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SUMMARY – Parasitic nematodes of the gastrointestinal tract remain a main constraint associated with the breeding of small ruminants. Up to now, these parasitic diseases have been controlled by anthelmintics. However, the large development of anthelmintic resistances in nematodes, combined with the increasing public concern on the use of chemicals in farm industry lead to seek alternative methods to chemotherapy. These solutions refer to 3 principles of action. (i) *To kill the parasites in the host* remains a main way to control infections but selective treatments have now been proposed, targeting the most susceptible animals within flocks. (ii) Programmes aiming at *improving the host response against the worms* have also been developed. They rely either on the genetic selection of "responder" lines of hosts or on the manipulation of nutrition to increase the host resistance. Within these solutions based on nutrition, the role of tanniferous plants to modulate the biology of worms is also investigated. And (iii) *methods to reduce the host contamination by various modes of grazing management* are also important to implement. The exclusive reliance on chemotherapy to control nematodes has shown its limits. An integrated approach, combining several methods, will be the only way to achieve a sustainable control of infections, but the alternative solutions have to be adapted to the objectives and the types of production. By decreasing the use of chemicals, these methods can also contribute to improve the quality of products.

Key words: Parasites, nematodes, sheep, goat, sustainable agriculture, anthelmintic.

RESUME – *"Méthodes alternatives pour le contrôle durable des nématodes gastro-intestinaux chez les petits ruminants". Les nématodes parasites du tractus gastro-intestinal demeurent une des principales contraintes associées à l'élevage des petits ruminants à l'herbe. Jusqu'à présent la maîtrise de ces maladies parasitaires reposait essentiellement sur l'emploi de molécules anthelminthiques. Cependant, le développement croissant des résistances aux anthelminthiques chez les nématodes et l'inquiétude grandissante des consommateurs sur l'usage d'intrants chimiques en élevage conduisent à rechercher des méthodes de lutte offrant des alternatives à la chimiothérapie. Ces solutions relèvent de 3 principes d'action. (i)* Tuer les parasites chez l'hôte *demeure l'un des principaux moyens de maîtrise des infestations, mais des applications plus sélectives des traitements sont désormais privilégiées en ciblant les animaux les plus sensibles au sein des troupeaux. (ii) Des programmes visant* à améliorer la réponse de l'hôte face aux vers *sont également développés. Ils se fondent soit sur la sélection génétique de lignées d'animaux, soit sur l'adaptation de composants nutritionnels pour améliorer la résistance au parasitisme. Parmi les solutions nutritionnelles, le rôle modulateur de plantes riches en tannins sur la biologie des vers est également analysé. Et (iii), des* méthodes visant à réduire la contamination de l'hôte par la gestion du pâturage *représentent enfin la troisième voie explorée. Face aux limites montrées par le recours exclusif à la chimiothérapie pour gérer ces infestations parasitaires, il importe de privilégier désormais une approche intégrée combinant plusieurs méthodes de lutte, seule garante d'une maîtrise durable de ce parasitisme. Le choix des diverses solutions alternatives à combiner doit aussi être adapté en fonction des systèmes et des objectifs de production. En favorisant un usage moins intense de molécules chimiques, ces méthodes contribuent également à améliorer la qualité des produits.*

Mots-clés : *Parasite, nématode, mouton, chèvre, agriculture durable, anthelminthique.*

Introduction

Parasitism of the gastrointestinal tract with nematodes remains one of the main constraints associated with the breeding of small ruminants. These nematodes inhabit the different segments of the digestive tract. Their life cycle is direct with the infective stages present on pastures and being ingested with grass. These helminths are responsible for severe pathophysiological disturbances which explain the major economic losses associated with their presence.

