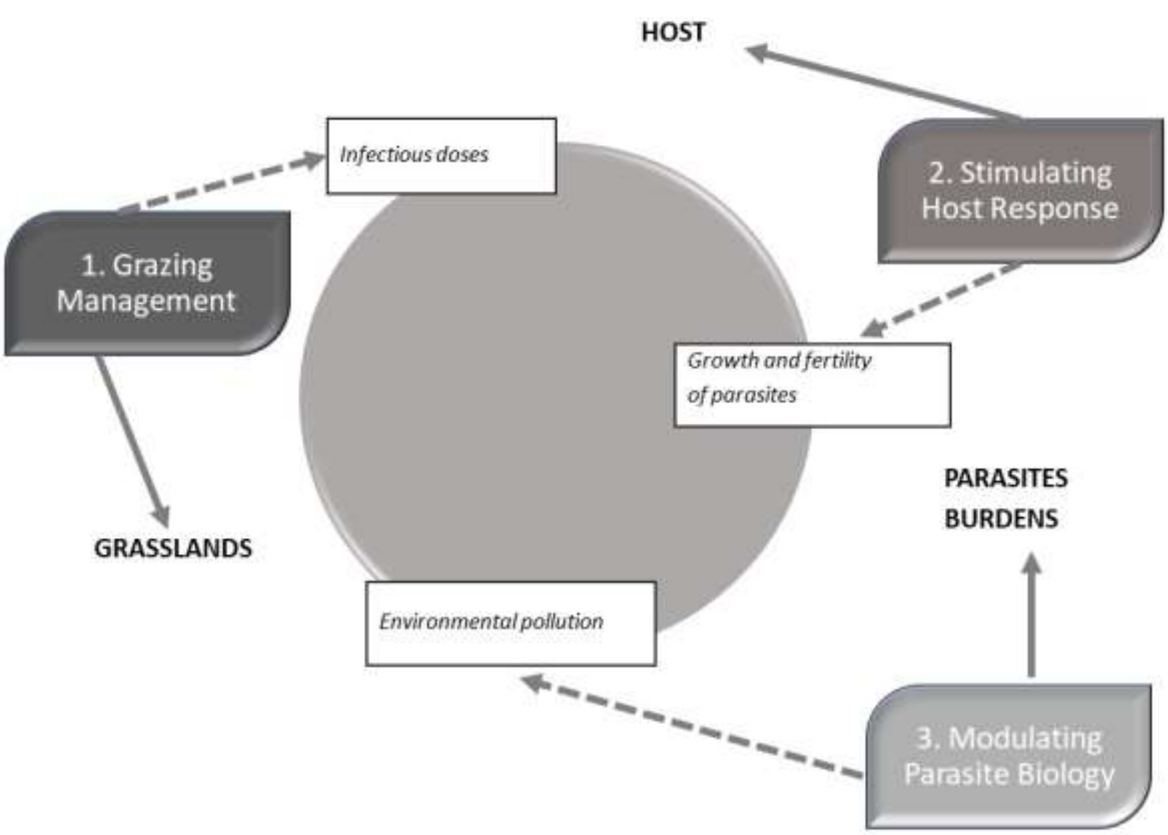
Principles of action to interrupt the life cycle of parasites

There are three principles of action used to interrupt the life cycle of parasites presented in figure 7.1 (Hoste & Torres-Acosta, 2011):

1. Reduce contact between the host and the infectious stage of the parasite
2. Stimulating the host response
3. Eliminate the parasite of the host

Similarly, there are different parasite control methods for each principle of action, it is important to use a combination of these methods to ensure animal health, low parasite burdens, and maintain the production parameters.

Figure 7.1 Three main principles of action to control gastrointestinal nematodes: bold arrows, target for action; dotted arrows, consequences on the life cycle of parasites



Reference Source: (Hoste & Torres-Acosta, 2011)

1. Reduce contact between the host and infectious stage of parasite

Grazing Management

These alternative methods of parasite control use grazing practices to diminish animal exposition to infectious stages of gastrointestinal nematodes (Sharma, Singh, & Shyma, 2015). To practice this type of control strategy, it is important to know and apply the knowledge about the epidemiological conditioning factors affecting local parasite, since different features could modulate the parasite's biology i.e. growth and survival of infective larvae in the paddock, which can affect the results obtained from this strategy (Reynecke *et al*., 2011).

This method can be divided into two strategies: in) Defense sanitary measures, ii) Offense sanitary measures (Hoste & Torres-Acosta, 2011).

i. Defense sanitary measures

Reduce animal load. Considered the most efficient way to reduce parasite problems, the less animal load allows the complete grasses recovery, reducing the impact of animal contamination of paddocks, and finally occurs fewer dose infection to the animals, this strategy generates a balance between components in the animal's production system and is the basis of organic farms in the United States of America (Hoste & Torres-Acosta, 2011; Torres-Acosta & Hoste, 2008). For the organic farms in the United States of America, a maximum of two animals units per hectare is required while in humid tropical conditions is established just one animal unit per hectare; in subhumid climate, like Campeche and Yucatan the value is around half-animal unit per hectare, this information was calculated by Comisión Técnico Consultiva de Coeficientes de Agostadero (Fernández-Reynoso, Martínez-Menes, Ramírez-Cruz, & López-Velasco, 2012; Hoste & Torres-Acosta, 2011).

Grassland rotation. This strategy is based on the knowledge of larval development from l1 to infective stage or L3, which is known as the viability of larvae in paddocks. Because L3 cannot feed these larvae have a period time of life, after this time larvae death by inanition, if this time knows it will be possible to use as the rest period for grasslands and in this way obtain grasslands clean and safe of parasites; It is important to consider the survival time of the larvae: in a temperate climate, it is known that larvae can survive form six to 12 months, however, in tropical conditions only survive four o fewer weeks this time is modulated by the season whether it's dry or rainy. Although good results are reported in temperate conditions at the moment remain as a good alternative for tropical conditions (Barger, *et al*., 1994; Burke *et al*., 2009). For humid tropical conditions three of four days of grazing and 27 to 28 days of grasslands rest is suggested (Vásquez-Hernández, *et al*., 2006).

ii. Ofense sanitary measures

With this principle, it is known the clean of grasslands from larvae nematode through chemical, physical and biological agents.

Sun and ultraviolet rays. The practice of intensive grazing generates that level of grass is cut close to the soil in this way the rays of the sun can penetrate, and the ultraviolet rays can reach the nematode larvae in the paddock, the latter is corroborated in zones with an intense dry season, in this scenario, there are no nematode larvae in the paddocks as a product of the sun rays intensity (Hoste & Torres-Acosta, 2011). This knowledge is in use in European countries with organic production systems since in this type of farms it is not possible to use commercial anthelmintics; in these farms are used grazing management taking into account dry and wet season to establish the rest period for the grasslands and in this way clean the pastures and return the animals when is considered that infective larvae decreased and the risk of infection is low for the animals (Napoléone *et al*., 2011).

Other organisms proved for the control of gastrointestinal nematodes. Some living organisms have been studied and classified as susceptible to use in the gastrointestinal nematodes control, the most studied are:

a) The fungi *Duddingtonia flagrans*, the fungus is marketed as a BioWorma the product, has a recommended dosage of 3x104 chlamydospores of a *D. flagrans* strains IAH 1297/kg of body weight/day. This product has proved in horses, bovine, goats, and the authors report a decrease in the fecal egg count of nematode larvae of these three species. The decreased in counts was recorded as follows: For the case of equine a large variability was reported, however, the number of larvae reduce by 84% at six weeks post-treatment; in the case of bovine was similar founding high variability for the first eight weeks of treatment and a decrease of 81% at the eight weeks of treatment; for the case of goats was similarly high variability and a reduction of the 86% at the eight weeks post-treatment (Healey *et al*., 2018).

b) Mix or alternate grazing system. The mix or alternate grazing system is an offensive method which use the parasites specificity, when using others hots species these have a vacuum effect and thus clean the grasslands and the consumed larvae cannot complete their life cycle and damage the host. Some authors published information about the use of this alternative control strategy i.e. in animal production system with mix grazing of bovine and sheep a decontamination of infective nematode larvae occur in grasslands with time this strategy help to improve the productive parameters (Rocha *et al*., 2008).

c) On the other hand, in farms with alternate grazing with horses and bovine has recorded a decrease in nematode egg excretion in horses by 50% compared with a horse grazing system (Forteau, *et al*., 2020).

d) Other evaluated methods are, i.e. sodium hypochlorite and citric extracts, these alternatives were evaluated on laboratory conditions and showing good control results after this step methods were in field conditions, but it is necessary to assess their effect on the environment (González-Garduño, *et al*., 2010). Besides were evaluate on laboratory conditions sawdust of different trees species like pochote (*Bombacopsis quinata*), melina (*Gmelina arborea*), ciprés (*Cupressus lusitanica*) y teca (*Tectona grandis*), recording effects from 65.38% of reduction of larvae in the culture for teca; 87.57% of reduction for pochote; 91.46% for Melina and finally 97.94% of reduction for ciprés; sawdust were collected in sawmills and are promising; although they are not proved yet at field conditions (Álvarez *et al*., 2007).

