Chapter 16
Facing Anthelmintic Resistance in Goats

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Abstract Goats raised in pasture are inevitably infected by gastrointestinal nematodes, whatever the place and the climatic conditions. This parasitism results in production losses (growth or milk) and in some cases, in high mortality rates (with high parasite burden or in kids). For many years, these infections were controlled by conventional anthelmintics. Due to unsuitable usages (for example, high number of treatments or under-dosage), anthelmintic resistance has developed and is now very prevalent in goats as demonstrated by the numerous cases of simple or multiple anthelminthic resistance which have been reported throughout the world. Reports include resistance to the most recent anthelmintics, macrocyclic lactones and monepantel. Consequently, the way of managing gastrointestinal parasitism of goats has to move from anthelmintics alone to a more integrated management, including better use of anthelmintics, natural dewormers (nutraceuticals), enhancement of the immunity of the goats via alimentation or vaccination, selection of resistant goats or breeds and grazing management. The present chapter will give an overview of the situation regarding anthelmintic resistance in goats and integrated parasitism management.

16.1 Introduction

Goat population is expanding worldwide with more than 90% of the animals being found in Asia and Africa providing meat and/or milk in small farming systems (Hoste et al. 2010). Helminth infection is considered as a major threat for outdoor breeding of goats affecting health and production. The main helminth species found in goats are grossly similar to those of sheep and include numerous species belonging to trematodes (e.g. flukes), cestodes (e.g. tapeworms) and

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J. Simões and C. Gutiérrez (eds.), *Sustainable Goat Production in Adverse Environments: Volume I*, https://doi.org/10.1007/978-3-319-71855-2_16

nematodes (e.g. gastrointestinal nematodes like *Haemonchus*, *Teladorsagia* and *Trichostrongylus*), for which the occurrence and frequency strongly depend on altitude, climate (tropics vs. temperate) and more generally on breeding location and management. Among these parasites, gastrointestinal (GI) nematodes are of particular concern because of their economic importance (loss of production and mortality of kids) and because of the escalating issue of anthelmintic resistance over the past 25 years (Hoste et al. 2010; Kaplan and Vidyashankar 2012). This problem can no longer be ignored in ruminants and especially in goats considering the high frequency, the nature (multi-resistance) and the widespread distribution of anthelmintic resistance deeply impacting the parasite control programs and calling for a shift to a less reliance on anthelmintics and a development of novel non-chemical approaches (Kaplan and Vidyashankar 2012).

The present chapter addresses anthelmintic resistance in goats and provides a holistic approach for parasitism management.

16.2 Anthelmintics

There are three main broad spectrum anthelmintic families against GI nematodes affecting goats: benzimidazoles (BZD) and probenzimidazoles, imidothiazoles (levamisole), and macrocyclic lactones (ML) (avermectins and milbemycins). Alongside these broad spectrum products, there are two narrow spectrum anthelmintics against haematophagous nematodes, mainly *Haemonchus*, namely salicylanilides (closantel) and nitrophenols (nitroxinil). The 'anthelmintic resources' may be considered to be limited or even stagnating: nearly 30 years passed between the release of MLs (ivermectin in 1981) and the launch of monepantel (firstly marketed for sheep in 1999 in New Zealand) which is a member of the Amino Acetonitril Derivatives (AAD) class and has a unique mode of action. Another anthelmintic with a unique mode of action, derquantel, is a member of the Spiroindol class and was registered for sheep in 2012 in Great Britain in the form of a combination with abamectin (Epe and Kaminsky 2013). Monepantel and derquantel are unavailable for goats.

Goats have specific pharmacological parameters regarding anthelmintics (Lespine et al. 2012). They generally have higher metabolisation capacities compared to sheep or cattle; this leads to higher elimination and consequently to lower exposure of the parasites to the anthelmintics.

Anthelmintics play a central and at times exclusive role in controlling goat nematodes. This has resulted in an overuse which may have had consequences in terms of anthelmintic resistance.

16.3 Anthelmintic Resistance

16.3.1 What Is Anthelmintic Resistance?

For a given population, resistance is the existence of a larger proportion of parasites able to survive a given exposure to an anthelmintic compared to a normal reference population. This characteristic is heritable. For an anthelmintic, one conventionally speaks of resistance when the reduction related to a treatment (faecal egg count or necropsy exam) is under 95% (Coles et al. 1992).