Up to now, these parasitic diseases were mainly controlled by the repeated use of anthelmintic treaments in order to prevent and/or to cure infections. However, anthelmintic resistances in nematode populations is now a world wide phenomenon, in constant expansion (Jackson and Coop, 2000) and the presence of resistant worm populations in sheep and goat farms severely limit the efficiency of control based on chemical treatments (Van Wyck *et al.*, 1997). In parallel, the concern of consumers on the use of chemicals in farm industry is increasing, including in regard of methods for the control of diseases. These reasons explain the growing interest for alternative methods to chemotherapy aiming at controlling nematode parasitism of the digestive tract in small ruminants but compatible with the concept of sustainable agriculture. These different solutions can be classified into 3 categories according to the main principle of action.

To kill the parasites within the host

To eliminate the worm populations in sheep and goats remains obviously one of the most efficient ways to improve animal health, to restore production and to break the dynamics of infections. However, a high frequency of treatments, their systematic application to all animals within a flock, the exclusive reliance on one family of anthelmintics have also been identified as main factors contributing to increase the pressure of selection on nematode populations and hence, favouring the development of anthelmintic resistances. Nowadays, the farmers have to face a double challenge: to control the parasites and to avoid the diffusion and the development of anthelmintic resistance within the worm populations.

Basically, most of the strategies which have been proposed to manage anthelmintic resistances, aimed at maintaining a sufficient proportion of alleles of susceptibility in the worm populations in order to dilute the genes of resistance. This objective is usually achieved by preserving a balance between the parasite populations on pastures (the infective larvae, which are not in contact with anthelmintics), and the adult worms in the hosts, which are directly submitted to the drug action.

One of the main solutions to preserve the efficacy of the current drugs is to stop using anthelmintics without discrimination and to promote a more selective mode of treatment, by targeting the most infected animals within a flock. The cornerstone for such application of selective treatments is the need to identify with confidence, those highly infected animals which represent the main epidemiological risk.

Depending on the epidemiology of parasite infections and on the objectives of production, two ways to identify the highly parasitised sheep or goats within a flock have been explored. In tropical and sub tropical countries where *Haemonchus contortus* is the dominant species, regular individual assessment of clinical signs of anaemia, associated with the presence of this hematophagous worm, has been proposed for targeted administration of drugs in order to decrease mortalities (Van Wyck and Bath, 2002). On the other hand, in French dairy goat farms, where the main objective is to maintain milk production, selective treatments have been applied based on repeated epidemiological data indicating that does in first lactation and those with the high level of production are more susceptible (Hoste *et al.*, 2002).

To improve the host response against nematodes

Two main components composed the host response to the trichostrongyles, i.e. the resistance and the resilience. Resistance is defined as the ability of the host to regulate the nematode populations. On the other hand, resilience refers to the aptitude of a host to withstand the negative effects of nematode infections and to maintain productions under parasitic challenge. The major options to improve these 2 faces of the host responses are either genetically or nutritionally based.

Genetics of resistance and resilience to nematode infection

Differences in the level of gastrointestinal infections between breeds have been documented both in sheep (Gray, 1997) and in goats (Jackson, 2000). Moreover, the possibility to improve, through genetic selection, the resistance against nematodes, of lines of sheep or goats within a breed, has received attention for several years in many countries (Albers *et al.,* 1987; Gruner *et al.*, 1998, Patterson *et al.*, 1996). In most studies, the main phenotypic measurement used for selection of the responding animals has been the level of nematode egg excretion. This was usually found to be moderately repeatable and heritable, but, nevertheless, allows to substantially reduction of faecal egg output after several generations (Jackson *et al.*, 1999). The benefits from selection for resistance are expected to result from both the lower number of worms in the animals combined with a lower contamination of the pastures. On the other hand, selection for resilience, based on criteria measuring the production of animals under parasitic challenge, represents another option to improve the host response against nematodes. For example, in New Zealand, lines of sheep have been selected according to the number of anthelmintic treatments necessary during the grazing seasons (Bisset *et al.*, 1996). Although resilience is probably the most important issue for the farmers, because this notion is related to production parameters, this aspect of the host-parasite relationship has been much less examined than the resistance status.