2. Stimulate the host response to withstand or set up an immune response

Different methods help hosts to resist the parasites or to set up an immune response against them. The latter is mediated by the coevolutive history of the species as well as epidemiological factors. Among these strategies exists ones to help the host to repair the damage induced by parasites and them that stimulate the immune response (Torres-Acosta & Hoste, 2008).

a) Vaccines againts nematodes

Vaccines are a way to protect animals through the stimulation of immunity in this manner the host can deal with the field parasites infection due to the defense system recognize the etiological agent and can develop an immune response to oppose and eliminate from the body the etiological agent. There is a huge market in this field due to a large number of animals (18 billion) and an enormous interest of researchers to find the best way to immunize animals; regrettably, there are few effective vaccines to protect productive animals from helminths (Morrison & Tomley, 2016).

The latter could be due to the complexity and diversity of parasites involves and due to the complexity of the immune response such as macrophages antibody-dependent, granulocytes natural killers dependent of antibodies and non-lymphoid action of particular way at the intestinal level (Hewitson & Maizels, 2014). Despite these factors nowadays, has been developed vaccines against the *Dictyocaulus viviparus* nematode in bovine, *Haemonchus contortus* in sheep and the cestode *Echinococcus granulosus* in sheep (Claerebout & Geldhof, 2020).

– *Vaccine against Dictyocaulus viviparus in bovine.* Vaccines are composed of X-ray irradiated larvae, these vaccines stimulate a strong immune response and they have been effective to reduce the dictyocaulosis outbreaks (McKeand, 2000). Strube *et al*. (2015) in their study found that a dosage of a suspension of 1000 to 2000 irradiated larvae (Bovilis, Huskvac, MSD animal health, Ireland) had an impact on the number of adult parasites which was reduced by 93.3%; in this context, the low number of adults parasites affected the larvae excretion on feces which decreased by 93.5%; these results show that the vaccine have a good effectivity to reduce the grasslands larval contamination and therefore to avoid new reinfections during the grazing.

– *Vaccine against Haemonchus contortus of sheep.* The intestinal antigen was discover 20 years ago and, it was reported these specific antigens could neutralize enzymes related to the digestive process of the adult parasites (Smith & Smith, 1993). Two different studies prove the vaccine and have obtained the following results:

i. In their study, Bassetto *et al*. (2014) using doses of 50 mg, 5 mg in groups of males and females and their related control groups; found that females, despite to show titles of antibodies against *H. contortus* these antibodies were not high enough to show an effect over the variables of fecal egg count and hematocrit and some females had to be dewormed due to low hematocrit; on the other hand, males developed a strong immunity, until ten folds compared with females, and the 5 mg dose had the best results by significantly reducing the egg counts per gram of feces without affecting the hematocrit, finding a reduction in eggs per gram of up to 72% during the experiment. The physiological demand of pregnancy affects the immunity development (Valderrábano *et al*., 2006), however, females immunized when they were lambs were better protected during their adult life (Bassetto *et al*., 2014).

ii. Teixeira et al. (2019) report that vaccines show good protection in tropical conditions, where the rainy and dry seasons are well established. The application of the first dose at the beginning of the wet season decreased the eggs per gram count by 90%, and four more applications were enough to protect the sheep until the end of the trial when the risk of exposition decreased. In addition, they report that lambs of vaccinated females receive this immunity through colostrum and can be vaccinated until the next wet season.

The main effect of the vaccines is to decrease the *H. contortus* female parasites oviposition which in turn reduces the pasture contamination (Barnes *et al*., 1995). However, the trial was executed to prevent the oviposition of the parasite females during the wet season; these authors recommend this model of control and argue is not expensive and do not has a withdrawal time (Teixeira *et al*., 2019).

b) Genetic selection

Even though the exact mechanism is not yet known, naturally exist some animals which are capable to withstand the detrimental effects of parasites infections, these type of animals present reduce parasites implantation, reduced parasites burden, and low quantity of excreted eggs to the grasslands which bring with it a reduction in the infectivity of the pasture (Hoste & Torres-Acosta, 2011). In countries like Australia and New Zeland, some enterprises which produce sheep have been reduce the use of commercial anthelmintics by using genetic selection based on the test of reduction of fecal egg count this test is used to select animals naturally resistant to nematodes (Hunt *et al*., 2008). Some reports show that the use of progeny test under standardized conditions is an appropriate alternative to evaluate genetically for resistance to gastrointestinal nematodes (Heckendorn *et al*., 2017).

In this sense, it has been shown that livestock associations of producers can select their studs and establish programs directed to prove the futures studs, consistent of artificially infecting them with some specific parasite strain, evaluate the challenge, and using it as a phenotypical resistance test. This methodology allowed select the parents of future generations and, at the same time, this selection enable improving the resistance of the descendant females of this program even under high natural levels of infection (Aguerre *et al*., 2018). Recently have been published works that propose the genetic markers as a quick way to select naturally resistant animals to nematodes, the DIS3L2 gene is suggested for Katahdin sheep (Becker *et al*., 2020). As well as the role of simple nucleotide polymorphism of genes of immune response located on OAR3 and other sections of the genome of Corriedale and Pampinta sheep (Raschia *et al*., 2021).

c) Use of nutrition

The pathological effects caused by nematodes in animals result in more nutritional needs and a decrease in animals productive indicators and is considered an important factor to tolerate the parasitosis caused by nematodiasis (Burke & Miller, 2020). It mentions that the level of protein is necessary for this context, however, recent literature has identified that the balance between protein and energy of the diet is essential to maintain adequate health status and tolerate the presence of the parasites (Méndez-Ortíz et al., 2019)

And it is reported that in humid tropics environment where leguminous are an essential part of the diet of small ruminants, supplementation with an energy source like sorghum, maize, or molasses of sugar cane, by itself improve the resilience of the animals to parasites (Gárate-Gallardo *et al*., 2015; Hoste & Torres-Acosta, 2011). There are reports of the supplementation use to control nematodiasis, i.e. in one experiment, the authors administrated 200g/d of pelletized food of cotton seed (384g/kg/ DM; 12 MJ/kg DM; approx. 45% of dietetic protein non-degradable in the rumen) three times a week, Monday, Wednesday and Friday to merino sheep during prepartum and found that protein supplementation was effective to increase the body weight, fat, and muscle of the carcass of female sheep and this effect moved to the lamb's weight (Macarthur *et al*., 2014). Similar results were reported by Houdijk *et al*. (2012)

They used merino sheep and a supplement (400 g/d) with this level of supplementation achievement decrease the fecal egg count (fewer grasslands contamination) and positively affected the sheep body weight. In addition, reduce the use of anthelmintics by 33% and improve lambs weight gain by 20% (Houdijk *et al*., 2012).

In other experiment Crawford *et al*. (2020) studied changes in the source of protein in a series of trials, using pellets of alfalfa with 15% of protein, maize and soybean flour with 19% of protein, and maize, soybean flour, and fish mixed flour with 19%; the flours were administered at 1.28% for alfalfa and 1% for the others supplements to equally the administered protein and using Suffolk sheep; these authors found that fish mixed flour as a non-degradable rumen protein source increase the body weight, hematocrit, reduce the FAMACHA and the fecal egg count and these changes occurs when the addition of flour reach the 2% of the animal's bodyweight.

In humid tropical conditions where exists an abundance of tropical leguminous, which are a source of natural protein, it has been tested supplement strategies only with energy, since protein requirements are acquired from grazing. As an example, exist the work of Gárate-Gallardo *et al*. (2015) in this trial one group of animals was fed with 108g fresh basis of ground maize, and two more groups were fed with ground maize at 1% and 1.5% daily, and the control group remain without supplementation; it is found animals supplemented with 1.5% of body weight increased their daily weight gain in24% compared to animals infected a no supplemented, besides, there was a decrease in the fecal egg count by 55% and the partial budget shows better total gains and a net gain of 5.8 dollars per animal (Gárate-Gallardo *et al*., 2015). Similarly, it is reported that the use blocks of urea-molasses decrease the fecal egg count and help animals to withstand the detrimental effects of the parasite and getting gains plus 45% in treated animals (Waruiru *et al*., 2004).