Within a parasite population that has not been previously selected by an anthelmintic, a tiny but not nil proportion of worms has the genetic ability to resist this anthelmintic (preadaptive phenomenon). The genetic diversity of nematode populations explains this pre-existence of resistant populations with a likely very low allele frequency. Resistance develops within a parasite population when the allele frequency of one or several resistance genes increases and leads to a reduced efficacy of the treatment compared to what is normally observed. Genotypic resistance (increase in the resistance allele frequency) evolves slowly and silently until, after reaching a certain allele frequency threshold, phenotypic resistance (reduced efficacy of the anthelmintic) brutally manifests itself (Kaplan and Vidyashankar 2012).

Anthelmintic resistance must be distinguished from the situation where worms naturally tolerate a given anthelmintic (for example, the ineffectiveness of levamisole against whipworms). It must also be distinguished from the general meaning of 'inefficacy'. Four causes of inefficacy have to be considered: (i) misdiagnosis; (ii) poor compliance of drug use, especially under-dosing; (iii) poor drug quality; and (iv) modified pharmacology of anthelmintic due to the way of administration, to the diet, to the level of parasitism and to body condition (Paraud and Chartier 2015).

Several mechanisms involved in resistance have been described. Some of them are specific (involving the target of the molecule), other ones are non-specific (detoxification) (Wolstenholme et al. 2004). Current scientific evidence about these phenomena is not consolidated in particular for the MLs where they are constantly evolving, which is notably the reason for the deficit of routine molecular diagnostic tools.

16.3.2 Factors Influencing Selection Pressure for Resistance

Several risk factors were identified in sheep and goats by Silvestre et al. (2002) and confirmed by Falzon et al. (2014a) by a meta-analysis:

- Indiscriminate and/or excessive use of anthelmintics;
- Under-dosing: this was experimentally demonstrated as a factor of selection of resistant populations of *Teladorsagia circumcincta* to BZD in sheep by Silvestre et al. (2001);
- Variability in pharmacokinetics and efficacy of ML: studies on ivermectin, eprinomectin and moxidectin formulations (oral, subcutaneous and pour on) have shown variability in bioavailability and efficacy in connection with variability in absorption (Lespine et al. 2012). This variability in parasite exposure to the drug, particularly when underexposed, could occur notably with pour on formulation and could result in an increased resistance selection process;
- Lack of nematode populations *in refugia* at the time of treatment. The population *in refugia* is defined as the parasite population (worms or infective larvae) unexposed to the anthelmintic and thus unselected during treatment; they thereby contribute to maintaining susceptibility alleles in the population. The use of *refugia* is a key component of sustainable treatment programs by limiting the selection pressure and thus slowing down the emergence of resistant populations (van Wyk 2001). There are three sources of refuge: infective larvae on pastures, worms in untreated animals, or inhibited stages (for the anthelmintics which do not affect these stages). With regard to infective larvae, refuge will be weak in all situations where pasture infectivity is low (e.g. end of winter, drought, resting plots, new pastures in temperate areas, etc.);
- Lack of effective quarantine anthelmintic treatments: as quarantine procedures and associated anthelmintic treatments are poorly practiced, the probability of buying animals carrying resistant worms is high. An example is given by Schnyder et al. (2005) in Switzerland with the importation of Boer goats from South Africa and the concurrent introduction of resistant strongyles.

In addition to the previous risk factors, the development of resistant populations depends on numerous factors associated with the parasite's biology (Churcher et al. 2010): biology (fecundity) and epidemiology of the nematode species, natural frequency of resistance genes in an unselected population, resistance genetics (mono, multigenic; recessive or dominant character, etc.). The issue of the fitness (biotic potential) of resistant versus susceptible worms is still open to debate although the hypothesis of a decreased fitness of resistant worms is not supported by evidence (Elard et al. 1998). In the absence of the anthelmintic, a resistant parasite population does not seem to return to susceptibility, although one case of reversion was recently described in sheep (Leathwick et al. 2015).

16.3.3 Detection of Anthelmintic Resistance

The methods to detect anthelmintic resistance were the subject of a reference publication in 1992 (Coles et al. 1992) and were amended in 2006 (Coles et al. 2006).

The main detection technique remains today the post-treatment Faecal Egg Count Reduction Test (FECRT); it can be used with all anthelmintics and is based on counting nematode eggs in faeces (eggs per gram of faeces) before and after treatment, with interval following treatment varying depending on the anthelmintic (e.g. 7–10 days for levamisole, 14 days for benzimidazoles and 16–17 days for ML). Several criteria need to be considered to obtain a reliable estimation of resistance with this test and are level of egg excretion, number of animals per group, sensitivity of the coproscopical method, among others (Levecke et al. 2012). Several calculation methods have been proposed, which can lead to different conclusions regarding resistance (Falzon et al. 2014b).