Examples exist of commercial implementation of selective programmes for resistance to trichostrongyles (Jackson, 2000). However, the main questions remain to be addressed in particular those referring to the possible interactions between selection for resistance and productivity of animals or to the by-side consequences of resistance to nematodes on the response to other pathogens. In some cases, highly selected lines of sheep for response against nematodes have been found to over expressed hypersensitivity reactions, resulting in digestive clinical signs after contact with the third stage infective larvae (Watson *et al.*, 1986). On the other hand, some negative phenotypic relations have been found in lines of sheep selected for resistance to gastro intestinal nematodes with the level of infection with the nasal-bot fly, *O. ovis (*Jacquiet *et al.*, 1999).

Host nutrition-parasite relationship

The interactions between nematode infections and host nutrition refer to two related aspects. First, it has been established for a long time that the main pathophysiological consequences of parasites affect the host digestive physiology. The presence of the different nematode species in the various parts of the digestive tract is usually associated with: (i) a decrease in food consumption; (ii) a malabsorption/maldigestion syndrome; and (iii) changes in the host metabolism in order to maintain tissular and blood homeostasis (Hoste *et al.*, 1997). Conversely, more recent studies have brought evidence showing that manipulation of the host nutrition could represent an option to improve the host resistance and or resilience to parasites. Most of the studies have been performed in sheep. In addition, because nematode parasites mainly affect the host protein metabolism and because the protein part of the diet is usually the main limiting factor, the bulk of the studies has been dedicated to investigation on the benefits associated with manipulation of diet protein components (see reviews by Van Houtert and Sykes, 1996; Coop and Kyriazakis, 1999, Hoste *et al.*, 2001). A general model framework has even been proposed which allow to explain most of the results, acquired from the previous studies, according to a scale of priorities expressed by the animal, depending on its reproduction and its immunological status in front of nematode parasitism (Coop and Kyriazakis, 1999). The few results acquired in goats also fit with this framework (Hoste *et al.*, 2001). In addition, some results suggest that in situation where energy represents the main limiting nutritional factor, manipulation of the energy component of the diet could also lead to major improvement of the host response to infections (Torres Acosta, 2003).

More recently, another aspect of the host nutrition-parasite relationships has received a growing interest. Several studies, performed in sheep, goats or deer, have underlined the possible antiparasitic effects of plant secondary compounds on nematodes. Amongst these secondary metabolites, tannins, present in some legume forages (*Lotus pedonculatus* or *L. corniculatus*, *Hedysarum coronarium*, or *Onobrychis viciifolia*) or in woody plants (*Quercus robur, Coryllus avellana…)* composing the vegetation of rangelands have been investigated. Results from both *in vivo* and *in vitro* studies suggest an action of tannins on the biology of the most prevalent worm species in small ruminants (Athanasiadou *et al.*, 2003; Paolini and Hoste, 2003). The possible applications in the field which have been evoked refer either to incorporation of anthelmintic pasture in the rotation system, or to the repeated distribution of hay from tanniferous legumes during the grazing season to regulate worm populations. However, before tanniferous plants become an available option to complement the effect of anthelmintics in the field, it is essential to assess the range of concentrations associated with positive effects against nematodes in infected ruminants without detrimental effects on host physiology, to identify the factors modulating the plant concentrations and to understand the mechanism of action of these compounds.

To reduce the contamination of host by decreasing contact with the infective larvae

The last option to control nematode infections in small ruminants aims at avoiding contact between susceptible host and a large number of infective larvae. The amount of these infective third-stage larvae (L3) on pastures is the result of a dynamic process depending on the number of eggs deposited by infected animals, the rate of development from eggs to L3 and eventually, the death rate of the larvae.

Because the pastures represent the main source of infective larvae for small ruminants, the proposed solutions are mainly based on grazing management practices. The interest of grazing management measures to complement the action of anthelmintics has been recognised for several decades (Michel, 1985; Barger, 1999). These grazing strategies for controlling nematode parasites can be classified according to 3 main options: (i) to wait for elimination of the infective larvae related to their natural death rate; (ii) to act on pastures in order accelerate the L3 death rate, and (iii) to dilute the risk.