3. Eliminate parasites from the host

a) Use of cooper oxide wire particles.

Copper oxide wire particles are commercial products used to treat deficiencies of this mineral in livestock in deficient areas, the wire particles lodge in the abomasum of the animals from where they degrade and give off copper ions, however, when producers use this product they observe that gastrointestinal nematodes loads, were also reduced; the use of 5 grams of this mineral supplement reduced the parasite loads in sheep by 96% for the case of Haemonchus contortus; by 56% in the case of Ostertagia circumcincta and did not affect Tricostrongylus colubriformis because it is intestinal and not an abomasal parasites (Bang *et al*., 1990). Recently, in a semi-arid region of Kenia, Africa, a trial using 45 indigenous goats in a free-grazing system was conducted, authors reported that the use of copper oxide particles in a dose of 1.7 g of copper (Copinox®, Animax Ltd, UK) did not significantly reduce the fecal egg count, however, after animals were humanely slaughtered, it was observed a reduction in the number of adult parasites by 58.8% for the abomasal nematode Haemonchus contortus; by 9.1% for the intestinal nematode Trichostrongylus colubriformis; and by 16.7% for the nematode Oesophagostomum venulosum (Waruiru *et al*., 2017).

In another study, carried out in North Carolina, USA, using Dorset Katahdin, and Barbados sheep with ages of 3 months and with one or two applications of two-gram capsules (Copasure®, Animax) on days 0 and 42, reductions were reported; for the double application of the copper oxide wire particles by 78.4% at the end of the experiment; while in sheep treated on one occasion there were reductions by 53.7%; on the other hand, slight improvements in weight gains and hematocrit were reported (Schweizer *et al*., 2016).

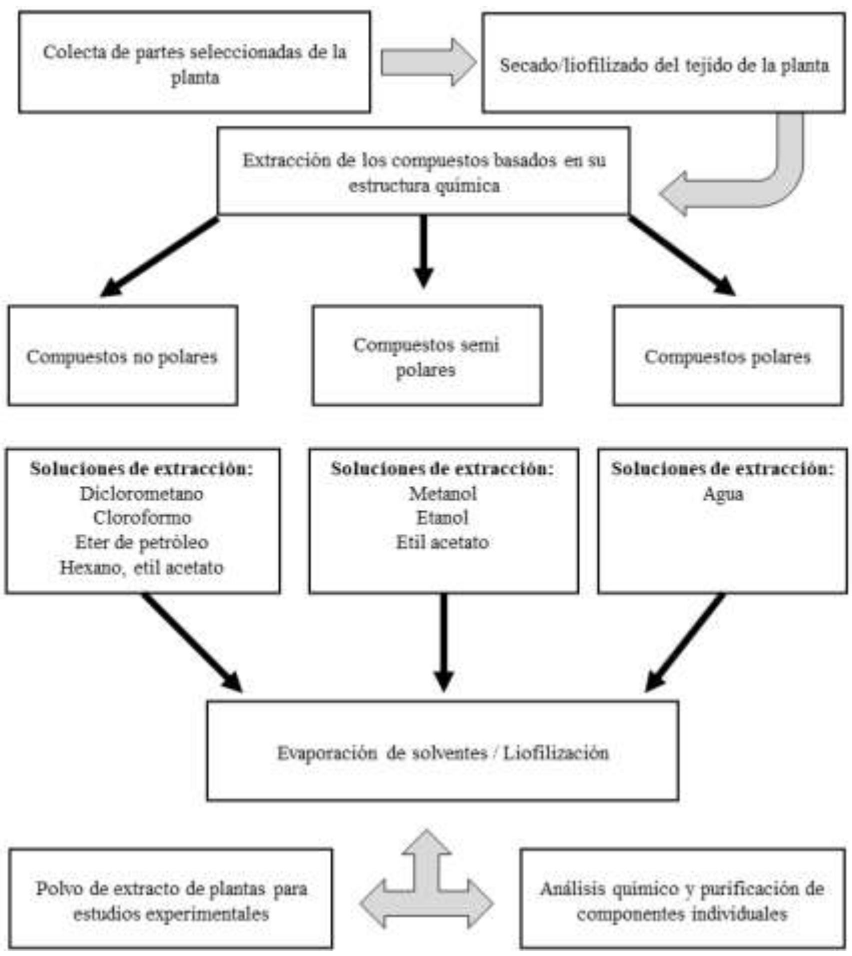
In another study, Campigotto *et al*. (2019) in a trial carried out on a farm in Brazil with multiparous lactating females of the Lacaune breed and with the use of two 1.74 g copper capsules (Copasure®, Animax, UK) in a humid subtropical climate the treated groups had significantly lower fecal egg counts from day 15 post-application.

b) Use of biactive products of plants and herbs

With the development of anthelmintic resistance to broad-spectrum families of antiparasitics currently used, one of the alternatives that have developed the most is the search for plants and herbs as a part of the local pharmacopeia. Plants play a critical role in maintaining human and animal life in harmony; they have interactions with herbivores parasites, and establish interactions and affect them in various ways (Mendoza-de-Gives *et al*., 2012). Before creating modern anthelmintics, humans used plants to control parasites of both humans and those that affect livestock in empirical way (Mendoza-de-Gives et al., 2012). Different studies confirm the effectiveness of these plants; and some commercialized products contain mixtures of plant extracts and use as supplements in diet (Castagna *et al*., 2019).

On the other hand, some effects of these plants contribute by reducing the dynamics of parasite infections, reducing the contamination of grasslands. In addition, it has a positive effect on the resilience of animals (Hoste & Torres-Acosta, 2011). Different plants and plant parts have been studied; however, different results have been obtained, the latter since plants produce different metabolites that in turn are influenced by the time of year, temperature and amount of rainfall recorded, plan growth periods, parts composing the plant, predation degree (herbivory) (Garcia-Bustos *et al*., 2019). There are different methodologies to test and use these plants, they have been proved in vitro and in vivo employing extracts made with different groups of solvents with different polarity grades that can extract the different secondary compounds from the plants, followed by a lyophilization process for their conservation and subsequent use (Fig. 7.2) this has also been tested with plant materials dried in stoves and with plants offered as food on a fresh basis (Hrckova & Velebny, 2013).

Figure 7.2 schematic representation of steps to obtain the groups of phytochemical compounds of plants



Reference Source: (Hrckova & Velebny, 2013).

Different substances with anthelmintic potential have been reported in this list it can find:

Fenoles

These substances are the most widely distributed in nature, are components of natural products which include: monophenols or terpenoids (thymol, cresol, and carvacrol); benzenediols (catechols and resorcinols); flavonoids (quercetin); substitutes of benzoic acid (gallic acid and vanillic acid), and cinnamic acid; their antiparasitic potential comes from its antioxidant properties (Garcia-Bustos *et al*., 2019). Different studies report the efficacy of these substances. In in vitro study, is reported that carvacrol and thymol at doses of 0.33 mM (0.05 mg/ml) cause the death of the Ascaris suum parasite more than 80% (Lei, Leser, & Enan, 2010). While the hatching of Haemonchus contortus eggs at a dose of 0.781 mg/mL decreased by 90%, finally larval motility reduced by 97% with a dose of 3.125 mg/mL (Ferreira *et al*., 2016).

Another promising substance belonging to the polyphenols group (tannins, flavonoids, and isoflavonoids) is the cinnamic acid and its derivatives which are obtained from the Acacia cochliacantha plant leaves; this substance is extracted with less polar solvents which collect fractions with the best anthelmintic effect. These extracts decrease the hatching of H. contortus eggs using doses of 1 mg/mL more than 98% (Castillo-Mitre *et al*., 2017). While extracts of the A. cochliacantha plant foliage on a dry basis and inclusions of 10% fecal egg count decrease more than 50% in Creole kids (León-Castro *et al*., 2015).