The necropsy examination test following an experimental infection and anthelmintic treatment could be considered as the reference method to use in confirmation and research studies but is quite expensive and incompatible with field surveys.

In vitro tests have also been described, including the egg hatch test, indicated only for benzimidazoles (ovicidal activity), and larval tests (larval development or motility) for the two other anthelmintic families (Demeler et al. 2012).

Lastly, PCR techniques have been published for benzimidazoles but molecular techniques remain in the domain of research and cannot be used for the routine diagnosis of resistance (Kaplan and Vidyashankar 2012).

16.3.4 Cost of Anthelmintic Resistance

Anthelmintic resistance is nearly undetectable by owners without doing faecal egg counts, unless the percentage of resistant adults in the parasitic population reaches very high levels. But even invisible, anthelmintic resistance has economic consequences. This was demonstrated in sheep by Sutherland et al. (2010). These authors compared weight gains of lambs treated with an anthelmintic fully efficient and weight gains of lambs treated with an anthelminthic showing efficacy from 40 to 50% and reported significant weight losses due to anthelmintic resistance. No similar experiment has been conducted in goats.

16.3.5 Epidemiology of Anthelmintic Resistance

Anthelmintic resistance in gastrointestinal strongyles in goats was first described in Australia and in France in the 1980s (Barton et al. 1985; Kerbœuf and Hubert 1985). These authors described strains of *Teladorsagia* and *Trichostrongylus* resistant to benzimidazoles in goat farms. Since then, resistance descriptions have been reported from all over the world, wherever there are goats raised on pasture, whatever the environmental conditions (humid, arid or semi-arid, highland or lowland) (Tables 16.1, 16.2, 16.3 and 16.4). Resistance has been reported in meat, fiber and dairy goats. The mainly involved genuses are *Haemonchus* in tropical and

Table 16.1 Anthelmintic resistance cases described in goats in Asia and Oceania (SCOPUS® search 'Goat' AND 'Anthelmintic resistance', 31/07/2017)

Country	Main anthelmintics	Main genus	References
India	BZD > LEV > AVM	Haem > Tricho	Ghalsasi et al. (2012) Singh et al. (2013) Jaiswal et al. (2013) Rialch et al. (2013) Arunachalam et al. (2015) Chandra et al. (2015) Kumar and Kumar (2015) Manikkavasagan et al. (2015) Rialch et al. (2015) Gelot et al. (2016) Singh et al. (2017)
Malaysia	Cases of multi-resistance BZD-LEV-ML	Haem > Tricho	Rahman (1994) Chandrawathani et al. (1999), (2004) and (2013) Abubakar et al. (2015)
Pakistan	BZD > LEV	Haem—Tricho	Saeed et al. (2007) and (2010) Jabbar et al. (2008) Muhammad et al. (2015)
Philippines	BZD	Haem	Venturina et al. (2003) Ancheta et al. (2004)
Australia	BZD, LEV	Tela, Tricho, Haem	Barton et al. (1985)
New Zealand	ML—monepantel	Tela/Tricho	Leathwick (1995) Scott et al. (2013)

BZD benzimidazoles; *LEV* levamisole; *AVM* avermectins; *ML* macrocyclic lactones
Haem Haemonchus contortus; *Tricho Trichostrongylus* spp.; *Tela Teladorsagia* spp.

subtropical countries and *Teladorsagia* and *Trichostrongylus* in temperate regions. All anthelmintic families are concerned even the last launched, monepantel (Scott et al. 2013). Moreover, multi-resistance (involving two or more anthelmintic families) is regularly described.

When evolution along time is considered, the situation regarding resistance becomes usually worst with years. Mahieu et al. (2014) reported that in Guadeloupe (French West Indies) goat farms, resistance progressed from a single benzimidazoles resistance to a double benzimidazoles plus MLs resistance in 15 years.