The first principle provides the rationale for rotations of pastures. The general goal is that animals should return on a pasture which has been previously grazed only after a time exceeding the survival rate of the L3. In this case, one can expect a partial decrease in infectivity of the parcels. Because the survival of larvae is dependent on the nematode species and the environmental conditions, the success of grazing rotation systems is largely influenced by these factors. For example, the efficiency of rationalised short term rotation systems to control nematode infections has usually been found to be higher in tropical or subtropical conditions, where the life span of larvae, and particularly *Haemonchus contortus,* is relatively limited (Barger *et al.*, 1994), than in temperate countries where the larval survival is prolonged (Hoste *et al.*, 1999).

Actions on the pastures to accelerate the larval death can rely on exploitation of either physical, chemical or biological agents. For example, this provides the rationale for including crop aftermaths in the rotation systems. On the other hand, the bulk of results obtained on methods of biological control have been acquired with some species of nematophagous fungi which present the ability to trap and to kill the larvae within the faeces and therefore to decontaminate the environment (Larsen, 2000).

Although the relationship is clearly not linear, a low stocking rates of hosts on pastures has usually been associated with dilution of parasites in the environment and therefore, with lower levels of infections. To this respect, extensive systems, and particularly those which include rangelands, because they favour the browsing rather than the grazing behaviour, can be perceived as minimising the risk of gastro intestinal infections. Based on the relative specificity of nematodes for one host, cograzing (either simultaneous or alternate) between different host species has also been described as a mean to reduce the infectivity of pastures (Barger, 1999).

The sustainability of the alternative solutions

Overall, the general objective of the alternative methods which have been briefly described is to reduce the reliance on chemotherapy to control the nematode infections in small ruminants. Because some of these anthelmintics are suspected to present some ecotoxicity on the microfauna of pastures, these alternative solutions can therefore be perceived as contributing to reduce any ecological impact and to preserve biodiversity. Moreover, a reduction in the use of chemicals in farming industry is nowadays usually associated with an improvement of image and /or quality of the product and can contribute to increase the economical inputs for the farmer. Last, it can be argued that a general trend for reducing the use of anthelmintics should participate to limit the expansion of anthelmintic resistances within the worm populations and therefore, would help to preserve the long term efficiency of control.

These possible interactions with the ecology, the economy and the transmissibility of the farm system correspond to 3 out of 4 of the main criteria proposed by Landais (1999) to characterise the sustainability of a system.

Which solutions for which systems?

The choice of the various solutions to combine is also dependent on the system and on the objectives of production. Clearly, the criteria used to characterise a production system, both those related to the flock (size, stocking rate, breed) or to the environment (physical, pedo climatic, technical) are also main factors known to influence parasitism with nematodes. On the other hand, the environmental factors, associated with the different types of production system, also condition the applicability of various methods of parasite control. For example, regulation on the use of drugs and on the choice of anthelmintics is usually more drastic in ruminants producing milk than in those bred for meat or fibre. In addition, the threshold of acceptable parasitism is generally lower in intensive systems where the objectives of production have to be achieved in order to ensure the economy of the farm than in more extensive systems. Consequently, the need for measures to control nematode infections will differ between the farming systems. In extensive systems, the low stocking rates associated with the dilution of parasites, the incorporation of rangelands, the use of indigenous breed more adapted to the local environment and the flexibility obtained through the flock management, should allow to mainly rely on pertinent application of plan of surveillance. In more intensive systems, methods of control are more likely to be needed. Nowadays, it should be based on selective use of anthelmintic associated with management of pastures but it is reasonable to assume that some of the currently explored alternative approaches would lead to field application and will be incorporated in parasitism management.

In the future, it is unlikely that helminth control in small ruminants will rely only on one single approach. The sustainability of control will be largely conditioned by the possibility to combine several solutions, corresponding to the 3 different principles previously mentioned, in order to achieve an integrated management of nematode parasitism (Waller, 1999).

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