Tannins

These chemical compounds are a highly studied group of polyphenols, and several studies have been developed to prove their efficacy both live and in vitro. In this regard, a study using sheep fed with Sulla (Hedysarum coronarium) with a percentage of inclusion in the diet of between 10 and 12% of dry matter and with artificial infections with Trichsotrongylus colubriformis and Teladorsagia, it is reported a reduction in fecal egg counts and the load of Teladorsagia (abomasal parasite) was reduced by 48%, but there was no effect on T. colubriformis which is an intestinal parasite (Niezen *et al*., 2002). On the other hand, it is reported that the acetone/water extract of the sainfoin plant (Onobrychis viciifolia) alters the anatomy of the larvae of H. contortus and T. colubriformis at the hypodermis sections since separations were observed between the cuticle and the hypodermis; on the other hand, muscle degradation, and lysis of the non-striated region with disruption of the organelles and swollen cytoplasm were observed (Brunet *et al*., 2011). In live studies, it is observed, after the recovery of adult nematodes from goats fed a plant rich in tannins Lysiloma latisiliquum supplied to the animals at a rate of 800 g fresh base that parasites suffer pathological damage such as vacuolization of their muscle cells, and hypodermic, which damages motility, nutrition and could eventually damage your reproductive processes (Martínez-Ortiz-De-Montellano *et al*., 2019).

The use of another tropical plant, Havardia Albicans, administered to sheep at a rate of 14 g / kg of live weight and with artificial infections, found that the use of this plant decreased the excretion of fecal eggs by 58.8% (Francisco Alejandro Méndez-Ortíz, Sandoval-Castro, & Torres-Acosta, 2012). The use of this plant also showed a reduction in parasitic female's size by 7% and a significant decrease in the parasite female's fertility (Galicia-Aguilar *et al*., 2012). In the same way, the use of Sericea lespedeza pellets, either from leaves or the whole plants (stems and leaves) include at 50% of the diet of goats for 42 days, had significant reductions in the nematode fecal egg count, and even had an effect on coccidia oocyst count from day 7 to 42; an antiparasitic effect was observed when including at 25% of the diet, however, it was more effective for the leaf pellet diet group (Dykes *et al*., 2019).

Terpenos

Terpenes also have been tested, and their nematicidal effect reported. The essential oils of Melaleuca alternifolia at a dose of 1.7 mg/mL reduce the hatching of H. contortus eggs by 98%, and at doses of 56 mg/mL reduce larval motility until 88% (Grando et al., 2016). (Grando *et al*., 2016).

Saponins

Saponins are a group of triterpenoids reported with an inhibitory effect against parasites of animals. These substances are obtained from oats and edible mushrooms. In one study, extracts of Calotropis procera were tested with the techniques of egg hatching and larval development tests using different concentrations; at a dose of 4 mg/mL, the hatching of H. contortus eggs was reduced by 91.8%, and at 2 mg/mL, it was reduced by 48.2%; while at 1 mg/mL, larval development decreased by 99.8% (Cavalcante *et al*., 2016). On the other hand, the use of Zizyphus joazeiro bark showed an antiparasitic activity over the egg hatch with a mean lethal concentration value of 90% at 1.79 mg/mL; the extracts did not affect the larval stages and motility on H. contortus (Gomes *et al*., 2016). In the same manner, the ethanol-water extract of the basidiocarp of the edible fungus Pleurotus djamor was studie to know the ovicidal and larval motility inhibition effects on H. contortus parasite; the extract was fractionated by phases using silica gel column chromatography; and a fraction with 100% inhibition of hatching was found at a dose of 10 mg/mL, after 72 hours of exposure, the latter fraction contained free fatty acids ≤ 1% of the triterpenoid β-sitosterol (Pineda-Alegría *et al*., 2017).

There are compounds or mixtures of herbs or plants, that are on sale to the public for the control of nematodes, some extracts of plants of the *Lauraceae* family, in addition to some Australian species of *Hylandia* and *Fontainea* (Garcia-Bustos *et al*., 2019). In this context, it is relevant to test these commercial products, to know their anthelmintic activity. A product with a mixture of plants from the *Compositae*, *Cesalpinacae*, *Liliacae*, *Bromeliaceae*, and Labiatae families, which provide anthelmintic ingredients such like essential oils, resins, tannins, organic acids, and mucilages, was tested; the product was given at a dose of 10g and 20g per lamb which are the highest doses; these mixtures reduced parasite loads until 33%, according to the formula used to calculate the efficacy of commercial drugs, in this sense, the authors recommended that the use of these substances should be accompanied by other control strategies such as those outlined above to complement the control and reduce dependence on commercial antiparasitic (Castagna *et al*., 2019).

Use of by-products to control gastrointestinal nematodes

The agro-industrial and livestock sector by-products represent sources of environmental pollution, and their management is a key element to reduce this pollution; around 16 million tons of agro-industrial by-products are produced just in Europe. Therefore, use these kinds of waste as ingredients back in the food chain is crucial to prevent contamination (Correddu *et al*., 2020). In this sense, they have tried agro-industrial by-products such as those generated by the cocoa industry (Cocoa), coffee waste (coffee percolation), peanut waste, hazelnut waste, and Yucca. For the case of Theobroma cacao, it has proved extracts of the leaves of the annual pruning, and the peel of the fruit of three cacao species (AZT, CAL, and CEY). The result showed good nutritional values since leaves and peel are rich in protein, the latter assessed throughout a proximate analysis: parasitological in vitro tests showed that both extracts can stop larvae unsheathing, although leaves extract is better and when exposing the larvae to extract of the variety CAL damage to the sheath and muscles were observed (Mancilla-Montelongo *et al*., 2021).

On the other hand, it has been reported that cocoa husk and pulp extract produce an ovicidal effect, that kills nematode eggs at doses of 1200 µg/mL for pulp and 2400 µg/mL for shell (Vargas-Magaña *et al*., 2014). In the case of the coffee percolate residue, a water acetone extract was made and its effect in vitro and in vivo was evaluated, two varieties of coffee (Clean and Smooth (CS) and Shade Grown (SG) Starbucksĭ) were used with the inclusion of 100 g of coffee percolating in a comprehensive diet, for the in vivo test, growing sheep were used, and is reported that the CS strain showed anthelmintic effect from 150 µg/mL, while the SG strain reached 1200 µg/mL, for the in vivo effect 100 g of inclusion in the diet did not decrease the number of eggs found a reduction of only 10% (Ortiz-Ocampo *et al*., 2016). For the case of the inhibition of hatching, is reported that the acetone extract water from the percolate of Coffea arabica; Garat®, Mexico does not produce a significant effect (Vargas-Magaña *et al*., 2014). For peanut (Arachis hipogaea) and its methanolic and lichen extracts, anthelmintic activity was reached at concentrations of 10 to 15 mg/mL for the methanol extract, achieving inhibitions of 66% and 79% respectively, while for the lichen extract the inhibition was reached at 62% and 71% respectively and at doses of 20 mg/mL is reported 87% and 80% of efficacy respectively (Tahir *et al*., 2020).

Its effect in vivo as a supplement in meat-producing goats has also been studied and it was found that using 15% and 30% inclusions animals improve their daily weight gain, finding a better yield with the inclusion of 15%, on the other hand, the fecal accounts of eggs of nematodes were reduced 36% and 71% respectively for the percentages of inclusion (Min *et al*., 2019). Another important product is banana bracts, which were dried and ground lately hydroalcoholic extracts were made and tested within vitro tests for egg hatching and larval migration assay; the best inhibition of hatching was achieved with a concentration of 2.5 mg/mL, achieving 88% inhibition, while the best inhibition of motility was achieved with the concentration of 5 mg/mL (Kakimori *et al*., 2019). For the case of Yucca (Manihot esculenta), the use of the methanolic extract of the leaves of Yucca at a dose of 2400 µg/ml was effective to inhibit larval development (of L1 L3), on the other hand, when included in the diet, yucca foliage in an amount of 450 g/lamb/day the average excretion of fecal egg count is decreased by 41%, and the development of eggs to larvae reduced by 60% (Marie-Magdeleine *et al*., 2010; Marie-Magdeleine *et al*., 2010).

Combined use of alternative methods

The resistance of living organisms to different substances used for their control is a natural process of defense, therefore, the sustainability of the control strategies used against gastrointestinal nematodes of ruminant must be based on the use of several alternative methods together (Hoste & Torres-Acosta, 2011). In addition, this group of strategies must be suitable to the production system, which is why is difficult to carry out this kind of evaluation, however, some works evaluate the combination of methods. In this regard, the use of copper oxide particles and the nematophagous fungus *Dudingtonia flagrans* has been combined, and it was found that the use of copper oxide particles did not affect the ability of the fungus to trap nematode larvae and found a beneficial effect of treating the animals with copper and fungus as they excreted fewer eggs and the larvae are trapped by the fungus which means less contamination of the meadow resulting in a lower dose infection for the animals (Burke *et al*., 2005). The use of copper oxide particles and food supplementation in goats has been evaluated with good results (Martínez-Ortiz-de-Montellano *et al*., 2007).