Table 16.2 Anthelmintic resistance cases described in goats in South and North America (SCOPUS® search 'Goat' AND 'Anthelmintic resistance', 31/07/2017)

Country	Main anthelmintics	Main genus	References
Brazil	Cases of multi-resistance BZD-LEV-ML-closantel	Haem > Tricho, Oeso	Vieira and Cavalcante (1999) Lima et al. (2010) Nunes et al. (2013) Bichuette et al. (2015) Borges et al. (2015)
Guadeloupe (French West Indies)	BZD (1997), BZD-AVM-LEV (2014)	Haem > Tricho	Barré et al. (1997) Mahieu et al. (2014)
Mexico	BZD	Haem	Torres-Acosta et al. (2005)
United States of America	Cases of multi-resistance BZD-LEV-ML since the 90s	Haem > Tricho	Craig and Miller (1990) Miller and Craig (1996) Zajac and Gipson (2000) Terrill et al. (2001) Mortensen et al. (2003) Kaplan et al. (2007) Howell et al. (2008) Crook et al. (2016) Goolsby et al. (2017)

BZD benzimidazoles; *LEV* levamisole; *AVM* avermectins; *ML* macrocyclic lactones
Haem Haemonchus contortus; *Tricho Trichostrongylus* spp.; *Tela Teladorsagia* spp.; *Oeso Oesophagostomum* spp.

16.4 How to Delay the Development of Resistance in Goat Farming?

Several methods have been proposed to prevent the development and spreading of anthelmintic resistance (Hoste and Torres-Acosta 2011; Kearney et al. 2016). They are based on three principles: (i) combining better use of anthelmintics and use of

Table 16.3 Anthelmintic resistance cases described in goats in Africa (SCOPUS® search 'Goat' AND 'Anthelmintic resistance', 31/07/2017)

Country	Main anthelmintics	Main genus	References
Ethiopia	Multi-resistance (2006 et 2009) Tetramisole (2010)	Haem	Sissay et al. (2006) Kumsa and Abebe (2009) Kumsa et al. (2010)
Kenya	LEV	Haem	Wanyangu et al. (1996) Waruiru et al. (2003) Mungube et al. (2015)
Nigeria	Suspicion with ML and LEV	Haem, Tricho, Oeso	Adediran and Uwalaka (2015)
South Africa	BZD, closantel, ML, LEV	Haem > Tricho	Bakunzi (2003) Tsotetsi et al. (2013) Bakunzi et al. (2013)
Uganda	ML, LEV, BZD	Haem	Byaruhanga and Okwee-Acai (2013) Nabukenya et al. (2014)

BZD benzimidazoles; *LEV* levamisole; *AVM* avermectins; *ML* macrocyclic lactones
Haem Haemonchus contortus; Tricho Trichostrongylus spp.; *Tela Teladorsagia* spp.; *Oeso Oesophagostomum* spp.

natural dewormers to reduce the worm population's burden; (ii) to reinforce immunity of the host; and (iii) to avoid contact between the third stage larvae and their hosts. These strategies have to be combined in an integrated management system.

16.4.1 Better Use of Anthelmintics

First, better use of anthelmintic means to avoid all the factors of anthelmintic resistance selection previously described: avoid under-dosing, reduce the number of annual treatments, prevent introduction of resistant strongyles and preserve *refugia* when treating.

One way of preserving *refugia* to delay the apparition of resistance is to use selective anthelmintic treatment. This strategy is based on the fact that strongyle infection is overdispersed in a flock, with most animals being slightly infected and few animals being heavily infected (Hoste et al. 2002b), the latter being the only ones needing treatment. The *refugia* will be determined by the untreated goats. Mathematical models have shown that a low to very low percentage of untreated animals (sometimes less than 5%) may be enough to significantly reduce selection pressure (Leathwick and Besier 2014). However, other results indicated a much higher percentage of untreated animals (70–80%) necessary to act as effective *refugia* (Gaba et al. 2010). Interestingly, according to the models of Leathwick et al. (2008), the size of successful refugia is linked to the proportion of resistant worm in

Table 16.4 Anthelmintic resistance cases described in goats in Europe (SCOPUS® search 'Goat' AND 'Anthelmintic resistance", 31/07/2017)