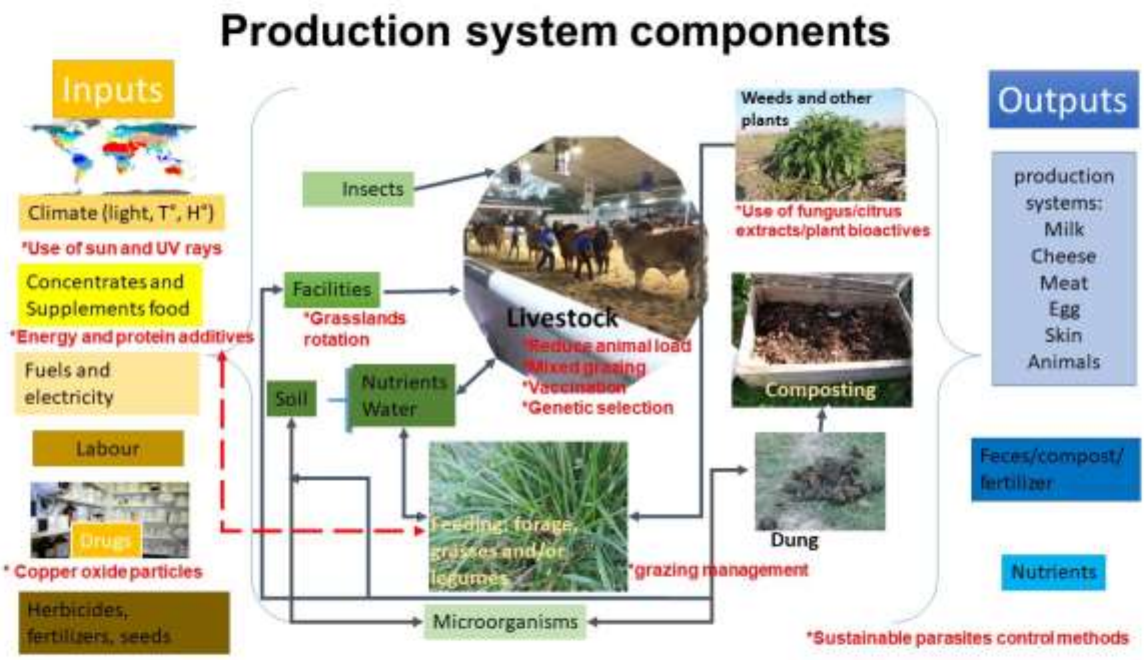
The use of nutritious materials with secondary plant metabolites improves nutrition and affects parasites was also evaluated, and a decrease in periparturient relaxation of immunity is reported (Kidane *et al*., 2010). Fruit flour of native tropical species (*Caesalpinia coriaria*) with anthelmintic potential and a percentage of inclusion of 10% and the use of overpass soybean protein to improve animal nutrition has been tested, in this context, there is an effect on parasites attributed to tannins and the combination of fruit flour with soybean paste shows a protective effect on the protein reaching its greatest effect at the ratio 80:20 (Palma-García *et al*., 2019). Alternative control methods are not potentiated between them, they have additive effects if they are alternatives that affect in a different way parasite, that is to say, they are focused on different biological stages of the parasite (Hoste & Torres-Acosta, 2011).

Conclusion

It must be recognized that the control of parasites in a sustainable way is not an absolute concept given the different regions and productive systems of the world and, therefore, could have different levels of adoption and impact on farmers (Henrioud, 2011). Therefore, for control programs of parasites in productive systems to be sustainable, a type of management of parasite behavior is required, this management seeks to minimize the damage caused by parasites, not control them excessively (selection pressure), and carry out a preventive approach that pays close attention to changes at the ecosystem level caused by human activities and that are suited to the productive system in a particular way. The challenge is to use good animal husbandry practices and the principles of integrated parasite management (IPM) in a pragmatic way that allows sustainability in production; For this reason, the aspects proposed by Horwitz & Wilcox, (2005) must be considered, which among their recommendations include:

- Put Attention to the host's ability to resist infection through its well-being, nutritional status, and/or immune system.
- Ensuring the strategic application of chemical controls; only in combination with other practices.
- Habitat management to maximize the effects that other organisms might have on the parasite.
- Continuous analysis of each component of the production system (Figure 7.3) to know when and where to implement or modify the parasite control approach and even identify those factors that are influencing the presentation of parasites at a certain moment

Figure 7.3 Relationship of parasite control methods and the components of the production system to reach sustainability



Reference Source: author´s own elaboration

Several authors agree that the management of alternative methods of parasite control should take into account the different stages of the life cycle of parasites to find strategies that affect parasites at different sites of action: i) modulating its biology, ii) increasing the resistance and resilience of the host, iii) decreasing its amount in the pastures Table 7.1 (Burke & Miller, 2020); for example, the use of copper oxide particles either in combination with secondary plant metabolites affecting the larval establishment, grazing systems that minimize infection and improve the nutritional status of animals that increase their resilience and resistance to gastrointestinal nematodes, in this sense the selective use of anthelmintics is not ruled in production systems (Burke & Miller, 2020).

Tabla 7.1 Alternative control methods for gastrointestinal nematodes in ruminant livestock

Método	Objetivo
Copper oxide particles	Adults *Haemocnhus contortus* parasite
Plant secondary compounds	*Haemocnhus contortus* adults and other gastrointestinal nematodes depending on plant species; possible involvement of larval development
Nematophagous fungi	Free-living stages of the nematode larva
Genetic resistance	All parasitic stages of nematodes

Reference Source: (Joan M. Burke & Miller, 2020)

Similarly, owners of animal production systems should use the alternative control method available to them, considering the epidemiological characteristics of the production area, and do not forget the importance of anthelmintic selective treatments. As examples include some systems in use in northern and southern regions of the United States of America Tables 7.2 and 7.3 (Hildreth & McKenzie, 2020; Navarre, 2020). On the other hand, some techniques make a progressive adaptation in the management of the herd, coherent with practices used by farmers in terms of time and space, in such a way an analysis of the possible combinations of the management of the resources of grazing, the management of production, the epidemiology of gastrointestinal nematodes are used as models of parasitic infections to find the management that minimizes risks and increases production (Napoléone *et al*., 2011).

Table 7.2 Determinants of the prevalence and degree of cattle nematodosis

Nature of challenge
Overriding determinants
Climate
Weather
Season
Region
Pasture and management determinants
Pasture quality and productivity
Pasture type
Pasture topography and drainage
Grazing management: age group separation, alternate species, stocking rates, rotation, supplemental feeding
Production type: dairy (confined vs pastured), beef (stocker vs cow/calf vs feedlot, etc)
Animal-based determinants
Immunologic status
Physiologic status
Health
Nature of parasiticidal effort
Effectiveness of parasiticide usage
Effectiveness of product: spectrum of activity, larvicidal versus adulticidal, degree of resistance
Persistence of product Diminished efficacy: formulation considerations (topicals vs injectables, etc), dietary considerations (gut flow, ingredients, closures, etc), generics
Coordination of epidemiology with treatment
Time and extent of posttreatment challenge

Reference Source: (Navarre, 2020)

Table 7.3 Principles of control of gastrointestinal nematodes in cattle in the Southern United States

Increase overall herd immunity
Proper nutrition Decrease stressors Decrease other disease pressures
Graze cows after calves
Maintain biosecurity practices to prevent introduction of resistant GIN with herd additions
Incorporate resistance to GIN in genetic selection programs
Keep refugia
Avoid deworming all animals before turnout onto clean pastures - Especially critical with macrocyclic lactones and other long-acting products In cow/calf operations consider only deworming cattle younger than 5 years and allow older cows to serve as refugia - Be aware of special circumstances that may alter this recommendation such as nutritional stress, treatment of liver flukes
Use and store products properly
Always use at least 2 classes of anthelmintics at the same time Dose based on actual weights if possible Do not store products at the processing area unless it is climate controlled - Follow label directions for storage

Reference Source: (Navarre, 2020)

References

Aguerre, S., Jacquiet, P., Brodier, H., Bournazel, J. P., Grisez, C., Prévot, F., … Moreno, C. R. (2018). Resistance to gastrointestinal nematodes in dairy sheep: Genetic variability and relevance of artificial infection of nucleus rams to select for resistant ewes on farms. *Veterinary Parasitology*, *256*(December 2017), 16–23. https://doi.org/10.1016/j.vetpar.2018.04.004

Álvarez, C. V., Hernández, J., & Wingching, R. (2007). Eficacia de aserrines para inhibir el desarrollo in vitro de larvas de parásitos gastrointestinales de ovinos. *Agronomía Costarricense*, *31*(1), 71–75.