Country	Main anthelmintics	Main genus	References
Denmark	BZD, LEV, ML	Haem, Tricho	Maingi et al. (1996) Holm et al. (2014) Peña-Espinoza et al. (2014)
France	BZD > LEV	Tela/Tricho > Haem	Kerbœuf and Hubert (1985) Kerbœuf et al. (1988) Hubert et al. (1991) Beugnet (1992) Chartier and Pors (1994) Cabaret et al. (1995) Chartier et al. (1998) and (2001) Paraud et al. (2009)
Germany	BZD	Haem, Tela/Tricho	Bauer (2001)
Greece	BZD	Tela	Papadopoulos et al. (2001)
Italy	BZD, ML	Tricho, Tela	Cringoli et al. (2007) Zanzani et al. (2014)
Netherlands	BZD, ML	Haem, Tricho, Tela, *Cooperia* spp.	Borgsteede et al. (1996) Eysker et al. (2006)
Norway	BZD	Tela/Tricho, Haem	Domke et al. (2012)
Switzerland	ML, BZD	Haem, Tela/Tricho	Schnyder et al. (2005) Artho et al. (2007) Scheuerle et al. (2009) Murri et al. (2014)
Slovakia	BZD		Čorba et al. (2002)
Spain	BZD	Tela, Haem	Calvete et al. (2014) Requejo-Fernández et al. (1997)
United Kingdom	BZD, LEV	Haem, Tela/Tricho	Hong et al. (1996)

BZD benzimidazoles; *LEV* levamisole; *ML* macrocyclic lactones
Haem Haemonchus contortus; *Tricho Trichostrongylus* spp.; *Tela Teladorsagia* spp.; *Oeso Oesophagostomum* spp.

the population: when the resistance allele frequency is low, the percentage of animals to be left untreated can be reduced. For example, when allele frequency is 0.1%, keeping 1% of animals untreated could be enough whereas for allele frequency of 5%, the proportion of untreated animals should increase to 34%.

Several methods have been tested in goats to identify animals needing anthelmintic treatment in a flock: egg excretion counting, age (primiparous vs. multiparous), individual milk production, consistency of faeces, body condition scoring (BCS) (Fig. 16.1) and FAMACHA® method (Fig. 16.2).

Fig. 16.1 Body condition scoring (provided by the authors)

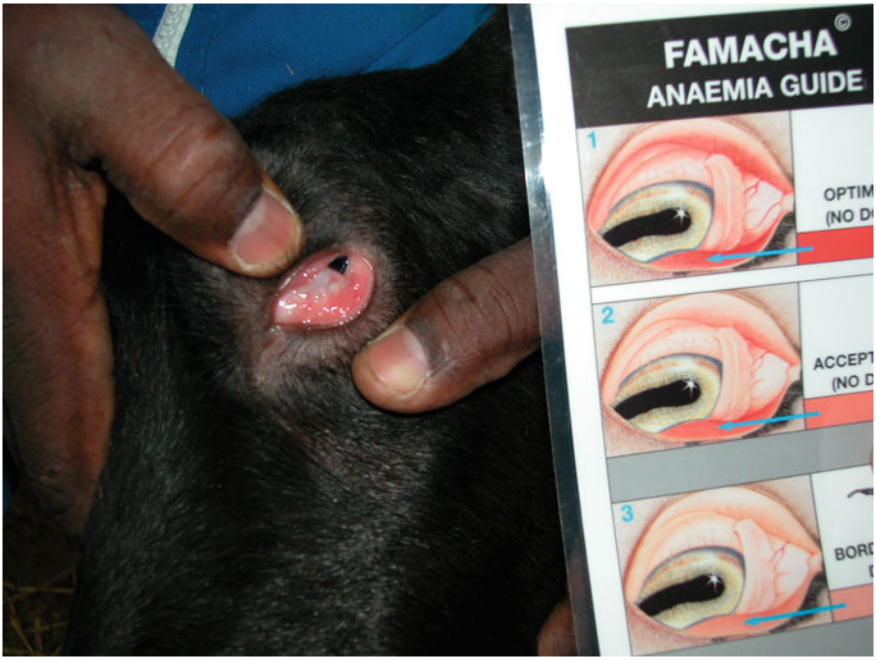

Fig. 16.2 FAMACHA® scoring (provided by the authors)

Individual egg excretion counting might be quickly excluded as it needs individual faecal sampling and individual laboratory analysis, which is not suitable for farmers (Gallidis et al. 2009).

Hoste et al. (2002a) compared the egg excretion, the milk production and the mean number of annual anthelmintic treatments between systematic (whole) treatment strategy and targeted selective treatment based on high-producing goats and primiparous goats. No difference was seen between the two strategies regarding mean egg excretion and mean milk production. The reduction of the number of treatments due to selective treatment was about 40%.

Gallidis et al. (2009) scored the body condition of adult dairy goats each 4 months for 1 year, treated only the goats presenting a bad condition score and evaluated the percentage of reduction of the number of treatments compared to the usual treatment scheme (all goats twice a year). This reduction of the number of treatments ranged from 37 to 83% according to the farm.