Bang, K. S., Familton, A. S., & Sykes, A. R. (1990). Effect of copper oxide wire particle treatment on establishment of major gastrointestinal nematodes in lambs. *Research in Veterinary Science*, *49*(2), 132–137. https://doi.org/10.1016/s0034-5288(18)31065-8

Barger, I. A., Siale, K., Banks, D. J. D., & Le Jambre, L. F. (1994). Rotational grazing for control of gastrointestinal nematodes of goats in a wet tropical environment. *Veterinary Parasitology*, *53*(1–2), 109–116. https://doi.org/10.1016/0304-4017(94)90023-X

Barnes, E. H., Dobson, R. J., & Barger, I. A. (1995). Worm control and anthelmintic resistance: adventures with a model. *Parasitology Today*, *11*(2), 56–63. https://doi.org/10.1016/0169-4758(95)80117-0

Bassetto, C. C., Picharillo, M., Newlands, G. F. J., Smith, W. D., Fernandes, S., Siqueira, E. R., & Amarante, A. F. T. (2014). Attempts to vaccinate ewes and their lambs against natural infection with Haemonchus contortus in a tropical environment. *International Journal for Parasitology*, *44*(14), 1049–1054. https://doi.org/10.1016/j.ijpara.2014.07.007

Becker, G. M., Davenport, K. M., Burke, J. M., Lewis, R. M., Miller, J. E., Morgan, J. L. M., … Murdoch, B. M. (2020). Genome-wide association study to identify genetic loci associated with gastrointestinal nematode resistance in Katahdin sheep. *Animal Genetics*, *51*(2), 330–335. https://doi.org/10.1111/age.12895

Brunet, S., Fourquaux, I., & Hoste, H. (2011). Ultrastructural changes in the third-stage, infective larvae of ruminant nematodes treated with sainfoin (Onobrychis viciifolia) extract. *Parasitology International*, *60*(4), 419–424. https://doi.org/10.1016/j.parint.2010.09.011

Burke, J. M., Miller, J. E., Larsen, M., & Terrill, T. H. (2005). Interaction between copper oxide wire particles and Duddingtonia flagrans in lambs. *Veterinary Parasitology*, *134*(1–2), 141–146. https://doi.org/10.1016/j.vetpar.2005.06.018

Burke, J. M., Miller, J. E., & Terrill, T. H. (2009). Impact of rotational grazing on management of gastrointestinal nematodes in weaned lambs. *Veterinary Parasitology*, *163*(1–2), 67–72. https://doi.org/10.1016/j.vetpar.2009.03.054

Burke, Joan M., & Miller, J. E. (2020). Sustainable Approaches to Parasite Control in Ruminant Livestock. *Veterinary Clinics of North America - Food Animal Practice*, *36*(1), 89–107. https://doi.org/10.1016/j.cvfa.2019.11.007

Campigotto, G., Gebert, R. R., Santos, D. S., dos Reis, J. H., Alba, D. F., Cazarotto, C. J., … Da Silva, A. S. (2019). Effects of oral administration of copper capsules on helminth control in lactating dairy sheep: An effective alternative to replace conventional antiparasitics during lactation. *Experimental Parasitology*, *205*(July), 107735. https://doi.org/10.1016/j.exppara.2019.107735

Castagna, F., Palma, E., Cringoli, G., Bosco, A., Nisticò, N., Caligiuri, G., … Musella, V. (2019). Use of complementary natural feed for gastrointestinal nematodes control in sheep: Effectiveness and benefits for animals. *Animals*, *9*(12). https://doi.org/10.3390/ani9121037

Castillo-Mitre, G. F., Olmedo-Juárez, A., Rojo-Rubio, R., González-Cortázar, M., Mendoza-de Gives, P., Hernández-Beteta, E. E., … Zamilpa, A. (2017). Caffeoyl and coumaroyl derivatives from Acacia cochliacantha exhibit ovicidal activity against Haemonchus contortus. *Journal of Ethnopharmacology*, *204*, 125–131. https://doi.org/10.1016/j.jep.2017.04.010

Cavalcante, G. S., de Morais, S. M., Andre, W. P. P., Ribeiro, W. L. C., Rodrigues, A. L. M., De Lira, F. C. M. L., … Bevilaqua, C. M. L. (2016). Chemical composition and in vitro activity of Calotropis procera (Ait.) latex on Haemonchus contortus. *Veterinary Parasitology*, *226*, 22–25. https://doi.org/10.1016/j.vetpar.2016.06.012

Claerebout, E., & Geldhof, P. (2020). Helminth Vaccines in Ruminants: From Development to Application. *Veterinary Clinics of North America - Food Animal Practice*, *36*(1), 159–171. https://doi.org/10.1016/j.cvfa.2019.10.001

Correddu, F., Lunesu, M. F., Buffa, G., Atzori, A. S., Nudda, A., Battacone, G., & Pulina, G. (2020). Can agro-industrial by-products rich in polyphenols be advantageously used in the feeding and nutrition of dairy small ruminants? *Animals*, *10*(1), 1–25. https://doi.org/10.3390/ani10010131

Crawford, C. D., Mata-Padrino, D. J., Belesky, D. P., & Bowdridge, S. A. (2020). Effects of supplementation containing rumen by-pass protein on parasitism in grazing lambs. *Small Ruminant Research*, *190*(August 2019), 106–161. https://doi.org/10.1016/j.smallrumres.2020.106161

de Gives, P. M., Lopez Arellano, M. E., Libano, E., & Aguilar, L. (2012). Plant Extracts: A Potential Tool for Controlling Animal Parasitic Nematodes. *The Biosphere*. https://doi.org/10.5772/34783

de Montellano, C. M. O., Vargas-Magaña, J. J., Aguilar-Caballero, A. J., Sandoval-Castro, C. A., Cob-Galera, L., May-Martínez, M., … Torres-Acosta, J. F. J. (2007). Combining the effects of supplementary feeding and copper oxide needles for the control of gastrointestinal nematodes in browsing goats. *Veterinary Parasitology*, *146*(1–2). https://doi.org/10.1016/j.vetpar.2007.02.012

Fernández-Reynoso, D. S., Martínez-Menes, M. R., Ramírez-Cruz, H., & López-Velasco, O. (2012). *Capacidad de carga e índices de agostadero*.

Ferreira, L. E., Benincasa, B. I., Fachin, A. L., França, S. C., Contini, S. S. H. T., Chagas, A. C. S., & Beleboni, R. O. (2016). Thymus vulgaris L. essential oil and its main component thymol: Anthelmintic effects against Haemonchus contortus from sheep. *Veterinary Parasitology, 228,* 70–76. https://doi.org/10.1016/j.vetpar.2016.08.011

Forteau, L., Dumont, B., Sallé, G., Bigot, G., & Fleurance, G. (2020). Horses grazing with cattle have reduced strongyle egg count due to the dilution effect and increased reliance on macrocyclic lactones in mixed farms. *Animal*, *14*(5), 1076–1082. https://doi.org/10.1017/S1751731119002738

Galicia-Aguilar, H. H., Rodríguez-González, L. A., Capetillo-Leal, C. M., Cámara-Sarmiento, R., Aguilar-Caballero, A. J., Sandoval-Castro, C. A., & Torres-Acosta, J. F. J. (2012). Effects of Havardia albicans supplementation on feed consumption and dry matter digestibility of sheep and the biology of Haemonchus contortus. *Animal Feed Science and Technology*, *176*(1–4), 178–184. https://doi.org/10.1016/j.anifeedsci.2012.07.021

Gárate-Gallardo, L., Torres-Acosta, J. F. D. J., Aguilar-Caballero, A. J., Sandoval-Castro, C. A., Cámara-Sarmiento, R., & Canul-Ku, H. L. (2015). Comparing different maize supplementation strategies to improve resilience and resistance against gastrointestinal nematode infections in browsing goats. *Parasite*, *22*(June). https://doi.org/10.1051/parasite/2015019

Garcia-Bustos, J. F., Sleebs, B. E., & Gasser, R. B. (2019). An appraisal of natural products active against parasitic nematodes of animals. *Parasites and Vectors*, *12*(1), 1–22. https://doi.org/10.1186/s13071-019-3537-1

Gomes, D. C., de Lima, H. G., Vaz, A. V., Santos, N. S., Santos, F. O., Dias, Ê. R., … Batatinha, M. J. M. (2016). In vitro anthelmintic activity of the Zizyphus joazeiro bark against gastrointestinal nematodes of goats and its cytotoxicity on Vero cells. *Veterinary Parasitology*, *226*, 10–16. https://doi.org/10.1016/j.vetpar.2016.06.004

González-Garduño, R., Cordero-Ortega, J. C., Torres-Hernández, G., Arece-García, J., & Mendoza-de-Gives, P. (2010). Efecto del hipoclorito de sodio y extracto de cítricos en la reducción de la infestación con nematodos gastrointes. *Revista Mexicana De Ciencias Pecuarias*, *1*(2), 179–187.

Grando, T. H., De Sá, M. F., Baldissera, M. D., Oliveira, C. B., De Souza, M. E., Raffin, R. P., … Monteiro, S. G. (2016). In vitro activity of essential oils of free and nanostructured Melaleuca alternifolia and of terpinen-4-ol on eggs and larvae of Haemonchus contortus. *Journal of Helminthology*, *90*(3), 377–382. https://doi.org/10.1017/S0022149X15000401

Gregory Dykes, Thomas Terrill, Niki Whitley, Anil Singh, Jorge Mosjidis, Joan Burke, & James Miller. (2019). Effect of Ground and Pelleted Sericea Lespedeza Whole Plant and Leaf Only on Gastrointestinal Nematode and Coccidial Infection in Goats. *Journal of Agricultural Science and Technology A*, *9*(2), 93–102. https://doi.org/10.17265/2161-6256/2019.02.003

Healey, K. V. pdf., Lawlor, C., Knox, M. R., Chambers, M., Lamb, J., & Groves, P. (2018). Field evaluation of Duddingtonia flagrans IAH 1297 for the reduction of worm burden in grazing animals: Pasture larval studies in horses, cattle and goats. *Veterinary Parasitology*, *258*(June 2017), 124–132. https://doi.org/10.1016/j.vetpar.2018.06.017

Heckendorn, F., Bieber, A., Werne, S., Saratsis, A., Maurer, V., & Stricker, C. (2017). The genetic basis for the selection of dairy goats with enhanced resistance to gastrointestinal nematodes. *Parasite*, *24*(3), 1–11. https://doi.org/10.1051/parasite/2017033

Henrioud, A. N. (2011). Towards sustainable parasite control practices in livestock production with emphasis in Latin America. *Veterinary Parasitology*, *180*(1–2), 2–11. https://doi.org/10.1016/j.vetpar.2011.05.026

Hewitson, J. P., & Maizels, R. M. (2014). Vaccination against helminth parasite infections. *Expert Review of Vaccines*, *13*(4), 473–487. https://doi.org/10.1586/14760584.2014.893195

Hildreth, M. B., & McKenzie, J. B. (2020). Epidemiology and Control of Gastrointestinal Nematodes of Cattle in Northern Climates. *Veterinary Clinics of North America - Food Animal Practice*, *36*(1), 59–71. https://doi.org/10.1016/j.cvfa.2019.11.008

Horwitz, P., & Wilcox, B. A. (2005). Parasites, ecosystems and sustainability: An ecological and complex systems perspective. *International Journal for Parasitology*, *35*(7), 725–732. https://doi.org/10.1016/j.ijpara.2005.03.002

Hoste, H., & Torres-Acosta, J. F. J. (2011). Non chemical control of helminths in ruminants: Adapting solutions for changing worms in a changing world. *Veterinary Parasitology*, *180*(1–2), 144–154. https://doi.org/10.1016/j.vetpar.2011.05.035

Houdijk, J. G. M., Kyriazakis, I., Kidane, A., & Athanasiadou, S. (2012). Manipulating small ruminant parasite epidemiology through the combination of nutritional strategies. *Veterinary Parasitology*, *186*(1–2), 38–50. https://doi.org/10.1016/j.vetpar.2011.11.044

Hrckova, G., & Velebny, S. (2013). *Parasitic Helminths of Humans and Animals: Health Impact and Control*. https://doi.org/10.1007/978-3-7091-1325-7_2

Hunt, P. W., McEwan, J. C., & Miller, J. E. (2008). Future perspectives for the implementation of genetic markers for parasite resistance in sheep. *Tropical Biomedicine*, *25*(1 Suppl), 18–33.

Kakimori, M. T. A., Debiage, R. R., Gonçalves, F. M. F., Da Silva, R. M. G., Yoshihara, E., & De Mello-Peixoto, E. C. T. (2019). Anthelmintic and antioxidant potential of banana bracts (Musa paradisiaca) extract in ruminants. *Acta Veterinaria Brasilica*, *13*(1), 18–23. https://doi.org/10.21708/avb.2019.13.1.7917

Kidane, A., Houdijk, J. G. M., Athanasiadou, S., Tolkamp, B. J., & Kyriazakis, I. (2010). Effects of maternal protein nutrition and subsequent grazing on chicory (Cichorium intybus) on parasitism and performance of lambs. *Journal of Animal Science*, *88*(4), 1513–1521. https://doi.org/10.2527/jas.2009-2530

Lei, J., Leser, M., & Enan, E. (2010). Nematicidal activity of two monoterpenoids and SER-2 tyramine receptor of Caenorhabditis elegans. *Biochemical Pharmacology*, *79*(7), 1062–1071. https://doi.org/10.1016/j.bcp.2009.11.002

León-Castro, Y., Olivares-Pérez, J., Rojas -Hernández, S., Villa-Mancera, A., Valencia-Almazan, M. A., Hernández-Castro, E., … Jiménez-Guillén, R. (2015). Effect of three fodder trees on Haemonchus contortus control and weight variations in kids. *Ecosistemas y Recursos Agropecuarios*, *2*(5), 193–201. Retrieved from http://marefateadyan.nashriyat.ir/node/150

Macarthur, F. A., Kahn, L. P., & Windon, R. G. (2014). The influence of dietary manipulations and gastrointestinal nematodes on twin-bearing merino ewes and determinants of lamb survival. *Livestock Science*, *167*(1), 342–352. https://doi.org/10.1016/j.livsci.2014.05.019

Mancilla-Montelongo, M. G., Castañeda-Ramírez, G. S., Gaudin-Barbier, E., Canul-Velasco, M. L., Chan-Pérez, J. I., De la Cruz-Cortazar, Á., … Torres-Acosta, J. F. de J. (2021). In vitro Evaluation of the Nutraceutical Potential of Theobroma cacao pod Husk and Leaf Extracts for Small Ruminants. *Acta Parasitologica*. https://doi.org/10.1007/s11686-021-00354-y

Marie-Magdeleine, C., Mahieu, M., Philibert, L., Despois, P., & Archimède, H. (2010). Effect of cassava (Manihot esculenta) foliage on nutrition, parasite infection and growth of lambs. *Small Ruminant Research*, *93*(1), 10–18. https://doi.org/10.1016/j.smallrumres.2010.04.024

Marie-Magdeleine, C., Udino, L., Philibert, L., Bocage, B., & Archimede, H. (2010). In vitro effects of Cassava (Manihot esculenta) leaf extracts on four development stages of Haemonchus contortus. *Veterinary Parasitology*, *173*(1–2), 85–92. https://doi.org/10.1016/j.vetpar.2010.06.017

Martínez-Ortiz-De-Montellano, C., Torres-Acosta, J. F. D. J., Fourquaux, I., Sandoval-Castro, C. A., & Hoste, H. (2019). Ultrastructural study of adult Haemonchus contortus exposed to polyphenol-rich materials under in vivo conditions in goats. *Parasite*, *26*. https://doi.org/10.1051/parasite/2019065

McKeand, J. B. (2000). Vaccine development and diagnostics of Dictyocaulus viviparus. *Parasitology*, *120*(SUPPL.), 17–23. https://doi.org/10.1017/s0031182099005727

Méndez-Ortíz, F.A., Sandoval-Castro, C. A., Vargas-Magaña, J. J., Sarmiento-Franco, L., Torres-Acosta, J. F. J., & Ventura-Cordero, J. (2019). Impact of gastrointestinal parasitism on dry matter intake and live weight gain of lambs: A meta-analysis to estimate the metabolic cost of gastrointestinal nematodes. *Veterinary Parasitology*, *265*, 1–6. https://doi.org/10.1016/j.vetpar.2018.11.008