FAMACHA® method is a clinical indicator based on the evaluation of anaemia due to *Haemonchus contortus* (Fig. 16.3). It was initially developed for sheep in South Africa (Malan et al. 2001). Anaemia is measured at the lower eyelid and scored from 1 to 5 according to a chart (Fig. 16.2). Only animals that scored 3, 4 or 5 need to be treated. This method was tested and validated in goats in regions where *H. contortus* is the main strongyle species: Peru (Rendón et al. 2017), Brazil (Sotomaior et al. 2012; Vilela et al. 2012b), United States (Kaplan et al. 2004; Burke et al. 2007a), Nigeria (Idika et al. 2013), South Africa (Vatta et al. 2001; Sri Jeyakumar 2007), Uganda (Nabukenya et al. 2014) and Kenya (Ejlertsen et al. 2006). These last authors reported percentages of untreated goats higher than 77% after using the FAMACHA® chart in farm conditions. On the contrary, in temperate places where *H. contortus* is not dominant, the results of assays are less conclusive (Koopmann et al. 2006; Paraud et al. 2007b).

Combination of two nematocides is practiced on sheep in New Zealand and Australia and appears, through simulation models, to be more effective in slowing the development of resistance than alternating between two families (Leathwick

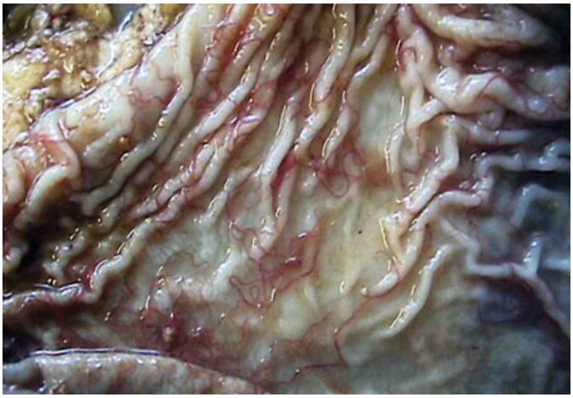

Fig. 16.3 *Haemonchus contortus* adults in abomasum (provided by the authors)

2012). This strategy is developed notably with the new molecules available for sheep. This approach remains nonetheless very theoretical and runs up against many practical difficulties.

16.4.2 Copper Oxide Wire Particles (COWP)

Administration of copper oxide wire particles (COWP) was evaluated as an alternative treatment to conventional anthelmintics. Chartier et al. (2000) reported that the curative or preventive administration of copper oxide needles to goats in both experimental and natural conditions reduced significantly the worm burden and the egg output of *H. contortus*. No significant effect was observed on intestinal species. These results were confirmed later by Burke et al. (2007b, 2010) and Vatta et al. (2009).

16.4.3 Natural Dewormers

Among natural dewormers, tannin-containing legumes have received a lot of attention. Three potential impacts of these tannin-containing legumes on the strongyle life cycle have been identified (Hoste et al. 2015): decrease of the establishment of infective larvae in the host; reduction of the female fertility and/or of the worm population, leading to a decrease of egg output; lower development of eggs into infective larvae. Two hypotheses exist regarding the mode of action: a direct action based on pharmacological-type of interactions between tannins and the parasitic stages or an indirect action by a possible improvement of host resistance via the nutritional effect of tannin-containing legumes (Hoste et al. 2015).

These legumes are qualified as nutraceuticals as they are considered as food while improving health. The healthy effect is obtained only after several days of distribution (Hoste et al. 2012).

Cultivated legumes can be distributed via direct grazing (Fig. 16.4), as hay or silage or as dehydrated pellets, so they need to be sufficiently palatable to be consumed by the goats. Tannin-containing legumes can also be part of native vegetation used to feed the animals (Brunet et al. 2008).

Several plants have shown anthelmintic properties in in vivo studies in small ruminants (Hoste et al. 2012): sulla (*Hedysarum coronarium*), big trefoil (*Lotus pedunculatus*), birdsfoot trefoil (*Lotus corniculatus*), sericea lespedeza (*Lespedeza cuneata*), sainfoin (*Onobrychris viciifolia*) and the tropical legume tree *Lysiloma latisiliquum*.

Sources of variability of the tannin content of the legumes and consequently of their anti-parasitic effect have been identified in small ruminants: type of legume, environmental conditions in which the legume is grown, technological processes

Fig. 16.4 Alpine goats at pasture (provided by the authors)

(fresh vs. hay, silage and pellet samples), parasitic species or stages, hosts (Hoste et al. 2012, 2015).

16.4.4 Action on the Host Immunity

The expression of immune response in goats and thus the ability to control challenge infections seem to be much lower compared to sheep, although this limitation does not always result in heavy infection, particularly when goats are raised on rangelands and are able to fulfil their browsing behavior (Hoste et al. 2010).

Immunity of the host can be enhanced in two ways, improvement of alimentation or vaccination.

The relationship between immunity towards gastrointestinal nematodes and alimentation was first explored in sheep and led to a theory of protein partitioning between maintenance/gain of body protein, acquisition/expression of immunity and production efforts (pregnancy or lactation) (Coop and Kyriazakis 1999). This framework was confirmed in goats in pens and in field studies reviewed by Hoste et al. (2008) and Torres-Acosta et al. (2012).

In French dairy goats, Etter et al. (1999) eliminated the periparturient rise of egg excretion by increasing the protein supply to 128 or 144% coverage of requirements. This was later confirmed under tropical conditions (Faye et al. 2003; Nnadi et al. 2009). These last authors showed that feeding high protein to West African Dwarf goats experimentally infected by *H. contortus*, from the day of mating to 6 weeks post-partum, significantly improved the BCS of the does and the birth weights of their kids.

In growing kids, positive effects of dietary supplementation were also demonstrated. In browsing Criollo kids, supplementation significantly improved packed cell volume, significantly reduced the length of *Trichostrongylus colubriformis* females and the number of eggs in utero of both *T. colubriformis* and *H. contortus* females compared to non-supplemented kids (Martínez Ortiz de Montellano et al. 2007). Bambou et al. (2011) reported a significant reduction of faecal egg count excretion and an improvement of packed cell volume in experimentally infected and supplemented Creole kids (whatever the level of supplementation) compared to infected non-supplemented kids.

As mentioned before, distribution of tannin-containing legumes may also improve immunity due to an improvement of the protein supply.

Attempts of vaccination in goats were mainly directed against *H. contortus*, with several proteins (Ruiz et al. 2004; Yanming et al. 2007; Sun et al. 2011; Han et al. 2012; Zhao et al. 2012; Yan et al. 2013; Meier et al. 2016) and generally concluded to a partial induced protection. A commercial vaccine against *H. contortus* was launched in 2014 in Australia for sheep, Barbervax®. This vaccine was tested in Anglo-Nubian and Saanen goats in Brazil by Matos et al. (2017). These authors reported a significant reduction of faecal egg outputs in the two breeds and a significant improvement of the packed cell volume (PCV) and of the total plasma proteins for Anglo-Nubian goats only.

16.4.5 Breeding for Resistance

Host resistance limits larvae installation and/or reproduction of the strongyles, which leads to a reduction of the contamination for the rest of the flock.

Several goat breeds, usually originating from tropical places, show natural resistance traits against gastrointestinal parasites, as reviewed by Zvinorova et al. (2016): Small East African goats, Jamunapari goats, Creole goats and West African Dwarf goats. However, little work has been done to take advantage of these genetic traits in breeding schemes.

On the contrary, breeding for resistance to strongyles in selected breeds has been extensively studied in sheep and is now integrated in selection schemes in Australia and New Zealand (Woolaston and Baker 1996) for a long time and, more recently, in France (Jacquiet et al. 2015). The selection of the most resistant animals is possible due to the genetic diversity among a flock. Selection is mostly based on phenotypic markers, like faecal egg counts. Genetic markers of resistance in goats are under research. For example, about ten quantitative trait loci (QTL) related to resistance, resilience and humoral response towards *H. contortus* infection have been identified in Creole goats (de la Chevrotière et al. 2012).

16.4.6 Grazing Management

Practising grazing management requires knowing numerous epidemiological data (Barger 2001), in particular survival rate of infective larvae and climatic requirements for egg hatching and larval development.

The strategies of grazing management can be classified as preventive strategies, i.e. putting worm-free animals on clean pastures, evasive strategies as removing animals before the pasture contamination becomes too high (rotational grazing) and diluting strategies, e.g. reducing the pasture contamination by grazing animals of different susceptibility together or alternatively (different ages or species) (Barger 1997).