Méndez-Ortíz, Francisco Alejandro, Sandoval-Castro, C. A., & Torres-Acosta, J. F. de J. (2012). Short term consumption of Havardia albicans tannin rich fodder by sheep: Effects on feed intake, diet digestibility and excretion of Haemonchus contortus eggs. *Animal Feed Science and Technology*, *176*(1–4), 185–191. https://doi.org/10.1016/j.anifeedsci.2012.07.022

Min, B. R., Frank, A., Gurung, N., Lee, J. H., Joo, J. W., & Pacheco, W. (2019). Peanut skin in diet alters average daily gain, ruminal and blood metabolites, and carcass traits associated with Haemonchus contortus infection in meat goats. *Animal Nutrition*, *5*(3), 278–285. https://doi.org/10.1016/j.aninu.2019.05.006

Morrison, W. I., & Tomley, F. (2016). Development of vaccines for parasitic diseases of animals: Challenges and opportunities. *Parasite Immunology*, *38*(12), 707–708. https://doi.org/10.1111/pim.12398

Napoléone, M., Hoste, H., & Lefrileux, Y. (2011). The use of grazing pastures in goat production: Development of an approach to combine optimized use of the forage resource and the control of related risks. *EAAP Scientific Series*, *129*(1), 307–316. https://doi.org/10.3920/978-90-8686-726-4_49

Navarre, C. B. (2020). Epidemiology and Control of Gastrointestinal Nematodes of Cattle in Southern Climates. *Veterinary Clinics of North America - Food Animal Practice*, *36*(1), 45–57. https://doi.org/10.1016/j.cvfa.2019.11.006

Niezen, J. H., Charleston, W. A. G., Robertson, H. A., Shelton, D., Waghorn, G. C., & Green, R. (2002). The effect of feeding sulla (Hedysarum coronarium) or lucerne (Medicago sativa) on lamb parasite burdens and development of immunity to gastrointestinal nematodes. *Veterinary Parasitology*, *105*(3), 229–245. https://doi.org/10.1016/S0304-4017(02)00014-6

Ortiz-Ocampo, G. I., Pérez, J. I. C., Covarrubias-Cárdenas, A. G., Santos-Ricalde, R. H., Sandoval-Castro, C. A., Hoste, H., … Torres-Acosta, J. F. J. (2016). Efecto antihelmíntico in vitro e in vivo de residuos de coffea arabica sobre un aislado de haemonchus contortus con baja susceptibilidad a taninos. *Tropical and Subtropical Agroecosystems*, *19*(1), 41–50.

Palma-García, J. M., Santos-Méndez, L., & Rodríguez-Ruiz, M. L. . (2019). *Control of parasites and protein protection through implementation of Silvopastoral Systems*. *5*(9), 18–25.

Pineda-Alegría, J. A., Sánchez-Vázquez, J. E., González-Cortazar, M., Zamilpa, A., López-Arellano, M. E., Cuevas-Padilla, E. J., … Aguilar-Marcelino, L. (2017). The Edible Mushroom Pleurotus djamor Produces Metabolites with Lethal Activity Against the Parasitic Nematode Haemonchus contortus. *Journal of Medicinal Food*, *20*(12), 1184–1192. https://doi.org/10.1089/jmf.2017.0031

Raschia, M. A., Donzelli, M. V., Medus, P. D., Cetrá, B. M., Maizon, D. O., Suarez, V. H., … Poli, M. A. (2021). Single nucleotide polymorphisms from candidate genes associated with nematode resistance and resilience in Corriedale and Pampinta sheep in Argentina. *Gene*, *770*(July 2020). https://doi.org/10.1016/j.gene.2020.145345

Reynecke, D. P., Waghorn, T. S., Oliver, A. M. B., Miller, C. M., Vlassoff, A., & Leathwick, D. M. (2011). Dynamics of the free-living stages of sheep intestinal parasites on pasture in the North Island of New Zealand. 2. Weather variables associated with development. *New Zealand Veterinary Journal*, *59*(6), 287–292. https://doi.org/10.1080/00480169.2011.610280

Rocha, R. A., Bresciani, K. D. S., Barros, T. F. M., Fernandes, L. H., Silva, M. B., & Amarante, A. F. T. (2008). Sheep and cattle grazing alternately: Nematode parasitism and pasture decontamination. *Small Ruminant Research*, *75*(2–3), 135–143. https://doi.org/10.1016/j.smallrumres.2007.09.001

Schweizer, N. M., Foster, D. M., Knox, W. B., Sylvester, H. J., & Anderson, K. L. (2016). Single vs. double dose of copper oxide wire particles (COWP) for treatment of anthelmintic resistant Haemonchus contortus in weanling lambs. *Veterinary Parasitology*, *229*(2016), 68–72. https://doi.org/10.1016/j.vetpar.2016.09.011

Sharma, N., Singh, V., & Shyma, K. P. (2015). Role of parasitic vaccines in integrated control of parasitic diseases in livestock. *Veterinary World*, *8*(5), 590–598. https://doi.org/10.14202/vetworld.2015.590-598

Smith, W. D., & Smith, S. K. (1993). Evaluation of aspects of the protection afforded to sheep immunised with a gut membrane protein of Haemonchus contortus. *Research in Veterinary Science*, *55*(1), 1–9. https://doi.org/10.1016/0034-5288(93)90025-B

Strube, C., Haake, C., Sager, H., Schorderet Weber, S., Kaminsky, R., Buschbaum, S., … Von Samson-Himmelstjerna, G. (2015). Vaccination with recombinant paramyosin against the bovine lungworm Dictyocaulus viviparus considerably reduces worm burden and larvae shedding. *Parasites and Vectors*, *8*(1), 1–12. https://doi.org/10.1186/s13071-015-0733-5

Tahir, A., Akhtar, R., Lateef, M., Sattar, F., Hafeez, M.A. Omer, M. O., Zahid, B., & Javed, A. (2020). J Hellenic Vet Med Soc. *J Hellenic Vet Med Soc*, *71*(2), 2179–2184. https://doi.org/10.23959/sfjcr-1000004

Teixeira, M., Matos, A. F. I. M., Albuquerque, F. H. M. A., Bassetto, C. C., Smith, W. D., & Monteiro, J. P. (2019). Strategic vaccination of hair sheep against Haemonchus contortus. *Parasitology Research*, *118*(8), 2383–2388. https://doi.org/10.1007/s00436-019-06367-x

Torres-Acosta, J. F. J., & Hoste, H. (2008). Alternative or improved methods to limit gastro-intestinal parasitism in grazing sheep and goats. *Small Ruminant Research*, *77*(2–3), 159–173. https://doi.org/10.1016/j.smallrumres.2008.03.009

Valderrábano, J., Gomez-Rincón, C., & Uriarte, J. (2006). Effect of nutritional status and fat reserves on the periparturient immune response to Haemonchus contortus infection in sheep. *Veterinary Parasitology*, *141*(1–2), 122–131. https://doi.org/10.1016/j.vetpar.2006.04.029

Vargas-Magaña, J. J., Torres-Acosta, J. F. J., Aguilar-Caballero, A. J., Sandoval-Castro, C. A., Hoste, H., & Chan-Pérez, J. I. (2014). Anthelmintic activity of acetone-water extracts against Haemonchus contortus eggs: Interactions between tannins and other plant secondary compounds. *Veterinary Parasitology*, *206*(3–4). https://doi.org/10.1016/j.vetpar.2014.10.008

Vásquez-Hernández, M., González-Garduño, R., Torres-Hernández, G., Mendoza-de-Gives, P., & Ruiz-Rodríguez, J. M. (2006). Comparación de dos sistemas de pastoreo en la infestación con nematodos gastrointestinales en ovinos de pelo. *Veterinaria México*, *37*(1), 15–27.

Waruiru, R., Gitari, R., Otieno, R., & Mavuti, S. (2017). *Efficacy of Copper Oxide Wire Particles against Predominant Gastrointestinal Nematodes of Indigenous Goats in Kenya*. 8–12. https://doi.org/10.21276/sjavs.2017.4.12.2

Waruiru, R. M., Ngotho, J. W., & Mutune, M. N. (2004). Effect of urea-molasses block supplementation on grazing weaner goats naturally infected with gastrointestinal nematodes. *Onderstepoort Journal of Veterinary Research*, *71*(4), 285–289. https://doi.org/10.4102/ojvr.v71i4.248