These methods were rarely evaluated in experimental or natural conditions, whatever the ruminant species considered. Evasive strategies were evaluated in cattle by Eysker et al. (1998) and Larsson et al. (2007) and by Eysker et al. (2005) in sheep. In goats, Silva et al. (2011) compared the strongyle infections among goats raised under rotational grazing and feed supplementation and goats using a permanent pasture and regularly dewormed. They demonstrated that strongyle infections can be well controlled by the system of rotational grazing. In the tropics, as the survival of infective larvae on pasture is limited to 6–7 weeks (Aumont et al. 1996), this can be exploited through very effective pasture rotation strategies as demonstrated by Barger et al. (1994). Mathematical models were developed to predict the risk of larval contamination so that owners know when they have to move their animals to another pasture. These models take into account meteorological data, grazing management practices and anthelmintic treatment (Chauvin et al. 2015). These models were developed in cattle and need to be validated in goats.

A few studies demonstrated the benefits of mixed grazing between sheep and cattle (Mahieu 1997; Mahieu and Aumont 2009). In French goats, Doumenc et al. (2004) evaluated the effects of different levels of mixed grazing with cattle on the intensity and diversity of goat parasitism (no mixed grazing, occasional alternate grazing, or continuous mixed grazing). These authors reported that when the highest level of mixed grazing was used, the lowest *Teladorsagia* and *Trichostrongylus* burden were obtained. Marshall et al. (2012) confirmed these results with *H. contortus* in the south-eastern region of the United States.

In Guadeloupe (French West Indies), a combination of alternate grazing between goat and cattle and pasture rotation allowed a very effective control of GI nematodes infection in goats (Mahieu 2013).

16.4.7 Nematophagous Fungi

Nematophagous fungi have the capacity to trap and destroy infective larvae before they leave the faeces and can be used as a mean for biological control of gastrointestinal nematodes. One species has received a lot of attention, *Duddingtonia flagrans*. This net-trapping fungus produces thick wall chlamydospores and is able to survive passage through the gastrointestinal tract of ruminants (Larsen 2000).

D. flagrans, administered as spores to goats by oral route for several days, has demonstrated its ability to reduce the number of gastrointestinal nematode larvae of the main nematode species in goat faeces in laboratory or plot studies (Chartier and Pors 2003; Paraud and Chartier 2003; Waghorn et al. 2003; Terrill et al. 2004; Ojeda-Robertos et al. 2005; Paraud et al. 2005).

Efficacy of administration of *D. flagrans* to goats was also tested in field conditions. In most studies, *D. flagrans* was administered as spores, in the daily feeding of the kids or does. One study used a pellet formulation in a sodium alginate matrix (Vilela et al. 2012a). Some authors reported positive effects of the distribution of the spores (Wright et al. 2003; Gómez-Rincón et al. 2007; Sanyal et al. 2008; Vilela et al. 2012a), while other studies showed inconstant or inconclusive results (Maingi et al. 2006; Paraud et al. 2007a; Epe et al. 2009).

D. flagrans spores are commercialised as a feed additive in Australia (BioWorma®, International Animal Health Products PTY LTD).

16.4.8 Integrated Parasitism Management

None of the methods previously described is sufficient on their own to control the gastrointestinal parasitism. Integrated approaches, based on a combination of different methods, targeting different parasite stages, with different ways of action, are needed (Hoste and Torres-Acosta 2011). Different combinations have already been tested in goats: supplementary feeding and COWP (Martínez Ortiz de Montellano et al. 2007), resistant host and supplementary feeding (Bambou et al. 2011), targeted selective treatment using FAMACHA® method and COWP (Spickett et al. 2012).

Goat owners will have to move from a simple option (anthelmintic treatment) to a wider range of options. These options should be practical, affordable, available and appropriate to be adopted by the farmers (Krecek and Waller 2006). Uptake of alternative methods can be difficult as underlined by Besier and Love (2012). This point has been considered by several authors. In the United States, Terrill et al. (2012) reported that FAMACHA® method was the most easily adopted by sheep and goat farmers; in a smaller proportion, farmers also used grazing management and genetic selection. In the same way, Walker et al. (2015) tested uptake of targeted selective treatment based on several criteria in resource-poor goat farms sharing communal pastures in Botswana. They demonstrated that engaged and formed farmers can use targeted selective treatment and save anthelmintic treatment while improving the health of their goats.

16.5 Conclusions

For the past 30 years, anthelmintics have represented an increasingly powerful therapeutic arsenal which has become more and more adapted to the requirements of veterinarians and farmers. We have now reached a point where this system must be rethought in terms of a dual objective, a quest for production performance but, at the same time, a reduced selection pressure and less development of resistant parasites. The adoption of integrated approaches including a rationalised use of anthelmintics by targeting animals which need to be treated and the use of the alternative methods to chemical products is required.

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